



UNIVERSITY of HAWAI'I at MĀNOA

INSTITUTE *for* SUSTAINABILITY *and* RESILIENCE

A Study of Shoreline Regulations and Managed Retreat for Hawai'i
A Cost Analysis for Paumalū, O'ahu



Photo Credit: Renee Setter. Kammie's on the North Shore of O'ahu, Hawai'i, October 2022.

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Executive Summary

The Intergovernmental Panel on Climate Change (IPCC) projects that global sea levels may rise up to approximately 3.2 feet (ft) by 2100, with a range of scenarios based on greenhouse gas emissions reductions achieved. As a result, coastal communities are at-risk of the consequences of sea level rise (SLR) with threats to people, infrastructure, and ecosystems. The Hawaiian Islands are already experiencing the impacts of SLR, including exacerbated effects of coastal erosion, storm surge, and coastal flooding. Beaches in Hawai'i are protected as a public trust resource. However, many beaches are experiencing chronic erosion and overall beach loss. To contribute to an understanding of SLR response for Hawai'i, this report reviews Hawai'i's shoreline regulations and identifies SLR adaptation options and mechanisms to implement managed retreat of coastal development in the context of residential areas adjacent to sandy beaches.

Using a case study of the Paumalū ahupua'a on the North Shore of O'ahu, 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. All-at-once retreat removes structures expected to be impacted by SLR as soon as possible, threshold-based removes structures when expected coastal erosion is within 20 ft, and reactive removes structures after they have fallen within the shoreline as predicted by the coastal erosion line. We estimate the following costs within the study area: property acquisition, property tax revenue loss, private structure removal, public infrastructure removal, public infrastructure relocation, and private property loss. As an indicator of benefits, we estimate beach area gained under the three retreat strategies.

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 O'ahu. We estimate the number of people, real estate value, and property tax revenues, located within 3.2 ft of SLR-XA for O'ahu.

Our key findings are as follows:

- Retreat is the current regulatory status quo for sandy beach areas in Hawai'i 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. The range of costs is due to the magnitude of area that is assumed to be retreated.
- All-at-once retreat is most likely enabled through full market buyout programs. Such a program introduces incentive to Hawai'i coastal investors to not fully incorporate future risk in their decision-making, which could pose additional costs for adaptation across the

island and state. As such, private landowners are financially best off under an all-at-once retreat.

- Threshold-based retreat is substantially lower in cost than all-at-once within our case study area, 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 in our case study area, 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 (and represented within our scenarios) 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.
- Lastly, the 3.2 ft SLR-XA has approximately 28,000 O'ahu residents within its boundaries, as well as \$18.6 billion (5%) in property value. The largest proportion of property types within SLR-XA are Residential, Residential A (i.e., investor-owned), and Hotel & Resort.

In conclusion, we find that the threshold-based approach merits further inquiry as an improvement towards a more proactive approach to retreat compared to the status quo. The threshold-based approach has comparable costs to reactive retreat and largely mitigates public safety concerns. The all-at-once approach is appealing from the perspective of beach area gained, however, 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 build a complete understanding of the benefits of retreat interventions.

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Glossary of Terms & Abbreviations

Ahupua'a - 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

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 - Hawai'i Administrative Rules

HMA - Hazard Mitigation Assistance

HMGP - Hazard Mitigation Grant Program

HRS - Hawai'i 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 – On-site 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 approximately 3.2 feet by 2100 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 and 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 amplify 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; Fletcher et al., 1997; Summers et al., 2018; Hawai'i Climate Change Mitigation and Adaptation Commission, 2021; IPCC, 2022).

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

Our report identifies SLR adaptation options and characterizes costs and tradeoffs of approaches to retreat of coastal development in the context of residential areas adjacent to

¹ IPCC (2021) estimates mean sea level rise of 0.9-3.3 ft by 2100 relative to 1995-2014 global mean sea levels. This likely range is determined based on assumptions of Shared Socioeconomic Pathway Scenarios (SSPs) regarding levels of continued fossil fuel combustion and other anthropogenic greenhouse gasses that cause climate change.

sandy beaches. To provide context, 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). This area was selected as it is a world-famous beach experiencing chronic erosion and 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 fill this need. We identify the types of costs related to three approaches to retreat and estimate the costs of the removal of dwellings and related infrastructure (like on-site disposal systems and local roads) and the relocation of the highway. We calculate 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 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 (above the flooding threshold of 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 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 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 of SLR, from 14,000 to 60,000 ft (Nakano et al., 2019). Coastal highways across Hawai'i 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. 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 of SLR, half of Hawai'i'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 (Summers et al., 2018). The further loss of Hawai'i's beaches has compounding detrimental impacts to gathering spaces for social and cultural events, ecological services and habitats for threatened and endangered species, and 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 migrating inland (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 further 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 sea levels rise (McKenzie et al., 2021). There are approximately 88,000 cesspool and septic systems in Hawai'i, 1,500 of which are within just 200 ft of the shoreline (State of Hawai'i 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 dwelling residents and the public. For residential areas, structure deterioration and collapse could pose potentially large risks to homeowners and public safety through introduction of contaminants from building debris into coastal environments. Many Hawai'i houses still contain asbestos in their ceilings and lead in their paint (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. Tarui et al. (2023) found that residential real estate transactions for O'ahu are already responding to SLR risk. Between 2014-2019, properties in SLR-XA were found to have a relative decline in transaction prices between 9 and 14%, where results are primarily driven by multi-family dwellings. 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. 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. The range of findings highlight the importance of 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; Fletcher et al., 1007; Gibson & Mullins, 2020; Hino & Burke, 2021; Jin et al., 2015; Krause, 2014; Walsh et al., 2019).

Coastal Governance in Hawai'i

Based on common law, Hawai'i'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). Hawai'i'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).

Hawai'i's Coastal Zone Management Act (CZMA), passed in 1975 and codified as Hawai'i 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 Hawai'i is within 30 miles of the ocean (OP-HCZM Program, 2011). Hawai'i'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; Hawai'i Administrative Rules (HAR) §13-222; Revised Ordinances of Honolulu (ROH), Ch. 23 and 25). 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

Hawai'i'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 Hawai'i Supreme Court decisions, notably *In re Ashford* (1968), *Sotomura* (1973), *In re Sanborn* (1977), *Diamond I* (2006), and *Diamond II* (2014).² 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).

² *Ashford* centered on the seaward boundary of two properties on Molokai. Royal land patents declared the properties ran *ma ke kai*, which the Hawai'i Supreme Court interpreted to mean that the seaward boundary of both was "along the upper reaches of the wash of the 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).

Recent judicial court proceedings have highlighted ongoing gaps in the definition of the shoreline. Specifically, *State of Hawai'i v. O'Shea* (2022) 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 O’ahu. The State sued the homeowner, arguing that the illegal seawall 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 Hawai'i, 2021). The Circuit Court ruled that an artificial structure could not set the seaward boundary. 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 Hawai'i 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 Hawai'i, 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 Hawai'i, 2021).^{3 4}

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 §13-222).⁵ The “shoreline” and “certified shoreline” are related but legally distinct and serve different purposes. The certified shoreline, although using nearly the

³ 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).

⁴ 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.

⁵ 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).

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 Kaua'i, *Diamond I* (2006), focused on the nuances of the shoreline certification process. The Court found that the homeowner's intentionally 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 Hawai'i 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).⁶ The use and enforcement of shoreline encroachment easements is still in flux.

Coastal Development Setbacks

Hawai'i'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 the property line to create what can be thought of as a buffer zone. In this shoreline setback area, structures are prohibited unless they obtain 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," the State Legislature via Act 16 (2020) removed this option from being available in county ordinances, leaving substantially fewer

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

justifications for variances (Lee, 2021a). The CZMA now “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 coastal hardening across Hawai‘i is now effectively prohibited to protect private property, 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 mauka of the shoreline, which is double the previous minimum of 20 ft. Kaua‘i and Maui Counties had already enacted greater, variable, erosion rate-based setbacks (Kaua‘i 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 with additions based on historic rates of erosion up to a total of 130 ft (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 shift landward. 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 Hawai‘i Supreme Court has already rejected such claims (Deputy A.G. Wynhoff & A.G. Chin, 2017). A 2017 Attorney General opinion clarified that because the State has an inchoate⁷ 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).

The government can also regulate land for the health, safety, and welfare of the public. The U.S. Supreme Court has 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 Hawai‘i. 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

⁷ “A legal right or entitlement that is in progress and is neither ripe, vested nor perfected” (Duhaime’s Law Dictionary, 2022).

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; Lee, 2021a).⁸

In Hawai‘i, the public trust doctrine and nuisance law have previously and will 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.”⁹ The question of “how much?” in the context of SLR is still unaddressed within research and legal frameworks, in Hawai‘i and elsewhere. Based on our research, condemnation has not yet been used in Hawai‘i 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 shoreline property and structures that are threatened or already being undermined by shoreline erosion for purposes of just compensation presents important and complex economic, legal, and policy issues that 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 Hawai‘i’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 SLR-XA (Act 179, 2021). Previously, the Hawai‘i 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.

⁸ 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).

⁹ 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).

III. Sea Level Rise Response

There are three generic categories of SLR adaptation responses, initially introduced by the IPCC: protect, accommodate, and retreat (Dronkers et al., 1990). To protect means to reinforce the shoreline and maintain existing land area (not to be confused with environmental protection and, in fact, is often at odds with 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. 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).

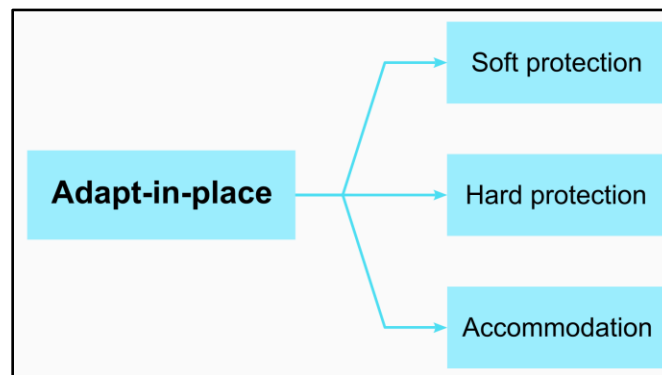


Figure 1. Adaptation in-place options

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 called “managed retreat.”¹⁰ The converse, retreat that is “unmanaged,” can be thought of as retreat that happens haphazardly and/or without shared intention.

