The Nature Conservancy
Hawaiʻi and Palmyra

Increasing Resilience of Coral Reefs and Coastal Communities in Olowalu, Maui, by Managing Land-Based Sediments

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Cover photo: Drew Sulock

Foreword

Since launching this work in 2019 and submitting our interim report in 2022, tragedy struck West Maui on August 8, 2023. The deadly wildfire that claimed the lives of at least 102 people and destroyed the beloved town of Lahaina reverberated throughout the island, the state, and the world. In the immediate aftermath, we united to support our home and our community, to mourn with those who lost their loved ones and their homes, to shelter and feed our community members in need, and to identify and implement the conservation actions necessary to mitigate impacts from the fire.

This tragedy reinforced the urgency of efforts discussed in this report to address challenges in high-risk leeward areas where arid conditions, drought, and fire-prone invasive species increase vulnerability to fire. The research and potential interventions the report highlights will help us address those challenges, reduce sediments on the reef, and build resilience to fire and other growing climate threats.

Authors' Notes

With an increased use of "Lāhainā" after the fire, we consulted community members and cultural experts for guidance on which spelling to use. Based on their recommendations, we continue to use the more common spelling and pronunciation of Lahaina without any diacritical marks.

Unless otherwise specified, references to Olowalu throughout this report refer to the project area: the ahupuaʻa of Olowalu and Ukumehame.

Unless otherwise specified, references to the Olowalu reef throughout this report encompass the reef areas of Olowalu, Olowalu Point and Ukumehame that together comprise a 939-acre reef.

Contents

1. Introduction

1.1 Need and Opportunity

Figure 1: The Olowalu reef is in West Maui, five miles south of Lahaina. Photo: TNC

Located south of Lahaina in West Maui, the expansive Olowalu reef is a social, cultural, and economic resource for Maui's people and an important source of larvae for other reefs in Maui Nui. It has been identified as one of Maui's most essential reefs to protect.

The reef and its associated marine life are integral to the community and the perpetuation of Hawaiian culture and traditional practices. The sacred creation chant Kumulipo teaches that the koʻa, or coral polyp, was the first organism to emerge from the darkness, the most ancient ancestor. By pairing land and sea life forms, the chant also shows that life in the sea and on land is inextricably connected, that what we do on land impacts our ancient sea-dwelling ancestors. This connection is clearly visible at Olowalu.

Surveys in recent decades show that local and global stressors have been detrimental to reef health. Poor water quality is a primary stressor to the coral reef ecosystems at Olowalu, with eroded sediments as the major contributor. The erosion and sediment flows stem from a combination of factors. Throughout the 20th century, land conversion and stream diversion to support sugar production and ranching and the introduction of invasive plants and free-ranging ungulates significantly degraded upland habitats and altered wetlands and other coastal habitats to the point that they no longer absorb and filter stormwater and sediments. Existing sediment retention infrastructure is insufficient, resulting in excessive sedimentation on the reef.

Declining rainfall and rising temperatures make the already degraded habitats more susceptible to wildfires. Fires fanned by the area's consistently high winds exacerbate the loss of native vegetation, and an explosion in the Axis deer population compounds the problem (Anderson 1992; Hess et al. 2015; Hess and Judge 2021).

The eroded sediments smother reef organisms, prevent new coral from settling, and by clouding the water, reduce light available for coral and algae to photosynthesize. As a result, reef growth, structure, and function are compromised and reefs are less resilient to other stressors, including coral bleaching and other impacts of climate change. Sea level rise is already taking a toll on the shoreline at Olowalu, which is impacted by beach erosion and chronic flooding. Hardened, or "grey", structures such as sea walls and concrete barriers have been installed to mitigate the erosion and flooding to the highway, however, these interventions perpetuate coastal and reef degradation by generating additional turbidity and reflective wave action.

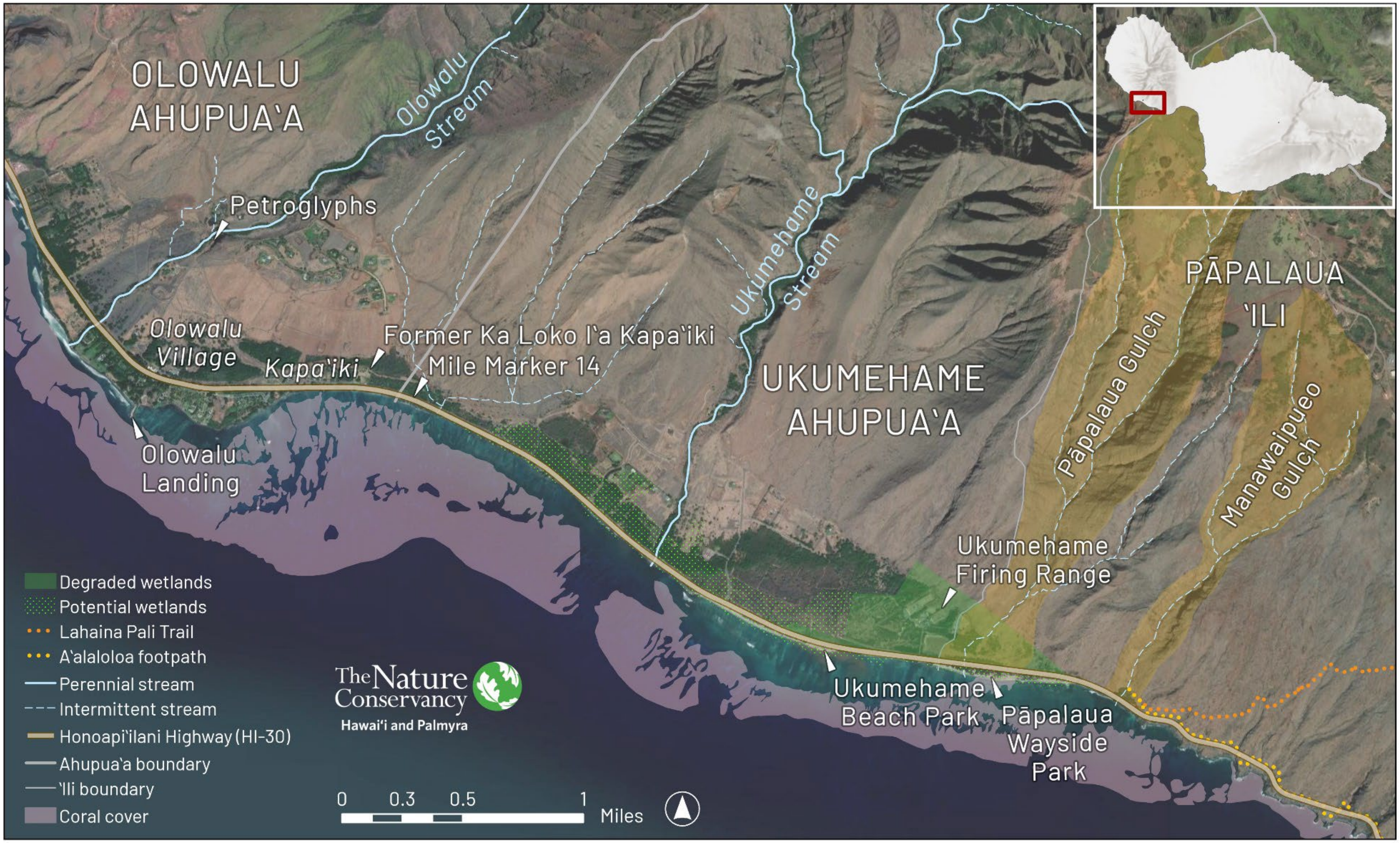
Figure 2: Ukumehame sedimentation event, December 2021.
Photo: John Brito, DLNR DOFAW

Urgent action is needed to reduce erosion and restore habitats across the landscape. We are working with community, landowners, agencies, non-profits, and academics to address challenges in mauka (upland) areas, to develop a vision for the coastal corridor in tandem with plans to move the highway inland, and to build reef resilience. The actions we are taking will enhance community well-being and ecological function and help the Olowalu reef survive and thrive in the decades ahead.

1.2 Project Area Description

The project area lies within the moku (district) of Lahaina and spans the ahupuaʻa (traditional land division) of Olowalu and Ukumehame, which extend from the peaks of Mauna Kahālāwai (also referred to as Mauna o ʻEʻeka or the West Maui Mountains) to the nearshore reef spanning roughly six miles of the coastline. The western ahupuaʻa boundary of Olowalu extends makai (toward the ocean) touching the landforms of Helu and Līhau, ending at Awalua. To the east of Olowalu is the large ahupuaʻa of Ukumehame, which extends to Kealaloloa Ridge and Papawai Point (Map 2).

The coastal and mid elevation areas, like those on the leeward side of most Hawaiian Islands, are characterized by low annual rainfall, gently sloping plains, deep gulches, intermittent streams, dryland vegetation, rocky cliffs, and shorelines interspersed with narrow white-sand beaches. The summit elevation is 5,788 ft at the highest peak where rainfall is 192.1 in per year, and at sea level where rainfall is just 10.7 in per year.



Map 1: Project area of Olowalu and Ukumehame Ahupuaʻa. Priority areas for sediment reduction referenced throughout this report are centered around the large gulches and two perennial streams

The lowland areas of Olowalu and Ukumehame were once salt marshes and wetlands that harbored native species, including seabirds and shorebirds, fish and mollusks, and native grasses and shrubs. Once nourished by streams and washed by the tide, these lowlands are now cut off from the sea by Honoapiʻilani Highway's elevated roadbed (Smith 2011).

The project area includes:

- The 939-acre Olowalu reef
- Two ahupuaʻa, Olowalu and Ukumehame, including the ʻili of Pāpalaua
- The Olowalu and Ukumehame perennial streams and several intermittent streams and gulches
- A portion of the coastal Honoapiʻilani Highway (HI-30) from about mile marker 11 to mile marker 17
- Three sparsely populated communities—Olowalu Village, Kapaʻiki, and Ukumehame
- Undeveloped coastal public lands that include degraded wetlands and sandy and rocky shorelines
- Two popular county-owned beach parks, Ukumehame and Pāpalaua Wayside
- Important recreational sites including popular surfing and snorkeling sites, Ukumehame Firing Range, and the Lahaina Pali Trail
- Cultural sites such as Olowalu Landing, the termination of the Aʻalaloloa footpath that connects Wailuku to Ukumehame, petroglyphs, heiau (ceremonial site), remains of traditional agriculture systems, and the former site of Ka Loko Kapaʻiki, an inland fishpond near the shoreline
- State-owned West Maui Forest Reserve and West Maui Natural Area Reserve, Lihau Section

In both ahupuaʻa, above the highway, the coastal alluvial plains give way to gulches and sloping hillsides, and above that, steep mountains and valleys. After sugar cane operations ended in the 1990s land use transitioned to cattle grazing and development. Today, most former sugar cane fields remain fallow, vegetated by invasive grasses and trees.

In Ukumehame Valley, next to Ukumehame Stream, a decommissioned reservoir remains and some families maintain loʻi kalo (taro patches) there. Push piles of rocks from preparing old sugar fields are visible, as is the fresh water delivery system of ʻauwai (ditches) and reservoirs used to irrigate the fields. Further into Olowalu Valley, there are homes and a pig farm. Above that, along Olowalu Stream,the community organization Kipuka Olowalu restores loʻi kalo and other Hawaiian agricultural systems, the riparian corridor, and native dryland forest.

We examined place names to better understand the characteristics and resources of sites throughout Olowalu and Ukumehame. In Hawaiian culture, place names typically reflect an area's ecological significance and other customary values. Place names are often connected to moʻolelo (stories) or named for resources or natural phenomena in the area.

In the preface of "Place Names of Hawaiʻi" (Pukui et al., 1974), Samuel Elbert states that:

> Hawaiians named taro patches, rocks and trees that represented deities and ancestors, sites of houses and heiau, canoe landings, fishing stations in the sea, resting places in the forests, and the tiniest spots where miraculous or interesting events are believed to have taken place.

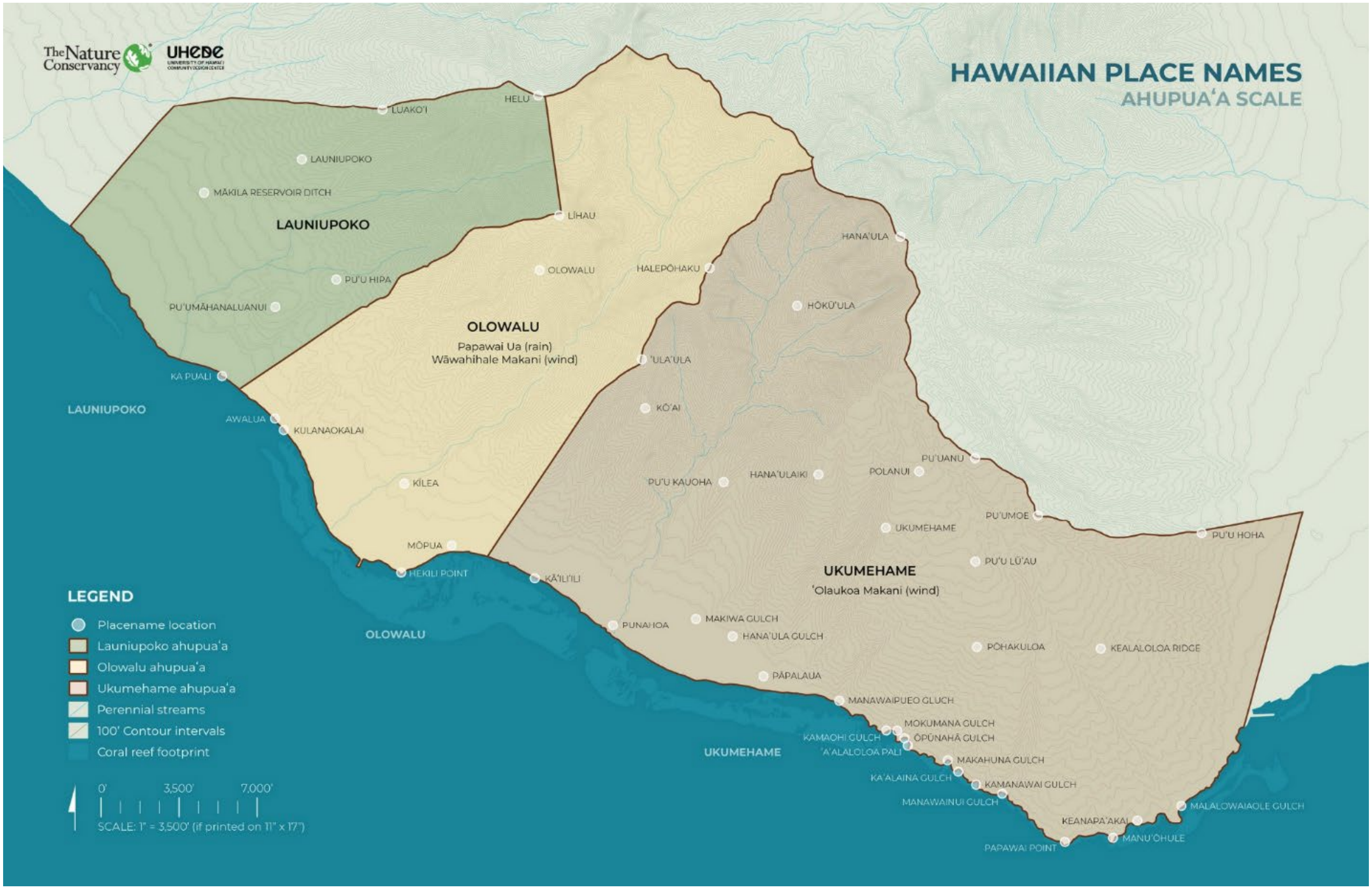
The oldest place names hold meaning and tell the story of a complex society prior to European contact, as well as characteristics of the land. The name of a place will often describe the geology, climate, or most abundant resource of the area. For example, Olowalu is defined as both a group, as of hills, and a storehouse, as for chief's property (rare); Ukumehame is defined literally as "to pay with mehame wood" and is the largest ahupuaʻa in the moku of Lahaina (Pata 2022); and Kaʻiliʻili gulch was named for the ʻiliʻili or little rocks traditionally used for hula that can be found there.

We consulted local kūpuna (elders), ahupuaʻa residents, the Office of Hawaiian Affairs Kipuka Database, and historic U.S. Geological Survey (USGS) maps to better understand the area's wahi pana (special places) and place names, many of which reflect or identify land divisions, fisheries, markers, and sites of homes and other resources, including:

ʻIli small delineated areas	Hawaiikekee, Kaluaaha, Kamani, Kaunukukahi, Kuekue, Maomao, Ohiʻa, Paʻapa, Paumaumau, Wailoa, Pāpalaua
Puʻu hills, hilltops, precipices	Halepohaku, Hanaula, Hanaulaiki, Hokuula, Koaʻi, Lihau, Pohakuloa, Polanui, Puʻu Moe, Puʻu Anu, Puʻu Kauoha, Puʻu Kauoha, Puʻu Luau, Ulaula, Ulaula
Wahipana important places	Aalaloa Pali, Awalua, Awalua, Hanulaiki, Hekili Point, Kaluakanaka, Kapaiki, Kawailoa Heiau, Kihau, Kilea, Mopua, Pakala, Papawai Point, Puʻu Kilea, Punahoa
Awāwa gulches/drainages (subwatersheds)	Hanaula, Kaʻiliʻili, Kaʻalaina, Kamanawai, Kamaohi, Makahuna, Makaiwa, Manawaipueo, Mokumana, Mopua, Olowalu, Opunaha, Pāpalaua, Ukumehame

The place names reflect an abundance of water, springs, and coastal vegetation, demonstrating that with land use changes and water diversion, the environment is significantly different than it once was. With the challenges facing Olowalu and Ukumehame mauka to makai, there is an opportunity to look to the wisdom of the people who live there today and the deep knowledge in place names, wahi pana, mele (songs), and historical accounts to build coastal and reef resilience. A future study of these place names and resources can also yield important insights into understanding and living in right relationship with Olowalu and Ukumehame today.

Additional information on the cultural context and historical land uses of the area can be found in Appendix A, and more information on Hawaiian place names in Olowalu and Ukumehame can be found in Appendix B.



Map 2: Place names in Ukumehame, Olowalu, and Launiupoko Ahupuaʻa. Source: University of Hawaiʻi Community Design Center

1.3 Coral Reef Ecosystem Description and Status

The 939-acre Olowalu reef spans nearly six miles of Maui’s leeward coast from Olowalu to Pāpalaua. The reef boasts a stunning diversity of coral, including some of the oldest and largest coral colonies in Hawaiʻi, and harbors a diversity of fish, algae, invertebrates, including the largest known manta ray population in the United States. Notably, the Olowalu reef is a primary source of larvae for the reefs of Lānaʻi, Molokaʻi, and West Maui (Field 2011; Figure 3). Due to its significance as a place that is critical to the health of our oceans, the Olowalu reef was declared a Mission Blue Hope Spot in 2017.

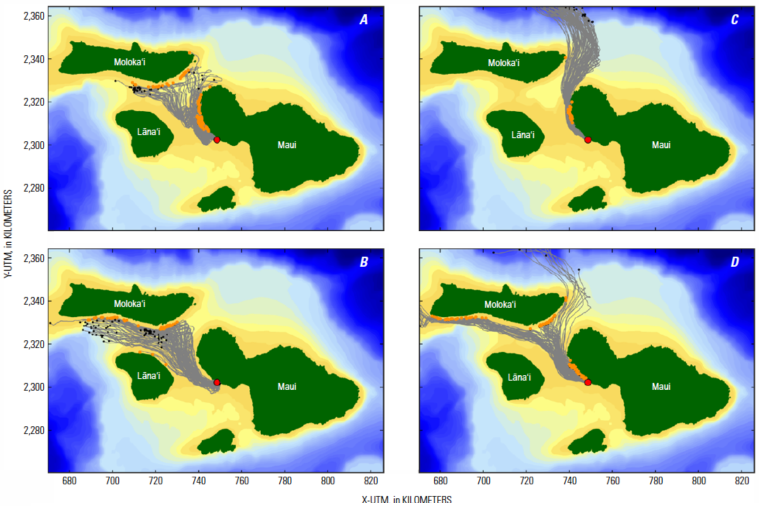


Figure 3: A U.S. Geological Survey study illustrates how currents carry larvae from Olowalu north and west to other Maui Nui reefs (Storlazzi et al., 2017).

The *Atlas of the Reefs of West Maui* (Minton et. al. 2020) summarized declines in reef fish populations and coral health across three reef tracts—Olowalu Point, Olowalu, and Ukumehame—based on an analysis of all available scientific surveys of the area from 1999-2019. Despite these declines, the Olowalu reef tract consistently ranked among the best reef areas in West Maui and the state, with high coral cover and benthic diversity and medium-high total fish and resource fish biomass, and it is still considered to be the “gem” of Maui. Though the Olowalu Point and Ukumehame reef tracts did not fare as well when compared to other reefs in West Maui, their prime spawner biomass—the key factor for replenishing fish populations—was above average when compared to reefs across the state prior to the coral bleaching event in 2015 (Figure 4).

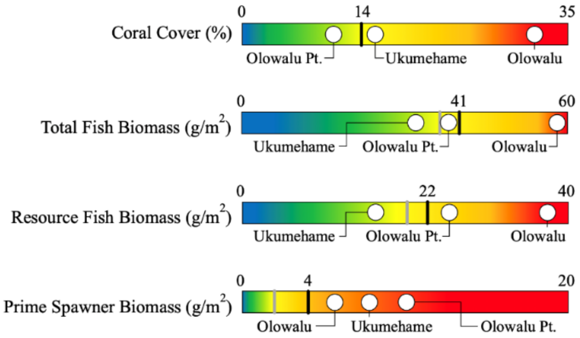


Figure 4: Olowalu Reef Tracts vs. Statewide Average. The *Atlas of the Reefs of West Maui* (Minton et al. 2020) analysis confirmed that coral cover and fish biomass on the Olowalu reef tracts are significantly above statewide averages (black line), making the reef a high priority for protection. The grey line on the biomass scales reflects the statewide mean.

Figure 5: Coral bleaching in Olowalu, Maui. Photo: Drew Sulock

The Olowalu reef was heavily impacted by the 2015 marine heat wave and statewide coral bleaching event. Surveys show that Olowalu lost up to 45% of its live coral cover, decreasing vital habitat for reef-dependent organisms (DLNR DAR 2020; Figure 5).

The loss of live coral cover is often followed by erosion of the reef's structure, which reduces habitat complexity and ultimately alters the reef community composition and ecological function (Matsuda et al. 2020).

Despite the loss of live coral, resilience surveys conducted on the Olowalu reef following the 2015 statewide coral bleaching event confirmed some sites as having above average resilience to bleaching, including two deep-water sites on the Ukumehame reef tract (Maynard et al. 2019). Scientists believe that the cool, freshwater upwellings on the reef are likely helping to mitigate rising sea surface temperatures, providing some natural protection to the corals.

