

Appendix

Site Summaries

Site summaries for each CR4 project site include project descriptions, maps showing the project overview, flood maps from Storlazzi et al. (2019), reef characteristics, primary coastal hazards of concern, and results from the preliminary BCA. General reef condition assessments were determined from the Atlas of the Reefs of West Maui (Minton et al., 2020) and the Assessment of the Resilience of Leeward Maui Reefs (Maynard et al., 2019). It's important to note that in 2015 the Main Hawaiian Islands experienced a mass bleaching event that greatly impacted the reefs on Maui, resulting in an estimated 20-40% loss of coral cover (SSRI, 2017). Still, where appropriate, reef condition also includes the relative reef resilience potential from Maynard et al. (2019). Resilience is the ability of a reef to withstand stressors and maintain a level of ecosystem health that provides key ecological services and functions (Mumby et al., 2007; Nystrom and Folke, 2001). Potential reef resilience is an indication of potential reef restoration success at any particular reef. Reef profiles were approximated using the profile tool in QGIS. However more high-resolution reef profiles should be evaluated for the development of an actual CR4 project at any site.

Based on the information in the study and the site summaries, we assessed a preliminary determination of feasibility for each site. Feasibility includes assessments of the value of flood protection provided by reefs, coral reef condition, reef profile, level of community buy-in, competing projects or plans, and cost-effectiveness as determined by the BCR.

PRELIMINARY DETERMINATION OF FEASIBILITY *

**given stated assumptions in the study*

SITE NAME	FEASIBILITY	CORAL GARDENING BCR	HYBRID REEF BCR
Ka'anapali Beach Club	High	4.69	10.65
North Kihei	Med	2.89	6.61
Lahaina	Med	5.33	12.11
Kahana	Low	0.48	1.06
South Kihei	Med	5.98	13.60
Ka'anapali Ali'i	High	3.40	7.70
Ka'anapali Marriott	Med	12.52	28.52
Kahana Sunset	Low	0.18	0.39
Napili Bay	Low	0.49	1.08
Kahanaiki Gulch	Med	0.71	1.58
Kuleana Resort	Med	0.95	2.13
Maui Sands	Med	1.62	3.66
Westin Ka'anapali	Low	0.26	0.54
Kauaula Stream	Med	1.60	3.61
Olowalu Beach	Low	0.23	0.47

A. Ka'anapali Beach Club

Location: 20.9488458° -156.689947°

PROJECT DESCRIPTION

The Ka'anapali Beach Club site is situated at the southern end of the Honokowai region, adjacent to Honokowai Point. This site was selected because the Ka'anapali Beach Club has previously investigated groins and grey infrastructure projects to retain the sandy beach in front of the resort. This site is particularly interesting because the resorts on both sides of the Beach Club have historic seawalls protecting their shoreline, but the Beach Club does not. This site is relatively smaller than the other sites because we wanted to consider a more targeted CR4 project where one or two primary beneficiaries receive the benefits.

COASTAL HAZARD(S) OF CONCERN:

- Coastal Erosion
- Beach Loss
- Sea Level Rise

PROJECT OVERVIEW

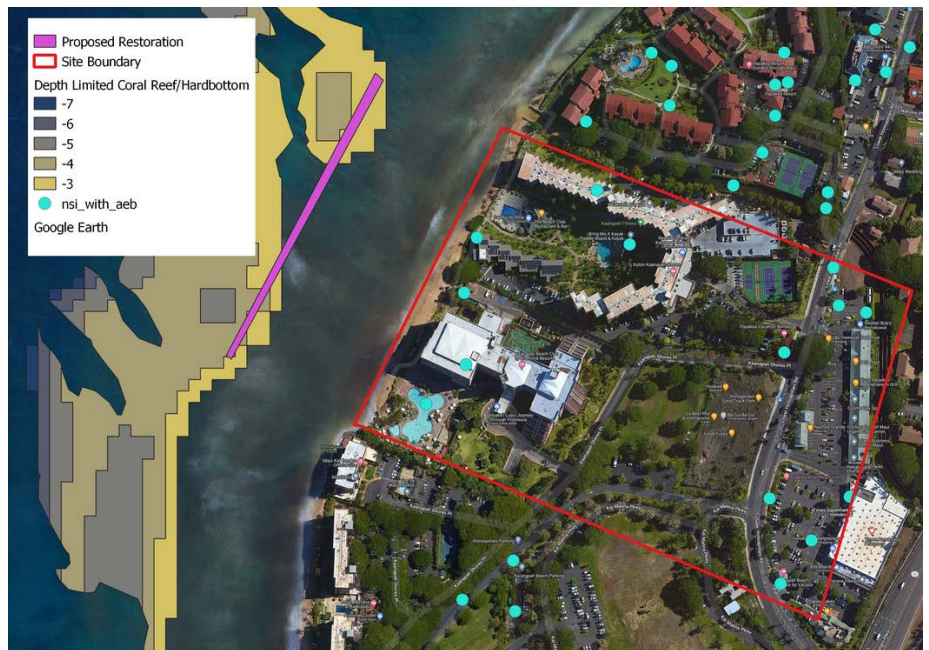


Figure 1A. Map showing the Ka'anapali Beach Club CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS



Figure 2A. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Ka'anapali Beach Club site.

REEF CHARACTERISTICS

Reef Condition Assessment

According to Minton et al. (2020), the reefs in the area of the Ka'anapali Beach Club have average to high abundance, biomass, and diversity of both benthic and fish assemblages. Compared to the statewide average, reefs in this area have high coral cover (32%) but are a “mixed bag” concerning fish. Turf algal cover was assessed at 46% in this area. The main coral species surveyed include *Porites lobata*, *Porites compressa*, and *Montipora capitata*. Reefs in this area have medium-low potential reef resilience (Maynard et al., 2019).

Reef Profile Assessment: convex or three-slope

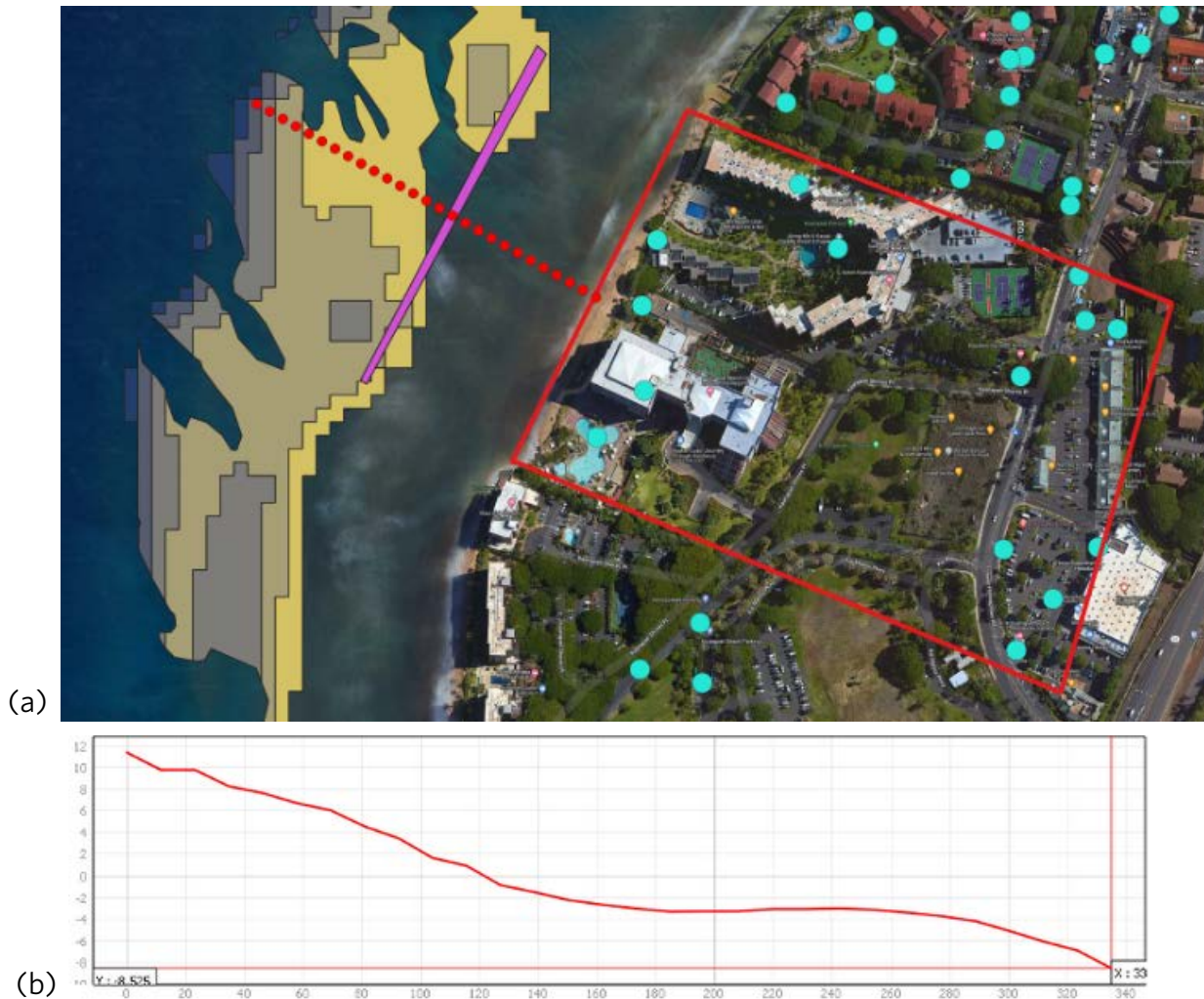


Figure 3A. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 140 value on the x-axis.