¹⁰ 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,

Retreat from the coastline can be classified into two general approaches, proactive and reactive. 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,” a concurrent and near-term form of retreat, and “threshold-based,” where a predetermined trigger is selected and catalyzes the retreat process for a parcel. Both types of proactive retreat should be enacted 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 reactive retreat, as well as means to mitigate public risk. Figure 2 displays a flow chart of tools that are available to enact these retreat scenarios.

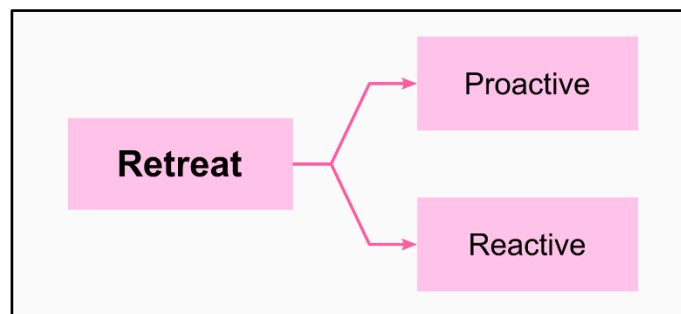


Figure 2. Approaches to implement retreat.

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). 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 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 cause to beach resources. Below, we describe several policy tools that could potentially be used to implement a retreat program.

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.”

Rolling Easements

A rolling easement enables the land ownership boundary of the shoreline to migrate inland (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 main challenges with the rolling shoreline approach are determining the party responsible for the removal of structures once they enter the easement/shoreline and enforcing actions to responsible parties. In Hawai‘i, there is little clarity 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.¹¹

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

¹¹ A coastline that is part of the Cape Hatteras National Seashore in Rodanthe, North Carolina 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 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).

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).

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, and the Building Resilient Infrastructure and Communities (BRIC) grant program. Prior to receiving any grants through FEMA's HMA program, state and local governments of 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 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). 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 and delays effective adaptation to flooding (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 Hawai'i, which may be due to the longer time scale at which SLR impacts occur compared to the sudden

impacts of rainfall flooding (Weber & Moore, 2019; Dobbyn, 2022). The only example of a federal buyout program in Hawai'i is 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). The maximum payout was \$230,000, which was the median pre-disaster (2017) total market value of properties used as primary homes (Moore, 2022).

The primary and most important existing challenge for Hawai'i to use federal buyout programs for SLR is that most federal programs tend to focus on post-disaster buyouts. Anticipating SLR is quite different from responding to a disaster event and this distinction is important in the context of maintaining Hawai'i's sandy beaches. Generally, SLR can be thought of as a "stressor" rather than a "shock" event (City and County of Honolulu Climate Change Commission, 2020). BRIC is currently the only proactive federal program of which we 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, as BRIC program funding accounts for 4% of buyouts historically (Weber & Moore, 2019). 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. The introduction of moral hazard is a common critique of the National Flood Insurance Program (NFIP)¹² (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.

¹² 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.

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 Hawai'i could be justified by the (re)establishment of the beach or coastline, because there is a clear public purpose. Eminent domain is used in Hawai'i 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 retreat approach 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.

Buyouts with Rentbacks

Buyouts with rentbacks, also called "leasebacks," are when a government entity buys a property but allows the former owner to stay on-site 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 threshold for when the property is no longer suitable for residential use and the former property owner must move out (Keeler et al., 2022).¹³ Conceptually, Hawai'i 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 Hawai'i.

Buyouts with rentbacks have been implemented in Mecklenburg County, North Carolina by the Charlotte-Mecklenburg Storm Water Services 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). The buyouts with rentbacks offered 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).

¹³ 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).

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).

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 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).¹⁴

For a true buyout with rentbacks approach to be cost-effectively implemented in Hawai'i 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 Hawai'i 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; DePasquale, 2016). 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).¹⁵ 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

¹⁴ 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.

¹⁵ 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).

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).

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 for requirements such as parking or open space (Nelson et al., 2011). In contrast to other purchase of development rights programs (like conservation easements) which typically use grant or taxpayer dollars to purchase and retire development rights, TDR can be funded by developers and, thus, has relatively low direct public cost (Kaplowitz et al., 2008). Municipalities can create a TDR bank and incentivize the purchase of development credits as needed to balance the market such that receiving area developers and sending area property owners would participate (Machemer & Kaplowitz, 2002). However, TDR has potentially notably high indirect public cost in the form of development that may have otherwise been thought to be undesirable by the community (i.e., not currently allowed by zoning), as well as pushes costs to new buyers.

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 TDR program focused on land restoration can offer incentives to sending area property owners for things such as early participation, demolishing existing structures, and restoring the property to native habitat at the time of transfer (Nellermoe, 2016).

TDR 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, is a barrier to a functioning voluntary TDR program 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).

In Hawai'i there have been recent attempts to implement a TDR program. The passage of H.B. 1436 in the 2022 Hawai'i 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 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 five 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 (Lee, 2021b). Currently there is no precedent for land swaps in Hawai'i, and if this tool is to be considered, the implications for the public must be carefully examined.

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

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 Paumalū¹⁶ ahupua‘a on the island of O‘ahu, as shown in Figure 3 below. The North Shore Coastal Resilience Working Group’s (2022) report found retreat is the only viable long-term solution for Sunset Beach, given the history of chronic and episodic erosion and the importance of the beach to residents and tourists. Within this area, there are 52 parcels adjacent to or makai of the 3.2 ft SLR-CE line and 83 parcels adjacent to or makai of the 3.2 ft SLR-XA border (shown in Figures 8 and 9). In our study area, there are approximately 200 people residing within 3.2 ft SLR-CE, and about 400 people residing within 3.2 ft SLR-XA.¹⁷ 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 O‘ahu (Cocke, 2022a). Additionally, this is an area with prime beach, ocean and surfing conditions. 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.

¹⁶ 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).

¹⁷ 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 Hawai‘i, 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 ahupua'a, 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).

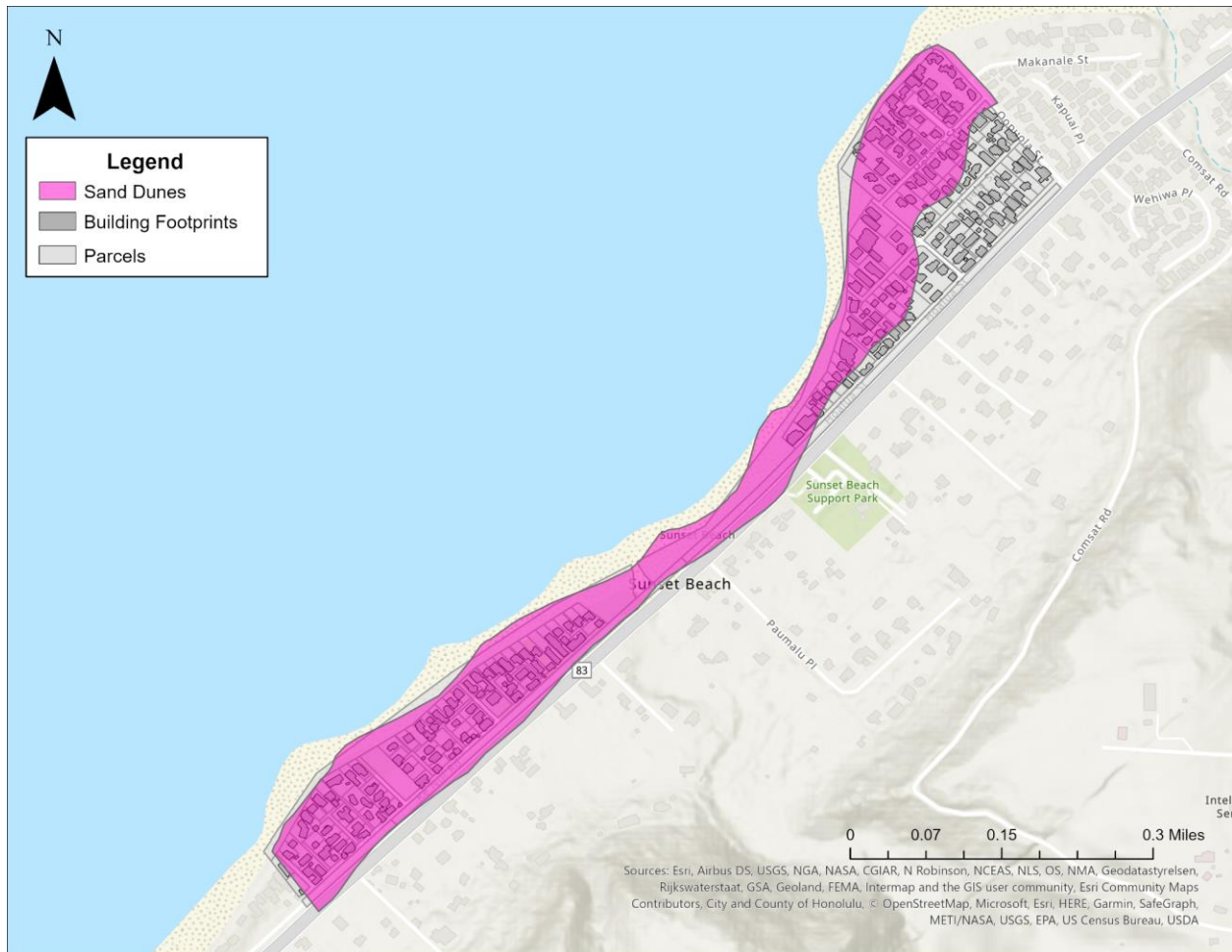


Figure 4. Sand dunes in case study area (from USDA NRCS Soil Survey). Due to construction of dwellings on top of sand dunes and accelerated erosion, sand dunes may have depleted or shifted.