When the *Atlas of the Reefs of West Maui* was published in 2020, considerable data were available for most reef tracts, however, information for some, including the Ukumehame reef, was limited in the number of sites sampled and/or the number of years for which it was collected. To fill this data gap, TNC conducted benthic and fish surveys across the Ukumehame reef tract in 2022 and 2023 (Minton 2024).

We found that the benthic communities of both the Ukumehame and Olowalu reef tracts were dominated by turf and coral with Olowalu having about greater cover for both. Coral cover in both shallow and deep assemblages tended to increase from west-to-east along the Ukumehame reef tract. Along this spatial gradient, the cover of all species showed similar relative increases—all dominant species showed an increase in cover from west-to-east. This shift in coral assemblage structure is likely driven by variation in the environmental conditions and likely associated with inputs of sediment and other potential pollutants at the western end of the reef tract near Ukumehame Stream. *Porites lobata* is tolerant of sediment and burial and is often found on reefs with high turbidity or that experience periodic sedimentation events. Interestingly, while *P. lobata* cover generally decreased from west to east, it increased at the most easterly sites surveyed, near the outflow of Manawaipueo Gulch, a known source of sediment.

Average total fish biomass was close to the average for West Maui reefs but low when compared to reefs on East Maui or within protected areas. Fish biomass was highest adjacent to the Olowalu reef tract. Without this high-biomass area, fish biomass at Ukumehame reef would be among the lowest on Maui.

1.4 Community Engagement

In 2022, with Coral Reef Alliance and Kipuka Olowalu, we engaged partners and community members in a participatory mapping process to create an Olowalu and Ukumehame Ahupuaʻa Snapshot—a status report on the health of the watersheds for decision-makers and communities**.**

The group reviewed aerial photographs of Olowalu and Ukumehame from 1949 to the present and shared how the land and land use has changed over time. They indentified and discussed important historical dates of land use changes, place names, sources of sediment, heiau and other cultural sites, historic wetland locations, and the challenges discussed throughout this report, including the relocation of Olowalu Stream and when that occured, sugar production and processing, urban development, erosion from the uplands, and coastal erosion. They also identified priorities for protection, including the coral reef, cultural sites, heiau, places of recreation, places for cultural and traditional practices, wetlands, place-based learning, ʻōpeʻapeʻa (Hawaiian hoary bat), and seabird nesting.

The information gathered through this process will inform planning and outreach products, including a map and infographics, as will interviews we conducted with kūpuna and cultural practitioners from the area and efforts discussed in Section 3.3. This process has also guided the next steps of community engagement for coastal resilience planning and design discussed in Section 4.1 and 4.4.

2. Technical Assessment

2.1 Problem Statement

Marine life—including corals, algae, and fisheries—needs consistent, abundant freshwater flows and specific and stable temperature, salinity, and nutrient levels to thrive. In an ideal scenario, after rainfall is captured by vegetation in forest watersheds, it is filtered as it moves through the hydrologic system, including in estuaries, wetlands, and alluvial plains that absorb sediments. In West Maui, the amount of rainfall, cloud cover, and water available has decreased significantly over time, and is generally considered a symptom of the reduction of forest cover. Less rainfall and fog drip in the uplands, as is predicted for the region, will change the ecosystem downstream. While corals do not generally do well in fully brackish, lower pH systems, nutrient-rich groundwater inputs have been shown to increase coral growth.

The most visible water quality problem on the reef today is sedimentation, with pockets of darker, fine sediments common in between the spur and groove system offshore. After storm events, sediments are ubiquitous in the shallow reef area, emerging from a dozen or so drainage points along Honoapiʻilani Highway and at Ukumehame Stream and Manawaipueo Gulch crossings. Over the last 20 years there have been nearly annual fires in the priority watersheds above Olowalu reef, some of which have been thousands of acres in size. In addition, since 2015 the Axis deer population has exploded on Maui, adding pressure to already vulnerable native vegetation (Anderson 1992; Hess et al. 2015; Hess 2021).

Sediments on the reef are the product of erosion from the land surface upland, increased delivery through surface runoff which is prevalent during flashier storms, and a lack of retention in the coastal plains because of channelization and changes in land use.

Minimizing sediments in coastal waters is a vital step toward building reef resilience. Efforts to reduce sediments to the reef are focused on restoring functioning watersheds, improving fire management and ungulate control, installing and maintaining stormwater and sediment detention basins in Pāpalaua and Manawaipueo Gulches, and restoring the hydrologic functioning and connectivity of former wetland ecosystems. Our analysis objectives were to collect and synthesize information on each of these topics:

- Surface and ground water delivery—freshwater availability, including storm intensity, baseflow, and peak discharges
- Source of sediments—soil, geologic, and vegetation characteristics, land use patterns, and fire frequency and extent
- Retention in coastal plains—wetland features and drainages
- Coastal sedimentation—location of sediments, turbidity and transport pathways

2.2 Wai: Surface and Groundwater Resources

2.2.1 Water management in the Olowalu area

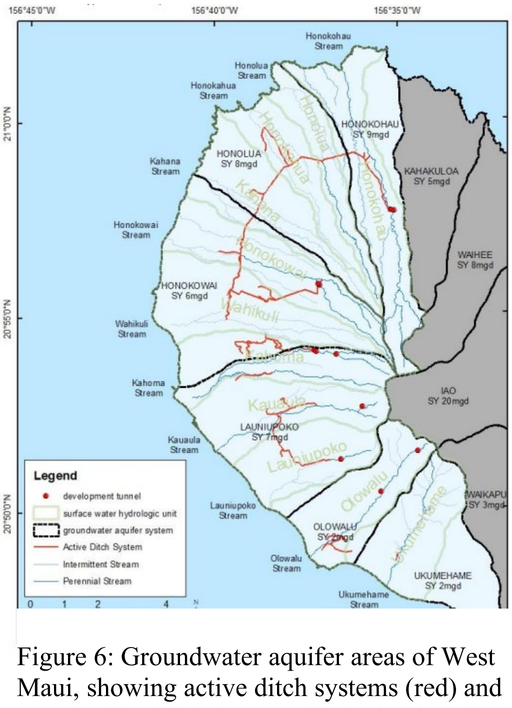


Figure 6: Groundwater aquifer areas of West Maui, showing active ditch systems (red) and sustainable yields (2MGD for both Olowalu and Ukumehame. CWRM Final Findings of Fact

Water use in the Olowalu and Ukumehame Watersheds is managed by the state Commission on Water Resource Management (CWRM) for surface and groundwater use in the Water Management Area Designation: Lahaina Aquifer Sector Area. The area includes all West Maui, Olowalu and Ukumehame Surface Water Hydrologic Units (Federal Hydrologic Unit No. 6004 and 6005) and Groundwater Hydrologic Units (60205 and 60206). The 2022 designation was made in accordance with Part IV (Regulation of Water Use) of the state Water Code, Chapter 174C, Hawaiʻi Revised Statutes, and Title 13, Chapter 171 (Designation and Regulation of Water Management Areas), and Hawaiʻi Administrative Rules (Figure 6).

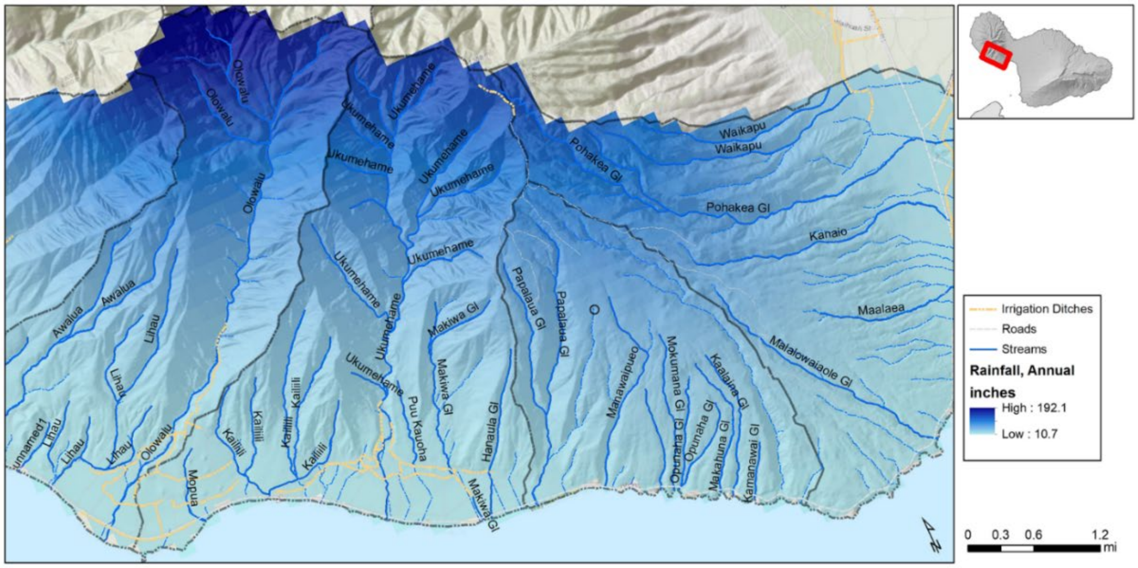
The Olowalu Water Company Inc. manages surface water systems in Olowalu. West Maui Investors, LLC uses non-potable well water for irrigation and residences. Although not in operation now, there is a 3,000 ft tunnel that intersected dike-entrained water in Olowalu at 1,710 ft elevation.

With both Olowalu and Ukumehame now designated as Surface Water and Groundwater Hydrologic Units, the maximum yield, or the amount of fresh water that can be withdrawn from an aquifer, is regulated by the CWRM, with each allowed to withdraw two mgd from groundwater wells.

There are four wells in Olowalu and five wells in Ukumehame that have pumping capacities of 4.954 mgd and 8.553 mgd, respectively. Reports on maximum pumping in 2020 in Olowalu and Ukumehame show that pumping from groundwater is much less than the proposed capacity of 2mgd—0.15 mgd and 0.045 mgd, respectively. For residential and commercial development planned in Ukumehame, 1.42 mgd (or 71% of the calculated sustainable yield) has been authorized for future use. Because groundwater use has not exceeded sustainable yields, no chlorides have been detected in groundwater samples (CWRM, Lahaina Surface-Groundwater Management, Appendix B).

2.2.2 Rainfall and Fog Drip

The orographic rainfall in Olowalu and Ukumehame produces a strict gradient from Mauna Kahālāwai to the coastal areas, with relatively low-intensity rainfall consistently hitting the more windward facing mountaintops about 70% of the year. There is also a gradient from north to south, with higher rainfall levels in the Olowalu Watershed and decreasing levels moving south to the Ukumehame and Pāpalaua Watersheds. The highest annual rainfall in the region is 192.1 in/yr in the northernmost areas, while the lowest is just 10.7 in/yr at Pāpalaua Wayside Park (Map 3). Two types of storm systems are important for delivering high intensity rainfall. Kona low systems come from the south and are historically more typical in winter months (Kodoma and Barnes 1997), while hurricanes and tropical storms can bring heavy rain from variable directions.



Map 3: Annual rainfall for Olowalu-Ukumehame.

An additional source of fresh water comes in the form of fog drip, which occurs at the tops of the ridges of Ukumehame as shown in Figure 7.

We searched the National Climate Data Center for rainfall gauges that were near the project area and included multi-decadal daily rainfall to understand how storm intensities were changing over time. There were no sites with sub daily data available, so we used the daily data to best advantage. Using the gauge in Ukumehame that was operational from 1990-1999, we estimated that the average daily 10-year storm rainfall per storm event was 3.8 in at Ukumehame station.

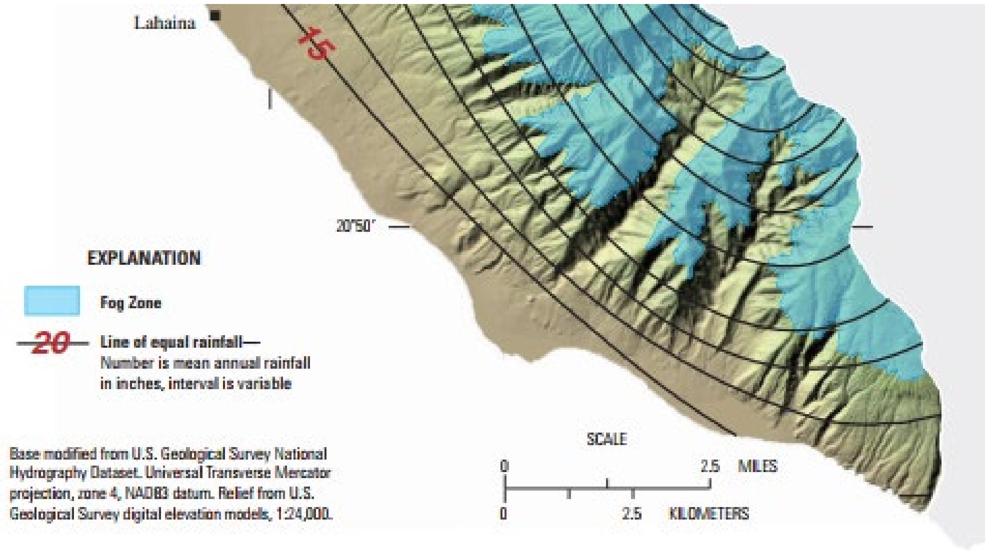


Figure 7: Fog drip and rainfall isohyets, modified from Giambelluca and others, 1986 (Gingerich and Engott, 2023).

We used two main nearby stations, Ukumehame Station (1942-1999) and Pohakea Bridge (1950-2013), and two which had long time series, Waihee Valley 482 and Waikapū 390 (at Waikapū Country Club). The noteworthy storms of 2017 and 2021 brought some of the highest single storm rainfall totals yet to the state and produced some of the largest runoff events. On Jan. 18, 2021, nearby Māʻalaea Bay recorded 79.7 mm (3.1 in) in a single storm event. At Pohakea Bridge on Dec. 22, 2017, 111 mm (4.38 in) was recorded in a single day. Because the Pohakea station was discontinued, we also considered Waiheʻe and Waikapū Stations that are current. The highest values were 9.15 in at Waikapū and 8.35 in at Waiheʻe for the same 2017 storm (Figure 8).

In a ranking analysis of daily data at Pohakea station since 1950 (a 66-year record), we determined the following amounts of rainfall for return intervals (Table 1):

Return Interval (yr)	**Rainfall in 24-hour period (in)**
50	3.66

25	1.81
10	1.15
5	0.93

Table 1: Rainfall amounts and return intervals from data collected at the Pohakea station from 1950-2013.

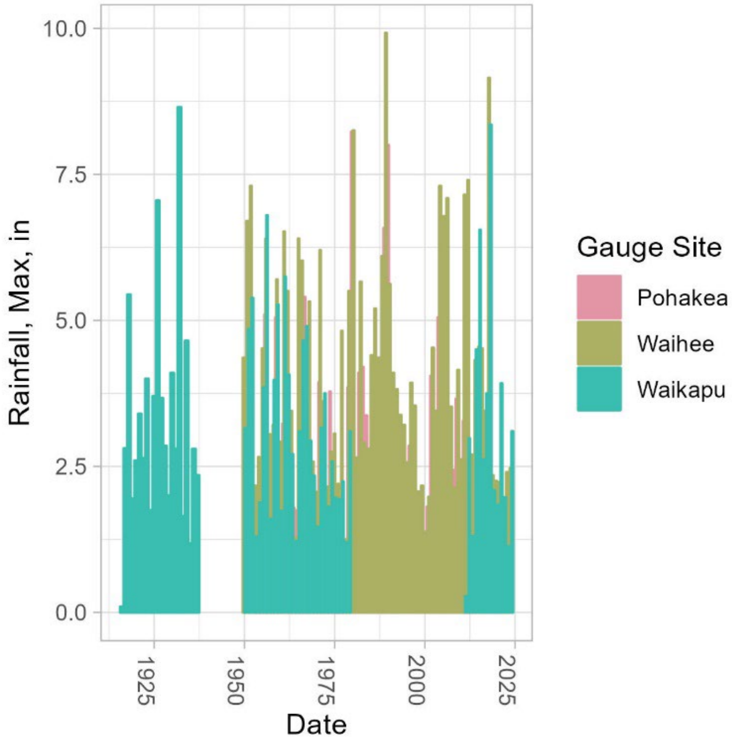


Figure 8: Rainfall amounts (in) recorded at Pohakea Bridge, Waihe‘e, and Waikapū rainfall gauges from 1918-2024 showing max rainfall event per water year (as defined from October to September).

Both the Olowalu and Ukumehame aquifers are modeled to be drier in the future (Frazier et al. 2022). In the modeled rainfall historical scenarios, mean annual rainfall trends in Olowalu have changed from the period from about 1978-2007 versus about 1990-2009 from 60.4 in/yr to 53.1 in/yr, while Ukumehame has changed from 44.6 in/yr to 40.0 in/yr. The Hawai‘i Climate Data group, which collects current and historical data, has completed a similar analysis. In general, there continues to be a deficit in rainfall in the West Maui area. The drought contributes to vegetation loss, fire risk, and erosion. Additional metrics of the continued changing water environment are presented below.

2.2.3 Surface Water

Below we describe how the three big surface water discharges—Olowalu Stream, Ukumehame Stream, and Pāpalaua Stream—have changed over the last decades and whether there were corresponding changes in the amount of surface water available. Historic agricultural operations significantly altered the natural hydrologic regime of this area. Water was redirected from streams through an extensive ditching system to be utilized for crop irrigation. Continued diversions today maintain the altered system.

Stream discharge over time

There are two continuous stream discharges, from Olowalu Stream and Ukumehame Stream, though prior to a large storm in 2016 destroying an upper diversion on Olowalu Stream, water did not flow to the coast. Today, the CWRM has documented that Olowalu Stream is gaining flow consistently above the upper diversion and the partial-record gauging station (USGS station number 205000156355801) at 560 ft elevation. When the upper diversion was active, 100% of baseflows were diverted from the stream, although some water was returned to the stream from the ditch via leakage. From the upper diversion to the lower diversion, the stream loses flow at about 1.1 ft/s/mile. The lower intake at an elevation of approximately 220 ft was reestablished in November 2016 but diverts less water than the upper intake. In the lowest reaches, the stream is losing flow to groundwater so that on average flow days the stream does not reach the coast. Instream flow standard calculations conducted by CWRM assessed that discharge rates were Q50 for Olowalu and Ukumehame Streams was 3.23 mgd each (representing median discharge), while the Q90 for each was 2.07 mgd, respectively, representing low flow conditions (CWRM IIFS Olowalu 2018).

There are several USGS gauging stations that provide current (Ukumehame Stream from 2018) and historical data (Olowalu Stream from 1961 to 2008, Ukumehame mauka from 1911-1918). We conducted an analysis of low flow from 2018-2021 using the Ukumehame Stream gauge, and we also considered how peak flow in Olowalu Stream has varied over time. To estimate Q90 and Q10 discharge using daily and sub daily data, we used the ***lfstat*** package for R and computed Q90 and Q10 for each water year where data was available. The USGS designates a water year as beginning on October 1st and ending on September 30th.

Ukumehame Stream gauge is in the same place above the diversion since 1911, with data intermittent over the years. Data was available from 1911 to 1918 (Table 2) and 2018 to 2024 (Figure 9). The more recent low flow averages were about 50% less than the historic reported values from 1911.

Water year	**Q90 (low flow) cfs**	**Q10 (high flow) cfs**
1911	9.1	12.0
1912	4.5	12.0
1913	4.5	48.00

1914	7.4	32.00
1915	9.6	23.00
1916	6.2	19.50
1917	4.8	11.60
1918	3.1	5.32
2018 (only April to Oct)		
2019	5.10	11.10
2020	3.50	8.56
2021	3.21	9.17
2022	3.36	7.29
2023	2.68	8.12
2024	3.82	12.00

Table 2: Ukumehame Stream low and high flow values from 1911-1918 and 2019-2024

Although we suggested in the section above on rainfall that recent storms may be typical in their peak rainfall, the data for Ukumehame Stream showed the highest in early 2024 with a mean daily discharge of 72 cfs.

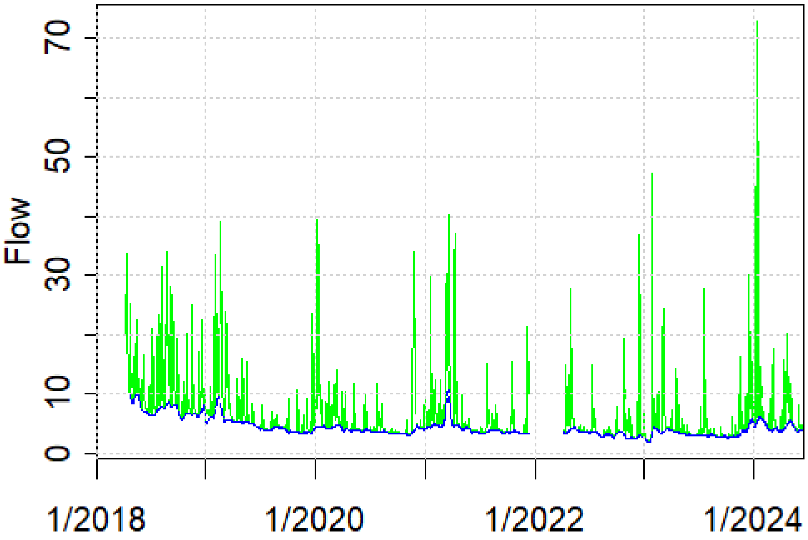


Figure 9: Ukumehame Stream baseflow (cfs in blue) has been decreasing since 2018. The green represents storm flow.

The analysis confirms the findings of Oki (2004), who determined that low flows generally decreased from 1913 to 2002 for 16 stations throughout the islands. This is consistent with the long-term downward trends in rainfall observed throughout the islands during that period.

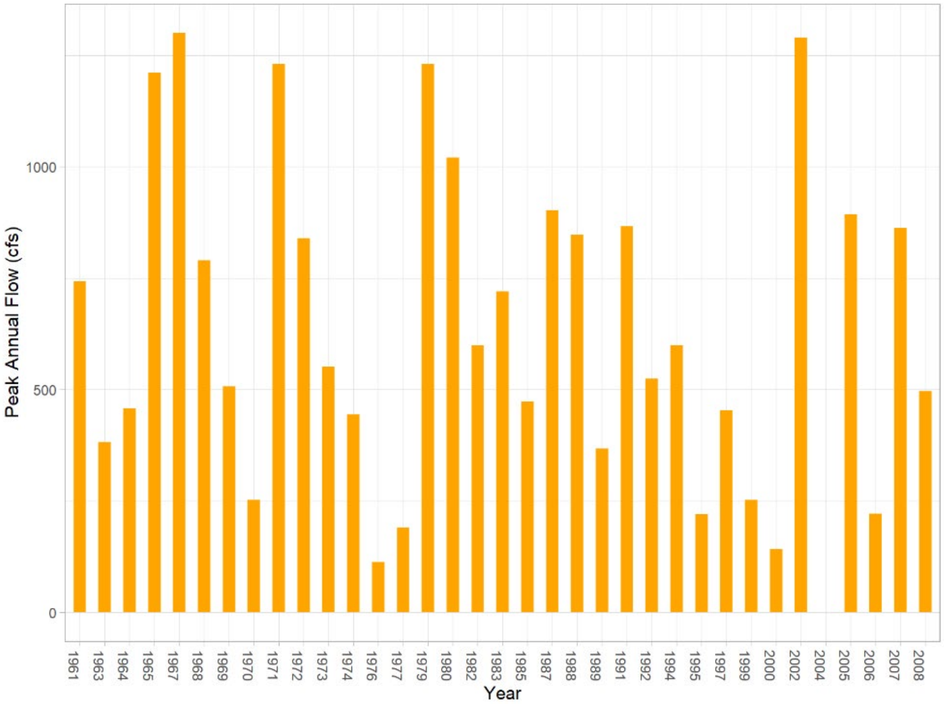


Figure 10: Peak annual flows from 1961 to 2008.