PRELIMINARY BCA RESULTS

RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.34	\$5,070,358	\$1,081,740	4.69
Hybrid Reef		\$14,418,105	\$1,354,338	10.65

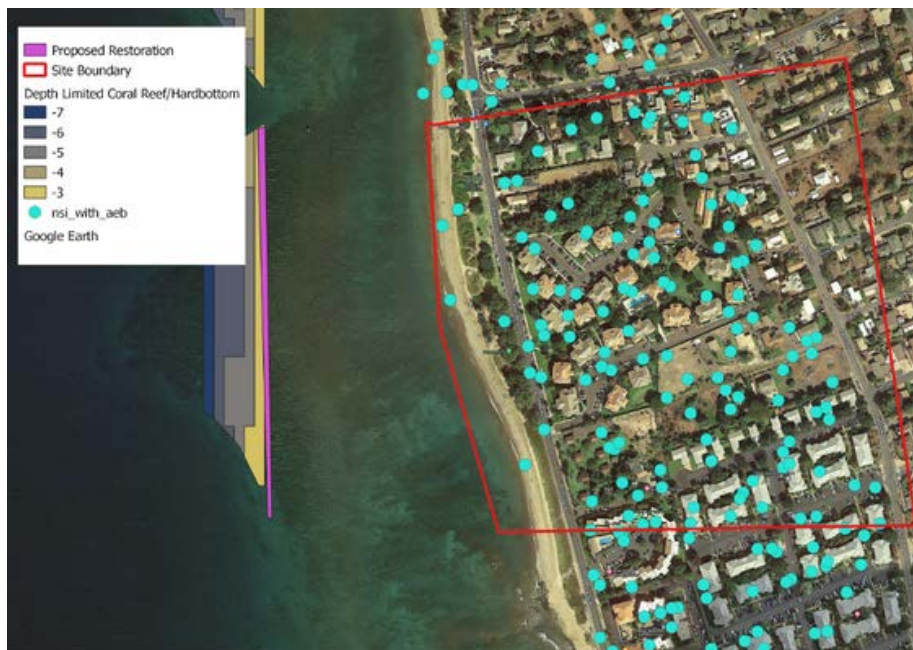
B. North Kihei

Location: 20.7724526° -156.4584742°

PROJECT DESCRIPTION

The North Kihei site extends from Kenolio Rd. on the south to Ohukai Rd. on the north. This site encompasses Kaipukaihina Beach Park and Mai Poina Beach Park. The adjacent community is mostly condominiums and rental properties with family homes scattered throughout. The reef offshore is a relatively isolated area of shallow, fringing reef. Reef degradation in this area makes the reefs offshore Kihei North potentially amenable to an active reef restoration project.

PROJECT OVERVIEW



COASTAL HAZARD(S) OF CONCERN:

- Coastal flooding
- Storm surge
- Sea level rise

Figure 1B. Map showing the North Kihei CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS

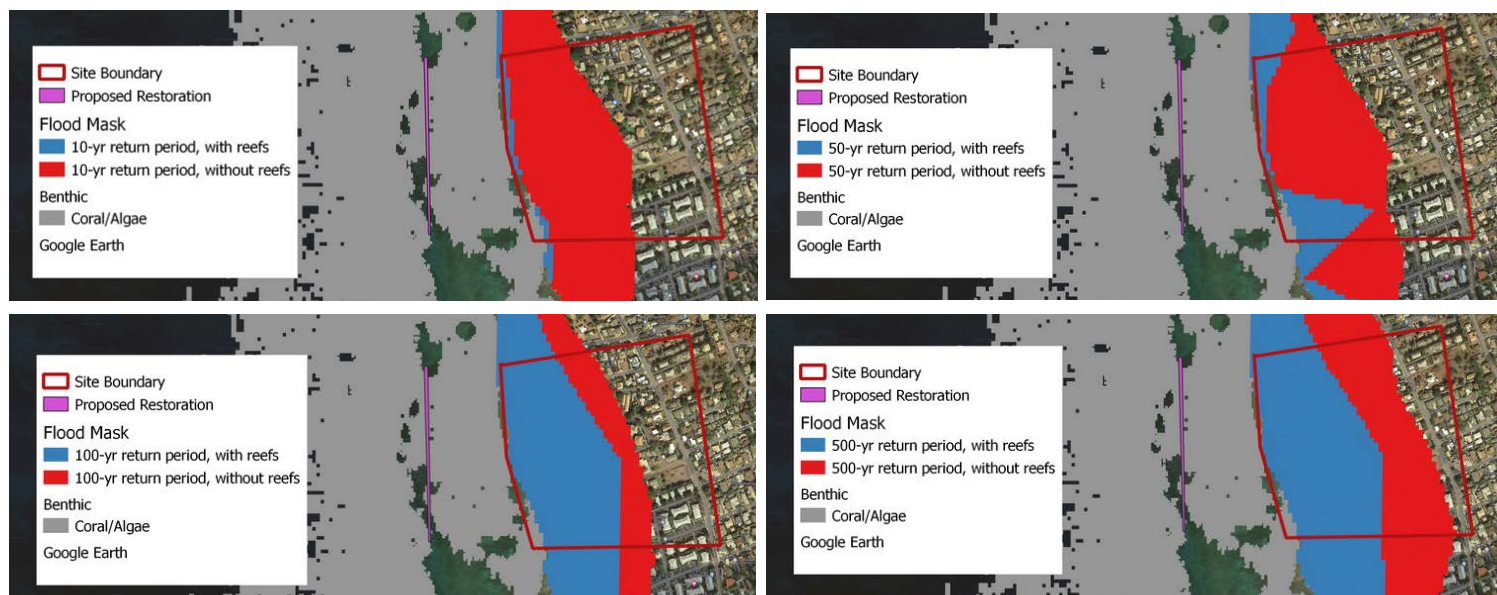


Figure 2B. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the North Kihei site.

REEF CHARACTERISTICS

Reef Condition Assessment

The reefs at the North Kihei site were assessed with high relative resilience in the NOAA Assessment of the Resilience of Leeward Maui Reefs, as well as a coral cover of 50%. Sedimentation and land-based sources of pollution may impact coral outplant survivability at this site.