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 frequently results in 20 ft sand cliffs (Wu, 2017b), or no beach at all in locations with protection measures (Cocke, 2021). As illustrated in Figure 5, there is an overall trend towards erosion in this area.¹⁸

¹⁸ 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 O’ahu vary depending on seasonality, there is documentation of chronic erosion occurring in this area, which can be seen in the changes in vegetation (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; Fletcher et al., 1997; 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 §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. 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 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 on-site sewage disposal systems (OSDS), consisting mainly of cesspools (Hawai'i 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 (Hawai'i Sea Grant, 2020).¹⁹

Case Study Approach

We operationalize two types of proactive retreat and one reactive. The first is all-at-once retreat, meaning that properties are acquired and retreated simultaneously and as soon as possible. Next is threshold-based retreat, which uses a predefined “trigger” for retreat. For our purposes, threshold-based retreat occurs when the projected erosion boundary is within 20 ft from a dwelling or infrastructure. Last, reactive retreat occurs when the erosion line has passed the dwelling or infrastructure’s makai boundary. Figure 6 displays the differences in retreat approach as used in the case study.

¹⁹ Act 125 (2017) requires all cesspools in Hawai'i to be converted to septic systems by 2050.

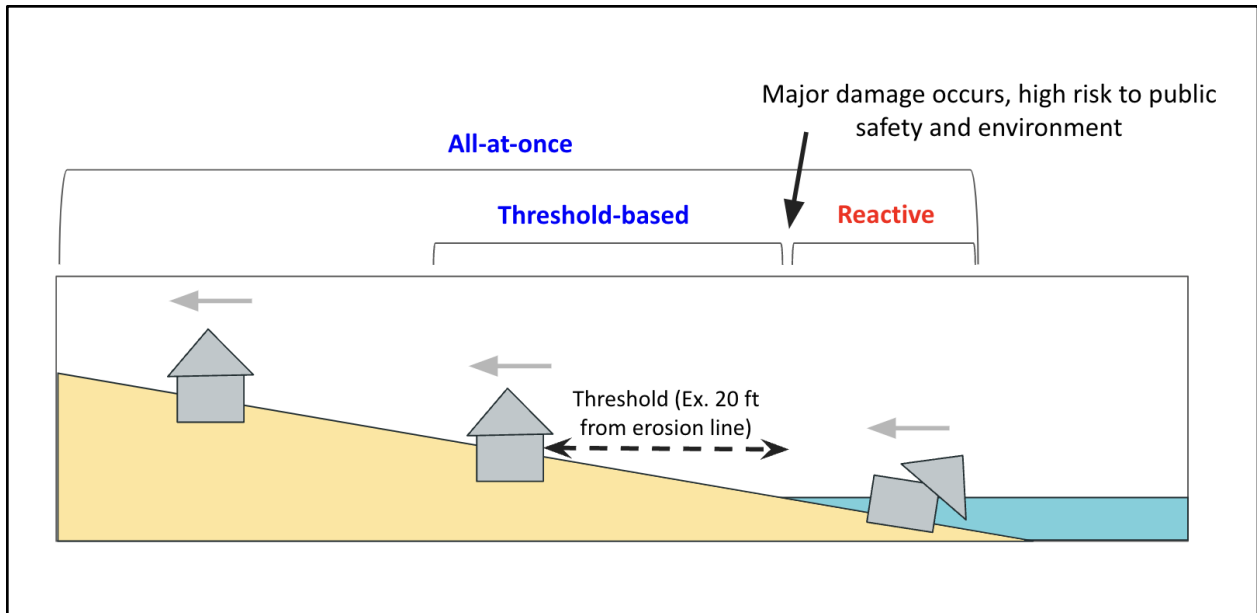


Figure 6. Depiction of retreat framework. Managed retreat approaches are shown in blue (all-at-once and threshold-based), and unmanaged retreat is shown in red (reactive).

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 retreat by the different retreat approaches within the study area. 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). The costs identified are relevant to communities with sandy beaches and natural coastlines (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.

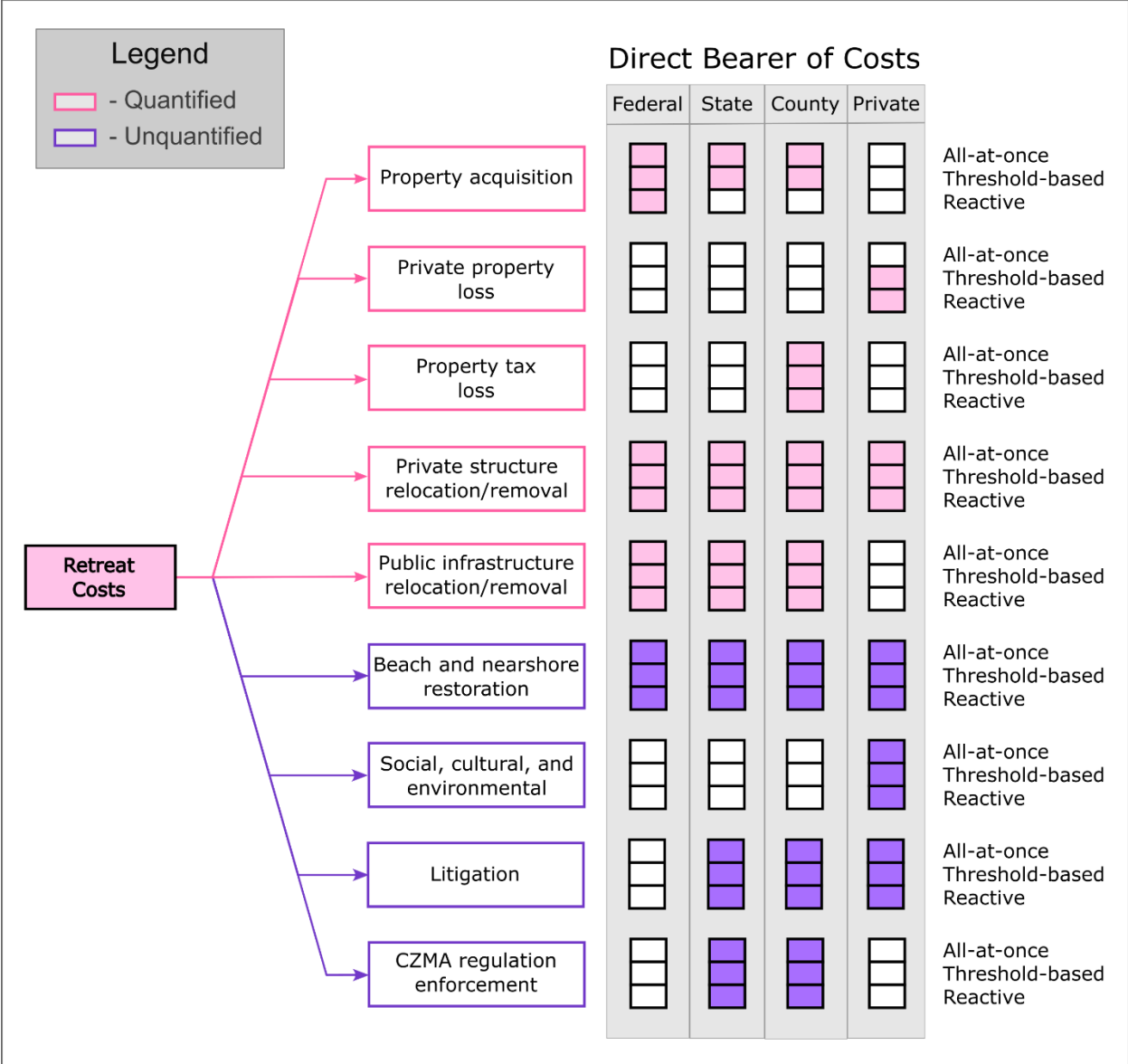


Figure 7. Types and bearers of costs related to retreat. A filled in box indicates if the burden of the cost is directly borne to an actor at each retreat approach (broader incidence is outside of the scope of this analysis). The cost categories that are operationalized and quantified within this case 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); loss of property tax revenues; and private property loss. Unquantified costs include litigation and enforcement costs as well as other and social, cultural and environmental costs. For example, potential loss of community cohesion due to dislocation (Mach & Siders, 2021). There are also 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). These incidents give insight into how the local community might be affected when coastal hazards reach 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 since 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 the variation in the costs of retreat relate to how long the community and its dwellings stay in place, rather than full degradation of the beach. If we were to study the difference in cost between 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 first dataset used is the SLR 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 applicable exemptions (City and County of Honolulu Department of Budget and Fiscal Services, 2021). The assessor's data is used 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., 2023), which is not accounted for in this study. The last datasets used are geospatial data for parcels, dwellings, and infrastructure (roads, bridges, and OSDS) (Hawaii State Office of Planning, 2022). There is no municipal wastewater or stormwater in the study area. Due to potable water geospatial data not being publicly available, we applied the reasonable assumption that potable water mains and laterals are housed within the roads of the study area.