The highest annual peak discharge from the USGS gauging station at Olowalu Stream indicates that there are no observable changes in peak discharge using this 48-year dataset (Figure 10). Future estimates of storm intensity are predicted to increase with climate change, with expected higher peak discharges similar to the higher peaks we found in analyzing the rainfall data.

Reservoirs and capacity, ditch system

Olowalu Water Company owns the reservoirs, tanks, inlets, and ditches that are associated with the Olowalu and Ukumehame stream water and surface water systems. The company provides 1.6 mgd (2014) of surface water to residents in the urban and rural boundary in lower Olowalu Watershed (Maui Board of Water Supply). During sugarcane cultivation there were two major operational earthen reservoirs in the area and four additional reservoirs that were features of the former irrigation network. Olowalu reservoir (1.3 ac) and Ukumehame reservoir (3.0 ac with two basins) were likely built in the early 1900s with the rest of the drainage system (Falinski and Penn 2018). Using the Hawaiʻi State Wetland layer, we were also able to identify another four basins in Olowalu or Ukumehame that are below regulatory size and area (each less than 2 ac) that might still be used to hold water as needed. Although their capacity is unknown, the four basins occupy 4.8 ac.

There were multiple diversions used to provide water for irrigating sugarcane in Olowalu and Ukumehame valleys. There are two diversions and a ditch system that carries non-potable water to agricultural fields and home lots. At the higher elevation, the upper diversion was the original source of water in the system, providing gravity-fed water to all fields. However, this diversion was damaged in a September 2016 flood and the current operator is using only the lower diversion (CWRM IIFS 2018).

In addition to the above features, the Pāpalaua sediment detention basin is 11.88 ac and is managed by the state Department of Transportation as a detention basin, not registered as a dam. It is located to catch the outfall of Pāpalaua Stream, and at one point was a registered wetland. Additional details are provided in the Groundwater section below.

Drainages

There are three main drainages, described below, which include many smaller drainages that flow onto the Olowalu reef. In this section we calculate the flow paths of those smaller drainages and estimate the different places that water might enter the ocean, thereby identifying places that water might be retained on the landscape to hold sediment.

Pāpalaua: Pāpalaua Watershed begins at the western boundary of Pohakea and continues west along the coast for roughly 2.5 mi. It rises to its terminus at approximately 3,700 ft along the Hanaulauiki Ridge on its western boundary and Kealaloloa Ridge on its eastern boundary. While relatively short in reach, eight different gulches exist within the Pāpalaua Watershed. They include from west to east: Pāpalaua, Manawaipueo, Kamaohi, Opunaha, Mokumana, Makahuna, Kaalaina and Kamanawai gulches. All eight gulches are ephemeral and flow south-southwest.

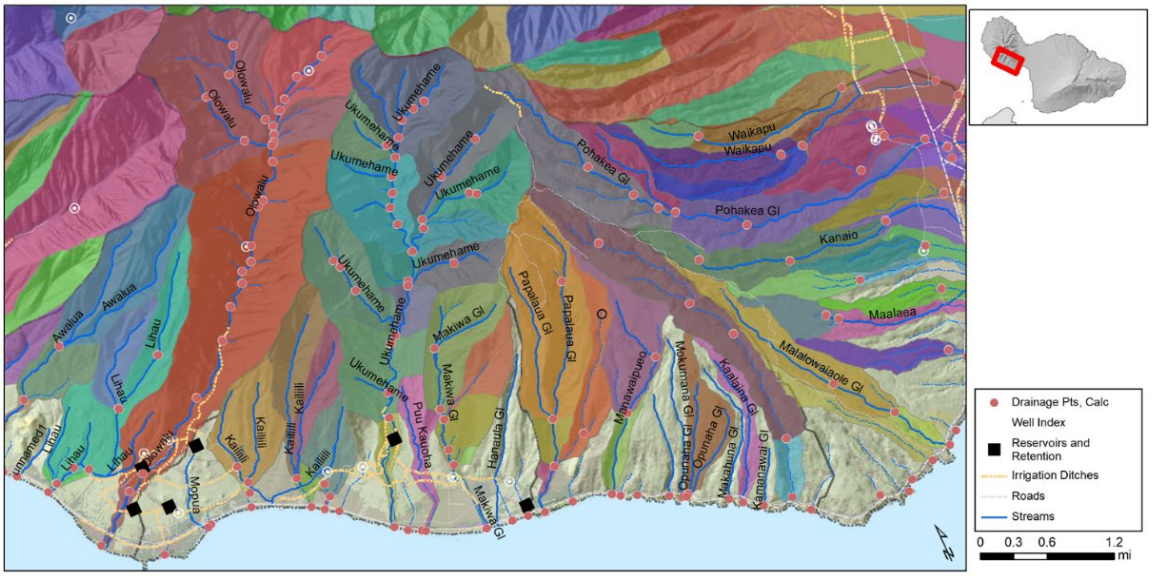
Ukumehame: The Ukumehame Watershed is approximately 5,637 ac. It begins at the western edge of the Pāpalaua Watershed and extends along the coast for roughly 2.8 mi. It rises above both the Pāpalaua and Pohakea Watersheds ending at the 4,000 ft ridge separating it from the

Waikapū Watershed flowing east on the opposite side of the West Maui Mountains. Five small gulches exist within the Ukumehame Watershed. All are ephemeral and generally flow southwest. They include from west to east: Ka‘ili‘ili, Ukumehame, a small gulch associated with Pu‘u Kauoha, Makiwa, and Hanaula gulches. This seaward area of Ukumehame is known for large boulders (located at the mouth of Ukumehame Stream) that are carried by the current and tumbled and eroded into smaller rocks and stones that are deposited near Ka‘ili‘ili stream.

Olowalu: The Olowalu Watershed is a single valley of 3,072 ac and a maximum elevation of 5,207 ft. The watershed is medium sized, steep in the upper reaches, and with little embayment. These watershed lands are designated for either agriculture (15.9%) or conservation (84.1%). Olowalu Stream may have shifted or been rerouted north over time by 100 m, based on patterns on the reef structure and verbal accounts that the stream outlet was once in a different location. Today, the stream mouth is on the north side of Hekili Point.

2.2.4 Calculation of drainage points

Methods: We calculated predicted streams, confluence, discharge points, and subwatersheds using ArcHydro Tools for ArcGIS 10.6.1. For the calculation, we used a drainage area of 20,000 m^2 to initiate surface flow, in line with the work of John Stock in the northern watersheds of West Maui (Stock and Deriau 2020). The elevation model used was a 1-m digital elevation model derived from LIDAR produced by NOAA.



Map 4: Hydraulic system of Olowalu and Ukumehame showing watershed boundaries, drainage points, and reservoirs.

Using the above method with high resolution elevation models, we identified 17 places where surface water is predicted to enter the ocean (Map 4). However, hundreds of years of routing water into irrigation channels and ‘auwai may channelize water in ways that cannot be predicted through elevation alone. In addition, the pathways that water would use during various-sized flood events may be impeded by sediment buildup in culverts or conduits meant for stormwater transport. In the large rain event of early December 2021, for instance, water was photographed coming from many different points along the Pali, which would not have been predicted through this exercise (Figure 11).

Figure 11: Overland flow on the Pali cliffs, an area that is not channelized, from the Dec. 5, 2021 storm. Photo: Maui News Now.

The above estimates of drainage point locations need to be verified during various-sized flood events to see where surface discharge accumulates above and below the highway. Another follow up step to this calculation would be to investigate the state of all the culverts that are meant to deliver stormwater and prevent flooding across the highway. As the highway is the only major road connecting West Maui with the rest of the island, the need to keep the road clear is an important consideration.

2.2.5 Groundwater

Groundwater is essential for a balanced ecosystem, having different physical and chemical properties than coastal waters. Many marine and estuarine species thrive in areas of groundwater discharge. Honolua-Mokulēʻia Marine Life Conservation District (MLCD), located north of the West Maui aquifer systems, has one of the most diverse, unique, and abundant reef formations on the island (DAR 2022; Environmental Consultants 1974; AECOS 1981). Here, schools of goatfish and flagtail overlap areas of groundwater discharge, where salinities can be as low as 3 ppt (very fresh) at the shoreline. Research has shown that native limu (seaweed) is well adapted to the salinity and nutrient gradients in these discharge areas, compared to non-native seaweed (Dulai et al 2021), and is at risk when the sustainable yield of an aquifer is exceeded, and groundwater recharge decreases because of less rainfall.

Fresh groundwater moves from inland recharge areas to coastal discharge areas. Recharge can occur through dike-impounded systems at the top of the mountain or from surface water losses as streams move down the mountain. The stream lengths in the alluvial plains of Olowalu and Ukumehame Streams are losing. A losing reach of a stream is a section where water from the stream is lost to the surrounding ground. This happens when the water infiltrates into the soil and recharges the groundwater. The consolidated sediments that line Ukumehame Stream (see Geology in 3.3.2) and the alluvial plain have a lower permeability (impeding groundwater flow) compared with high permeability basalt rocks (Oki 2005). In Olowalu and Ukumehame, 1.98 and 1.95 mgd of groundwater, respectively, are estimated to be recharged from stream losses (Gingerich and Engott 2012).

Future predictions of climate in both wet and dry seasons using a dynamical downscaling approach show that groundwater recharge is predicted to decline in the dry season by up to 2,000 mm in the area's headwaters of Mauna Kahālāwai (Fandrich et al 2022). The results of the modeling effort present urgency for future decisions made on sustainable groundwater use. For the purposes of this report, decreasing future groundwater recharge will impact both the total groundwater discharge to the Olowalu reef and the baseflow of streams used by native diadromous fish such as ʻoʻopu.

Wells

It is estimated that the first well was drilled in 1905 and included lateral tunnels designed to skim 3 mgd of freshwater from the Olowalu aquifer for irrigation. In 1908, an additional well was drilled at Ukumehame with a capacity of 1.25 mgd (Stearns and Macdonald 1942). Prior to 1917, all ditches were earthen with substantial infiltration, which resulted in less water delivery for growing sugarcane. Later irrigation efforts lined the ditches with concrete to better hold water.

As of 2022, there are eight wells licensed by the CWRM (in addition to the two tunnels) with a permitted capacity of 13.5 mgd. Olowalu Plantation/Pioneer Mill drilled one well (well no. 4835-01) for sugarcane irrigation in 1934, and three additional wells were drilled in Ukumehame more recently to supply potable water for residential development and domestic use. The Army National Guard drilled a single well (well no. 4834-01) to support their water needs near the Ukumehame Shooting Range. A list of the licensed wells can be found in Table 3.

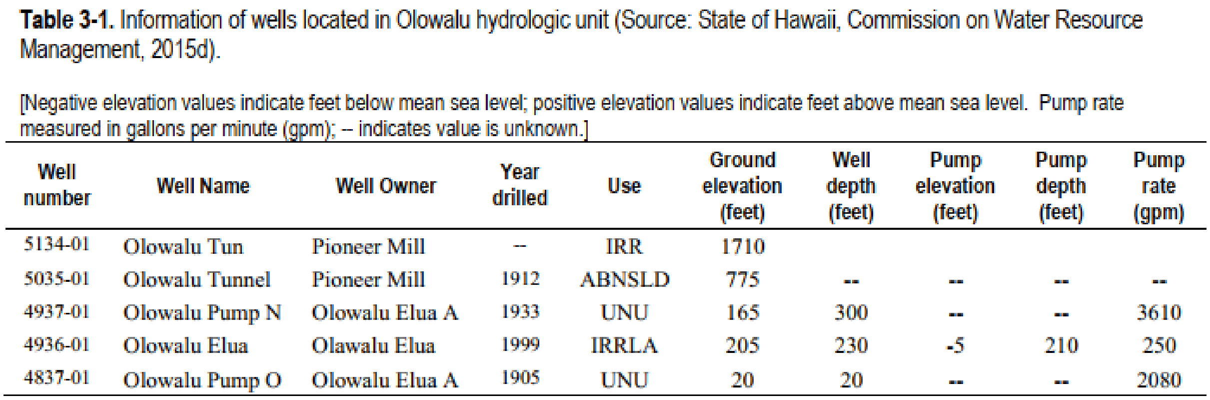


Table 3-1. Information of wells located in Olowalu hydrologic unit (Source: State of Hawaii, Commission on Water Resource Management, 2015d).

[Negative elevation values indicate feet below mean sea level; positive elevation values indicate feet above mean sea level. Pump rate measured in gallons per minute (gpm); -- indicates value is unknown.]

Well number	Well Name	Well Owner	Year drilled	Use	Ground elevation (feet)	Well depth (feet)	Pump elevation (feet)	Pump depth (feet)	Pump rate (gpm)
5134-01	Olowalu Tun	Pioneer Mill	--	IRR	1710				
5035-01	Olowalu Tunnel	Pioneer Mill	1912	ABNSLD	775	--	--	--	--
4937-01	Olowalu Pump N	Olowalu Elua A	1933	UNU	165	300	--	--	3610
4936-01	Olowalu Elua	Olawalu Elua	1999	IRRLA	205	230	-5	210	250
4837-01	Olowalu Pump O	Olowalu Elua A	1905	UNU	20	20	--	--	2080

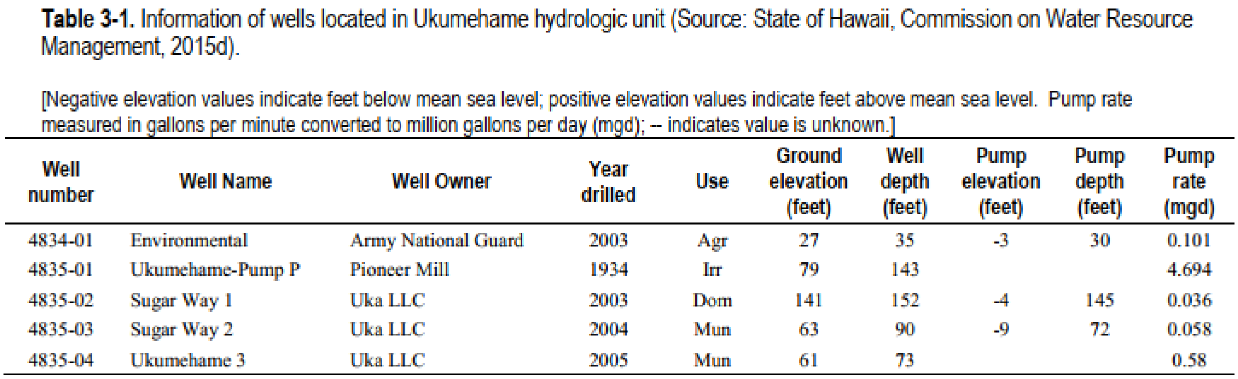


Table 3-1. Information of wells located in Ukumehame hydrologic unit (Source: State of Hawaii, Commission on Water Resource Management, 2015d).

[Negative elevation values indicate feet below mean sea level; positive elevation values indicate feet above mean sea level. Pump rate measured in gallons per minute converted to million gallons per day (mgd); -- indicates value is unknown.]

Well number	Well Name	Well Owner	Year drilled	Use	Ground elevation (feet)	Well depth (feet)	Pump elevation (feet)	Pump depth (feet)	Pump rate (mgd)
4834-01	Environmental	Army National Guard	2003	Agr	27	35	-3	30	0.101
4835-01	Ukumehame-Pump P	Pioneer Mill	1934	Irr	79	143			4.694
4835-02	Sugar Way 1	Uka LLC	2003	Dom	141	152	-4	145	0.036
4835-03	Sugar Way 2	Uka LLC	2004	Mun	63	90	-9	72	0.058
4835-04	Ukumehame 3	Uka LLC	2005	Mun	61	73			0.58

Table 3: Information on Olowalu and Ukumehame wells from the state of Hawaiʻi, Commission on Water Resource Management.

As of 2016, the 12-month moving average for existing groundwater withdrawals from the Ukumehame aquifer section was 0.031 mgd, which is well below the aquifer's current sustainable yield of 2 mgd (CWRM 2015). All this water is designated for municipal use in residential single-family dwellings, though groundwater is currently being used for agriculture in a sod farm and nursery (CWRM 2017).

2.2.6 Wai: Summary

The data presented above suggest that:

- Rainfall is highly variable throughout the watersheds and is decreasing over time.
- Surface water in Ukumehame Stream still connects to the ocean but volume is less than it once was.
- There is a lack of current monitoring information on Olowalu Stream, especially for peak flows, to determine whether peak flows have increased in the last 10 years. The data until 2008 suggests that peak storm flow has not changed in the last 40 years.
- There are eight reservoirs, including one large reservoir, which were largely created by the sugar industry as part of a complex system of irrigation channels that surely replaced former Hawaiian ʻauwai systems and are no longer being used.

- The surface water and groundwater systems are intertwined. The recent CWRM ruling to make it a combined surface water and groundwater use area confirms this. There is a limit on how much water is available for both people and nature.

2.3 Mauka: Sources of Sediment

In identifying sources of sediment, there are several factors to be considered. First, the type of vegetation, along with historical and current land use patterns, influences how much erosion is possible on a landscape. The general assumption is that the more canopy cover and groundcover, the less erosion. We estimated what the type of land cover and vegetation would be by comparing two existing models (C-CAP and LANDFire) with a classification more specific to this region generated from recent MAXAR satellite imagery. Second, the geologic characteristics influence infiltration rates and the likelihood that overland flow will occur. The effects of slope and the distance that sediments travel to get to stream channels where they can reach the ocean is included in this. Next, the soil type can also predict erodibility, with some soils having texture and organic matter content that predicts erosion. The above information, along with rainfall as described above, was used to identify source areas for sediments that reach the ocean.

2.3.1 Land Use

While the upland areas of each of the three main watersheds are dominated by grass, shrub, and forest as elevations increase, the alluvial plains of the watersheds have been significantly modified over time by the cultivation of Hawaiian crops, then sugarcane. To identify areas that are vulnerable to erosion, we looked for areas of disturbance upland (where either grass or shrub were sparse) and areas that clearly showed bare land. We did this using several methods, including field visits, aerial imagery analyses of current and historical land use, an assessment of land use maps completed by federal agencies, and our own classification of newer MAXAR satellite-derived remote sensing images.

Field investigations

From May through July 2022, we walked the lower two-thirds of Ukumehame Stream, the lower third of Olowalu Stream, and the areas above Pāpalaua Stream and Manawaipueo Gulch. Observations were recorded during watershed walk-throughs with members of the community, state and county agencies, and partner organizations. We used these trips to look for sources of sediment that might be stored in the streams themselves, evidence of overland flow on the plains, and the state of the gulch and gully walls of the most erodible areas (Figure 12; Figure 13). We also noted vegetation across the areas we visited, which was subsequently used in the machine learning analysis at the end of this section.

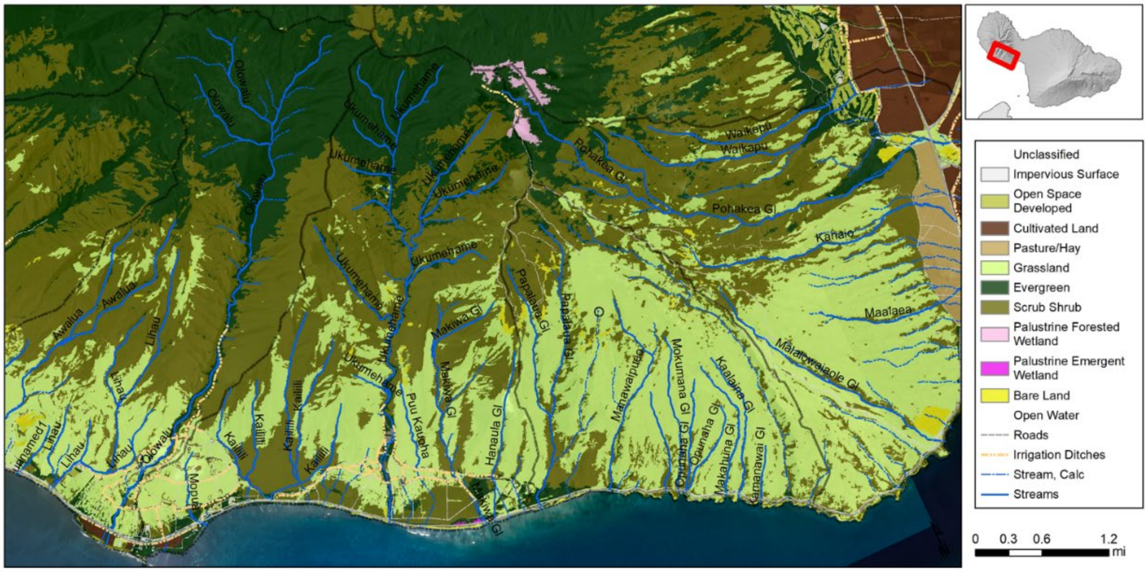
Inspection at the source waters for the Pāpalaua tributary shows that pedions (soils) are visible under plants that are now on pedestals approximately 50 cm in height. This indicates that the soil erosion is taking place at rates that exceed the growth of well-established shrubs. In addition, deer tracks could be seen making paths up the gully walls, destabilizing the soils and eating vegetation. We saw evidence of charcoal in the same location, indicating that fire had impacted these sites.

Figure 12: After the December 2021 storm, a 5-ft-high mound of fine sediment accumulated at the culvert in the Pali Trailhead parking lot. Photo: TNC.

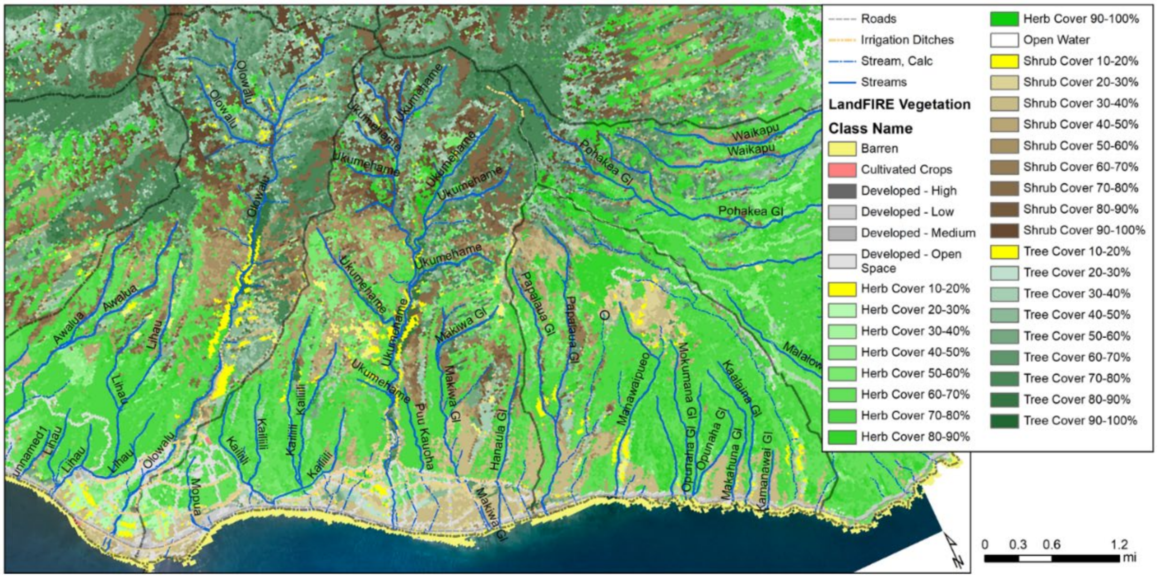
Figure 13: Erosion occurring at the top of Manawaipueo Gulch, on the east side of the gulch. Photo: TNC.