Reef Profile Assessment: linear

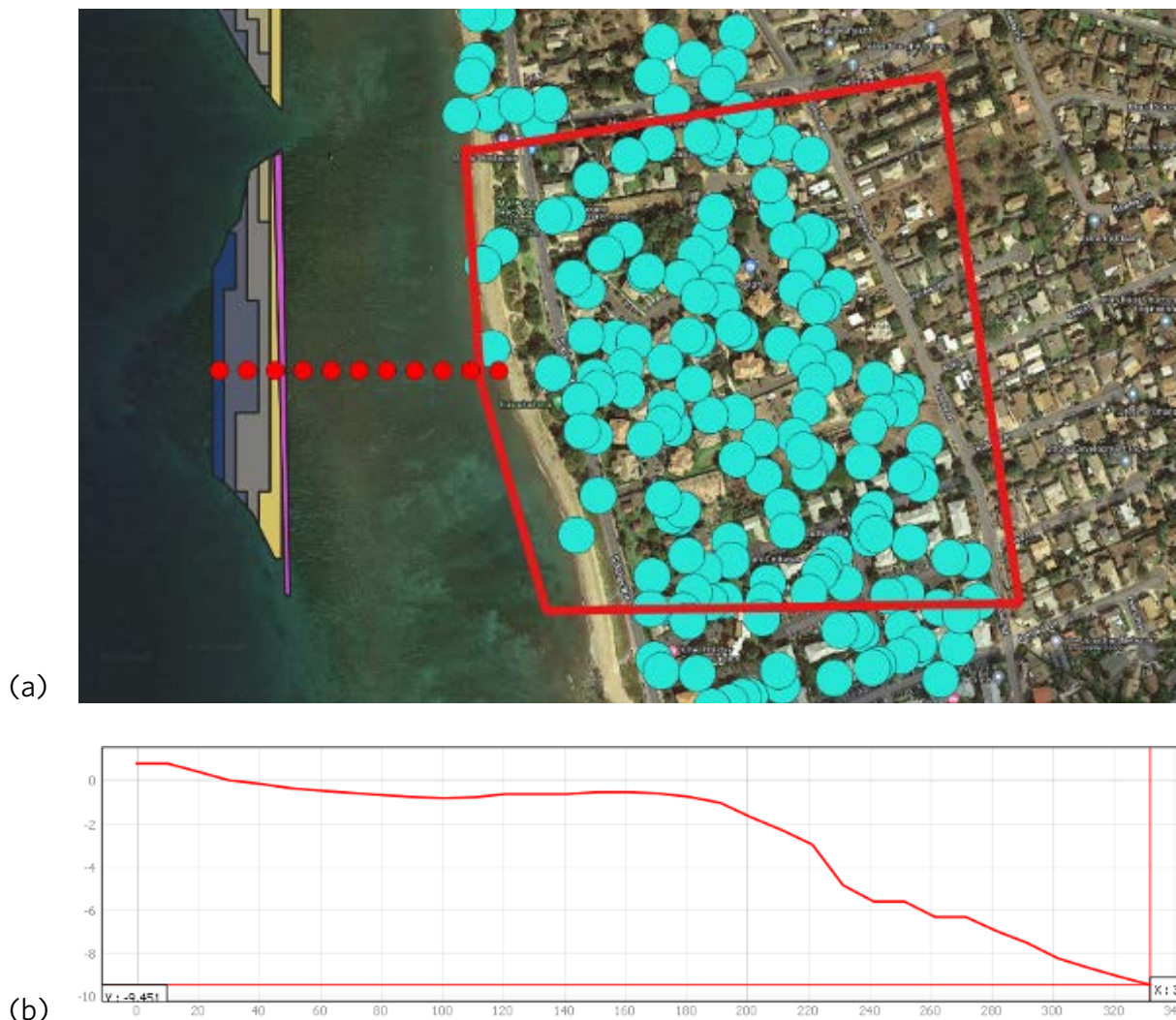


Figure 3B. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 200 value on the x-axis.

PRELIMINARY BCA RESULTS				
RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.5	\$4,593,867	\$1,590,793	2.89
Hybrid Reef		\$13,161,076	\$1,991,674	6.61

C. Lahaina

Location: 20.8788602° -156.6825517°

PROJECT DESCRIPTION

The Lahaina site is situated just south of Baby Beach in the heart of Lahaina Town. Lahaina is a site where coral reefs provide significant flood risk reduction to a large number of various types of infrastructure. Lahaina is home to 80% of Maui's tourism since it is filled with restaurants, shops, activity rentals, and several historic sites (lahainatown, 2020). The loss of the reefs offshore due to bleaching, disease, or other effects of climate change would greatly increase flooding in Lahaina. For this reason, it was selected as a site to examine whether a hypothetical restoration project has the potential to provide significant cost-effective risk reduction benefits.

COASTAL HAZARD(S) OF CONCERN:

- Coastal flooding
- Storm surge
- Sea level rise

PROJECT OVERVIEW



Figure 1C. Map showing the Lahaina CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS



Figure 2C. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Lahaina site.

REEF CHARACTERISTICS

Reef Condition Assessment

According to Minton et al. (2020), the reefs in the Lahaina area have medium-high coral cover and benthic diversity and an average total and resource fish biomass. Compared to the statewide reef average, reefs in the Lahaina Town zone have high coral cover (25%) but below-average fish assemblage. Because the reefs of Lahaina Town are observed in such good condition, a restoration project in this area would need to be sited carefully to avoid having negative impacts on the already existing healthy reef. Further, reefs in Lahaina are heavily impacted by fishing pressure and have issues associated with land-based sources of pollution. The most abundant coral species surveyed at this site include *Montipora capitata*, *Montipora patula*, and *Porites lobata*. Reefs in this area have medium-high potential reef resilience (Maynard et al., 2019).

Reef Profile Assessment: fringing

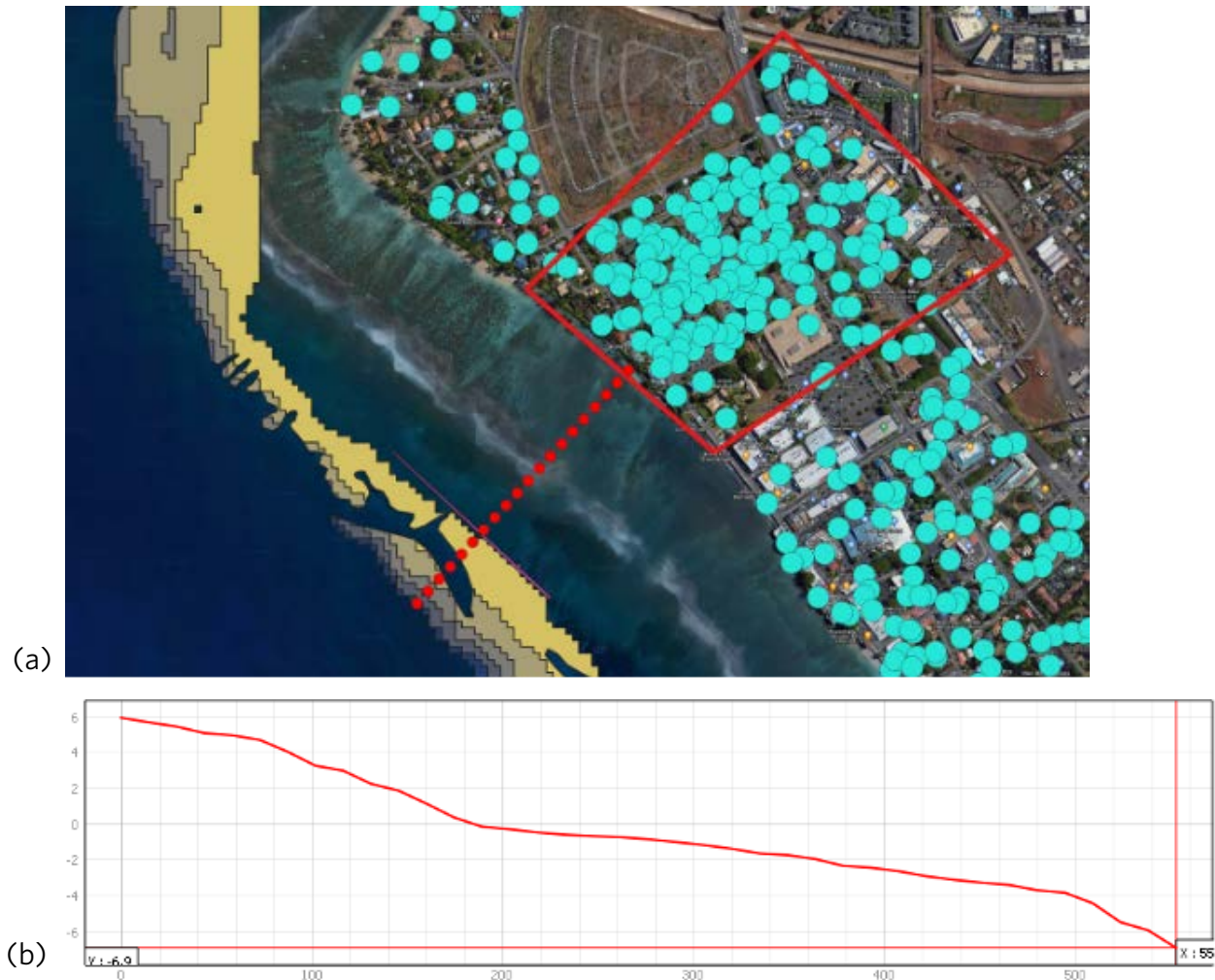


Figure 3C. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 375 value on the x-axis.

PRELIMINARY BCA RESULTS				
RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.41	\$6,953,682	\$1,304,451	5.33
Hybrid Reef		\$19,784,033	\$1,633,172	12.11

D. Kahana

Location: 20.9723392° -156.6784466°

PROJECT DESCRIPTION

The Kahana site extends from Kahana Village Vacation Rentals on the north end to Kahana Villas on the southern end. This site was selected because of multi-stakeholder interest in investigating the potential of a reef restoration project to deliver risk reduction benefits to the Kahana shoreline region in West Maui. This shoreline area has a history of significant erosion and flooding events, with most properties along the shore resorting to sandbags or grandfathered-in seawalls to protect their assets. While this is the largest proposed restoration project and associated land area to receive risk reduction benefits, it is crucial to consider this coastline because it contains the entire littoral cell of this region, and alternative proposed projects to mitigate erosion extend along this exact length. For example, the primary project proposed to retain and restore the sandy beach and reduce erosion in this area is to install a series of T-groins designed to protect the adjacent properties and keep the sand in place along the shoreline (see Fig. 1D).