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 Hawai'i 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

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 of SLR, which are related to years 2030, 2050, 2075, and 2100, respectively.²⁰

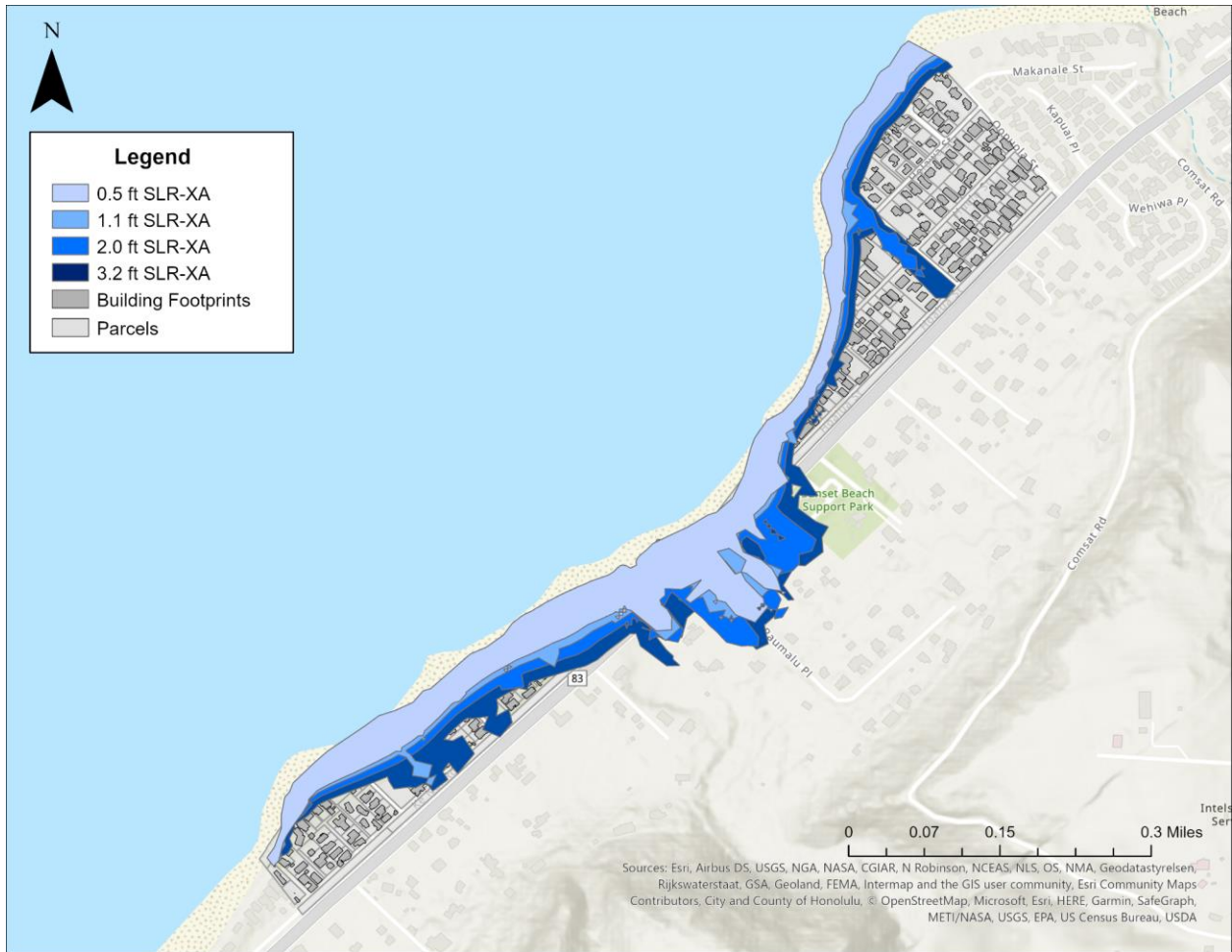


Figure 8. SLR-XA projections in the case study area.

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. 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.

²⁰ Using Representative Concentration Pathway 8.5 from IPCC Fifth Assessment Report.

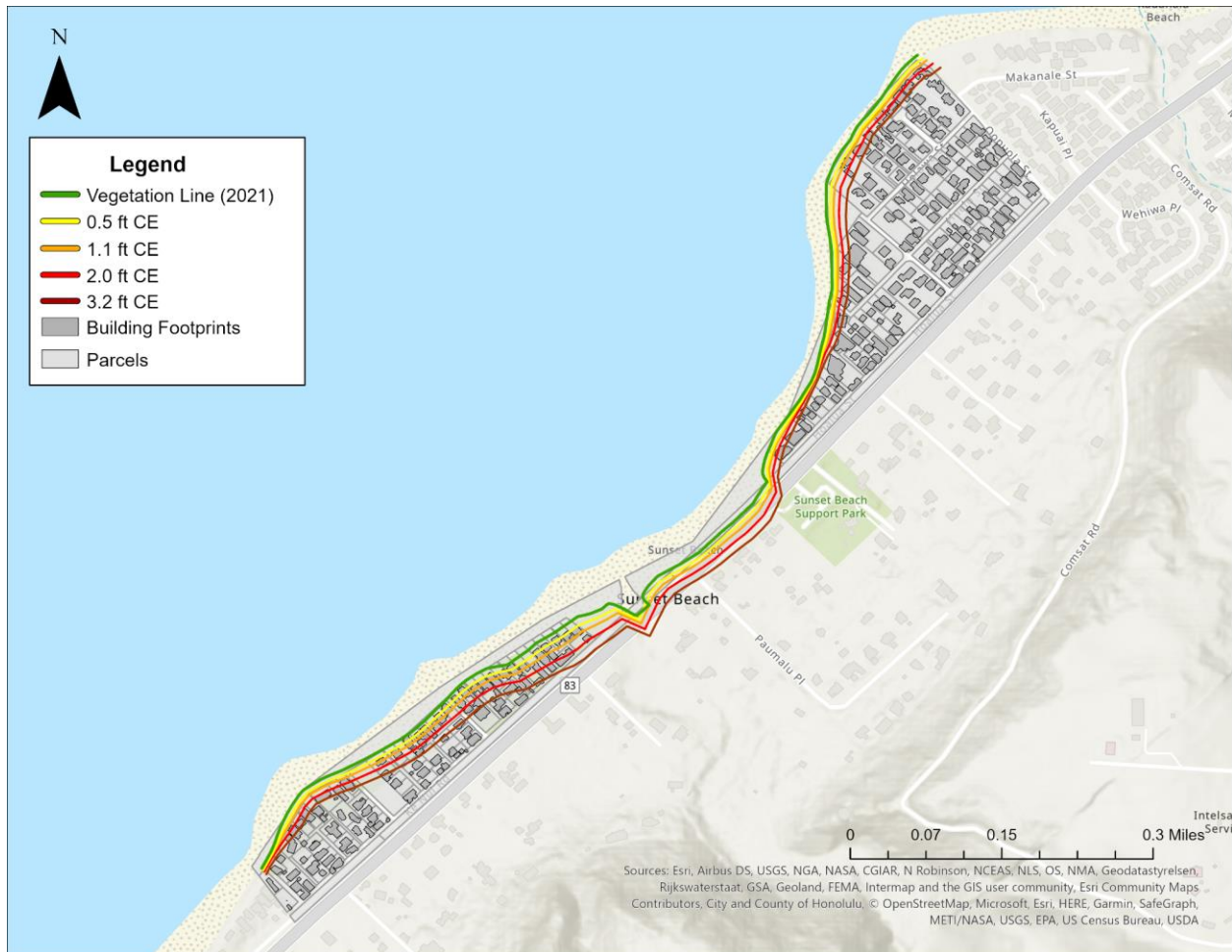


Figure 9. SLR-CE projections in the case study area. The most recently available vegetation line (2021) is included to illustrate the approximate shoreline.

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.

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.

The most extreme scenario for all-at-once retreat (All-at-once-XA) is that all parcels intersected by or within the 3.2 ft SLR-XA projection are acquired 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 with dwellings intersecting or makai of the 3.2 ft SLR-CE projection that are acquired 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.



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 consider two scenarios, where land transfer is determined through either (1) SLR-XA or (2) SLR-CE. 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., 2023). 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 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 chose 20 ft as the threshold since a property is considered “imminently threatened” if an eroding shoreline is 20 ft 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 year 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).

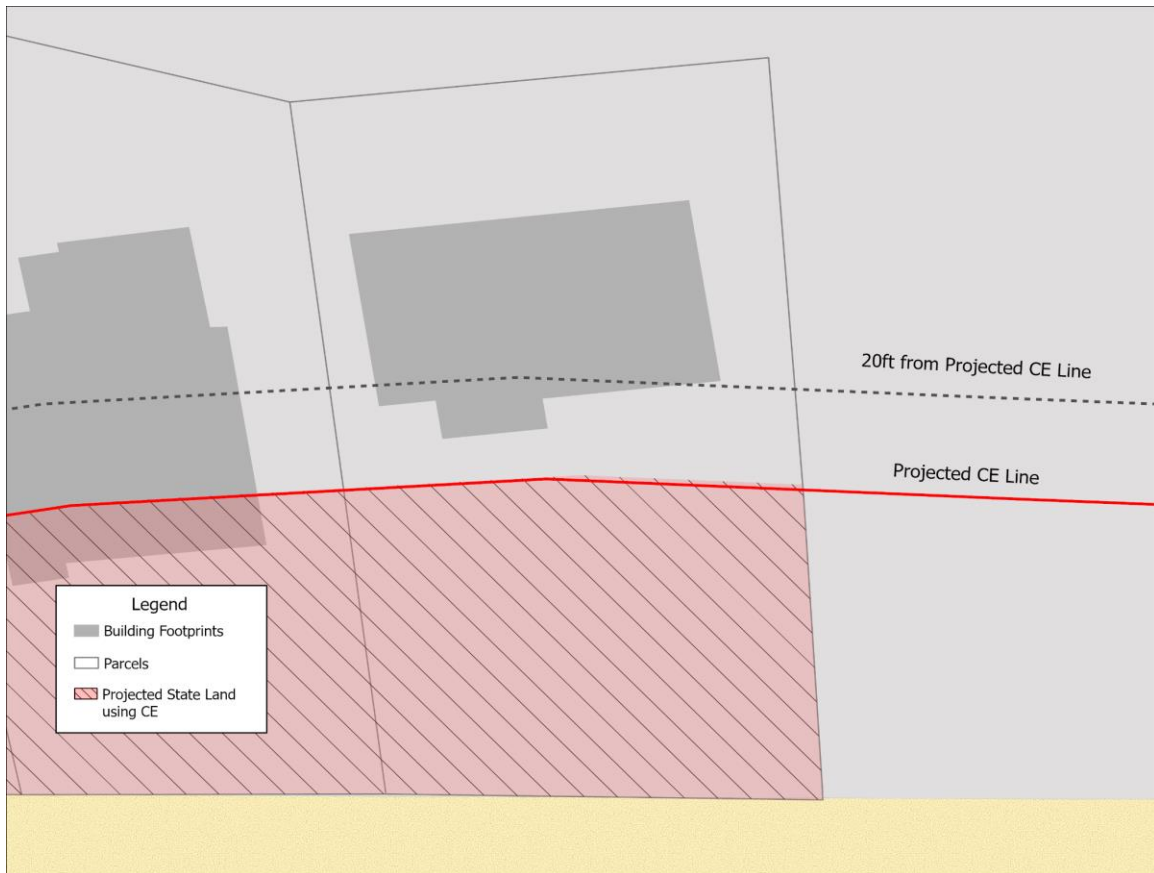


Figure 13 Threshold-based-Veg scenario for parcels and buildings.