Overall land use properties

To understand overall land use properties, we first considered the land use classifications that are publicly available—NOAA's C-CAP layer (2010, 2.4 m resolution) and LandFIRE's Vegetation layer (2012, 30 m resolution) (Map 5; Map 6).



Map 5: Land use according to NOAA's C-CAP 2.4 m classification system, estimated from 2010 satellite imagery.



Map 6: LandFIRE 30 m vegetation layer from 2012.

Table 4 shows the percent of each type of land use, according to NOAA's C-CAP 2010 imagery classification. The dominant land use types in these watersheds are natural, showing about 40% shrubland, 37% grassland, and 21% forest. Only small amounts of bare land, open water, wetland, and impervious surface were identified. The C-CAP layer was specifically good at identifying the high-elevation wetland at the top of Ukumehame and Pāpalaua Watersheds, which is a unique wetland type found in high volcanic islands (see "Palustrine Forested Wetland"). Note that only 0.80% of the land was identified as "Bare", and there was no way to tell whether grass or shrubs were sparse or dense. The forest was categorized as a single land use.

	Impervious Surface	**Open Space**	**Cultivated Land**	**Grassland**	**Evergreen Forest**	**Scrub Shrub**	**Palustrine Forested Wetland**	**Palustrine Emergent Wetland**	**Bare Land**	**Open Water**
Olowalu	0.72	0.11	0.40	22.29	36.84	38.76	0.00	0.07	0.66	0.16
Ukumehame	1.10	0.09	0.18	30.42	19.62	47.33	0.22	0.04	0.54	0.45
Pāpalaua	0.71	0.00	0.00	67.92	2.77	26.53	0.00	0.00	1.44	0.64
Total	0.88	0.07	0.21	36.61	21.54	39.37	0.09	0.04	0.80	0.40

Table 4: Percent of each land use type for the Olowalu, Ukumehame, and Pāpalaua Watersheds as designated by C-CAP, 2010.

From the LANDFire dataset from 2012, additional bare areas were identified by considering herbaceous plants, shrub, and tree cover areas with less than 20% vegetation. These areas totaled 2.7% of the total land use, compared with 0.80% in C-CAP. Similar to C-CAP, natural areas comprised 94.5% of total land use, including 23.7% trees, 27.4% shrubs, and 43.5% herbaceous plants or grass.

In this dataset, the areas identified included the sidewalls of Manawaipueo, Ukumehame, and Olowalu Valleys, some open areas in the alluvial plain that were former sugarcane and taro land, and patches in the headwaters of Olowalu Stream. The sidewalls of Ukumehame and Olowalu Streams were found to be made of older alluvial deposits, likely from former landslides and an aggregate of clastic sedimentary rock that has small pebbles entrained (Figure 14). These sidewalls are identified as bare and are unlikely to contain fine, silty sediments. The deposits in Manawaipueo Gulch, however, were found to be fine red ash-derived soils that are more erodible (Figure 15) (see the Soils section below).

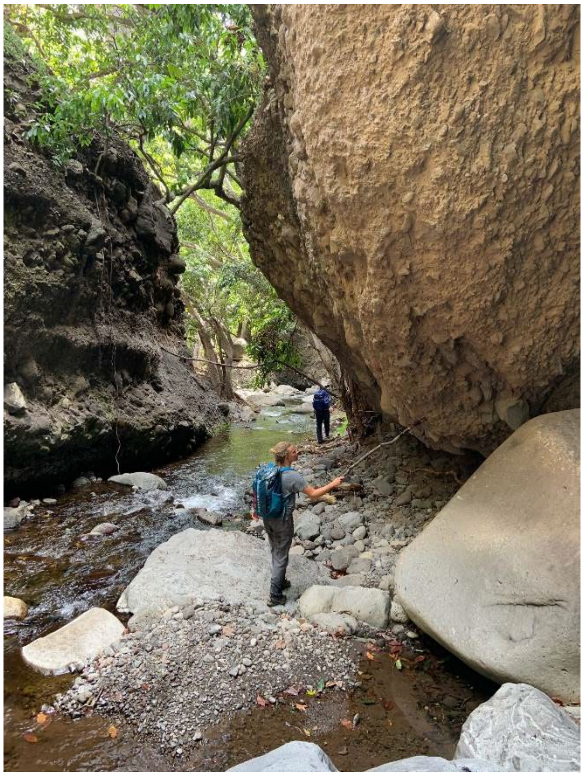


Figure 15: Older alluvial sediments from historical landslides on the banks of Ukumehame Stream. Photo: TNC.

Figure 14: Manawaipueo Gulch sediments are fine and erodible. Photo: TNC.

Land use classification using random forest methods

Because the NOAA C-CAP and LANDfire datasets predate the big wildfires in 2016 and neither of these layers specifically identified some of the trees and shrubs such as kiawe or areas of sparse grass and bare land that were the result of overgrazing, erosion, or fire, we obtained 2021 MAXAR 8-band satellite imagery, courtesy of NOAA, and used the random forest classification method to identify vegetation. Random forest classification is an ensemble method for using decision trees and has been used successfully with multiband remote sensed data to classify vegetation for many years (Gislason et al. 2006). In training, the random forest algorithm creates multiple classification and regression trees (Breiman et al. 1984), each trained on a bootstrapped sample of the original training data, and searches only across a randomly selected subset of trees.

To process a new classification, we used the MAXAR 8-band satellite imagery and first calculated the normalized vegetation difference index (NVDI) for that imagery according to equation 1:

$$\mathrm{NVDI} = \frac{\mathrm{NIR} - \mathrm{R}}{NIR + R}$$

where NIR and R are the near infrared and red bands, respectively.

From this, we were also able to calculate a C-factor or cover factor. The C-factor is one of the main factors used in the RUSLE model for soil erosion and can be used in later modeling efforts. We adopted the work of Suriyaposit and Shrestha (2008) who took field samples to estimate C-factor and correlated with the NVDI using the following equation:

$$C_{factor} = 0.227 \exp\,(-7.337 * NVDI)$$

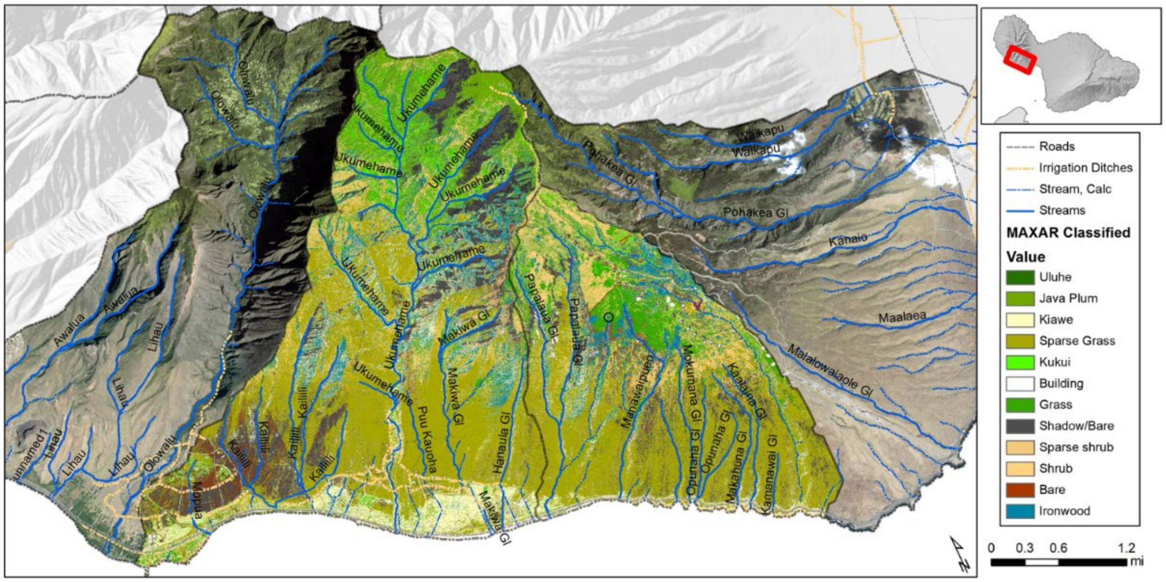
The map of the calculated NVDI and C-factor is presented in Figures 15 and 16. Shadows and clouds have a large effect on the NVDI, and areas in the upper watersheds on the east sides of the streams show evidence of shadows. Future versions will attempt to reduce the effects of shadows.

To classify the images, we used a random forest machine learning model that used 350 individual test points where the vegetation was previously identified through field or imagery verification as inputs. The training model used 5,000 trees, which were tested to be sufficient by plotting out-of-bag errors and looking for convergence. The values of all eight bands from the remotely sensed imagery, along with the calculated NVDI, were used to calibrate the model. Some of the classes were later combined for simplicity (2 and 7 identified all bare areas). The classification system was as follows:

1	Ironwood	7	Buildings
2	Bare ground	8	Christmasberry/Kukui
3	Native shrub/ shrub dense	9	Sparse vegetation
4	Sparse shrub	10	Kiawe
5	Shadow / Bare ground	11	Forest
6	Grass Dense	12	Uluhe

Table 5: Classification of vegetation for the Olowalu, Ukumehame, and Pāpalaua Watersheds using 2021 satellite imagery.

Olowalu and the seaward, western part of Ukumehame used a different satellite image than the rest of Ukumehame and Pāpalaua and the random forest algorithm needed to be run separately. To date, we are still working on classifying all three watersheds. Map 7 presents the results of the classification for Ukumehame Watershed.



Map 7: Land use classified from MAXAR satellite data with a random forest machine learning algorithm.

The MAXAR-classified land use layer offered a much finer resolution on the location of bare spots of current concern. Field visits confirmed that bare patches aligned with the MAXAR classification. The edges of Pāpalaua Stream and Manawaipueo Stream headwaters were hotspots of exposed soils in the custom layer (Figure 16). Notably, there were no bare areas visible in the back of Ukumehame Watershed. In addition to the classification, the MAXAR imagery alone in Map 5, with its 0.3-m resolution, offers a window into the current (2021) landscape of the headwaters of Manawaipueo and Pāpalaua Streams.

Historical land use change – gullies

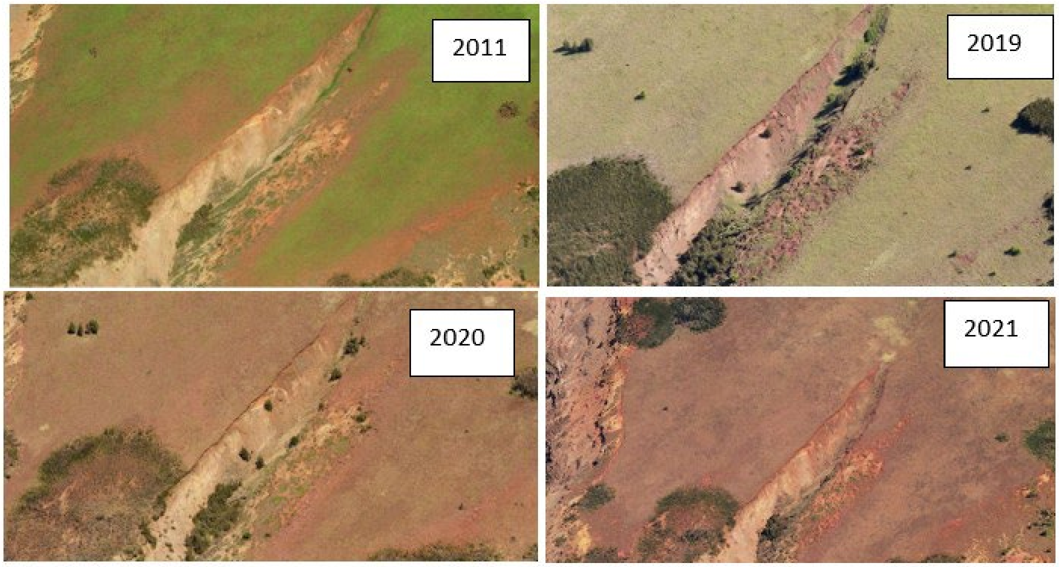


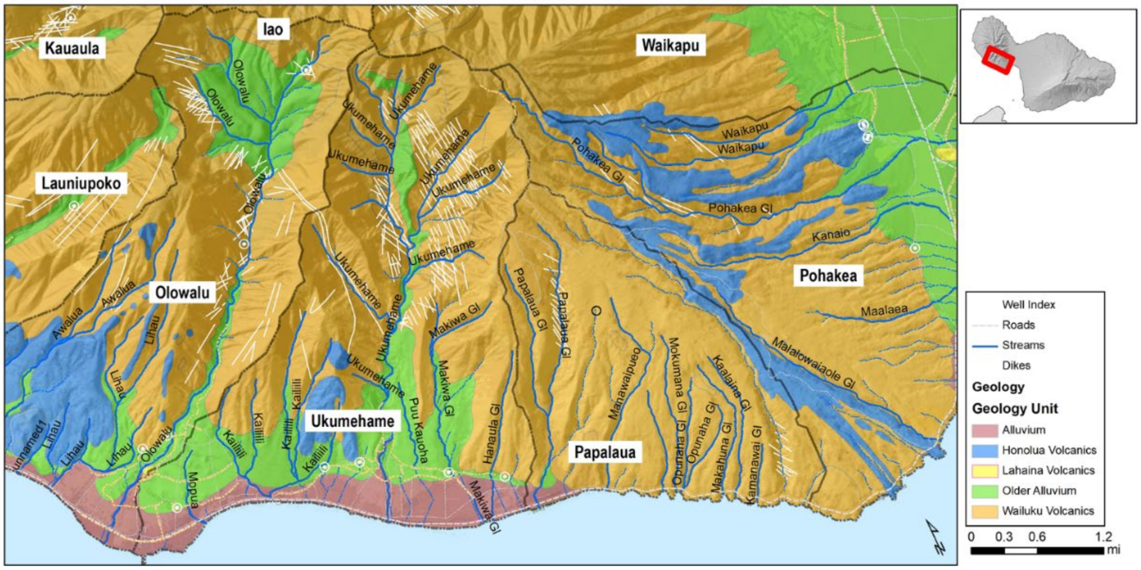
Figure 16: Pictometry photos documenting a time series for the headwaters of a tributary of Pāpalaua Stream.

2.3.2 Geology

The Olowalu and Ukumehame valleys are on the southern flanks of the West Maui Volcano. There were three separate volcanic phases in West Maui (Stearns and Macdonald 1942), with the Wailuku phase overlaid by the Honolua and Lahaina phases. The first phase called the Wailuku Volcanic Series, makes up about 97% of the volume of the volcano, and consists of thin pāhoehoe and ʻaʻā flows of tholeiitic olivine basalt with minor plagioclase basalt as thick as 1,700 m. The summit of this shield-building phase eventually collapsed to form a caldera approximately 3.2 km across, with horizontal post-caldera lava flows. The Honolua Volcanic Series, the second phase, was dominated by alkali rocks that formed an incomplete cap to the volcano ranging from single flows less than 10 m thick but several flows as thick as 230 m on the northeastern slopes (Macdonald and Abbott 1970). Occasionally viscous trachytic magma formed domes with steeply sloping flow planes, especially in the Kahoma and Launiupoko areas. Many dike and vent formations were produced in the Honolua Series, although due to the lack of well-developed rift zones, their distribution is somewhat irregular. The Honolua Series finished about 500 kya, followed by a brief third phase of activity which included four small eruptions occurring on the southwestern slope forming the Lahaina Volcanic Series. These lava flows were all silica undersaturated basanitoids or basanites. (Strauch, CWRM IIFS).

Olowalu and Ukumehame valleys are formed mostly from Wailuku basalts that have been dated to about 1.97 Ma, with remnant patches of Honolua volcanics present on the Kaheawa windmill road. There is only one small remaining outcrop of Lahaina volcanics in the Olowalu, Ukumehame, and Pāpalaua Watersheds. This outcrop in Olowalu is co-located with an area that has heiau and petroglyphs and is of high cultural importance. Notably, the Honolua volcanics series, owing to their different geologic and alkali signatures, presents itself on the landscape as having whitish colored rock.

Ukumehame Stream is lined by consolidated sedimentary deposits that are remnants of former landslides (Figure 17). The Olowalu and Ukumehame Streams are some of the most incised in all of West Maui, producing a canyon-like effect of high walls comprised of former rockslide material (Sherrod 2007). In Olowalu and Ukumehame, the buildup of former alluvial material originating in landslides is evident in the valleys and was dated to about 1.30 Ma (green on Map 8). The coastal plain is made up of more recent fertile alluvium (magenta on Map 8).



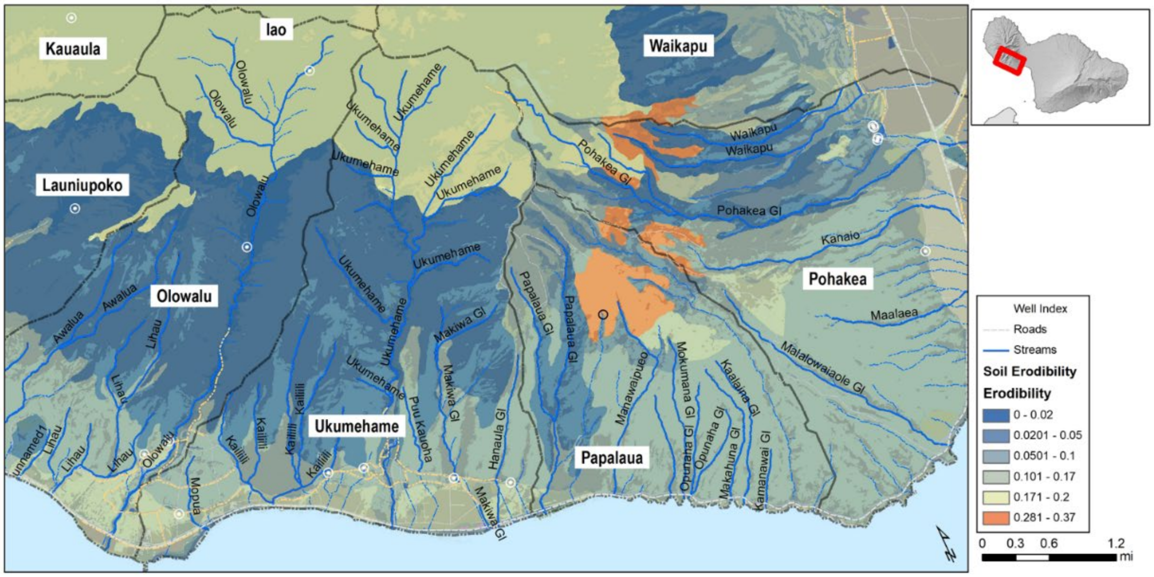
Map 8: Geology of Olowalu-Ukumehame.

For the parts of the Olowalu and Ukumehame stream systems that have not been modified, slopes are relatively steep, and step-pool and cascade stream morphologies are common. There are little active fine sediment deposits within the stream or as terraces, and the base is mostly boulders or cobbles. The ancient landslides that make up material that lines the walls of Ukumehame and Olowalu Streams is unsorted cobbles and boulders in a light silt matrix. In the active stream channels, there remain overhangs of the older alluvial material that may occasionally slide into the channels, but there is no evidence of storage.

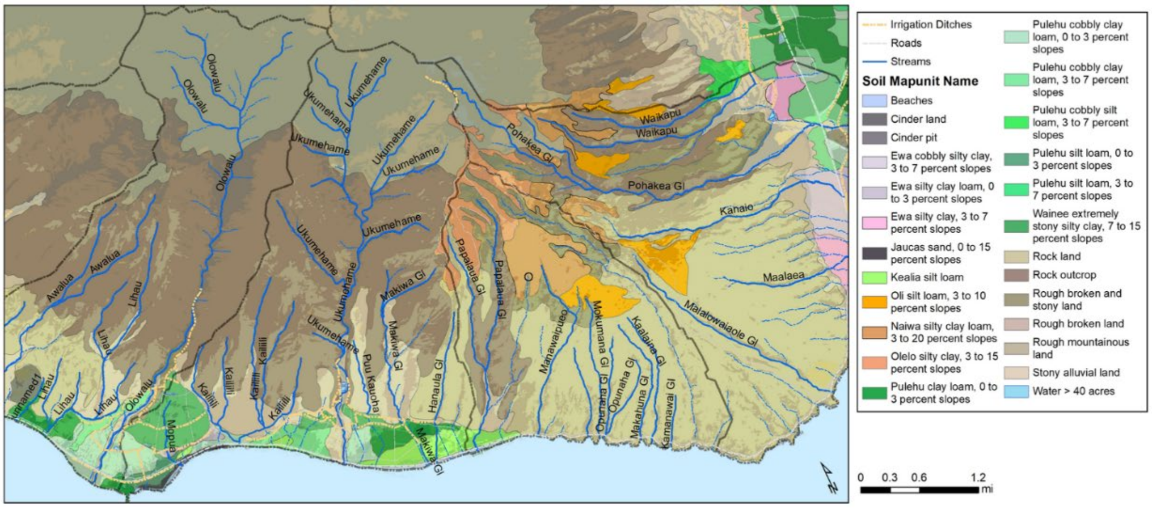
2.3.3 Soils

The K Factor (soil erodibility factor) is an index which quantifies the relative susceptibility of the soil to sheet and rill erosion. K Factor is used in the RUSLE soil loss prediction equation. Values range from 0.02 for the least erodible soils to 0.64 for the most erodible. The K-factor changes for a particular site based on organic matter, which is important information for locating restoration activities that can replenish organic matter to degraded soils.

In Ukumehame, there is notably a highly erodible area on the plateau adjacent to Pāpalaua Stream, above Manawaipueo Gulch, and along the Kaheawa windmill road (see Map 9). These are the Naiwa silty clay loam (3-20% slopes), Oli silt loam (3-10% slope) and Olelo silty clay (3-15% slopes) soil series (shown in orange on Map 10). These soils are derived from volcanic ash and were formerly covered in dry or mesic native forest, totaling 1,260 ac. They are not hydric or prone to ponding and are well drained (Hydrogroup B).