Figure 1D. A rendering of the proposed T-groin and beach restoration project to enhance and restore the beach and reduce erosion in the Kahana project area.

COASTAL HAZARD(S) OF CONCERN:

- Coastal erosion
- Sea level rise

PROJECT OVERVIEW



Figure 2D. Map showing the Kahana CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS

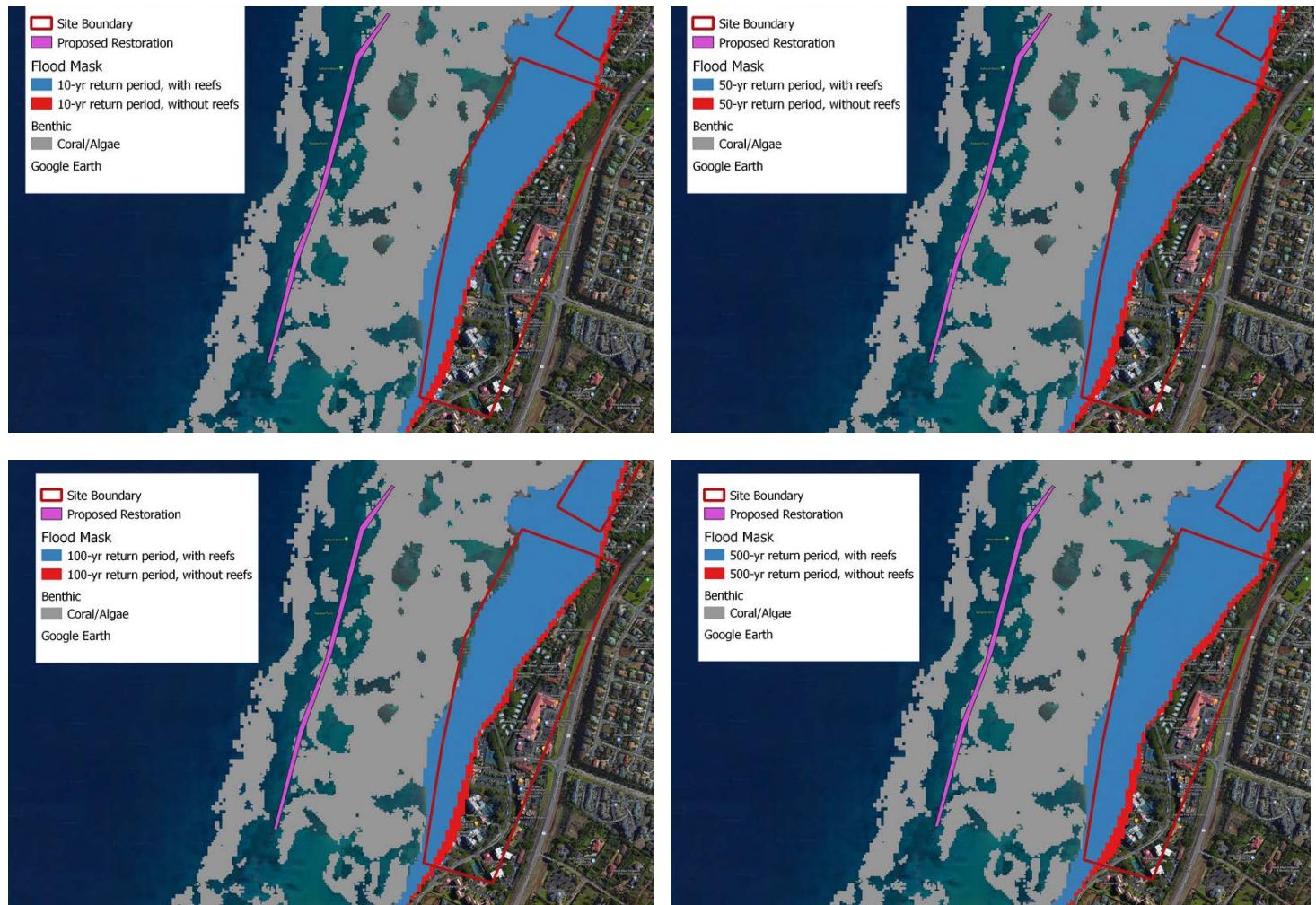


Figure 3D. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Kahana site.

REEF CHARACTERISTICS

Reef Condition Assessment

According to Minton et al. (2020), the reefs at Kahana have the lowest coral cover (7%) and resource fish biomass of all the West Maui reefs assessed. Kahana reefs are characterized by high turf algae (73%) and low benthic diversity. Coral cover displays particular variability with depth, where the highest coral cover extends from shallower waters out to 6 m depth and then drops significantly with deeper depths. The most abundant coral species in this area are *Porites evermanni/lutea*, *Monitpora capitata*, and *Porites lobata*. Reefs in this area have low potential reef resilience (Maynard et al., 2019).

Reef Profile Assessment: convex or fringing

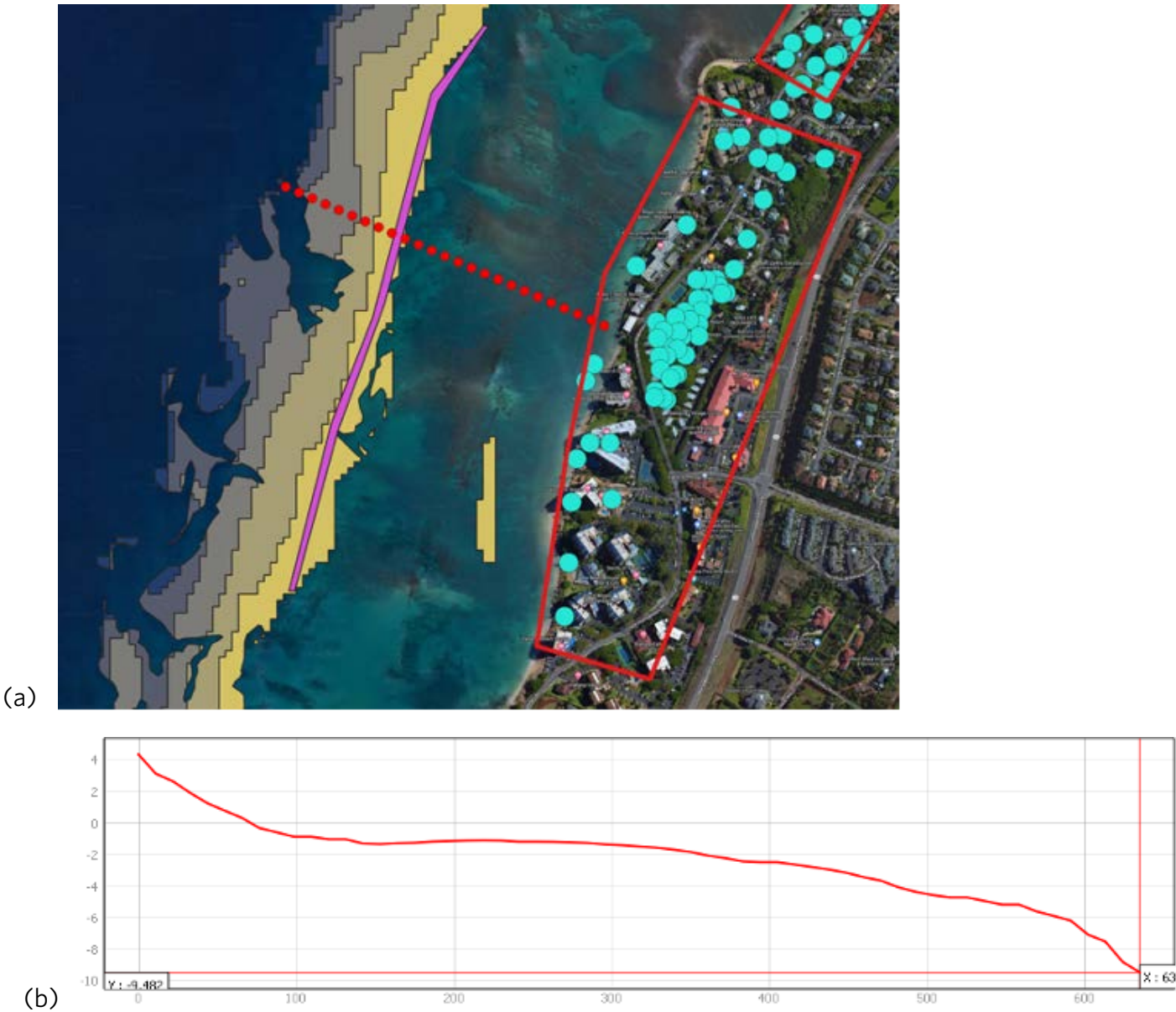


Figure 4D. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 400 value on the x-axis.