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, to address the scenario of the coastal erosion line nearing the dwelling, we assume no dwelling value remains—only the remaining land value is compensated (Figure 14). The same number of affected parcels and dwellings are affected in both threshold-based scenarios.

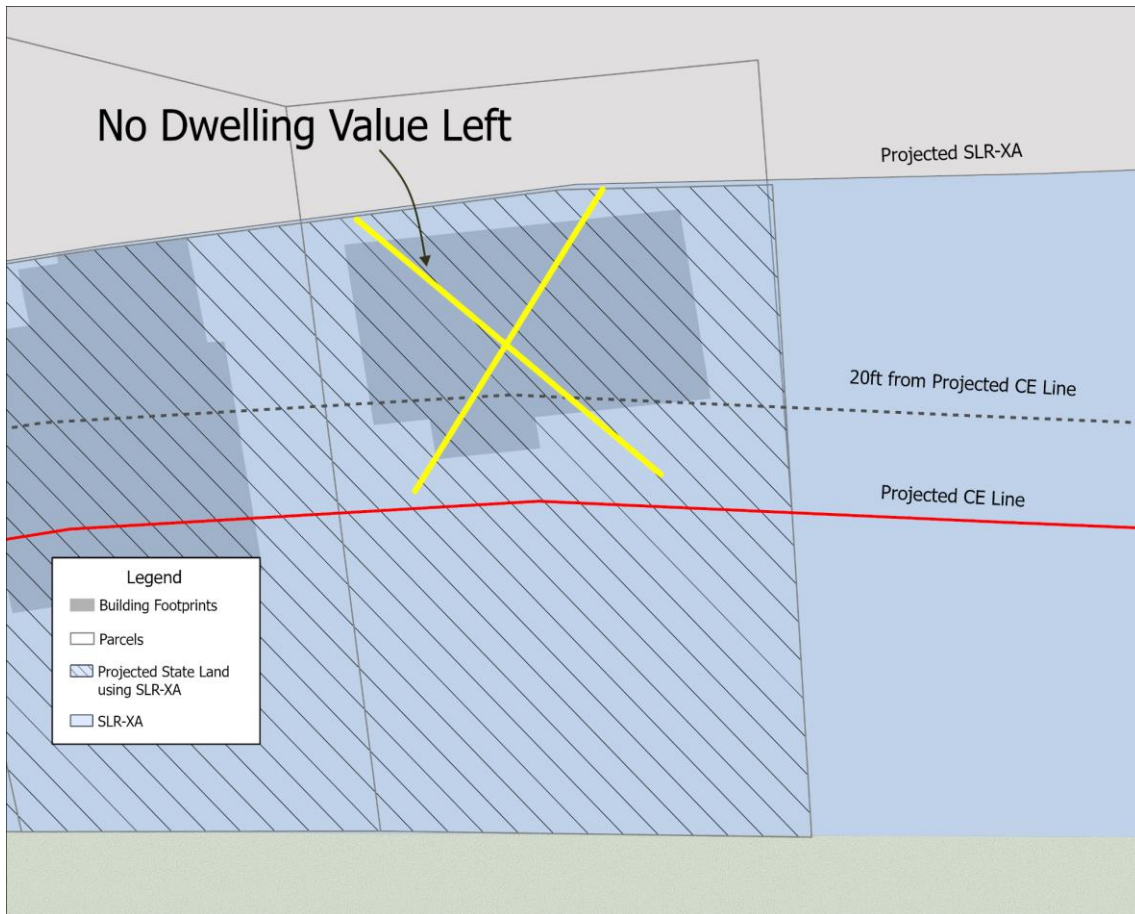


Figure 14. Threshold-based-Wave scenario for parcels and buildings.

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 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 of SLR. The values are in \$2021 using a 3% discount rate for public infrastructure, which is akin to the long-term bond rate.

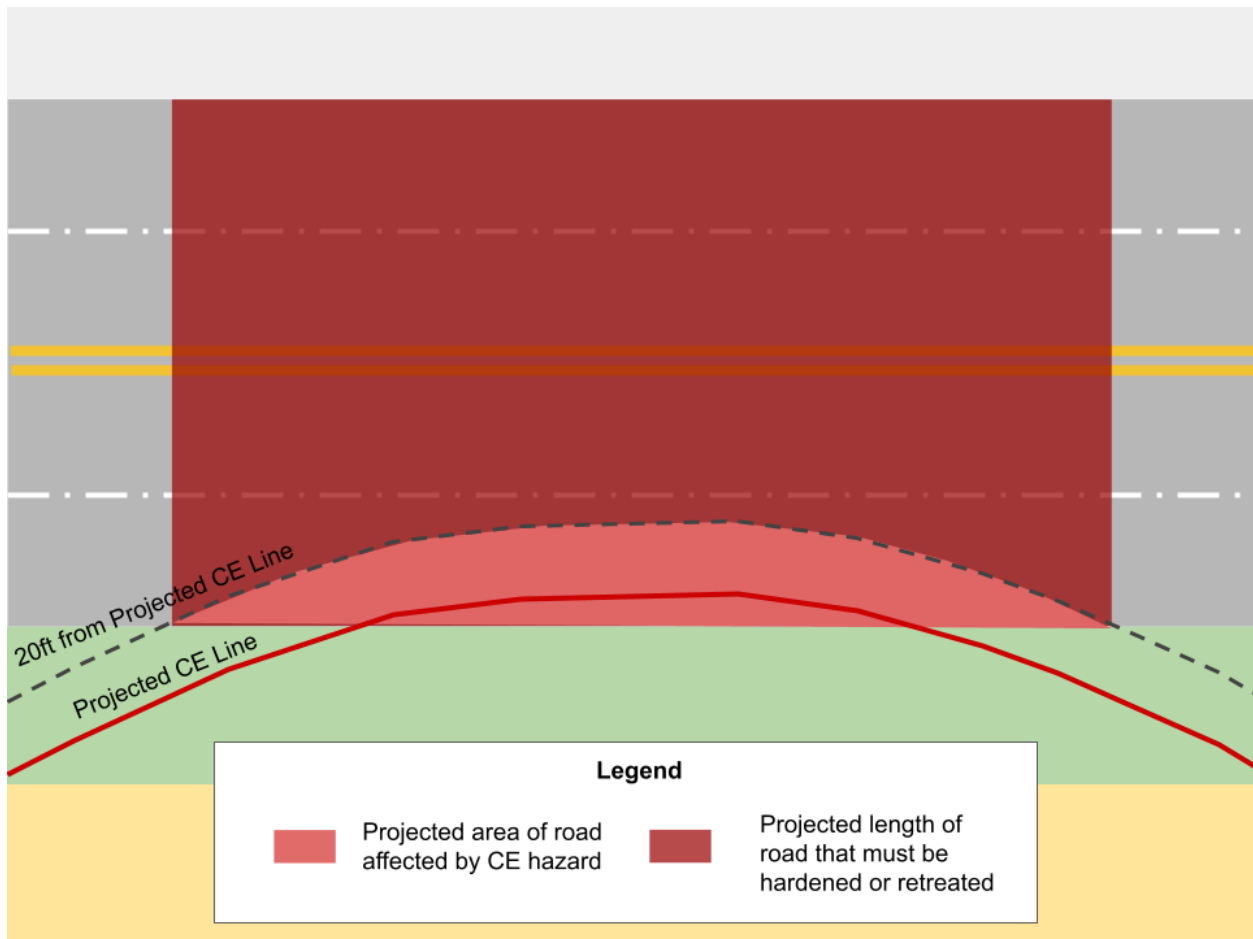


Figure 15. Threshold-based scenario for roads.

Reactive Retreat

Reactive retreat occurs 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 risk, 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 are 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, prompting the need for a crew to also be working offshore.

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. The higher clean-up cost option is added to the Reactive-Veg scenario to give the highest potential bound in the range of total costs.



Figure 16. Reactive-Veg scenario for parcels and buildings.

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 county development 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. Reactive-Full Loss scenario for parcels and buildings.

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).