Map 9: Soil erodibility, with most erodible areas within and adjacent to the study area shown in orange.



Map 10: Soil classifications and erodibility across Olowalu and Ukumehame.

2.3.4 Vegetation

According to the National Soil Survey Geographic Database (SSURGO) and verified by field walks, the highly erodible soil series (shown in orange on Map 9) are typically associated with the following native and introduced plants: *Stapelia tameiameiae* (pūkiawe), *Waltheria indica* (‘uhaloa), *Dodonea viscosa* (‘a‘ali‘i) *Pennesetum clandestinum* (kikuyu grass), *Cynodon dactylon* (bermuda grass), *Paspalum conjugatum* (hilograss), *Anthoxanthum odoratum* (sweet vernalgrass), *Lantana camara* (lantana), and *Psidium guajava* (guava).

National Resources Conservation Service (NRCS) suggestions for windbreaks include *Melaleuca leucadendron* (paperbark), *Eucalyptus sideroxylon,* and *Acacia confusa*. These plants are often invasive, but if managed can establish protection for reestablishing native species.

Further research and conversations are needed on the topic of selecting the best species for vegetating this area. For example, non-profit Kipuka Olowalu has planted native dryland species in Olowalu Valley, and the conservation community has much to learn from those experiences.

2.3.5 Mauka: Summary

- The soils map reveals that there are very specific areas on the upper plains of Pāpalaua and Ukumehame Watersheds that have highly erodible soils. These areas correspond to areas that have also been affected by wildfire and today are dominated by sparse grass.
- Stock and Deriau documented similar types of ash-derived soils in West Maui's Wahikuli Watershed and determined rates of infiltration to be very high. It is unclear in Pāpalaua what storm frequency may be needed to initiate overland flow events which would mobilize soils. Future work to calculate infiltration rates and storm frequency are needed.
- The upper watersheds of Olowalu and Ukumehame are categorized by many shallow landslides, which are most likely to be the source of finer sediments to the Olowalu reef. These landslides would be episodic and triggered by larger storm events. This is similar to the sources that were identified by Hill (1993) for Halawa Valley on O'ahu.

2.4 Mauka: Threats

2.4.1 Wildfire

Wildfire probability depends on local weather conditions and ignition sources (Maui Emergency Management Agency 2020). According to the Hawaii Wildfire Management Organization, most sources of fire in Hawai'i are human error or arson, and are found in developments, along powerline right of ways and roadsides (2024). The sources of road ignitions are sparks from cars, beach fires, and other anthropogenic influences. Possible inland fire sources include ignitions from Maui Electric Company equipment near wooden electric wire poles and from Ukumehame Firing Range.

In addressing the question of what went wrong with the Lahaina fire disaster, their top two pre-active wildfire challenges were complacency and lack of investment, particularly in unaddressed ignition issues from public utilities and other risks. Climate change and cyclical climate events like El Niño-La Niña, when conditions are typically warmer and drier, can have a dramatic effect on the risk of wildfires. Drought-deluge cycles can increase fire frequency, disrupt historical fire regimes, and contribute to increases in fire intensity and burn severity, which lead to increased erosion during flood events.

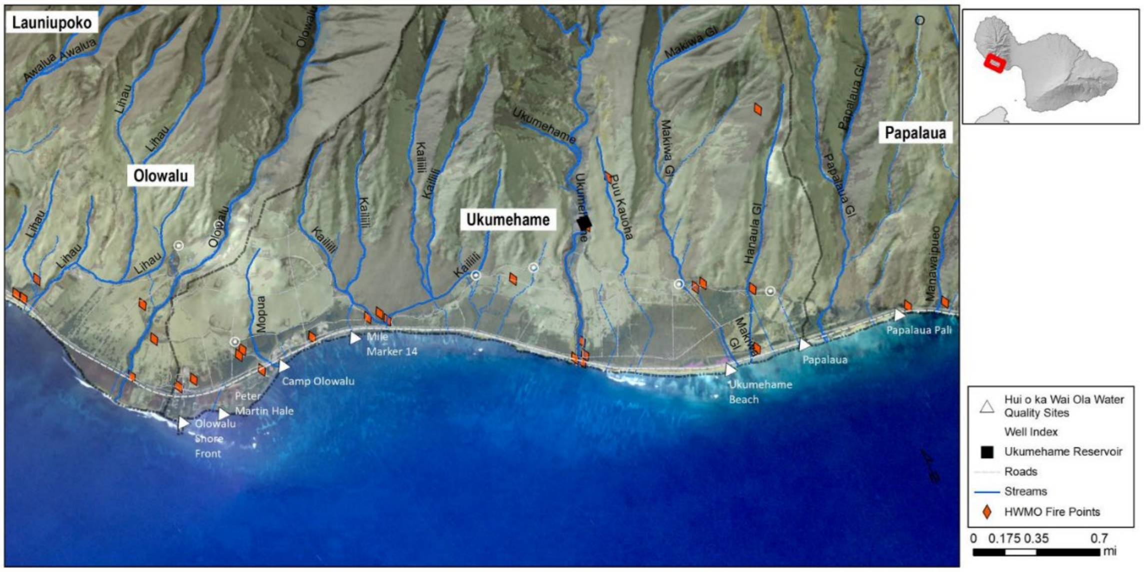
Hawaiian plants are poorly suited to fire. When fires burn native shrubs, non-native grasses typically overtake the area, adding to the overall fuel loads for the next fire cycle. Grass ecosystems are poor at recirculating water into the atmosphere (Mueller-Dombois 1972). Studies have found that while trees are able to transpire the incoming rainwater into the atmosphere, the grass cover is unable to remove excess soil water between rain showers. This results in increased runoff, erosion, and slumping of the soil under the grass cover, which then offers more potential for future burns (D’Antonio et al. 1992).

Fires in West Maui can be big enough that they can jump the two-lane highway, impeding access and egress for residents and tourists between West Maui and the rest of the island. Fires in 2016 and 2019 destroyed up to 4,801 ac in the area and required support from both the Department of Land and Natural Resources (DLNR) and the Maui Fire Department to be extinguished. More recent fires were fueled by more intense winds that are originating from different directions. In 2019, the Division of Forestry and Wildlife (DOFAW) created a dirt road fire barrier with controlled grass loads to protect some of the more vulnerable native shrubs in Pāpalaua Watershed.

The prevalence and increase of fires are a significant threat for the Olowalu reef, as newly exposed topsoil is vulnerable to erosion by high winds and rain events. This is why Hawaiian Electric Company’s Wildfire Safety Strategy submitted to the Public Utilities Commission in January 2025 is welcome news. Their four pillars of wildfire safety are: harden and redesign the grid, expand and improve situational awareness, improve operational practices, and strengthen stakeholder and community partnerships.

Past fire extent

We first investigated the known locations of historical fires using the database available from the Hawai‘i Wildfire Management Organization (HWMO), as shown in Map 11. The largest known fires in Olowalu and Ukumehame from 1999-2020 are summarized in Table 6. The frequency of fires indicates that at least once or twice per decade the area has a 3,000^{+}-ac fire. According to the Maui County Hazard Mitigation Plan Update (2020), the area has a comparatively low probability of ignition, but a high consequence for that ignition given its dry lowland areas, steep slopes, and lack of roads to control fire.

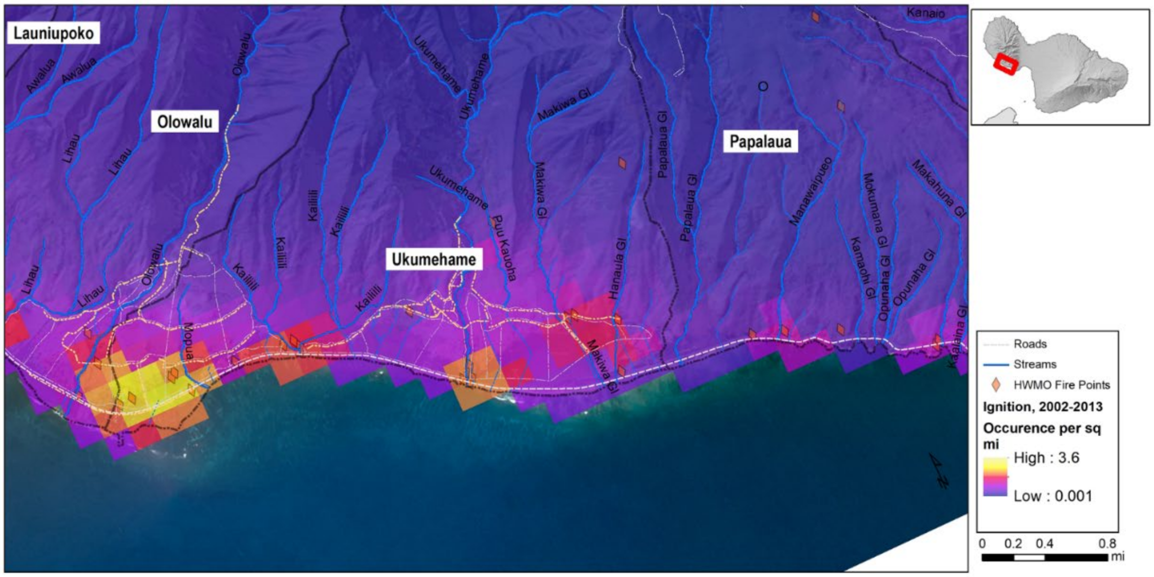


Map 11: Fires recorded in Olowalu and Ukumehame Ahupua‘a 1999-2020.

Date	Size (ac)	Fire name	Place
2002-07-28	231.73		
2006-08-20	4383.28		
2007-04-30	202.85		
2007-06-27	2550.69	Olowalu	
2010-05-03	635.32	KOAI	
2010-06-06	4809.7		
1999-05-13	150	Ukumehame area	20.81225, NA156.570557
2016-01-21	203	10NA700 HONOAPIILANI Hwy	Māʻalaea
2016-07-02	3756	Māʻalaea Nui Fire	
2016-07-08	1415	Ukumehame (Olowalu) Fire	
2018-06-28	7	Ukumehame Fire	Ukumehame, Maui
2018-08-31	341	Olowalu Fire	behind Olowalu General store
2019-01-05	192	Olowalu Fire	
2019-10-02	4801	Māʻalaea Fire	By windfarm
2020-02-25	38	Olowalu	Olowalu
2020-12-26	627	Olowalu	Olowalu

Table 6: Largest known fires in Olowalu and Ukumehame Ahupuaʻa from 1999-2020.

Using the same database, we mapped ignition history for Olowalu and Ukumehame fires from 2002-2013, noting that most fires start along the highway (Map 12) (Trauernicht and Kunz 2019; Trauernicht and Pickett 2016).



Map 12: Ignition history of fires for Olowalu and Ukumehame from 2002-2013.

In addition to using the HWMO fire database and informational products, we mapped fire risk and outcomes by considering the 2016 Māʻalaea fire using LandSat imagery before and after the fire. Images were processed using Google Earth Engine Python API. We found LandSat 8-band images that had limited cloud cover and were before and after the known fire of June 2016. We calculated the Normalized Burn Ratio (NBR) for both images, and then the differenced NBR for both images. Using this difference, we assigned a burn severity for the area. The result mapped well with the estimated extent of each of the fires. Grass coverage might not be the best indicator for fuel load in Hawai'i, where shrubs and forests are more likely to contribute to larger fires, yet the NBR algorithm was designed for places where grass loads are the most important. The result of approximately 25,000 acres burned, therefore, might be an overestimate of burn extent.

Geochemistry analysis

Wildfires create a class of contaminants called polycyclic aromatic hydrocarbons (PAHs), 16 of which are listed by the U.S. Environmental Protection Agency (EPA) as contaminants of concern because they persist in the environment, bioaccumulate, and can have adverse effects on aquatic organisms and humans. PAHs are also created during natural geologic petroleum-forming processes and by combustion of fuels such as gasoline, diesel, coal, and oil in urban and industrial settings. Identification of land-based sediment and contaminants, including those mobilized by wildfires, and their geographic sources can inform Olowalu reef protection efforts about key areas to target for runoff mitigation. A ridge-to-reef sediment and contaminant sourcing study was conducted by USGS Pacific Coastal and Marine Science Centers' Research Geologist Renee Takesue in February 2022, for Olowalu reef and the adjacent areas that contribute sediments, including Olowalu, Ukumehame, Pāpalaua, the Pali, Kealaloloa, and Māʻalaea (Figure 20), to identify PAH signatures and runoff to Olowalu reef. The study was led by the USGS, in collaboration with TNC, Maui Nui Marine Resource Council (MNMRC), and Hawai'i Association of Marine Education and Research (HAMER). The information and analysis below was provided by Renee Takesue.

Methods: Field sampling occurred in February 2022, approximately two months after heavy rains and flooding and approximately one month after 2-ft tsunami waves reached Hawai‘i from the Hunga Tonga volcanic eruption. Soil and sediment were collected: a) from streams and culverts flowing to Olowalu reef; b) near potential contaminant sources such as roads and recently burned areas; and c) from Olowalu reef. Parent and alkylated PAHs in 18 soils and sediments were measured by SGS AXYS Analytical Services, Ltd. in Sidney, British Columbia, an internationally accredited lab, to describe PAH concentrations and source signatures. Soil organic carbon contents, which are used to normalize PAH concentrations for site-to-site comparisons, were determined at the USGS Pacific Coastal and Marine Science Center Carbon Laboratory in Santa Cruz, California.

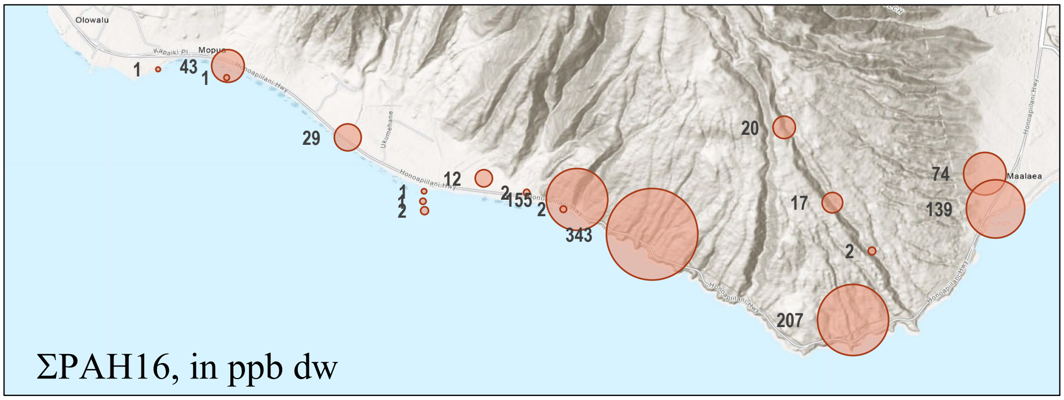


Figure 17: Summed concentrations in parts per billion dry weight (ppb dw) of the 16 polycyclic aromatic hydrocarbons (SPAH16) listed by the U.S. Environmental Protection Agency as contaminants of concern. All are more than an order of magnitude lower than the effects range-low from Long et al. (1995).

Results: Some individual PAHs were quantified below the lowest calibration standard, so reported concentrations should be considered maximum values. Summed concentrations of the 16 EPA-listed PAHs of concern (SPAH16) were very low in terrestrial and reef sediment in February 2022 (Figure 17). In terrestrial samples, only five of eleven sites (located on the Pali and in Mā‘alaea) contained all 16 EPA-listed PAHs, whereas sediment from Ukumehame Stream above the highway bridge had the lowest number of detectable PAHs, with only 6 compounds. In reef sediment, less than half of the PAHs were detected, ranging from 3-6 compounds. SPAH16 ranged from 2-343 parts per billion dry weight (ppb dw) in terrestrial soil and from 1-2 ppb dw in reef sediment (Figure 17), more than an order of magnitude lower than the effects range-low (ERL) value of 4,022 ppm dw, the concentration above which adverse effects to marine and estuarine biota are possible (Long et al. 1995).

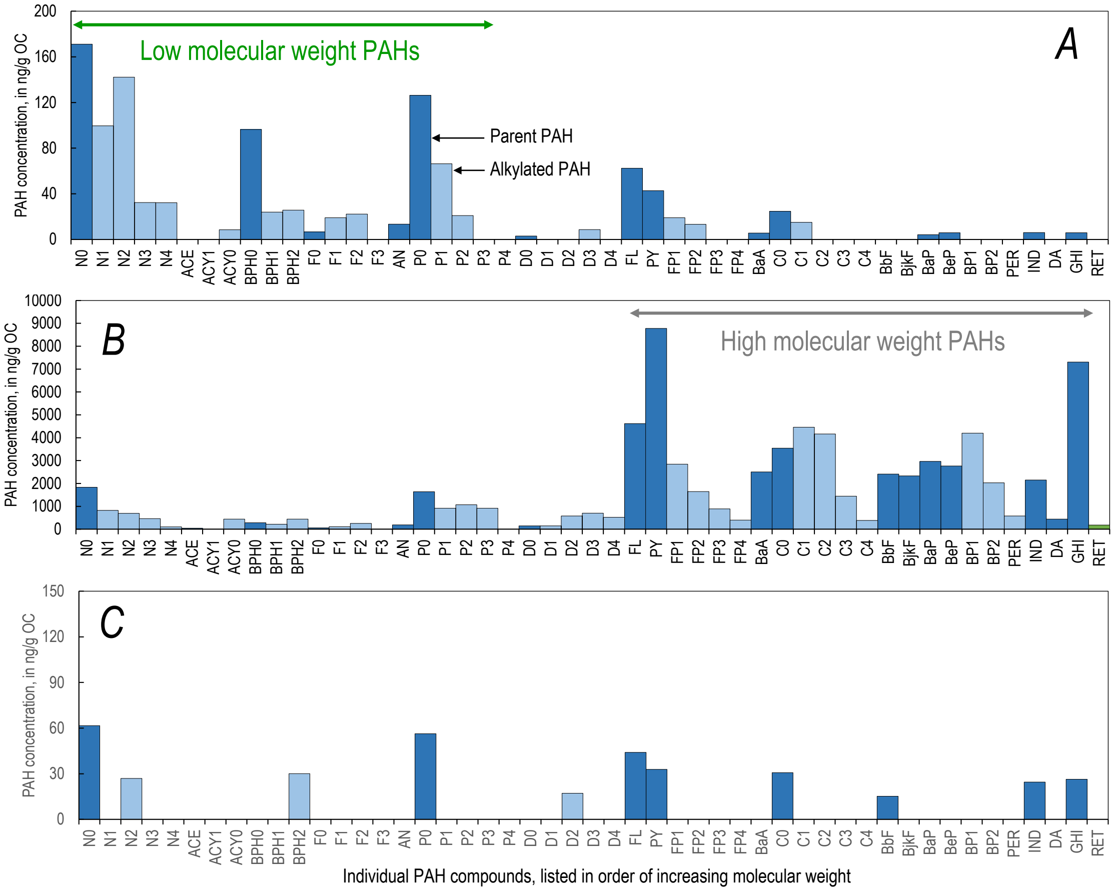


Figure 18: Distributions of parent (dark blue bars) and alkylated (light blue bars) PAH compounds normalized to the organic carbon content (OC) of the matrix listed in order of increasing molecular weight based on soils samples from. A) a retention basin above Pāpalaua Beach, B) roadside on the Pali, C) Kealaloloa Ridge at 570-ft elevation. Source: Renee Takesue, USGS.

PAH source signatures were clear from parent and alkylated PAH distributions, despite low concentrations. A wildfire PAH signature (Fig 18A), characterized by elevated low molecular weight PAHs (LMW) and equal or greater abundances of naphthalene (N0) than naphthalene with one alkyl group (N1) (Yunker et al. 2002) was apparent at all terrestrial sites except Ukumehame Stream mauka of the highway bridge (Figure 19). Wildfire signatures dominated overall PAH assemblages above Olowalu and Pāpalaua beaches, whereas high molecular weight (HMW) PAHs, likely from vehicle emissions (Stout et al. 2004), dominated overall PAH assemblages at the Pali, Kealaloloa Ridge, and Māʻalaea (Fig 18B). Ukumehame Stream mauka of the highway bridge and Kealaloloa Ridge at 570-ft elevation had mixed wildfire and emissions PAH signatures (Figure 18C).

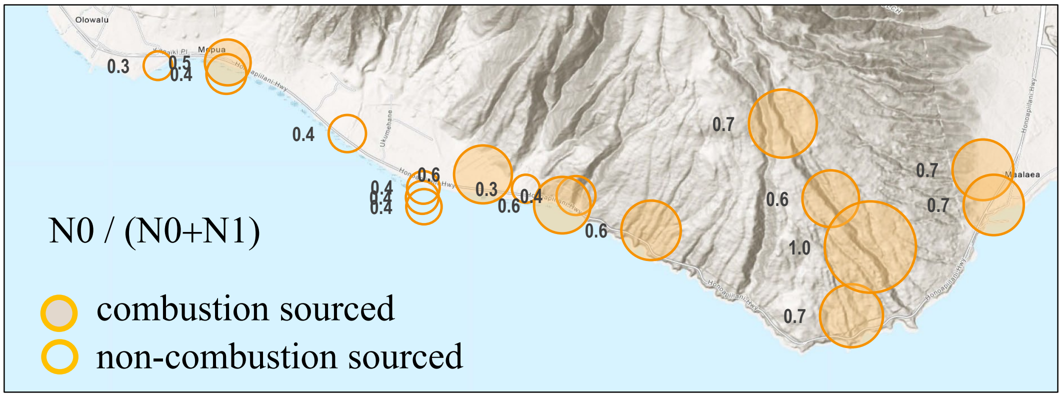


Figure 19: Ratios of naphthalene (N0) to naphthalene with one alkyl group (N1). N0/(N0+N1) > 0.5 is indicative of a combustion source. Source: Renee Takesue, USGS

The HMW PAH benzo[ghi]perylene, abbreviated GHI in Figure 18, is an emissions-sourced PAH and was highest at two roadside sites on the Pali adjacent to the highway. This compound was present at detectable levels in reef sediment 100 m offshore of mile marker 14, 450 m offshore of Ukumehame Beach Park, and 150 m offshore of the Pali Trailhead, and at terrestrial sites, but not at beach or inshore reef sites.

Conclusions: Signatures of wildfires, vehicle emissions, and naturally derived PAHs in terrestrial soil and reef sediment from Olowalu to Māʻalaea in February 2022, reflected a mix of environmental sources and human activities on the landscape. The shift in predominant PAH sources from vehicle emissions signatures in Māʻalaea, Kealaloloa, and the Pali to wildfire signatures at Pāpalaua and Olowalu could reflect the availability of wildfire fuels because the coastal plain broadens and is vegetated by grasses, shrubs, and hardwood kiawe trees west of Pāpalaua. The presence of an emissions-sourced PAH (GHI) on Olowalu reef indicates transport, likely as a sediment-bound phase for which HMW PAHs have an affinity, from the southeast where emissions PAHs dominate. There was no health risk to humans or biota from SPAH16 in soil and sediment because concentrations were very low.