PRELIMINARY BCA RESULTS				
RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	1.15	\$1,769,435	\$3,658,825	0.48
Hybrid Reef		\$4,839,329	\$4,580,850	1.06

E. South Kihei

Location: 20.7375801° -156.4539717°

PROJECT DESCRIPTION

The South Kihei site extends from Kalama Park north to just south of Welakahao Rd. Most structures in this area are single-family homes, with several businesses scattered throughout. This site was selected because the makeup of the adjacent impacted structures is significantly different from the resorts and condominiums in the NW Maui area. There is a history of serious erosion problems on the shoreline near Welakahao Rd. and human interventions have significantly altered the reefs offshore of the South Kihei site. These interventions include portions of the reef outside of Kalama Park, which was dynamited in the 1940s to make swimming areas for visitors. In general, the South Kihei region experiences less wave energy compared to the North West Maui region, so it may be that a CR4 project might be designed at a smaller scale to have the same level of wave attenuation. There is a seawall at Kalama Park, and the shoreline adjacent to Halama St. still experiences high levels of erosion.

PROJECT OVERVIEW



Figure 1E. Map showing the South Kihei CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS

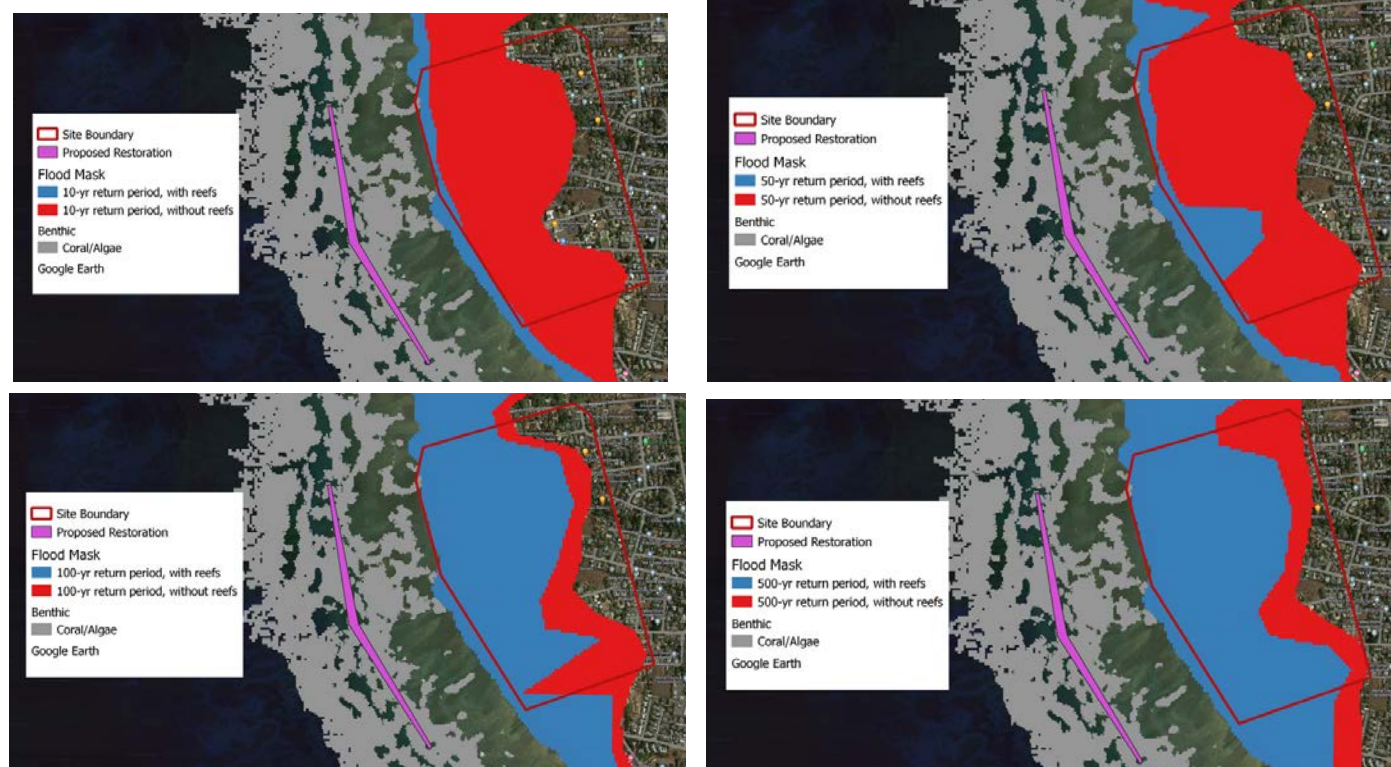


Figure 2E. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the South Kihei site.

REEF CHARACTERISTICS

Reef Condition Assessment

Based on a 2019 evaluation of resilience by NOAA, the reefs near Kalama Park have low relative resilience. This report also determined coral cover at Kalama Park to be 39%, which is on the higher end of coral cover for low resilience sites.

Reef Profile Assessment: convex

COASTAL HAZARD(S) OF CONCERN:

- Coastal flooding
- Storm surge
- Sea level rise
- Coastal erosion

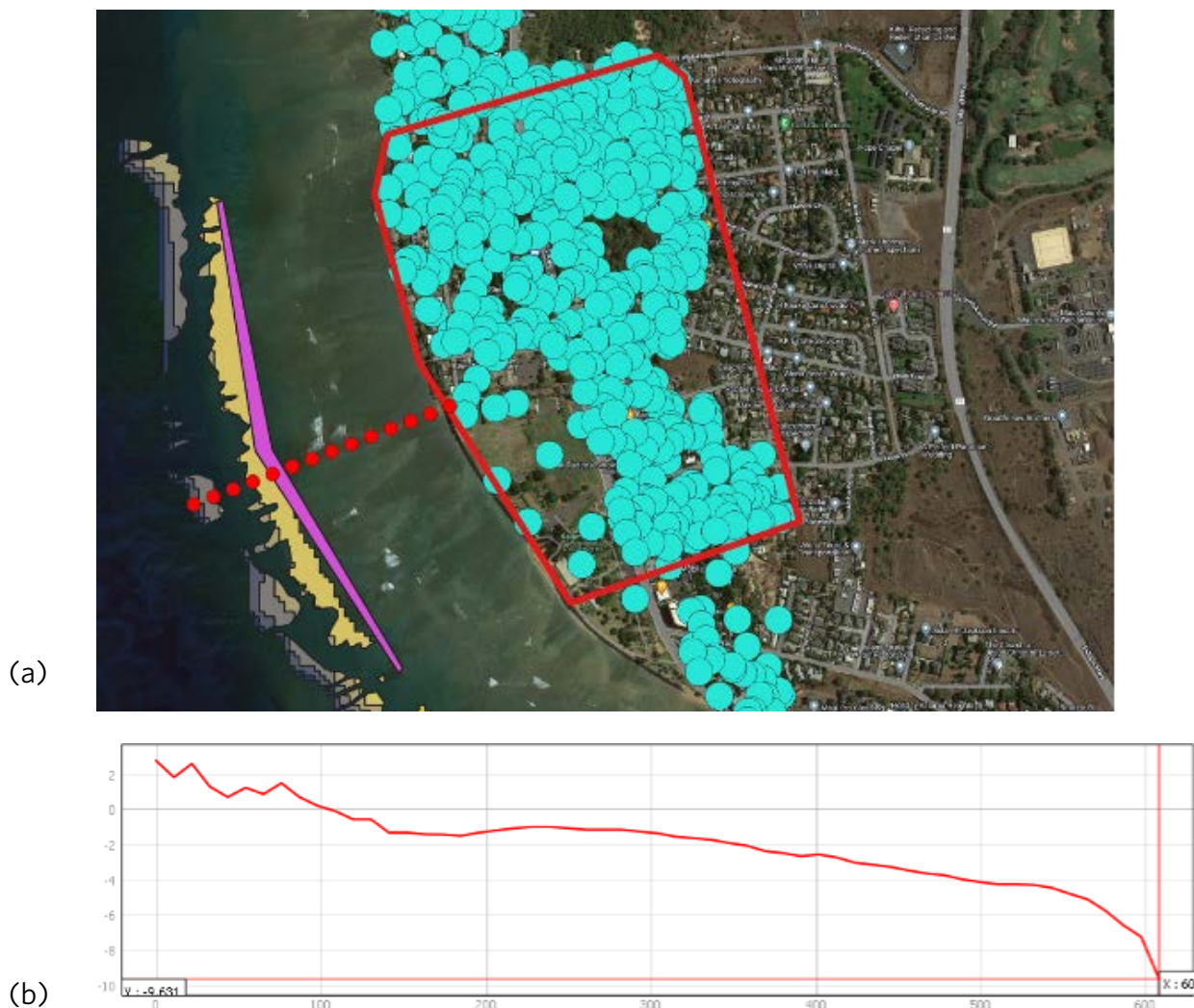


Figure 3E. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 400 value on the x-axis.