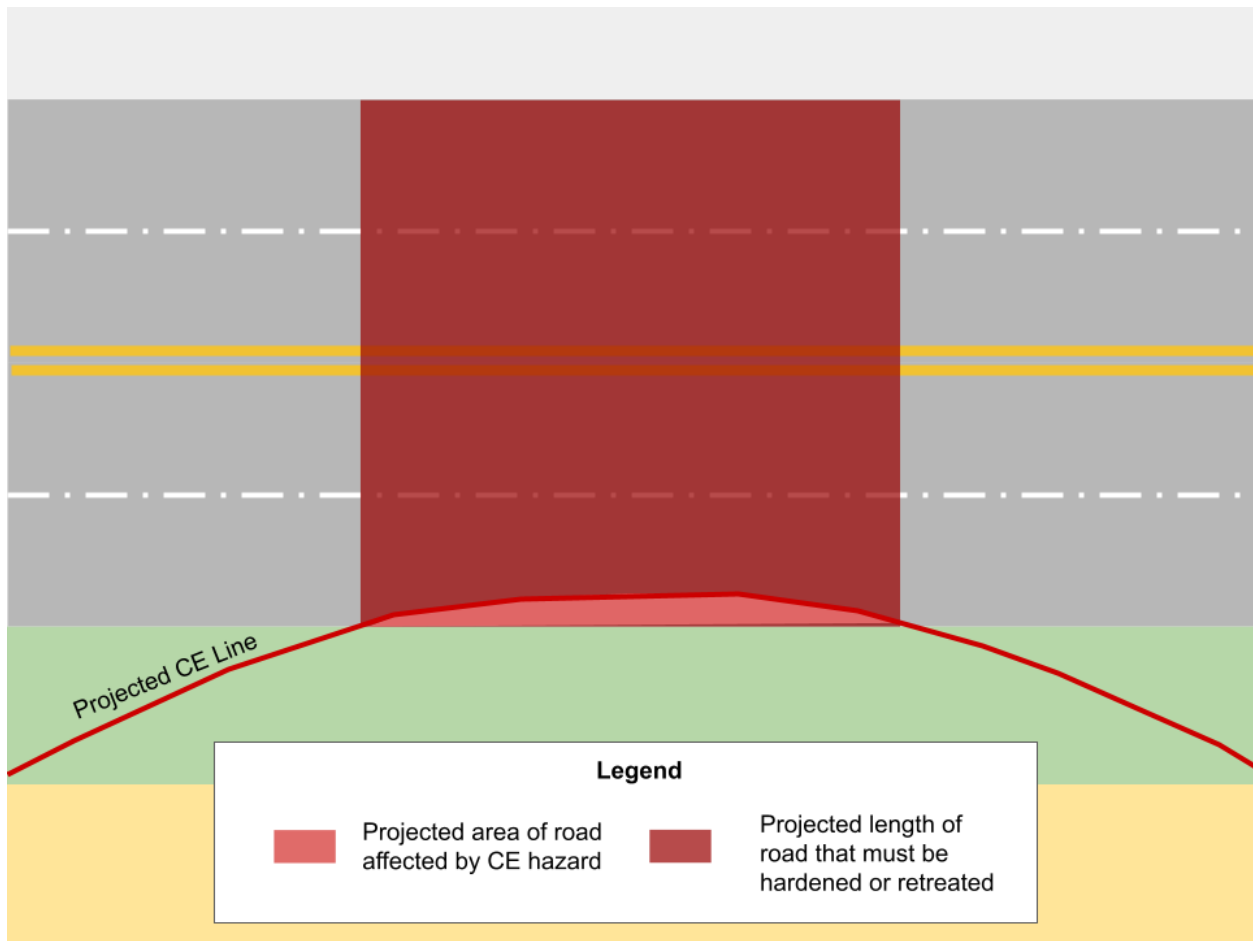


Figure 18. Reactive scenario for roads.

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.²¹ 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.²²

²¹ 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.

²² 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.

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, decommissioning, condemnation, and retrofitting of various infrastructure.

Table 1. Summary of scenarios.

Approach	Scenario	Dwelling Retreat Criteria	Land Transfer Criteria	Infrastructure Retreat Criteria
All-at-once	All-at-once-XA	3.2 ft SLR-XA	Full value	3.2 ft SLR-CE
	All-at-once-CE	3.2 ft SLR-CE		
Threshold-based	Threshold-based-Veg	≤20 ft from SLR-CE	SLR-CE	Harden ≤ 20 ft SLR-CE, retreat all at 2100 using 3.2 ft SLR-CE
	Threshold-based-Wave		SLR-XA	
Reactive	Reactive-Veg	Intersecting or makai of SLR-CE	SLR-CE	Harden road intersecting or makai of SLR-CE, retreat all at 2100 using 3.2 ft SLR-CE
	Reactive-Full Loss		No value left	

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. 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 home	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	All-at-once; Threshold-based	Babcock et al. (2019).
Structural debris clean-up	Post and pier, dwelling stays intact: \$10,000 - \$25,000 per home. Slab foundation, dwelling breaks apart and falls into ocean: \$100,000 - \$200,000 per home	Reactive	Estimated based on average values obtained from quote requests from local engineering and construction companies; extreme values are used for the range.

Remaining Retreat Costs

Other costs of retreat for the case study area include tax revenue loss and private property value loss. Tax revenue loss is calculated under the assumption 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,²³ 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 remaining values (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 direct 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. *Includes OSDS removal

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

Findings

Costs of Retreat

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. Table 4 shows the number of parcels and buildings categorized as all-at-once (XA and CE), threshold-based and reactive for each time period.

²³ 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).

Type of data	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 19, in Table 5 we display the range of total costs for each retreat approach (and each scenario therein). Figure 20 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).

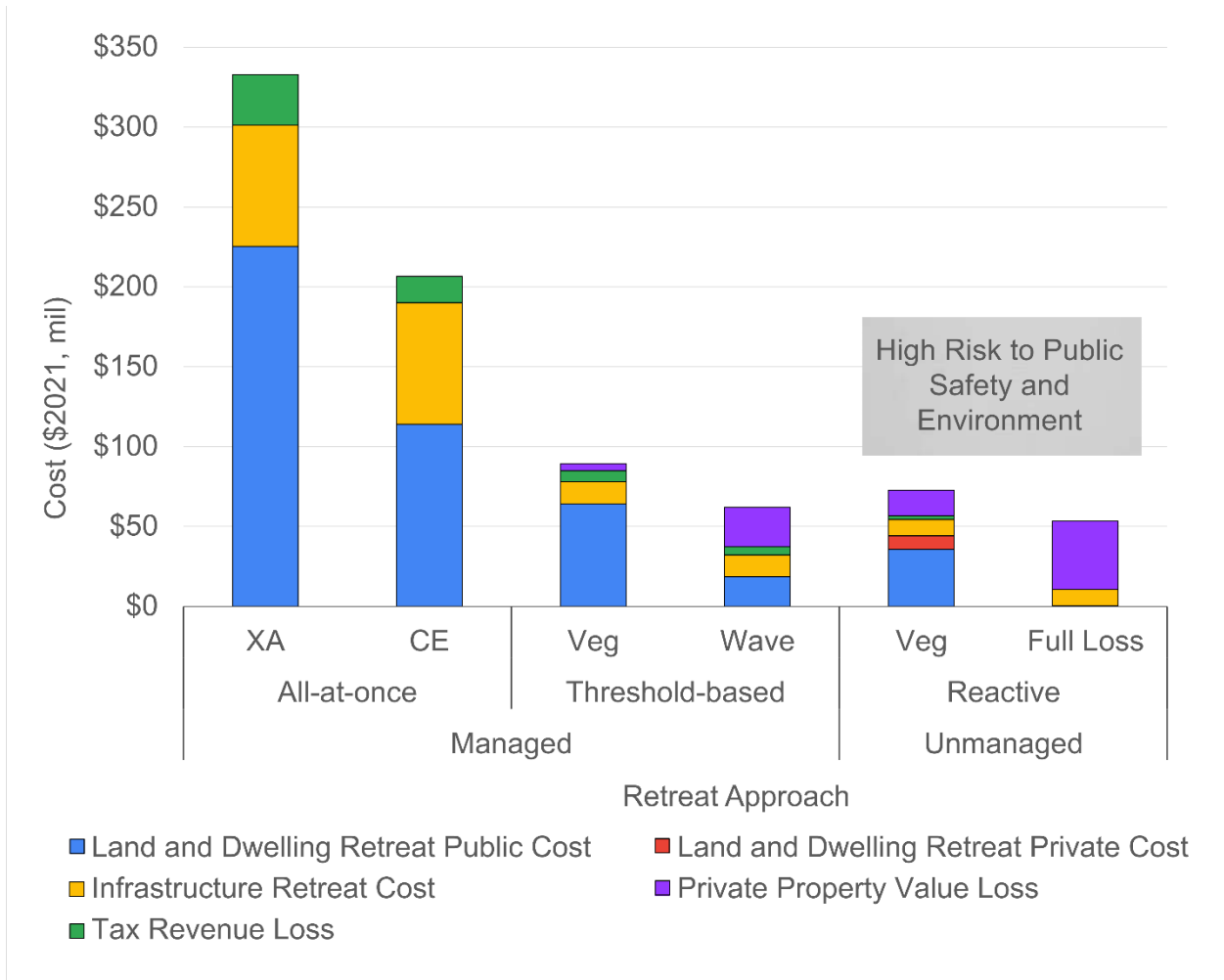


Figure 19. Costs of retreat approaches, by type of cost.

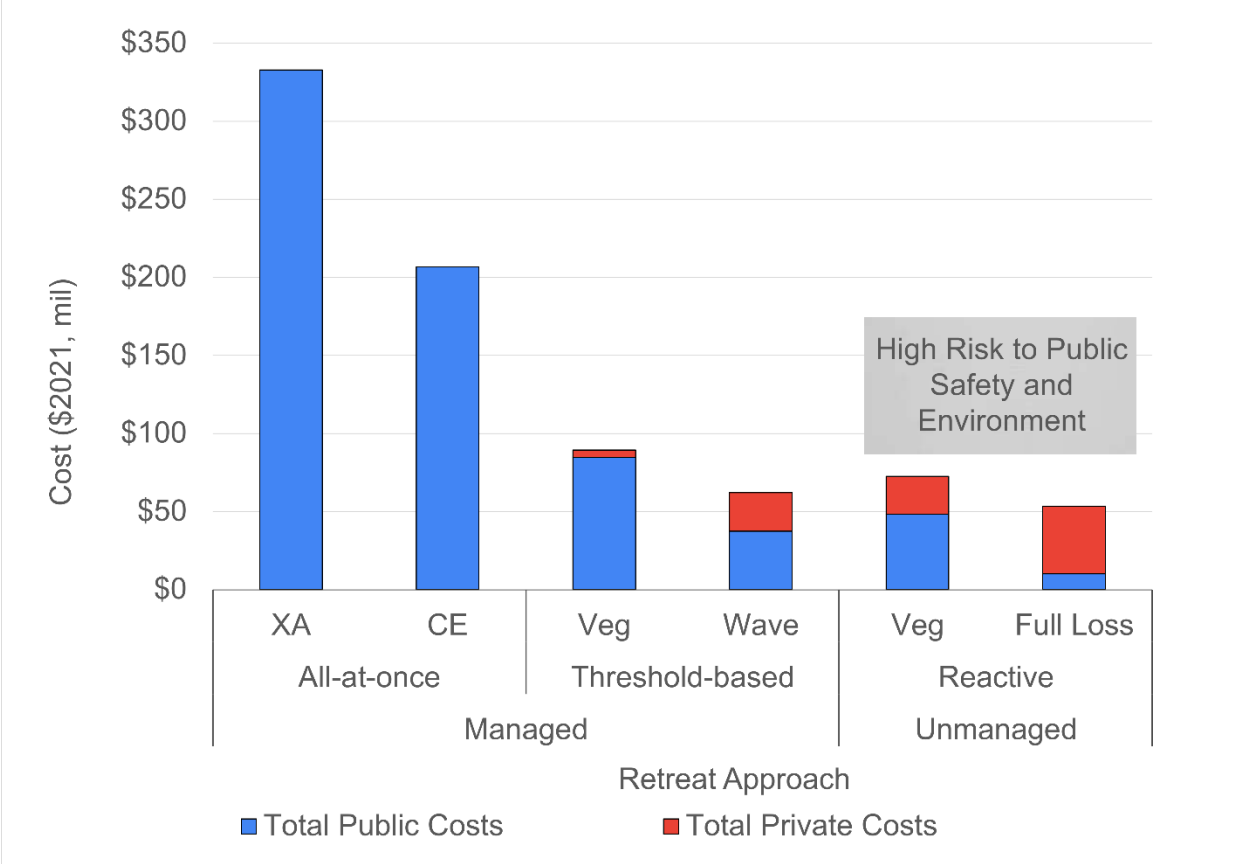


Figure 20. Public and private costs for three retreat approaches. Blue represents costs borne to the “public,” and red to the “private.”