2.4.2 Wildfire: Summary

Fire ignition risks are comparably low in Olowalu and Ukumehame, but the prevalence of dry grasses from previous fires, steep inaccessible slopes, and future drought conditions makes the overall risk of fire to the remaining forest and shrub ecosystem very high. In addition, the risk to infrastructure, including the main highway that connects West Maui to the rest of the island, is high. Erosion events occur after fires from bare, exposed land.

By using novel geochemical tracers, we were able to identify both vehicle emission and wildfire signatures in sediments taken across the study area from Olowalu to Pāpalaua. The data showed that vehicle emission signatures were common along the Pali, while wildfire signatures were dominant in Olowalu and Ukumehame. For coastal sediments, we identified vehicle signatures indicating that there are transport pathways that connect Pāpalaua, Manawaipueo, and the windmill road sediments directly to the Olowalu reef. The sediments off Pāpalaua retention basin, which correlate with the highest turbidity in the area (see section 2.5), were categorized by wildfire signatures. Addressing the sources of fire ignitions, fire breaks, wind breaks, and continued enforcement of fire safety actions would help prevent future devastating wildfires.

2.4.3 Axis Deer

Figure 20: Herd of Axis deer on Maui. Photo: DLNR

Overpopulation of ungulates, specifically Axis deer, is a major concern for this area. Goats and cattle were a problem previously, and both were removed through the efforts of the state Division of Forestry and Wildlife (DOFAW) and the Mauna Kahālāwai Watershed Partnership (MKWP). Ungulates directly and indirectly impact watershed health and native ecosystems in a variety of ways. These effects include grazing and uprooting native vegetation, spreading non-native and invasive plant seeds, disturbing soil, and increasing erosion. These activities decrease water retention of soils, contribute pathogens, and ultimately affect nutrient cycling and water quality (DLNR 2005).

The deer are particularly prevalent in Central and Upcountry Maui, and their populations are rapidly expanding to West Maui, leading Governor David Ige to issue four Emergency Proclamations between March and September 2022. A partial survey of the Maui Axis deer population in 2021 revealed 46,000 in Central Maui, putting the island wide estimates at perhaps 60,000 at that time. Since then, an island wide population management initiative was implemented to increase harvest rates to bring the population down. Those efforts are ongoing with early results showing progress. (Estimates by DOFAW, Maui Branch). The large number of Axis deer in Maui County impact agriculture, tourism, native ecosystems, and public safety.

Axis deer were introduced to Maui in 1959, as a game animal by the Territorial Government of Hawaiʻi. There are no natural predators for deer in Hawaiʻi, which allows for the species to thrive, and hunting is often selective as people will go for the larger individuals, either for sustenance, trophy, or protection on grazing and agricultural lands.

Deer are a significant threat to vegetative cover, which is crucial for keeping soil from eroding during storm events, especially in drought conditions. Deer preferentially eat shrubs and young trees, leaving grass as fuel for fires, but they will eat everything including grass if those are not available. They are moving deeper into the steep gulches, jeopardizing threatened and endangered plants (DLNR 2022). MKWP has several fences planned to keep deer from moving further into the West Maui Mountains, and DOFAW is working to remove the deer in the native forest areas.

2.5 Makai: Transport, Deposition, and Resuspension

As described in Section 2.2.3 (Drainages), there are at least 17 natural and manmade drainage points, including culverts, road crossings, and streams, where sediment-laden stormwater runoff might enter the ocean. In this section, we evaluate where turbidity is highest in the water column during both baseline conditions and storm events and consider how sediments are moving once they are in the coastal waters. We also consider where freshwater is entering the ocean, by describing results from coastal sampling.

To better understand whether the mauka sediment sources connect to the ocean and result in bright spots and problem spots along the Olowalu reef, we conducted long-term shore-based water quality sampling as one way to compare turbidity across the project area to complement ongoing long-term coastal water quality sampling by Hui O Ka Wai Ola (HOKWO) community volunteers. We also looked at aerial imagery from drones that would help to visualize the extent of sediment plumes. Lastly, we considered salinity data to better understand where freshwater is entering the ocean.

2.5.1 Coastal Water Quality Sampling

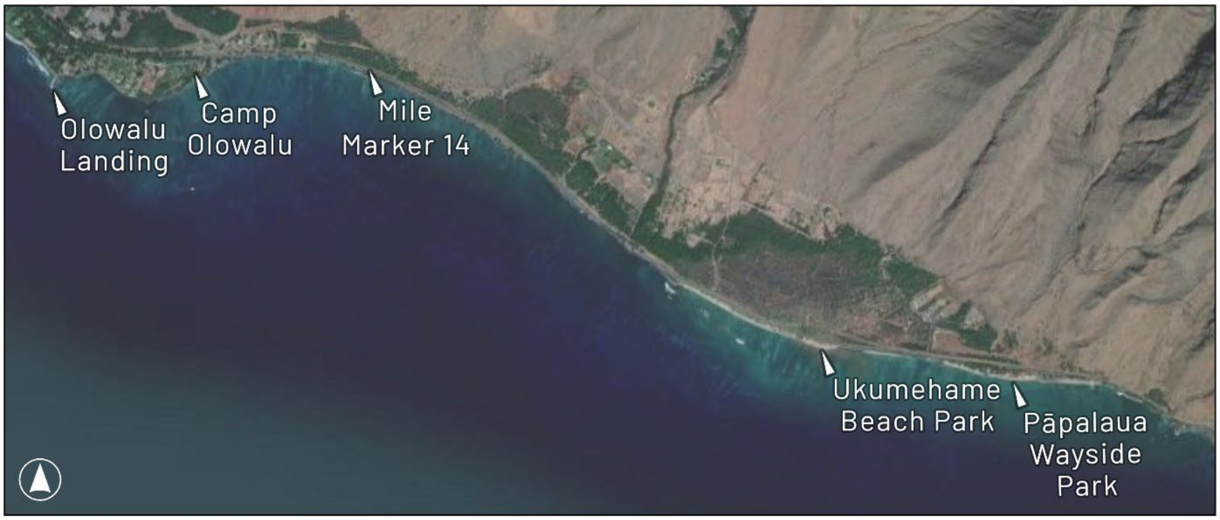


Figure 21: HOKWO sampling sites in the project area. Map: TNC

HOKWO adheres to the Hawaiʻi Department of Health's sampling program methods and monitors water quality at sites along the leeward Maui coast every three weeks. Its dataset includes sampling for total and inorganic nutrients and physical water quality parameters, including turbidity, temperature, and dissolved oxygen. The group samples five sites in the project area (Figure 21).

The geometric mean of turbidity remains above the Hawaiʻi state standard of 0.2 NTU for all sites monitored. Results demonstrate the close relationship between groundwater and nutrient delivery for this area (Figure 22). Our reefs depend on the nutrients that percolate through volcanic geology and are delivered through groundwater. Groundwater is a source of alkalinity for corals, which is important in supporting coral growth and counteracting the impacts of ocean acidification. While only certain species of corals are adapted to and thrive in lower salinity conditions, changes to the salinity composition have been shown to be detrimental to the reef community overall.

In general, the water quality in the project area is better than the rest of West Maui (most of the time), especially because of its relatively low nutrient concentrations. However, compared to other sites along the Olowalu reef, Olowalu Landing and Olowalu Point have elevated nitrate concentrations, with Olowalu Point exceeding the state standard for nitrate concentrations (Figure 22). Recently, Olowalu Landing has also shown exceedances for Enterococcus bacteria concentrations, when sampled by the Department of Health. The cause of these occasional exceedances remains unclear.

In 2024, the data for many of the Olowalu sites began to show exceedances. For turbidity (Figure 23), sediment export due to large storms showed as increased turbidity at Pāpalaua Pali, which has been confirmed by drone photos. More concerning is a spike in nitrate at Camp Olowalu (Figure 24).

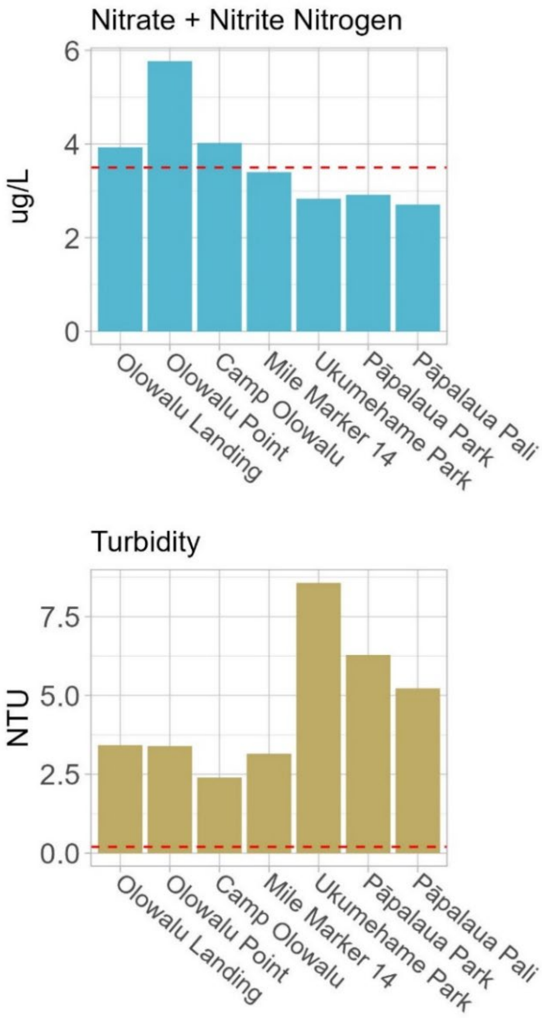


Figure 22: The geometric mean of nitrate concentrations (top) and the geometric mean of turbidity (bottom) across Olowalu reef sites from 2017-2024. In both figures, the dotted red line shows the state standard for that parameter.

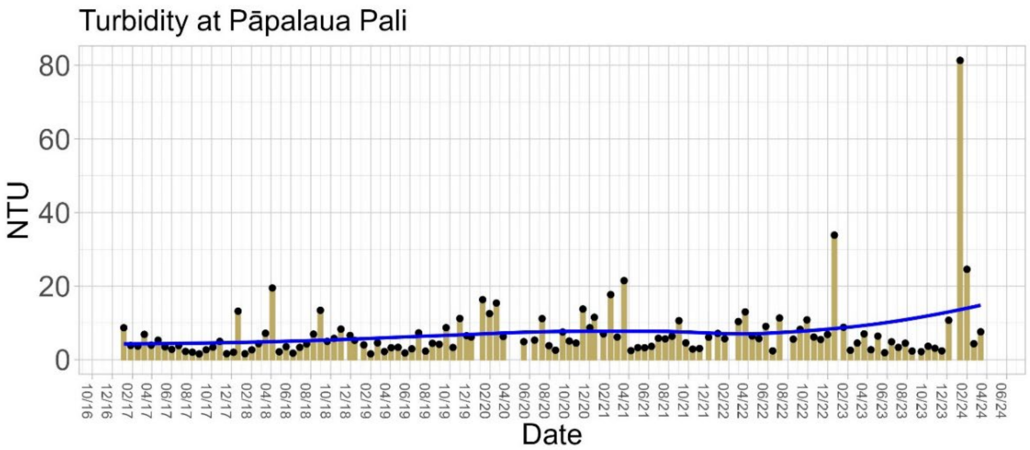


Figure 23: Turbidity at the Pāpalaua Pali monitoring site from 2016-2024. Note the increased turbidity events in 2024.

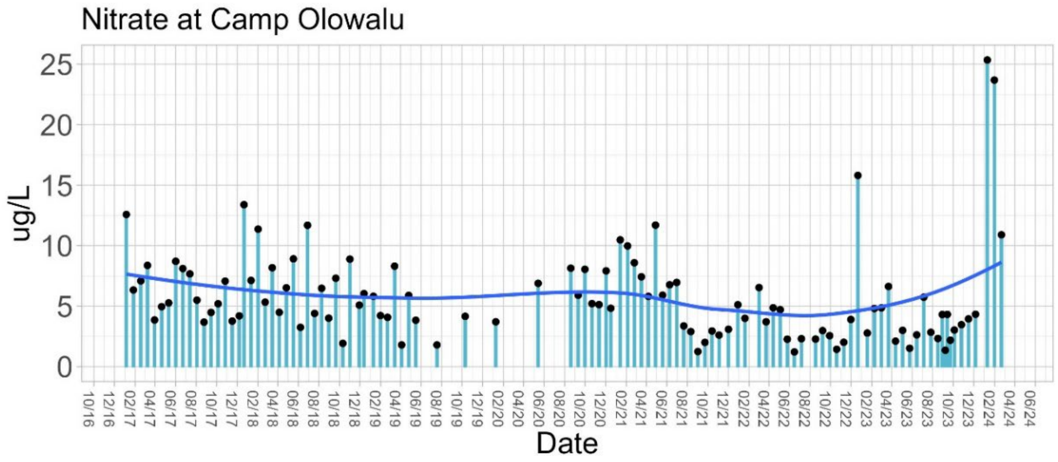


Figure 24: Nitrate at the Camp Olowalu monitoring site from 2016-2024. Note the increased nitrate events in 2024.

2.5.2 Coastal Sampling for Salinity, Turbidity, and Sedimentation Rate

On February 6-7, 2024, we conducted surveys of coastal water quality parameters, including turbidity, salinity, dissolved oxygen, and pH. Conditions on those days included a morning low tide, and northeasterly trade winds blowing to 20 kn. A Xylem YSI Pro-DSS was attached at the bow of a kayak, and recordings were made every five seconds.

HOKWO monitoring (described above) shows the highest turbidity values at Pāpalaua (Figure 25). The worst areas were concentrated in three places—in front of Pāpalaua Wayside Park, at mile marker 14, and in front of Hekili Point. The highest turbidity was over 120 FNU, nearly 500 times the state standard.

There is an abundance of freshwater entering the coast as submarine groundwater discharge. Brackish water (less than 30 ppt) was found along the entire coast. Although the mean was 34.75

ppt for the entire sampling event, salinity was documented as low as 5.11 ppt and showed localized lower averages in key hotspots along the coast.

Figure 25: Measured turbidity along the shoreline (top) and a focused look at Pāpalaua Wayside Park (bottom). Places where turbidity was greater than 10 FNU (where coral mortality is likely, according to Tuttle et al) are highlighted in a red outline.

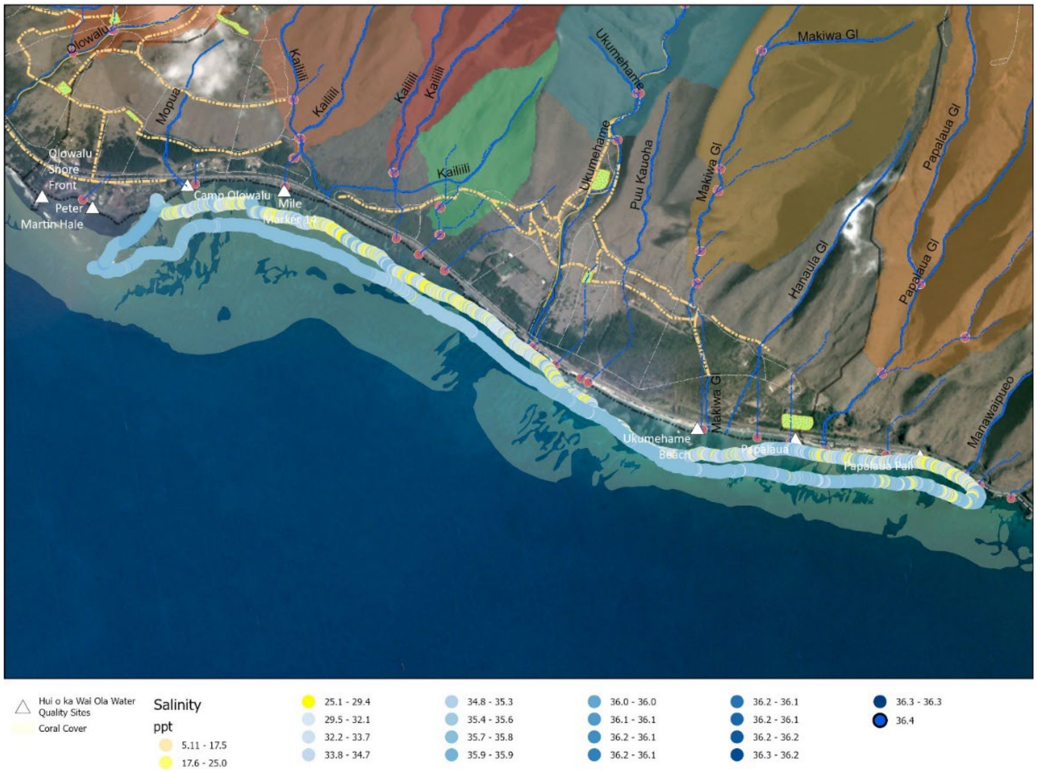


Figure 26: Nearshore salinity mapping along the Olowalu reef. Areas highlighted in yellow are less than 20 ppt and indicate submarine groundwater discharge areas.

2.5.3 Drone photos

On December 5, 2021, West Maui experienced heavy rain from a kona low storm, resulting in brown water at Olowalu and Ukumehame. This type of storm is known for coming from a southerly direction and releasing a large amount of rain in areas that do not usually get much rainfall. The Ukumehame Stream gauge reported a peak of 11.88 ft (an increase of over 2 ft on average height leading up to the event) (USGS 2022). Streamflow also peaked from an average of 4 ft^3/s to 40 ft^3/s.

In the days following the storm, drone photos were collected to analyze the extent of sediment runoff into the coastal waters. Turbidity appeared to be worse at the base of Manawaipueo Gulch, Pāpalaua Gulch, Ukumehame Stream, and Olowalu Stream, and stretched across approximately 5 miles of coastline (Figure 27).

Figure 27: Aerial view of brown water event following heavy rain in December 2021. The Ukumehame wetland is also filled with water, as seen towards the upper right of the photo. Photo: Jon Brito, DLNR DOFAW.

2.6 Wetlands

2.6.1 Historical Ukumehame wetlands

Kūpuna of the area describe the beautiful wetlands that were once seen at Ukumehame and how during the sugarcane era, planters needed to pump water to drain the area because of the abundance of water.

Figure 28: In this undated photo taken on the Pali Road above Manawaipueo Gulch, the wetlands of Ukumehame are seen in the distance. Photo: Courtesy of Save the Wetlands Hui.

Figure 29: 1950 aerial image of the area to the right (Pali side) of Ukumehame (Photo: USGS EROS Archive)

The former path of the highway can be seen slightly inland from where it is today. Also visible are the water channels and a reservoir.

Figure 30: The same area as above. Using the upper left reservoir as reference, this 1962 photo shows the development of the current highway and the increase in size of the agricultural footprint. (Photo: USGS EROS Archive)

Figure 31: By 1975, Pāpalaua sediment retention basin had been built, and additional channelization of the undeveloped area around it continued (Photo: USGS EROS Archive)

2.6.2 Current Wetland Conditions

Today, the area adjacent to the highway is mostly dry and typically is vegetated by kiawe and other invasive trees. A wetland survey conducted by Vuich Environmental Consultants in 2005 describes similar findings when investigating potential wetlands within the project area. Boundaries from a 1998 wetland delineation of the Ukumehame Firing Range also describe man-made disturbances that altered vegetative cover and hydrologic conditions of the landscape when compared to aerial imagery from 1950 and 1962 (Figure 29; Figure 30) (NRCS, Hawaiʻi National Guard, Oceanic Companies, Inc. 1998).

In 2023, TNC conducted another wetland survey with Maui Environmental Consulting using Wetland Rapid Assessment Procedure (WRAP) methodology. The soil, vegetation, and hydrology characteristics of the coastal area were assessed to determine the most promising areas for wetland restoration. The project also delineated wetlands that can still be identified today. Results showed that the construction of ditches that diverted stream flow and prevent groundwater recharge has depleted water resources that would otherwise support wetland habitats. Stream flow restoration would greatly impact the abiotic and biotic structure of the area adjacent to the Olowalu reef.

Figure 32: Current Ukumehame wetland (left) at TMK (2) 4-8-002:071 and drainage ditch (right) (2) 4-8-002:039. Photo: TNC.

Wetlands are typically delineated using a three-pronged indicator method that considers the hydrology, vegetation, and soils and whether each has markers of semi-hydric or perma-hydric features. For the study area considered adjacent to the coast, these three ecological and hydrologic features were considered.

Soils: One type of hydric soil is identified for the Ukumehame coastal area as described below.

> *Kealia Silt Loam, 0-1 percent slopes:* At elevations from 0-260 ft in areas with a mean annual precipitation of 10-41 in, this soil is found in tidal flats and salt marshes with alluvium as its parent material. The typical surface profile is silt loam from the surface to a depth of 3 in. From 27 in, the soil is loam followed by fine sandy loam to a depth of 64 in. Depth to a restrictive feature is more than 80 in with depth to the water table between 12-42 in. This soil type is considered poorly drained with frequent ponding and flooding. Kealia Silt Loam is considered hydric according to the *NRCS Web Soil Survey*.

Kealia Silt Loam soils make up a large portion of the project area. Comprising a small area to the west of the study area, and most of the eastern half, these soils are in areas where historical wetlands were likely to exist. This soil type also coincides with the location of dead and dying overstory vegetation.

Vegetation: Generally, greater than 75% of the plant species observed were considered undesirable. Dominant tree species were Manila tamarind (also known as Opiuma, or *Pithecellobium dulce*), Haole koa (*Leucaena leucocephala*), kiawe (*Prosopis pallida*), and milo (*Thespesia populnea*). Indian fleabane (*Pluchea indica*) was a common shrub species found throughout. Moving west to east, there is a shift in dominant canopy species from that of Manila tamarind and Indian fleabane to canopy dominated by kiawe.

Ditched waterways were observed to drain water from surrounding areas, providing opportunities for upland vegetation to become established. In areas where historical wetlands have been altered due to ditch creation, young and dead trees were observed, indicating occurrences of flooding long enough to stress and kill facultative upland and upland plant species. During times of inundation, we observed that the high-water table created anaerobic soil conditions and caused upland vegetation to become stressed and to die.

Groundcover vegetation included buffel grass (*Cenchrus ciliaris*), lion's ear (*Leonotis nepetifolia*), and ʻuhaloa (*Waltheria indica*). Large patches of Australian saltbush (*Atriplex semibaccata*) were found in areas where bare ground existed, with smaller patches of ʻakulikuli (*Sesuvium portulacastrum*) mixed within.

Pickleweed (*Batis maritima*), an invasive, obligate wetland plant was observed growing within ditches and in potential wetland areas, marking a distinct shift to a wetland vegetative community. This plant is known to be detrimental to waterbirds in that they reduce open water, mudflats, or shallows (Hawaiʻi State Wildlife Action Plan 2015). Though pickleweed is considered undesirable, some potential for wetland habitat support was present.