PRELIMINARY BCA RESULTS

RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	1.32	\$25,124,420	\$4,199,695	5.98
Hybrid Reef		\$71,511,972	\$5,258,020	13.60

F. Ka'anapali Ali'i

Location: 20.9180174° -156.6943214°

PROJECT DESCRIPTION

The Ka'anapali Ali'i site is adjacent to Ka'anapali Beach, in the area of Hanakao'o Point. The site extends from Ka'anapali Ali'i Resort on the south to The Westin Maui Resort and Spa, Ka'anapali on the north. This site was selected because of the high protection value of reefs in this area as modeled by Storlazzi et al. (2019). Maui stakeholders and coastal experts also identified this area as a site with potential for a future public-private partnership to financially support a CR4 project.

COASTAL HAZARD(S) OF CONCERN:

- Coastal flooding
- Storm surge
- Sea level rise
- Coastal erosion
- Beach Loss

PROJECT OVERVIEW

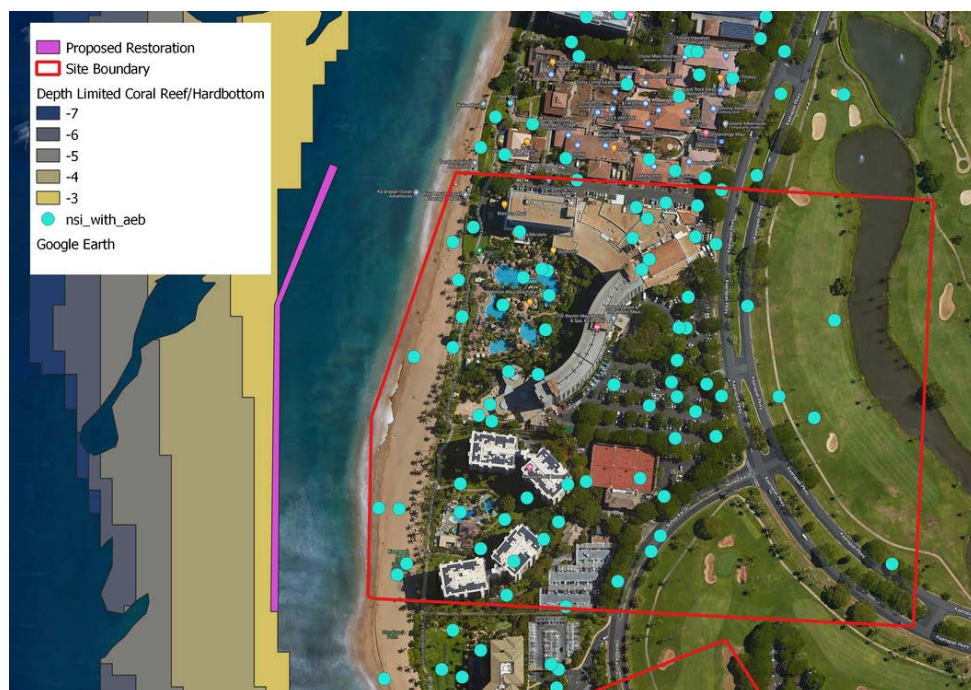


Figure 1F. Map showing the Ka'anapali Ali'i CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS

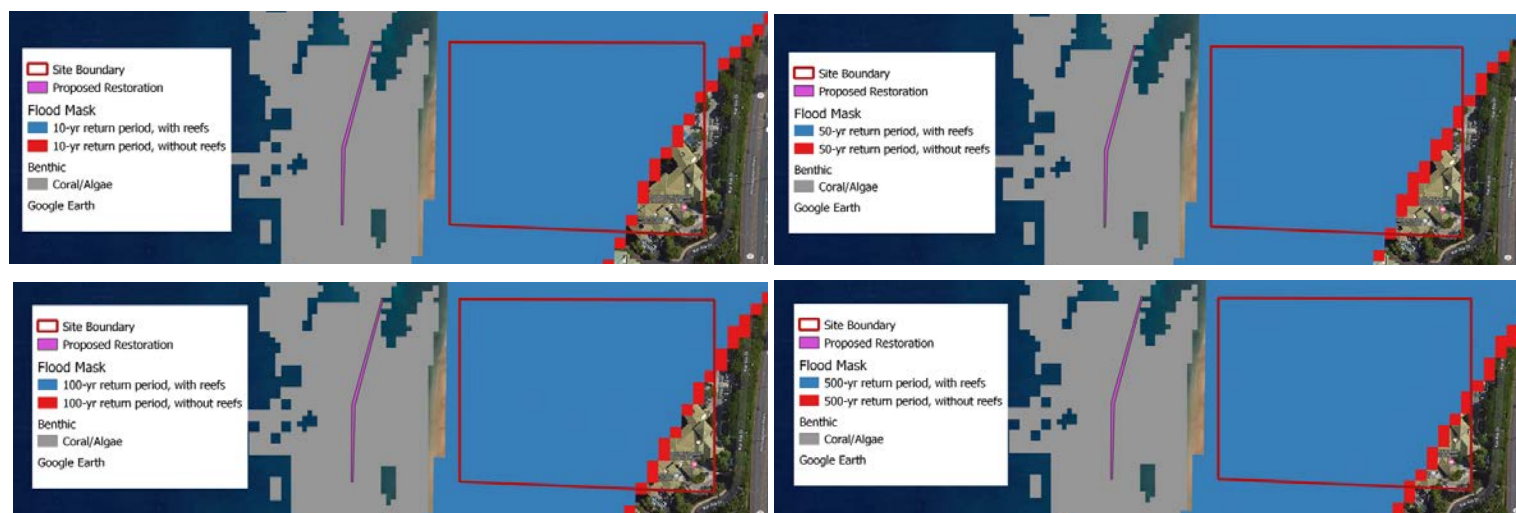


Figure 2F. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Ka'anapali Ali'i site.

REEF CHARACTERISTICS

Reef Condition Assessment

According to Minton et al. (2020), the reefs in this area, especially rounding Hanakao'o Point, have a medium to high coral cover (28%) compared to the statewide average (16%). The adjacent land has been converted to various heavy-impact uses such as golf courses, resorts, and manicured landscaping, resulting in regular sedimentation events in the adjacent waters. Higher than average organic nutrient loads were also assessed in this area, particularly with high phosphorous levels. The most abundant coral species include *Porites lobata*, *Porites compressa*, *Montipora capitata*, and *Montipora patula*. Reefs in this area have medium-high potential reef resilience (Maynard et al., 2019).