Table 5. Underlying results shown in Figure 19 – 21.

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 as real dollars expressed using 2021 assessed values (Figure 21).²⁴

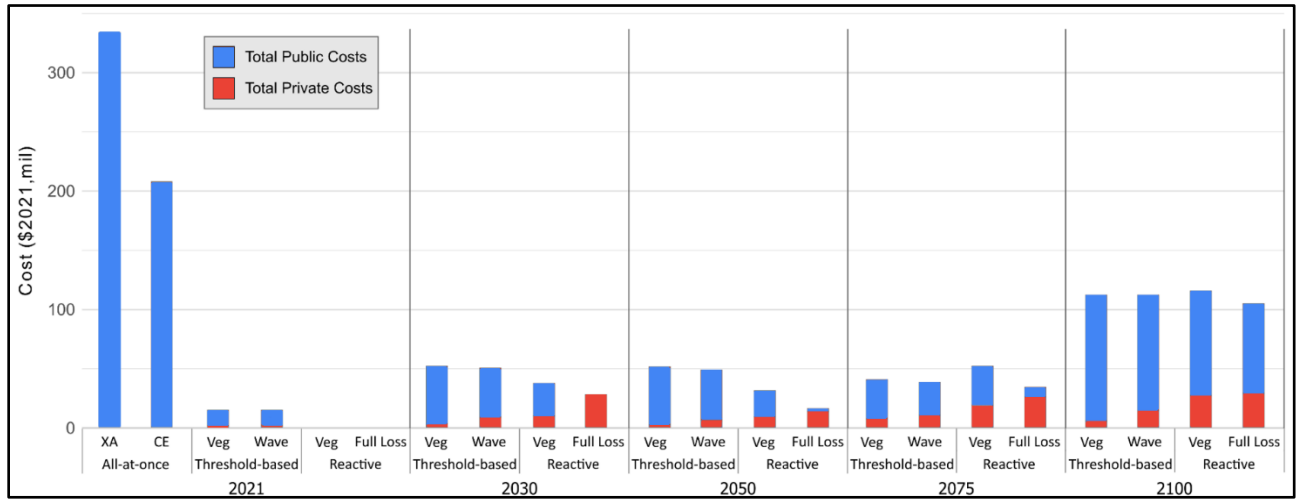


Figure 21. Retreat approach costs disaggregated by timing.

²⁴ 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.

All-at-once

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, accrue 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 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 enforcing the 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 retain their asset for a longer duration in reactive retreat, this time is not considerably longer than in the threshold-based scenario, and, thus, 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.²⁵ For this reason, private property owners experience the highest costs in this scenario.

Benefits of Retreat

While we do not claim 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.

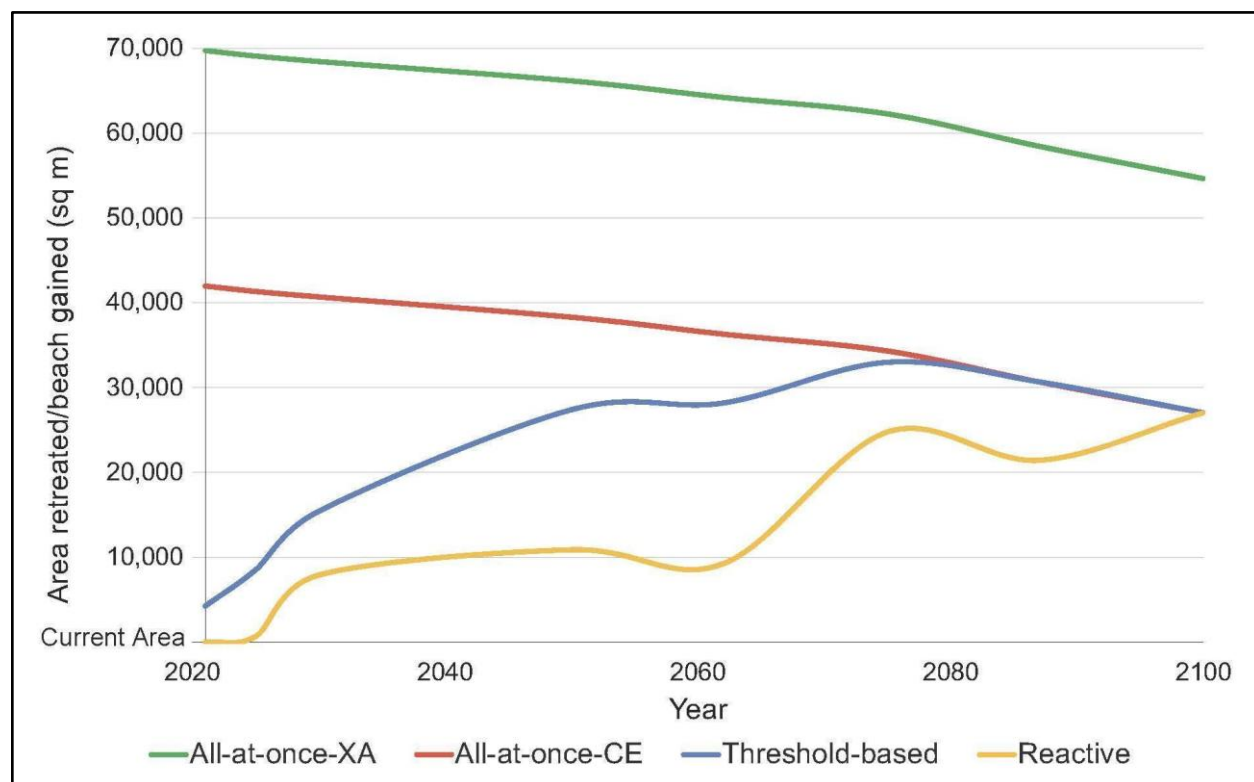


Figure 22. Case study beach area gained by retreat approach.

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 Figure 22, 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

²⁵ 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.

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 retreat scenarios consider the full loss of the beach, we nonetheless felt it 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 visitor information from a similar beach survey. The travel cost model 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 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).²⁶ In existing literature, there is a wide range for annual beach value due to the place-specific nature of these valuations, for example ranging 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 simplified and single-site modeling approach may overestimate the value by excluding the possibility of visitors going 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 care for future generations (National Research Council, 2005). More research is needed across Hawai’i on the value of beach resources to better inform tradeoffs as it relates to management decisions, particularly adapt-in-place.

²⁶ 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 Hawai’i 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 O’ahu 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 unexplored in our cost estimates is the potential environmental remediation required for older structures containing pollutants such as asbestos and lead. We note 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 the demolition of properties occurs, if environmental remediation is found to be required, costs can increase drastically.

The legal definition of the shoreline 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, as discussed previously). With a dataset on real estate transactions from Zillow going back to 1989, we find that 80% of beachfront parcels have transacted since 2006, with the most occurring recently between 2018 and 2022 (Figure 23). Only two of the 61 beachfront parcels in the study area were purchased before 1989 and thus the vast majority, if not all, of the properties have transacted since the rolling shoreline was established.