Hydrology: As discussed above, the natural hydrology in this area has been significantly impacted due to ditch creation from historical agricultural operations. Several well-defined ditches were observed throughout the historical wetland complexes, along with pump stations that may or may not be functional. Such water diversions have created a hydroperiod that no longer supports wetland plant and animal species. However, we did identify areas that show wetland-specific indicators of soils, vegetation, and hydrology. Restoration of natural hydrologic regimes and wetland habitats would positively impact surrounding waterways and ecosystems. Concerns within the study area include coastal erosion, sedimentation, coastal development, wildfires, and modern urban impacts. Based on WRAP scores generated during this assessment, Maui Environmental Consulting indicates that wetland restoration would be best suited for parcels (2) 4-8-002:002 and (2) 4-8-002:039 (Figure 34). These parcels receive inputs from Makiwa Gulch and potentially Hanaula Gulch during times of flooding. Hydrophytic vegetation and indicators of seasonal hydrology are evident in both parcels.

Figure 33: Potential historical wetlands as described by soils, vegetation, and hydrology and surveyed in 2023 by Maui Environmental Consulting.

2.6.3 Pāpalaua Sediment Retention Basin

Pāpalaua sediment retention basin, a large catchment at the outfall of Pāpalaua Gulch where there were likely former wetlands, was designed to be clear of vegetative cover, as vegetation impedes maintenance and regular removal of sediments. However, in recent years the basin has been overgrown with kiawe trees, some of which were partially removed by HDOT in 2022-2023. Since then, the growth of invasive shrubs and trees has increased.

During periods of flooding, water is designed to overtop to two grated standpipes along the west side of the northern boundary (see section 3.4.4). Stormwater captured by the retention basin discharges through the two grated standpipes in the southwest corner of the basin, which runs under the highway and a rock groin before entering the ocean.

3. Discussion of Potential Interventions to Reduce Mauka Sediments to the Olowalu Reef

We have identified 14 potential interventions to reduce mauka erosion and increase sediment capture across Olowalu and Ukumehame. Some interventions also offer opportunities for building pilina (relationships) through community-engaged stewardship. The interventions are discussed below with considerations and potential partners for each and summarized in Table 7. (Potential interventions to reduce coastal erosion and enhance coastal resilience are discussed in Section 4.)

A multi-agency and organization approach that applies a number of interventions simultaneously could multiply and reinforce their individual benefits. For instance, addressing feral ungulates and establishing additional fire control measures in mauka areas could lead to more effective reforestation, which would over time decrease the need for sediment management in the coastal region. Wetland restoration could serve several functions, including increasing sediment capture and filtration, as well as providing habitat for native coastal wildlife, and providing opportunities for renewed cultural practices and nature-based recreation. Riparian restoration would also serve similar stacked functions.

Using findings from the 2022 interim report, DOFAW was awarded NOAA funding in 2024 for the "Olowalu Mauka to Makai Project," which will implement a suite of these interventions to protect the Olowalu reef from land-based sources of sedimentation. Some of the activities will include axis deer removal and fencing, upland native plant restoration, riparian restoration, coastal sediment management, and planning for wetland restoration. TNC will support the three-year project with community outreach and education, project management, and technical assistance.

3.1 Potential Interventions to Reduce Erosion and Stabilize Soils through Improved Fire Management

3.1.1 Firebreak Road Maintenance and Expansion and Fuels Management

Intervention: Current firebreak roads appear to be effective at holding the fire line, as evidenced by the drastic difference in vegetation directly mauka and makai of the firebreak in Hanaula (upper Ukumehame near Kaheawa Ridge). In non-burned areas mauka of the firebreak, native scrubland vegetation (e.g., *ulei*, *ʻaʻaliʻi, ʻohiʻa*, and *pūkiawe*) thrives, whereas molasses grass and other invasive grasses have been established on the makai side post-fire. The project area is fire-prone due to the dry landscape and potential for high winds that increase the risk of ignition from the electrical grid. A comprehensive plan for

Figure 34: Ukumehame dry brush. Photo: Matthew Thayer

fuels management that mitigates known ignitions sources along the highway and electric infrastructure is needed. DOFAW maintains many of the fire break roads in the project area, requiring funding to keep maintenance crews employed. Partnerships with other organizations and agencies aid in funding this work. One example is funding received by the Maui Nui Marine Resource Council (MNMRC) from the County of Maui (CoM), who partnered with DOFAW to install firebreaks on the Ukumehame side of the Kaheawa windmills and mulching in-place two miles of invasive ironwood trees on either side of the firebreak. Current DOFAW priorities focus on brush management under power poles.

Considerations: In addition to fuels management under power poles, assessment and upgrades of power line systems should be considered to reduce potential ignition sources during high wind conditions.

Potential Partners: DOFAW acts as first and second responders for fires on state forest reserves and unencumbered lands and assists in locations that the CoM Fire Department cannot access with their vehicles. DOFAW maintains 16 miles of firebreak roads from Waikapū to Lahaina. Hawaiian Electric Company maintains the electric power infrastructure and in January 2025, submitted the 2025-2027 wildfire safety plan to the Public Utilities Commission.

3.1.2 Green Firebreak Installation

Intervention: Green firebreaks are areas of low-flammability vegetation that slow or stop a brushfire. They are typically planted around or between areas of more flammable vegetation and are most effective at ten or more meters wide.

Figure 35: Greenbreak in Wai‘anae, O‘ahu. Photo: Wai‘anae Mountains Watershed Partnership

Considerations: Green firebreaks with a multi-layered structure and a closed canopy have the potential to be an effective, long-term, biodiversity-friendly, and low-cost nature-based solution for fire suppression, complementing other fire suppression approaches. They are increasingly recommended for wildfire management and have been implemented in many countries. Studies suggest that the ideal species for green firebreaks should meet trait requirements from three perspectives: ecological, silvicultural, and economic. ‘Uala (Hawaiian sweet potato) or other low-stature plants that hold water could be part of a green firebreak design in this area and have been used for this purpose in the Wai‘anae Mountains Watershed Partnership on O‘ahu.

Green firebreaks could be suitable for any lands in the project area where ungulates are not present. Irrigation is required for establishment.

Potential Partners: DOFAW, MKWP), Kipuka Olowalu.

3.2 Potential Interventions to Reduce Erosion and Stabilize Soils through Improved Ungulate Management

3.2.1 Axis Deer Removal

Intervention: Since DOFAW removed all remaining goats and cattle in the project area in 2015, the Central Maui Axis deer population expanded into West Maui and has become a major concern for watershed management. Axis deer are in higher numbers from Pāpalaua Stream to Waikapū (east and north) and lower numbers west of Pāpalaua Stream.

Figure 36: Herd of Axis deer on Maui. Photo: Matthew Thayer

Considerations: Axis deer populations on Maui were estimated at 60,000 in 2021. Removal of deer from the project areas is essential to habitat restoration and soil stabilization.

Potential Partners: The Maui Axis Deer Task Force is leading management of Axis deer to reduce the overall population. This is underway island-wide in cooperation with landowners and hunters. Deer removal in designated Olowalu and Ukumehame restoration areas is led by DOFAW.

3.2.2 Axis Deer / Ungulate Fencing

Intervention: Fencing is the first line of defense to prevent Axis deer and other ungulates from entering watersheds and restoration areas. Fences also aid in ungulate removal.

Considerations: Preventing further encroachment into West Maui watersheds is essential to maintaining native forest cover and preventing further erosion. Axis deer and other feral ungulates must be removed and prevented from re-entering the project area before effective reforestation efforts can be initiated.

Potential Partners: The proposed Ukumehame fencing by DOFAW and MKWP will prevent pigs and goats from encroaching further into the Ukumehame Watershed and will strategically contain and prevent Axis deer from their expansion along a southern route from Central Maui into West Maui.

Figure 36: Ungulate proof fence. Photo: MKWP

3.3 Potential Interventions to Reduce Erosion and Stabilize Soils through Habitat Restoration


Figure 37: Native forest restoration. Photo: Ekolu Lindsey

Hawaiʻi's native forests are largely confined to upland areas that receive higher rainfall and have steeper topographies (Izuka 2012). If forests have been replaced by bare soil, invasive weeds, or grasslands, these upland areas are highly prone to runoff containing sediments and to fires. Erosion from barren slopes is a main cause of turbidity in streams and coastal seas. Statewide, 81% of marine water bodies sampled by the state Department of Health are classified as impaired, and turbidity was by far the largest cause of the substandard sampling results (DOH 2019).

Keeping upland areas forested is one of the most important ways to reduce sedimentation into streams. Vegetation prevents a condition called "overland flow" where bare soils erode during storms (Stock 2010 and Izuka 2010). Statewide, where goats and other hoofed animals have denuded vegetation and caused bare ground, annual erosion rates can remove up to 0.5 mm of soil per year, whereas other undisturbed forested areas have lower erosion rates at 0.01-0.05 mm per year (Stock et al. 2016). In other words, bare soils can increase erosion rates by 50-100 times that of forested land.

Hydrological models of the Kawela watershed in Molokaʻi predict that if the forested landcover converted to shrubs, shrublands became grasslands, and grasslands became barren, the top ten peak floods will increase in volume by 42.6%. Additionally, forests that are fenced and free from hoofed animals have significantly better rainfall and fog drip infiltration rates than adjacent unfenced forests (Fortini 2021). This provides a reasonable case study for Olowalu and Ukumehame, which have similar climate and geography.

This non-exhaustive list of digital resources offers guidance for applying the potential habitat restoration interventions listed below.

- VegSpec — A web-based decision support system that assists land managers in the planning and design of vegetative establishment practices.
- USDA Plants Database — An extensive database of native and non-native plants of the United States with over 100 plant characteristics.
- Hawaiian Native Plant Propagation Database — A database for propagation techniques for selected indigenous and endemic plants.
- Plant Conservation Research (laukahi.org) — A database for publications on related topics to inform conservation of native Hawaiian plants, including technical reports, dissertations, and published papers.

3.3.1 Native Plant Reforestation in Areas with High Erosion Rates

Intervention: Reforestation can be used strategically in areas such as the denuded slopes of Pāpalaua to reintroduce native trees and shrubs. Several methods can be used, including seedling outplanting, broadcast seed distribution, and hydromulching.

Considerations: Reforestation projects could include partnerships with entities already working in these areas to engage community in seedling cultivation, outplanting, and maintenance. Hydromulching with native seeds is a fast and cost-effective way of revegetating steep and inaccessible slopes like those in Pāpalaua. However, current stocks of native plant seeds may not be adequate for extensive efforts. For these efforts to be effective, feral ungulates must be removed and excluded by fencing prior to reforestation.

Potential Partners: DOFAW and MKWP could conduct native reforestation efforts in areas where the topsoil has been eroded.

Figure 38: Native reforestation outplanting.
Photo: MKWP

3.3.2 Riparian Restoration

Intervention: Riparian, or riverside, restoration can be a beneficial intervention to improve water quality by retaining nonpoint source pollution such as sediments. (Office of State Planning 1996).

Considerations: Full restoration involves removing invasive plants and may be difficult and expensive depending on many factors, including the complexity of the system and availability of functionally appropriate native plants. One of the most important factors for successful restoration is tailoring restoration practices to the specific ecosystem type and site conditions.

Potential Partners: Kipuka Olowalu is actively conducting riparian restoration trials around Olowalu Stream. Their efforts can provide lessons learned and examples for replication and iteration. Lineal descendants and other traditional practitioners could also be potential partners around Ukumehame Stream.

Figure 39: Riparian restoration.
Photo: Kipuka Olowalu

3.3.3 Reduce Gully and Head Cut Formation

Intervention: Planting native pili grass or other suitable vegetation on contour can prevent the expansion of gullies and head cuts, stabilize actively eroding hillslopes, capture sediment, and promote the infiltration of stormwater into the ground so that it does not move laterally across the landscape.


Figure 40: Head cut stabilization project in Pohakea. Photo: MNMRC

Considerations: The National Resources Conservation Service (NRCS) Practice 601 for vegetative barriers is an example of a method for addressing gullying and head cutting (NRCS 2003). This practice consists of planting rows of vegetation along contour lines with vertical distances of six feet between lines. This method has the potential to allow for the reintroduction of native plants and trees which can be planted behind the vegetation rows as a suitable soil base accumulates. Using trunks of invasive trees as soil erosion barriers and wood chips as mulch to stabilize soils within gulches is a practice that is used in regenerative forestation projects on Haleakalā and could be explored at priority sites across the project area.

Potential Partners: NRCS, DOFAW and MKWP.

3.4 Potential Interventions to Capture Sediments

3.4.1 New Sediment Detention Basin at Manawaipueo

Intervention: Designing a new sediment detention basin at Manawaipueo Gulch would redirect sediment runoff to a holding basin rather than it flowing directly to the ocean via the existing narrow gulch and under-the-highway culvert. The basin design must accommodate regular maintenance to maintain its functionality over time. Manawaipueo Gulch is one of two primary contributors to sediment in Ukumehame, the second being Pāpalaua. Increasing the stormwater and sediment detention capacity at this site would directly reduce sediment transport to the ocean.


Figure 41: Sediment flowing down Manawaipueo Gulch, January 2024. Photo: TNC

The soils maps in section 2.3.3 show the areas on the plains of Pāpalaua and Ukumehame Watersheds have highly erodible soils that contribute to the sediment runoff adjacent to Manawaipueo Gulch, confirmed by field observations. In December 2021, a major storm event transported large amounts of fine sediment into Manawaipueo Gulch, which filled the holding area behind a blocked culvert on Honoapiʻilani Highway, spilled over the road, and ran down the highway to Pāpalaua Wayside Park and into the ocean. This event corroborated models developed by TNC and identified a bottleneck in the drainage system, as well as opportunities to address this impact.

Considerations: Take steps to determine feasibility. Plan constuction to minimize traffic disruptions.

Potential Partners: DOFAW, HDOT and CoM.

3.4.2 Lahaina Pali Trailhead Parking Lot Redesign

Intervention: The existing dirt parking lot contributes to runoff to the ocean and could be regraded, graveled, or hardened and runoff directed to a new retention basin. Ideally, this upgrade would be in tandem with a new sediment detention basin at Manawaipueo.

Considerations: Plan constuction to minimize traffic disruptions.

Potential Partners: DOFAW, HDOT and CoM.

Figure 42: Lahaina Pali Trailhead Parking Lot and Manawaipueo Gulch. Photo: Stephanie Tom, TNC

3.4.3 Ukumehame Wetlands Restoration

Intervention: A 2023 wetland delineation assessment identified priority areas that are appropriate for restoration. A formal hydrologic assessment, plan, and cost analysis for restoring the area to its original grade and vegetation will inform and prioritize restoration.

Considerations: Ukumehame Stream and underground springs once fed into a wetland that is now mixed vegetation including kiawe. There are approximately 280 ac of current, former, degraded, and potential wetlands that, if restored, could capture and hold soils and stormwater in Ukumehame. For more information on the Ukumehame Wetlands, refer to section 2.6.

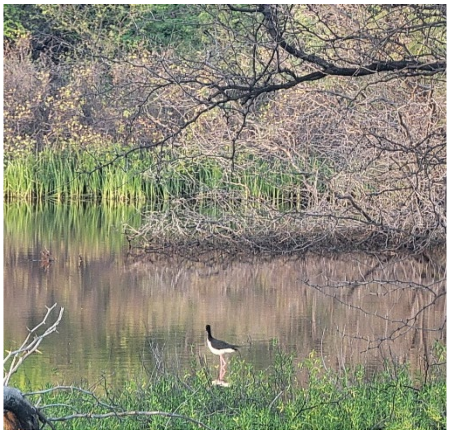


Figure 43: ʻAeʻo returning to water in the Ukumehame Wetland, 2024. Photo: Chris Brosius

Potential Partners: DOFAW is leading the hydrologic assessment, planning and cost analysis.

3.4.4 Pāpalaua Sediment Detention Basin Maintenance

Intervention: The 11.88-ac Pāpalaua sediment detention basin has been effective at capturing stormwater and sediments. However, dirt, silt, clay and vegetation in the detention basin has accumulated, decreasing its capacity to hold stormwater and settle out fine particles, such as the silt that stresses coral reefs. The two standpipes located at the western edge of the basin are almost fully buried, with only 2 ft of clearance above the ground. Once the basin is filled, sediment-laden water levels overtop the standpipes and empty through the pipes and connected culverts into the ocean near Pāpalaua Wayside Park.
The barely visible standpipes indicate that the original ground level in the basin was much lower, and retention capacity greater. Excavating deposited soil and reducing vegetation as part of a regular operations and maintenance plan would increase storage capacity and soil retention in the basin.

Considerations: Soil excavations would need to be repeated on a regular basis as part of operations and maintenance plan. Design alternatives that increase sediment retention capacity should be considered in tandem with the Honoapiʻilani Highway Improvement Project.

Figure 44: Pāpalaua Detention Basin and culvert locations. Photo: DOFAW

Potential Partners: The Pāpalaua sediment detention basin is managed by HDOT on lands owned by DLNR.

3.4.5 Kuāuna (Bioswales) Construction

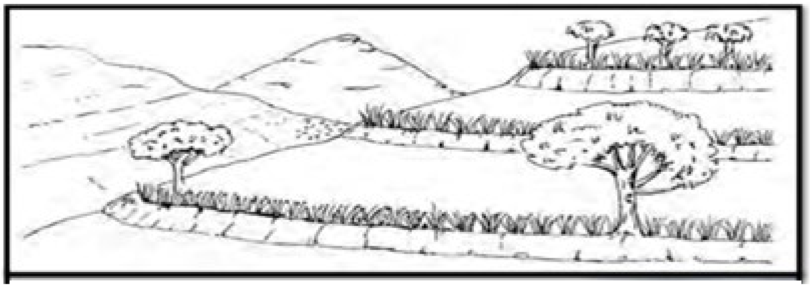


Figure 45: Example of contoured vegetative barriers. Photo: MNMRC

Intervention: Constructing kuāuna, large earthen mounds that can funnel water into wetlands, sediment detention basins, and low-lying areas between the current and future highways will increase infiltration and allow fine sediments to settle out. In the natural environment, low depressions of land such as swales and gullies reduce the amount of pollution that enters the ocean by intercepting, treating, and infiltrating stormwater into the ground and evaporating it back into the air. Kuāuna or bioswales are manmade landscape elements designed to mimic these naturally occurring depressions and can be incorporated into any urban landscape as an effective tool for reducing the stormwater and sediment that reaches the ocean. Creating berms along the contour allows for water collection and can be constructed using an excavator. Carefully considered kuāuna in this landscape could also be vegetated with native plants that retain water. Preference should be given to native vegetation specifically adapted to the region such as native sedges and important non-invasive grasses such as vetiver that can hold back soil and contaminants.

Considerations: A licensed landscape architect is essential to project design and vegetation selection. See digital resources in Section 3.3.

Potential Partners: HDOT, and coastal landowners, including the state and CoM.

3.4.6 Lo'i and Mala Restoration

Intervention: Restoring traditional flooded-field terraced agriculture can increase flood mitigation, aquifer recharge, sediment retention, nutrient uptake, and the supply of culturally important food crops such as kalo. Loʻi kalo, a type of traditional Hawaiian agriculture, use a series of terraces in which stream water is diverted through ʻauwai (ditches) and used to flood the fields before being returned to the stream. These multi-tiered wetlands have the potential to retain sediments and take up nutrients at a rate higher than conventional large-scale retention basins (Hogan 2007). Prior to 1900, it is estimated that 10,000 ac of kalo was in cultivation in Hawaiʻi using loʻi. Māla, garden, plantation, patch or cultivated fields are also important for land and soils management. In the dry, sunny climate and rocky soils of the project area, ʻuala, or sweet potato, was in widespread cultivation.

Figure 46: Restoration of loʻi at Kipuka Olowalu. Photo: TNC

Considerations: Depending on the type of terracing and stream diversion, the lo'i may or may not successfully manage large storm events.

Potential Partners: Kipuka Olowalu is restoring loʻi kalo and māla in Olowalu Valley. Guided by their mission "to perpetuate traditional and customary practices of kanaka maoli of these Hawaiian Islands and to regain the spiritual connection of hanai ʻāina of our Hawaiian ancestors by ensuring these beliefs and customs are passed down to future generations", they provide a variety of hands-on experiences for youth and

Figure 47: Participants weed the loʻi kalo during a workshop at Kipuka Olowalu in September 2022. Photo: TNC

adults. Their projects revive the loʻi kalo and engage in other traditional agricultural practices, while providing opportunities to learn about cultural protocols and help to protect the biodiversity and beauty of this region. Olowalu or Ukumehame lineal descendants or other traditional practitioners may also serve as partners.

3.4.7 Ukumehame Reservoir Improvement

Intervention: The Ukumehame Reservoirs are prime candidates for restoration projects to capture sediment. Projects could take the form of a wetland, loʻi kalo, bioretention micro basin, or constructed wetland. The off-stream Ukumehame Reservoirs 2 and 3 are earthen embankment dams constructed side-by-side along the western slope of Ukumehame Gulch that take water from the stream during high flows. The reservoirs are 770 ft in length and 29 ft high (Falinski and Penn 2018). In 2017, one of the reservoirs was decommissioned due to a leak of more than 100 gallons per minute and regulatory challenges. However, the area still holds water some of the time and is used as a refuge for waterbirds.

Figure 48: Ukumehame Reservoir 2. Photo: DLNR, Dam Safety Program

Considerations: An engineering assessment of the basins to increase their function could inform decision-making.

Potential Partners: CWRM; Landowner, West Maui Investors, LLC.

REDUCING EROSION AND STABILIZING SOILS	**Highest near-term impacts to reduce sedimentation**
Fire Management	
Firebreak Road Maintenance and Expansion and Fuels Management (3.1.1) Firebreak roads are effective at holding the fire line, as evidenced by the drastic difference in vegetation on either side of the firebreak at Hanaula. Assess the locations and efficacy of the current roads and add or relocate firebreak roads to reduce the spread of wildfires and manage ignition risk and vegetation along powerline corridors.	🟩
Green Firebreak Installation (3.1.2) Green firebreaks are areas of low-flammability vegetation that slow or stop a brushfire. They are typically planted around or between areas of more flammable vegetation and are most effective at ten or more meters wide. Assess appropriate locations.	