Reef Profile Assessment: convex or linear

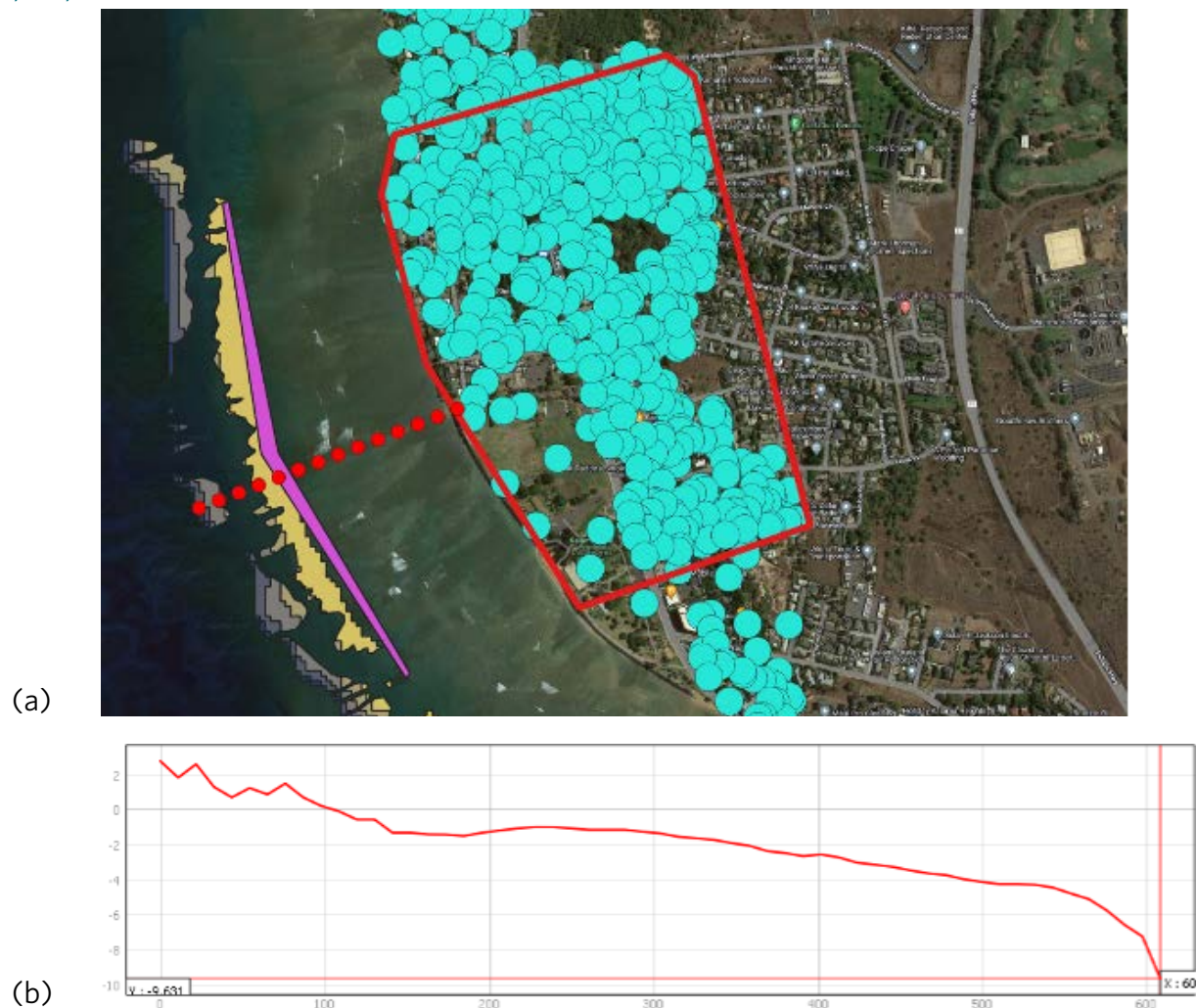


Figure 3F. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 110 value on the x-axis.

PRELIMINARY BCA RESULTS				
RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.47	\$5,078,910	\$1,495,346	3.40
Hybrid Reef		\$14,418,299	\$1,872,173	7.70

G. Ka'anapali Marriott

Location: 20.9152034° -156.6942021°

PROJECT DESCRIPTION

The Ka'anapali Marriott site extends around the southern end of Honokao'o Point but primarily encompasses the Marriott's property. This site was selected because of the structure and profile of the present-day reef and the high valuation of flood risk reduction benefits. This site also has the potential to investigate a public-private partnership to financially support a CR4 project. However, there are plans to implement significant beach restoration along this stretch of shoreline which could threaten a potential restoration project offshore.

COASTAL HAZARD(S) OF CONCERN:

- Coastal flooding
- Coastal erosion

PROJECT OVERVIEW



Figure 1G. Map showing the Ka'anapali Marriott CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS

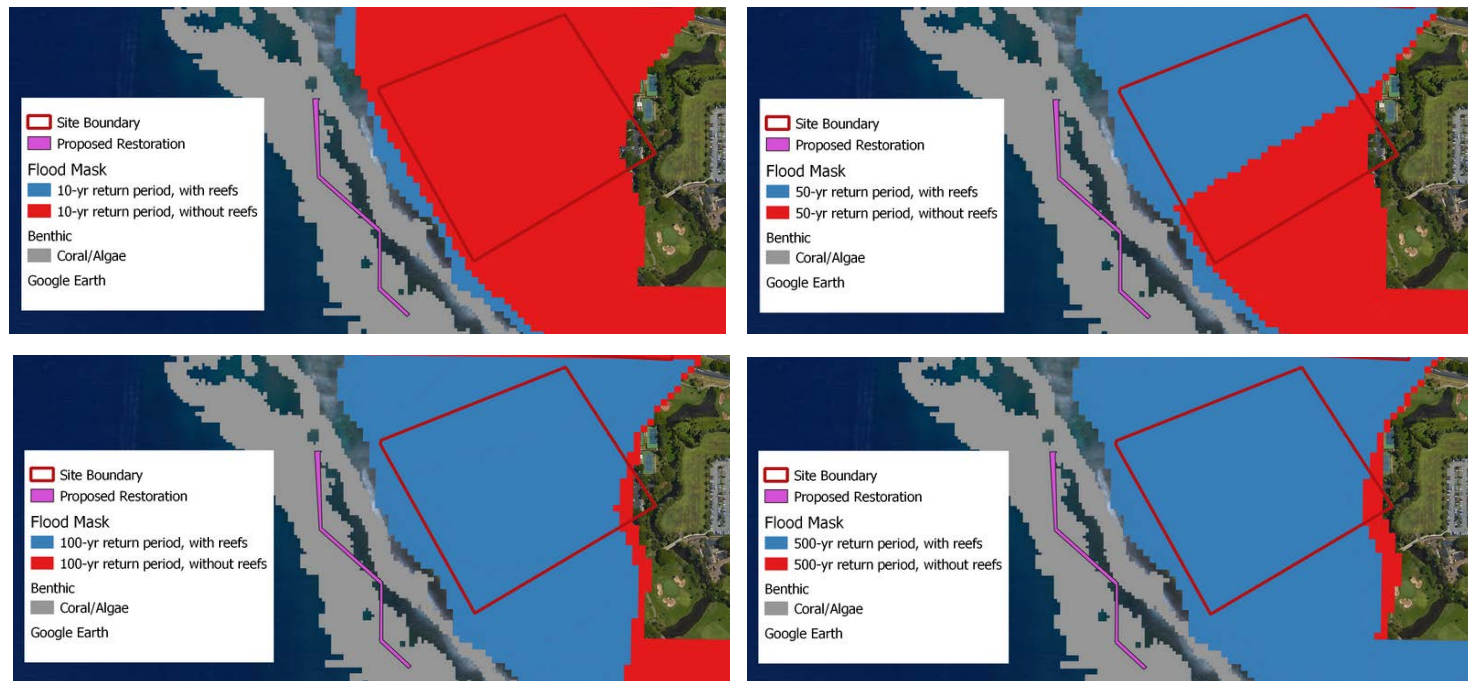


Figure 2G. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Ka'anapali Marriott site.

REEF CHARACTERISTICS

Reef Condition Assessment

According to Minton et al. (2020), the reefs in this area have low coral cover and species richness compared to the averages of the other West Maui reefs assessed. The adjacent land has been converted to various heavy-impact uses such as golf courses, resorts, and manicured landscaping, resulting in regular sedimentation events in the adjacent waters. Higher than average organic nutrient loads were also assessed in this area, particularly with high phosphorous levels. The most abundant coral species include *Porites lobata*, *Porites compressa*, *Montipora capitata*, and *Montipora patula*. Reefs in this area have medium-low potential reef resilience (Maynard et al., 2019).