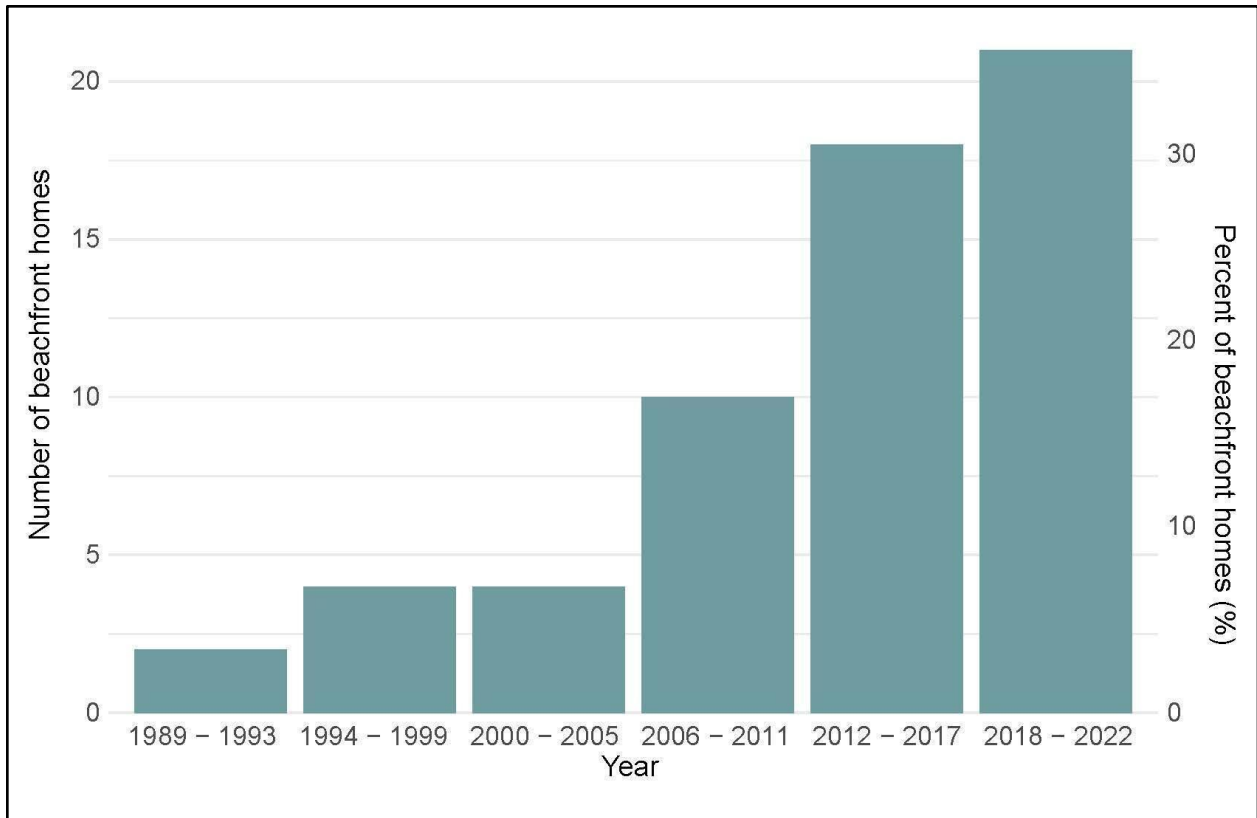


Figure 23. Most recent transaction year for each beachfront home in the case study area.

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., 2023), we acknowledge the limitation of relying on the assessor’s data. First, the assessor’s data reflects 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 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, there are 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 with no obvious clusters. Of these listings, 90% are listed as entire homes. Rental incomes 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

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 asset demolition, clean-up, and/or relocation 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 2023 assessor’s data.²⁷ 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 total assessed value for each parcel 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 24 displays the distribution of value within 3.2 ft SLR-XA at 2100 by property type.

Table 6. Total 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 Value (\$2023, mil)	\$3,734.8	\$4,838.1	\$7,772.1	\$18,605.0
% of Total Value within SLR-XA	1.0%	1.3%	2.1%	5.0%
Total Tax Revenue within SLR-XA	\$289.6	\$368.9	\$613.1	\$1,521.9
% of Tax Revenue within SLR-XA	1.5%	1.9%	3.1%	7.8%

²⁷ 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 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 as a result of data compilation or processing errors.

Table 7. Total assessed value within SLR-XA by property types for O'ahu, Hawai'i.

		SLR-XA 0.5 ft		SLR-XA 1.1 ft		SLR-XA 2.0 ft		SLR-XA 3.2 ft		
Property Type	Total Value (\$2023, mil)	\$2023 Total value within SLR-XA (\$2023, mil)	% of Value by Property Type	\$2023 Total value within SLR-XA (\$2023, mil)	% of Value by Property Type	\$2023 Total value within SLR-XA (\$2023, mil)	% of Value by Property Type	\$2023 Total value within SLR-XA (\$2023, mil)	% of Value by Property Type	% of Total Value
Agricultural	\$1,830.3	\$9.0	0.5	\$10.8	0.6	\$17.7	1.0	\$45.3	2.5	0.0
Vacant Agricultural	\$49.0	\$0.3	0.6	\$0.4	0.8	\$0.6	1.3	\$1.4	2.8	0.0
Commercial	\$36,575.3	\$189.5	0.5	\$257.2	0.7	\$524.4	1.4	\$1,383.4	3.8	0.4
Hotel and Resort	\$22,284.9	\$885.6	4.0	\$1,055.7	4.7	\$1,777.4	8.0	\$5,217.2	23.4	1.4
Industrial	\$19,459.2	\$43.0	0.2	\$89.5	0.5	\$319.6	1.6	\$871.3	4.5	0.2
Preservation	\$670.8	\$26.7	4.0	\$32.5	4.9	\$40.9	6.1	\$55.4	8.3	0.0
Public Service	\$1355.3	\$10.2	0.8	\$12.0	0.9	\$18.2	1.3	\$32.0	2.4	0.0
Residential	\$239,207.8	\$1,451.7	0.6	\$1,941.3	0.8	\$3,018.0	1.3	\$7,105.9	3.0	1.9
Residential A	\$48,647.2	\$1,118.7	2.3	\$1,438.5	3.0	\$2,055.4	4.2	\$3,893.0	8.0	1.1
Total	\$370,079.8	\$3,734.8	1.0	\$4,838.1	1.3	\$7,772.1	2.1	\$18,605.0	5.0	5.0

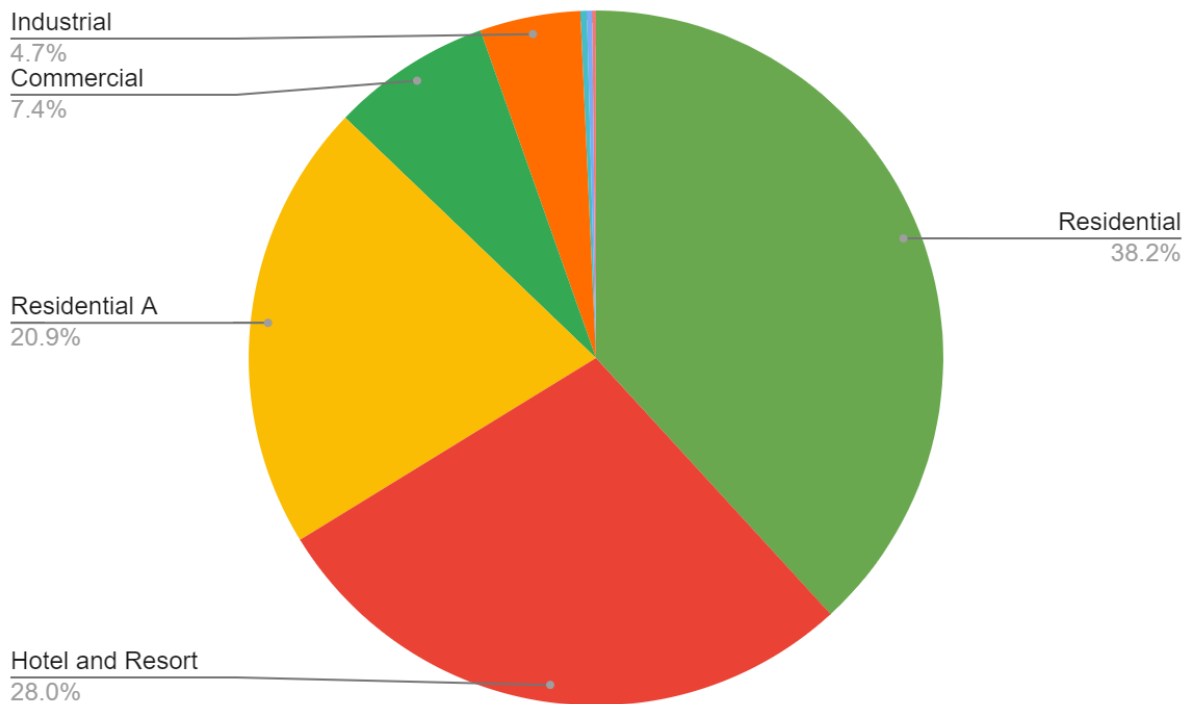


Figure 24. Property type of total exposed assessed (2023) value within 3.2 ft SLR-XA.

Taking the linear percentage of SLR-XA area to property value, a total of \$18.6 billion (5%) of O’ahu’s property value lies within 3.2 ft SLR-XA. This accounts for almost 8% of CCH property tax revenues. We also find that exposure to SLR-XA increases greatly from 2.0 ft to 3.2 ft of projected SLR. The property type with the highest total assessed value in SLR-XA is residential (where residential plus residential A are 60% of the land value in SLR-XA 3.2 ft). Next is Hotel and Resort, at 28% of the property value.

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 property values and tax revenues, it is likely that there is a shifting landscape of value inland (Keenan et al., 2018). Literature suggests some areas vulnerable to SLR are relatively decreasing in value (Bernstein et al., 2019; Tyndall, 2021).

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). 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, which likely biases the estimates downward.²⁸

²⁸ 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. These numbers are likely an underestimation for rural areas because their census blocks are typically much larger than the built area.

VI. Conclusion

General responses to SLR include protect, accommodate, and retreat. Beaches in Hawai'i are protected for public use and statutes require the State maintains beach access and beaches themselves, meaning 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 ahupua'a, extending from Rocky Point to Sunset Point on the North Shore of O'ahu. We compare key costs of approaches to retreat from the shoreline, categorized as all-at-once, threshold-based, and reactive retreat, informed by O'ahu'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 Hawai'i 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 (\$2021) in the case study area. The range of costs is due to the variation in area assumed to be retreated.
- All-at-once retreat is most likely enabled through full market buyout programs. Such a program introduces incentive to Hawai'i coastal investors to not fully incorporate future risk in their decision-making, which could pose additional costs for adaptation across the island and state. As such, private landowners are financially best off under an all-at-once retreat approach.
- Threshold-based retreat is substantially lower in cost than all-at-once within our case study area, 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 in our case study area, 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, which 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 (and represented within our scenarios) are dependent on the enforcement of the state's shoreline regulations, including enforcement of the definition of the shoreline to the highest wash of the waves and 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.
- Lastly, the 3.2 ft SLR-XA has approximately 28,000 O'ahu residents within its boundaries, as well as \$18.6 billion (5%) in property value. The largest proportion of property types within SLR-XA are Residential, Residential A (i.e., investor-owned), and Hotel & Resort.

In conclusion, we find the threshold-based approach merits further inquiry as an improvement towards a more proactive approach to retreat than today's status quo. The threshold-based approach has comparable costs to reactive retreat and largely mitigates public safety concerns. The all-at-once approach is appealing from the perspective of beach area gained, and more research is needed to understand dune restoration dynamics and the human and ecological values provided by maintained 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 build 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.

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