Ungulate Control	
Axis Deer Removal (3.2.1) Since DOFAW removed all remaining goats and cattle in 2015, Axis deer are now of major concern. Removing them is essential to forest restoration and to reduce erosion.	🟩
Axis Deer / Ungulate Fencing (3.2.2) Fencing is the first line of defense to prevent Axis deer and other ungulates from entering watersheds and managed areas. Fences also aid in ungulate removal.	🟩
Habitat Restoration	
Native Plant Reforestation in Areas with High Erosion Rates (3.3.1) Reforestation can be used strategically in areas such as the denuded landscape of Pāpalaua to reintroduce native grasses, trees and shrubs. Hydromulching can be used in post fire mitigation or landscape scale restoration.	🟩
Riparian Restoration (3.3.2) Riparian restoration in Olowalu Valley is helping to understand methods and level of effort required to improve water quality that addresses nonpoint source pollution and retain sediments.	
Reduce Gully and Head Cut Formation (3.3.3) Planting native pili grass or other suitable vegetation on contour can help prevent the expansion of gullies and head cuts, stabilize actively eroding hillslopes, capture sediment, and promote the infiltration of stormwater into the ground.	🟩
CAPTURING SEDIMENTS	
New Sediment Detention Basin at Manawaipueo (3.4.1) Designing a new sediment detention basin at Manawaipueo Gulch would directly reduce sediment transport to the ocean via stormwater.	🟩
Lahaina Pali Trailhead Parking Lot Redesign (3.4.2) The existing dirt parking lot contributes to runoff to the ocean during high rain events and could be redesigned, ideally in tandem with a new sediment detention basin at Manawaipueo.	
Wetland Restoration (3.4.3) A 2023 wetland delineation assessment identified priority state lands that are appropriate for restoration. A formal hydrologic assessment and cost analysis for restoring the area to its original grade and vegetation will inform and prioritize restoration activities.	
Pāpalaua Detention Basin Maintenance (3.4.4) Barely visible standpipes indicate the need to lower the ground level by excavating deposited soil, which will increase storage capacity and soil retention in the detention basin.	🟩
Kuāuna (Bioswales) (3.4.5) Constructing kuāuna, large earthen mounds that can funnel water into wetlands, detention basins, and low-lying areas, between the current and	

future highways will increase infiltration and allow fine sediments to settle out.	
Lo‘i Restoration (3.4.6) Restoring lo‘i kalo can increase flood mitigation, aquifer recharge, sediment retention, nutrient uptake, and the supply of culturally important food crops such as taro.	
Ukumehame Resevoir Improvement (3.4.7) The under-utilized reservoir can be improved or repurposed to serve as a retention basin, constructed wetland, or space for lo‘i cultivation, all of which would increase sediment capture.	

Table 7: Potential Interventions to Reduce Mauka Sediments to the Olowalu Reef

4. Potential Interventions for Reducing Coastal Erosion and Enhancing Coastal Resilience

Coastal erosion driven by sea level rise and storm surge is prevalent and increasing along the West Maui coast, where it accelerates the degradation of beaches and shorelines and destruction of coastal infrastructure. Olowalu has been hit particularly hard, with Honoapi‘ilani Highway impacted by regular flooding and roadway erosion. Though seawalls were installed to mitigate the flooding, this type of shoreline hardening can also impede natural ecological processes and exacerbate erosion and beach loss.

4.1 Enhancing Coastal Resilience With Nature-Based Solutions and Biocultural Practices

As HDOT prepares to move six miles of the highway inland to adapt to chronic flooding and erosion of the existing roadway, we have a unique opportunity to incorporate traditional biocultural practices and other nature-based solutions—specifically, restoration of the area’s natural features, including reefs, beaches, and wetlands—to mitigate the impacts of sea level rise and other coastal hazards. This natural ”green” infrastructure can be a more cost-effective alternative to "grey” infrastructure, as it builds coastal resilience by maintaining and expanding natural ecological systems and processes such as seasonal beach migration.

Figure 49: Olowalu: The Road to Resilience project area map. Source: UHCDC

In partnership with the University of Hawai‘i’s Community Design Center (UHCDC), we are engaging the community through “Olowalu: The Road to Resilience” to develop a vision for the coastal corridor when the highway is moved. Through a series of interactive in-person and virtual meetings, our goal is to identify nature-based and biocultural interventions that can be implemented in tandem with the road realignment and other coastal planning processes in the region. Based on the results of the visioning, analysis of current conditions, sea level rise modeling, and other technical studies, we will produce a conceptual design for coastal resilience with cost estimates, focusing on three “catalytic” priority sites.

Some nature-based interventions being considered are outlined in Appendix C. For more information, visit: *https://www.uhcdc.manoa.hawaii.edu/work/olowalu*

4.2 Monitoring Coastal Water Quality

Long term water quality data is needed to assess changing conditions in the coastal waters of Maui, which can be used to detect and quantify temporal trends in water quality and to support management decisions.

HOKWO volunteers conduct water quality monitoring on a regular schedule at fixed sites including where sediment runoff is a primary concern. Parameters studied are temperature, salinity, dissolved oxygen, pH, turbidity, and nutrients. Sample collection occurs at the same place and approximately the same time and from the same pool of water each time. When collecting water samples, three samples are collected and used for turbidity, nutrients, and physical measurements. Turbidity samples are analyzed in the field with a Hach 2100Q turbidimeter and read three times for redundancy. Nutrient samples are filtered into acid-washed bottles, frozen, and shipped to the SOEST Laboratory for Analytical Biochemistry for analysis. Physical measurements are taken on site using field Hach HQ40d multimeter and intelliCAL DO, salinity, and pH probes. Data is carefully recorded on datasheets and verified by team leads. HOKWO data, demonstrates the tight relationship between groundwater and nutrient delivery and is available for free upon request at *huiokawaiola.com*.

Figure 51: HOKWO water quality testing. Photo: Tova Callender

4.3 Building Reef Resilience

Because Olowalu is a primary source of coral larvae for other reefs in the area, it is especially vital to build its long-term resilience to climate change. While reducing land-based pollution stressors on the reef is an essential first step, TNC is also working with partners to plan for future coral restoration where appropriate at Olowalu, which has been identified as a priority restoration area by the state.

TNC’s Global Coral Reef Program has partnered with researchers from the Woods Hole Oceanographic Institution and Stanford University to identify Super Reefs—the reefs most likely able to withstand the impacts of climate change. In partnership with these researchers, the Maui Ocean

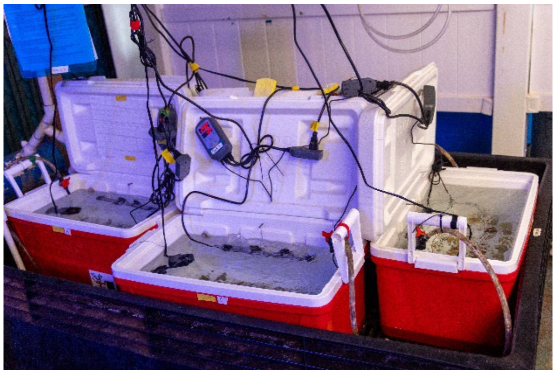


Figure 50: Super Reefs coral fragments thermal testing. Photo: TNC

Center Marine Institute, and local university students, we have been conducting hydrodynamic modeling and thermal testing on the Olowalu reef to determine which corals and reef locations are most likely to survive and thrive in warming ocean waters. Based on the results of the modeling and testing, we will begin outplanting coral fragments on the reef in 2025.

4.4 Establishing Effective, Community-Driven Management of the Olowalu Reef

TNC began to facilitate a community-led, place-based marine management planning process in 2023. Community-led marine management planning empowers local communities to actively participate in managing their coastal and marine resources, ensuring that plans reflect local knowledge, values, and priorities, leading to more sustainable and equitable outcomes. This process incorporates principles and practices from the Maui Nui Makai Network *Mālama I Ke Kai: Community Action Guide* for community-based marine management wherein stakeholders will craft a tailored marine management plan for Olowalu and Ukumehame.

Figure 51: Olowalu marine management community meeting. Photo: TNC

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Appendix A: Cultural Context and Land Use in Olowalu and Ukumehame Ahupuaʻa

Hawaiian Culture and Land Use

Figure 52: Olowalu Petroglyphs mark the footpath connecting Wailuku to the historic capital in Lahaina. Photo: TNC

Nourished by Olowalu Stream and washed by the tide, the lowland areas of Olowalu and Ukumehame were once salt marshes and wetlands that harbored native species, including seabirds and shorebirds, fish and mollusks, and native grasses and shrubs.

Olowalu Valley is a culturally and historically significant place, with many heiau (ceremonial sites), petroglyphs, and burial sites (Smith 2011; Figure 1). Records from early Hawaiʻi reveal that it was a puʻuhonua, a sanctuary or place of protection. Ukumehame once supported a large population with fertile lands and fisheries and was the site of a prominent canoe landing.

Remains of an inland fishpond called Ka Loko Kapaʻiki rests near the Olowalu shoreline. The pond sits between Honoapiʻilani Highway, the Aʻalaloloa footpath that circumnavigates Maui, and Chiefess Kalola's kauhale (house) site. Ponds like this—where seaweed-eating fish were grown and predatory species removed—were typically built and maintained to provide a sustainable source of protein for aliʻi (chief, chiefess).

These were also areas of extensive agriculture that provided for the growing population of native Hawaiians. Wood from native trees, including ʻiliahi (sandalwood), koa (acacia), *kou*, and *ʻohiʻa*, was harvested by the local population. The lower areas were abundant in food crops such as kalo (taro), ʻuala (sweet potato), ʻulu (breadfruit) and material crops such as kukui (candlenut), *ʻolonā*, *pili* and *naio*. A meandering stream and network of irrigation ditches nourished these crops (Smith 2011). A handbuilt trail connecting Wailuku to Lahaina called ʻAʻalaloloa was built for travel by horse or foot in the early 1800's, with much of the rock structure still visible today.

When missionaries arrived at Lahaina in the 1820s, they reported extensive loʻi kalo (wetland taro) terraces from mountain to sea, enabled by irrigation channels that moved water from the streams into the terrace system. Between 1810 and the 1830s, sandalwood forests were harvested for export and the original forest ecosystem in Olowalu and Ukumehame remain severely altered because of the extensive logging (Hammatt 2000). The sandalwood trade demanded that farmers leave their crops to harvest the valuable trees.

From 1845 to 1855, whaling was the prominent industry in the area. During the whaling years, there were eight times when the annual ship arrivals were more than five hundred (Speakman

2014). During this time, Hawaiʻi shifted to become completely economically dependent on whaling. When whaling declined, sugarcane farming was able to rapidly develop and overcome the economic instability of the whaling industry. When sugarcane planting began in Olowalu, the plantations altered the course of Olowalu Stream to increase acreage available for planting (Smith 2011).

By the early 1900s, most of the land had been converted to sugar by Pioneer Mill, who repurposed and expanded the irrigation system, installing reservoirs, a well, tunnels, and ditches (Wilcox 1996). The remnants of these systems remain in Olowalu and Ukumehame today and play a key role in the water and sediment carried to the reef.

History of Human Settlement

Eastern Asian migrants, who arrived in the Indonesian Archipelago around 10,000 BC and later spread across the South Pacific islands, are believed to be the initial settlers in Hawaiʻi between 0-500 BC. Skilled in long-distance ocean navigation, these immigrants introduced crops, chickens, and mammals to Hawaiʻi. Early Hawaiians settled in Lahaina, benefitting from freshwater streams that nourished crops like ʻulu, kalo, kō (sugarcane), niu (coconut), and maiʻa (banana). By 1820, Lahaina thrived as a hub for merchants and whalers, as described by William Ellis in 1823. However, with the government's move to Honolulu in 1845 and the decline of whaling, Lahaina reverted to a simple village, greatly slowing its economic significance. During this time Lahaina, Ukumehame, and Olowalu were deforested of once abundant sandalwoods prior to commercial sugar plantations becoming the dominant use of land.

Nearby Olowalu was famous for the luxuriant shade and nourishing bounty of ʻulu and for its dryland kalo cultivation (Whitney et al. 1939). Early life in Olowalu was based on farming and fishing. Olowalu residents turned their natural resources and crafts into products and services to support fishing, farming, and religious life, such as canoe building, tool carving, net and mat weaving, and tapa (beaten barkcloth) production. Just as the land was abundant with agricultural crops, so were the seas at Olowalu. These inshore waters were rich with fish, octopus, turtles and manta rays.

Olowalu was a junction for travelers on foot and in canoes, while Olowalu Valley was the primary route for aliʻi and others to travel between the governing and population centers of Wailuku and Lahaina.

As plantations expanded and the immigrant laborer population increased, Olowalu saw many changes, including a decrease in the proportion of Hawaiians in the community and the establishment of western institutions such as the Olowalu school, a Japanese language school, the Olowalu Hawaiian Protestant Church and a Roman Catholic Church by 1916 (Munekiyo 2015).

Sugar Production and Cattle Ranching

Sugar cultivation significantly transformed Olowalu and Ukumehame's landscape and water systems, impacting water and sediment flow and influencing the local reef ecosystem. In 1871, King Kamehameha V sought to lease Crown Lands in these areas to the West Maui Sugar

Association. Facing challenges, including the King's death and a decline in sugar value, West Maui Sugar sold its plantation to Pioneer Mill Company in 1874 (Lee-Greig 2015). In 1876, Olowalu Plantation was established, evolving into Olowalu Company in 1881 and cultivating sugar on former crown and kuleana lands in Olowalu and Ukumehame (Figure 2).

Figure 53: Olowalu pier and mill in the early 1900s. Photo: Lahaina News.

An extensive system of waterways and ditches diverting most of the water from Olowalu Stream was created to sustain water-thirsty crops in an arid geographical region. Olowalu Stream was moved from its original location to its current location (Figure 3). The Olowalu Stream originally emptied on the south side of Hekili Point, but was moved to empty north of the boat ramp to increase the arable acreage for sugar cane (Smith 2011). No records have been found that confirm when the stream was moved. By 1906, Olowalu Company's lease ended, and the lands were auctioned. Pioneer Mill company took over Olowalu Company in 1931, making changes to the water system and dedicating significant water resources to sugar production. However, the rise of cheaper foreign sugar sources and alternatives contributed to the decline of sugar profitability in Hawaiʻi, leading to Pioneer Mill Company's closure of the mill at Olowalu in 1999. Subsequently, its lands were subdivided for various agricultural uses or left fallow, marking the end of the sugar era in the region's economic history (Lee-Greig 2015).

Ukumehame was used for cattle ranching starting in the early 20th century, even though it was designated as a forest reserve in the 1920's, and the activity continued for nearly a century. Over time, overgrazing caused a decrease in vegetation and denuded landscapes. "As a result, the forest land is in a very poor condition and soil erosion has become a serious problem on the land. Erosion scars and eroded surfaces are very prominent in the forest area. The Forestry Division has indicated that they will be installing locks in the gates separating the boundaries of your general lease and the forest reserve line," state land agent James Shaw wrote in 1972." (Dawson 2002). Cattle grazing ceased as late as 1995, leaving behind large swaths of degraded lands bereft of native vegetation.

Current Conditions and Land Uses

In the late 1990s and towards the end of the sugar era, small scattered residential lots spanned the shoreline of Olowalu and the upper reaches of the valley. These parcels were all mostly kuleana lands and represented original boundaries of land claims made during The Great Māhele, Hawaiʻi's land redistribution proposed by King Kamehameha III.

After the final harvest and closure of the mill in 1999, lands that were formerly sugarcane fields were either left fallow, in pasturage, or were subdivided out of larger landholdings for development of agricultural estates. Starting in 1997, West Maui Land Company purchased 700 acres in Olowalu from previous landowner, Pioneer Mill. In 2000, a wind farm was constructed along the ridge between Pāpalaua and Māʻalaea to utilize the high winds that blow through the area to generate electricity.

In the early 2010s, the Olowalu Town project was proposed to develop Olowalu for approximately 1,500 homes, along with stores, schools, parks, and a small boutique inn on 636 acres of agricultural land partly owned by Olowalu Elua Associates and Olowalu Ekolu LLC (some overlap with West Maui Land Co.). In 2015, the state Land Use Commission rejected the project as it found that the nearly 4,000-page Environmental Impact Statement failed to answer questions from commissioners and residents about potential impacts on traffic, cultural resources and archaeological sites (Uechi 2019).

Currently, Olowalu remains a tree-lined, sleepy village with predominantly residential and recreational use and moderate business use. A few families still maintain loʻi kalo across Olowalu and Ukumehame; however, the decline of water resources and changing climate are not optimal for supporting loʻi cultivation. Remnant plantation ditches and waterway diversions remain in Ukumehame, unused for human activity, but still diverting stream flow from natural pathways and depositing sediments onto the reef.

Pāpalaua and Ukumehame mauka is now mostly unused for commercial purposes but is still subject to high rates of erosion and the encroachment by non-native grasses. Feral ungulates such as invasive Axis deer and increasingly frequent brushfires exacerbate upland erosion and the loss of native vegetation. In the mauka area near the Ukumehame firing range, a large basin was constructed to capture sediment runoff, which has reduced the amount of sediment flowing into the ocean and onto the coral reef. The Pāpalaua to Olowalu shoreline corridor continues to sustain heavy use by residents and visitors' ocean activities.

The shoreline is vulnerable to climate impacts, including sea level rise, roadway inundation, coastal flooding hazards, and beach erosion, all issues that impact reef health. Hardened structures such as sea walls and concrete barriers have been installed to mitigate coastal erosion and flooding to the roadway. However, this hardening degrades coral reefs by generating additional turbidity and "reflective" wave action. Conservation efforts to restore mauka, riparian, and coastal habitats are underway while HDOT prepares to construct a new highway, leaving the existing roadway in place. This provides an opportunity to plan and design for coastal and reef resilience in the area considering nature-based and indigenous solutions and addressing mauka sedimentation.

Appendix B: Hawaiian Place Names in Olowalu and Ukumehame

Manawaipueo Gulch is at the western base of the “Pali” in Ukumehame. This name translates to, literally, owl stream branch (Pata 2022). There are several modern accounts from people who have witnessed the gathering of pueo (owl) in this area. In “The Legend of the Battle of the Owls” (Uaua 1871), the author recounts “From there they flew to Molokaʻi, Lānaʻi and Kahoʻolawe and gathered together at a place called Manawaipueo with all the owls of West Maui” (Sterling 1998).

Other gulches in Ukumehame have similar names relating to streams, suggesting that water in this area was significant. These other place names include Manawainui (large stream branch), located on the southern side of the Ukumehame Ahupuaʻa, and Kamanawai (the stream branch), located just northwest of Manawainui. Kealaloloa (the very long path) is the name found on moderns maps for the prominent ridge that forms on the east side of Manawainui gulch (Pata 2022). This may refer to paths from Olowalu and Ukumehame through the mountain valleys to reach Wailuku. These references speak to the importance of fresh water to this area, a concept foreign to the now desolate and parched landscape.

Some place names denote heiau and other cultural sites in the area. One of the smallest land divisions, known as ʻili , in Olowalu is named Kaunukukahi, which means the altar that stands alone, suggesting spiritual importance for the area. One heiau in Olowalu is named Kawaialoa (the waters of Loa), and is perhaps related to an ʻili also in Olowalu named Wailoa. Wailoa (long stream) is also said to be the name of an ancient chief. Kaʻiwaloa (the great ʻiwa) Heiau served the entire region of West Maui from Ukumehame to Kekaʻa, an area frequented by ʻiwa (great frigatebirds), which aid Polynesian navigators. This heiau faces south-southwest toward Kahoʻolawe and Kealaikahiki channel and the navigation lane to Tahiti. Today, there are still ʻiwa flying above this area. These birds are also known as thunder birds, or birds that bring thunderstorms.

The northern end of Ukumehame is Pāpalaua (rainy fog), and is also the name of the beach park along the shoreline. A moʻolelo (story) regarding this area is that Pāpalaua was a violent moʻo (reptilian water spirit) from Molokaʻi. As Hiʻiakaikapoliopele journeyed toward Kauaʻi on her quest to find Lohiʻau, Pāpalaua swam forth to challenge her. The moʻo told Hiʻiaka that she would soon be stomping on her head, and a fight eventually ensued in which Pāpalaua was slain just off the shore of Ukumehame. Hiʻiaka cast the lifeless Pāpalaua up onto the land, where her body formed the large mountainous mass, and her head is buried under the sand at Pāpalaua Beach, where it would be trampled upon by beachgoers for eternity (Pata 2022). The moʻo in this story is also a reference to clean and abundant fresh water in this area.

Appendix C: Benefits of Nature-Based Solutions for Climate Resilience

The Nature Conservancy

UHCDC
UNIVERSITY OF HAWAIʻI
COMMUNITY DESIGN CENTER

Olowalu: The Road to Resilience

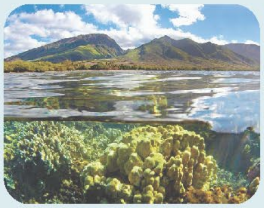
Benefits of Nature-Based Solutions for Climate Resilience

Nature-based solutions are sustainable planning, design, environmental management, and engineering practices that weave natural features or processes into the built environment to promote adaptation and resilience. These solutions use natural features and processes to combat climate change and reduce flood risk.

Source: www.fema.gov/emergency-managers/risk-management/climate-resilience/nature-based-solutions (accessed 2024)

Living Shoreline Systems

Natural and nature-inspired layered blue-green infrastructure that stabilizes and protects coastal edges and landscapes, absorbs flooding, attenuates wave energy, provides habitat, improves water quality, sustains biodiversity, and promotes coastal resilience.



Reef Restoration
- Increases biodiversity
- Protects coastline from wave impacts
- Creates habitat for native species

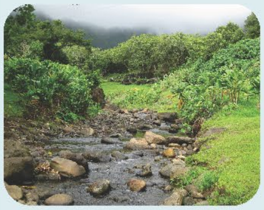
Living Breakwaters
- Increase biodiversity
- Protect coastline from wave impacts
- Create habitat for native species
- Contribute to layered living shorelines

Wetlands, Tidal Marshes, Coastal Buffers
- Provide ecosystem services
- Increase distance between water and development
- Absorb inundation and sediment
- Provide habitat

Dune Restoration
- Provides coastal protection
- Increases native habitat
- Reduces the risk of coastal hazards

Green Infrastructure

In the built environment, many vegetated landscape elements function as green infrastructure. Those systems harness natural processes, contribute to biodiversity, and increase resilience by providing critical ecosystem services for communities and sites.



Stream Bank Naturalization
- Increases vegetation cover
- Controls erosion
- Provides ecosystem services
- Supports native riparian habitat
- Increases biodiversity

Native Plant/Forest Restoration
- Creates native habitat
- Sequesters carbon dioxide
- Improves air and water quality
- Decreases runoff and erosion
- Provides economic benefits

Green Stormwater Infrastructure
- Mitigates and cleans runoff and sediment
- Reduces sediment discharge into water
- Provides other ecosystem services
- Increases biodiversity and habitat
- Benefits public health
- Reduces flood risk and increases resilience

Traditional Ecological Knowledge

The location-specific evolving knowledge acquired by indigenous and local peoples over hundreds or thousands of years through direct contact with the environment. Hawaiian biocultural land-water practices manage resources sustainably and create community.

Loʻi Kalo (Wetland Taro Farming)
- Filters water and capture sediment
- Promotes biodiversity
- Contributes to flood mitigation
- Regulates soil and water temperature
- Supports local food cultivation
- Provides cultural and educational opportunities
- Promotes public and community health

Loko Iʻa (Fishponds)
- Capture sediment
- Support local food production
- Provide cultural and educational opportunities
- Engage the community
- Contribute to living shoreline systems
- Provide ecosystem services and biodiversity
- Benefit local economy

Productive Landscapes

Intentional integration of landscape elements that produce food, energy/fuel, fiber and/or other resources in sustainable and locale-appropriate ways while providing environmental and social/cultural benefits.

Agroforestry
- Increases shade and regulate microclimate
- Enhances soil health and air quality
- Supports local food cultivation
- Sequesters carbon
- Reduces sediment and runoff
- Provides restorative properties
- Engages the community
- Creates wildlife habitat
- Supports mauka-makai connectivity

Traditional Agriculture and Farming
- Produce local food
- Establish pilina with ʻāina
- Promote food security
- Support pollinator species
- Reuse stormwater & greywater
- Enhance soil health
- Build community
- Benefit public health