Reef Profile Assessment: three-slope

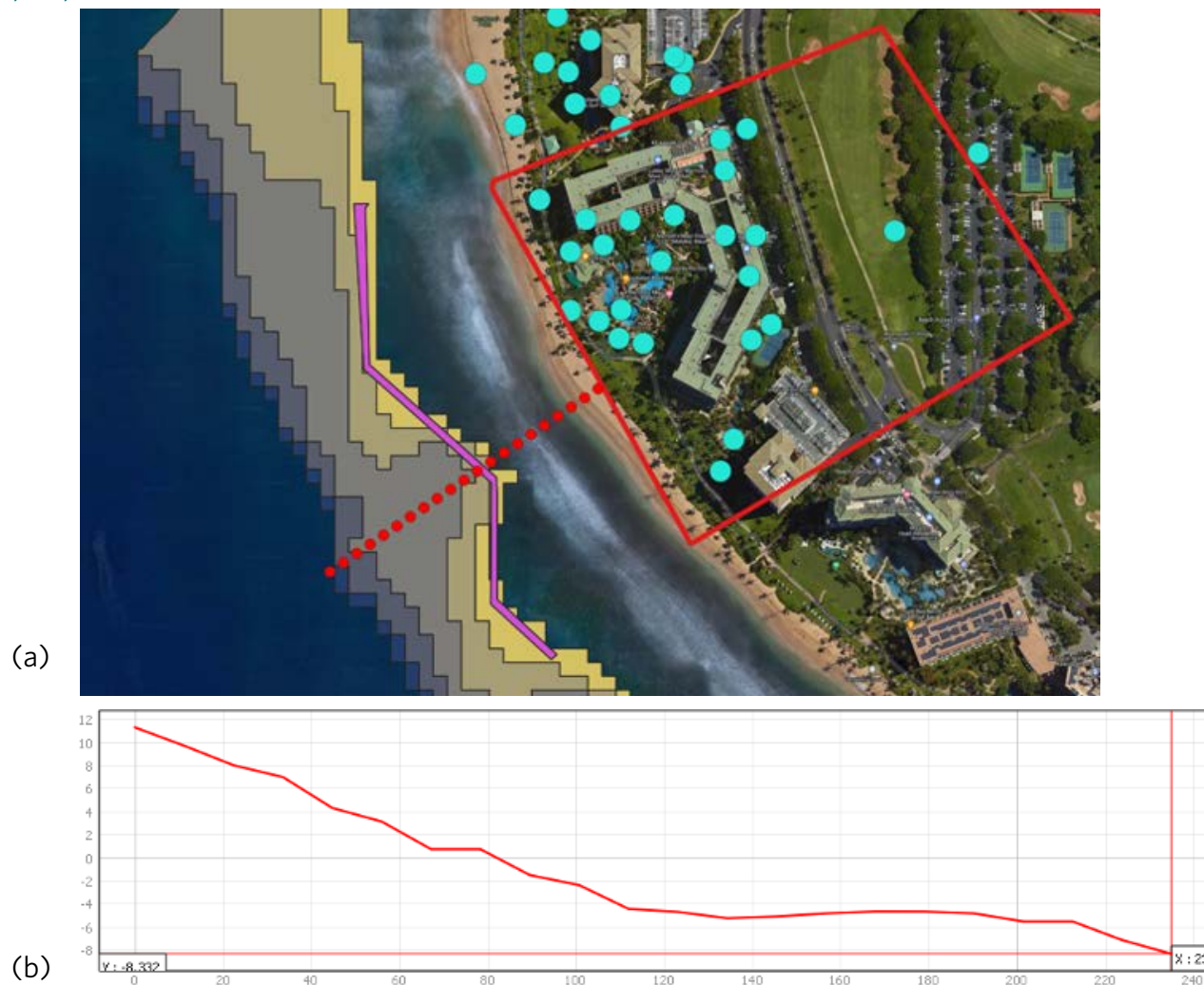


Figure 3G. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 70 value on the x-axis.

PRELIMINARY BCA RESULTS				
RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.46	\$18,326,313	\$1,463,530	12.52
Hybrid Reef		\$52,256,161	\$1,832,340	28.52

H. Kahana Sunset

Location: 20.9848429° -156.6725185°

PROJECT DESCRIPTION

The Kahana Sunset site encompasses the bay where the Kahana Sunset Condominium Unit A8 is located. This site was selected because it has a history of severe coastal erosion that threatens the integrity and safety of Unit A8 in particular. This site also provides a good opportunity to examine the cost-effectiveness of a very targeted CR4 project. Still, the benefit methodology used in this study only accounts for avoided flood damages. Thus while coastal erosion is the main coastal hazard of concern at this site, we only assessed the avoided damages provided by a CR4 project to infrastructure from coastal flooding which are minimal.

COASTAL HAZARD(S) OF CONCERN:

- Coastal erosion

PROJECT OVERVIEW



Figure 1H. Map showing the Kahana Sunset CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS



Figure 2H. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Kahana Sunset site.

REEF CHARACTERISTICS

Reef Condition Assessment

According to Minton et al. (2020), reefs at this site have low coral coverage (< 6.8%) and high turf algae (> 73%). In general, reefs in this region have low benthic diversity suggesting that much of the reef is in poor condition. The primary coral species present include *Porites evermanni/lutea*, *Montipora capitata*, and *Porites lobata*. The nearby long-term water monitoring site at Ka'opala Bay has found elevated nutrient levels in the waters near the Kahana Sunset site, which could impact the survivability of coral outplants.

Reef Profile Assessment: convex, fringing, or three-slope

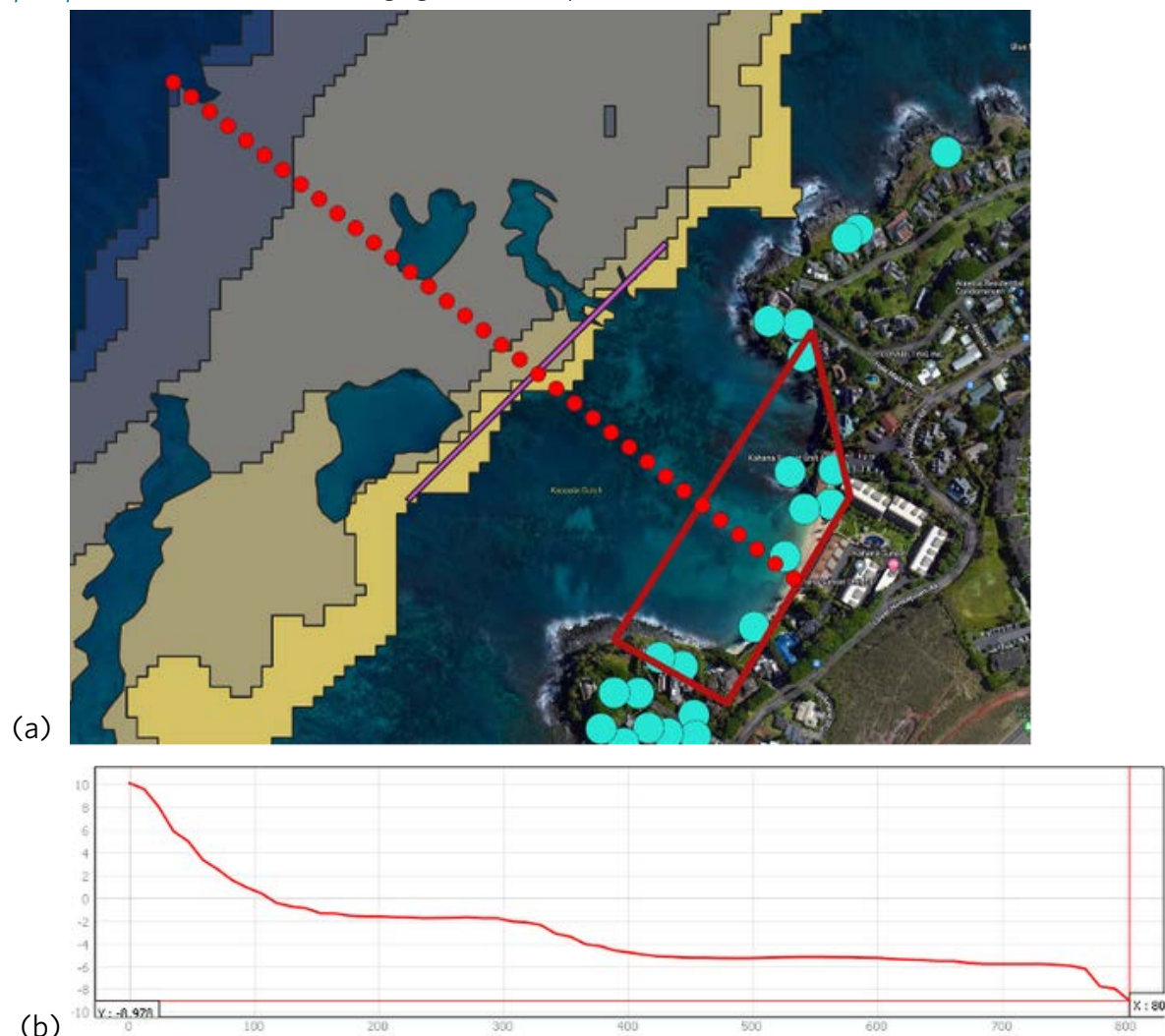


Figure 3H. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 350 value on the x-axis.

PRELIMINARY BCA RESULTS				
RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.43	\$264,831	\$1,368,082	0.19
Hybrid Reef		\$676,231	\$1,712,839	0.39

I. Napili Bay

Location: 20.9965412° -156.6642704°

PROJECT DESCRIPTION

The Napili Bay site is situated within the sandy embayment of Napili Bay which is backed by several condominiums. This site was selected because Napili Bay has active support from community stakeholders who seek solutions to retain the sandy beach in front of the condominiums which has experienced consistent severe beach loss. The Napili Bay and Beach Foundation previously developed and submitted a FEMA BRIC application to protect the shoreline and are actively interested in novel interventions to protect the community's assets.

COASTAL HAZARD(S) OF CONCERN:

- Coastal erosion
- Beach Loss

PROJECT OVERVIEW



Figure 1I.. Map showing the Napili Bay CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS

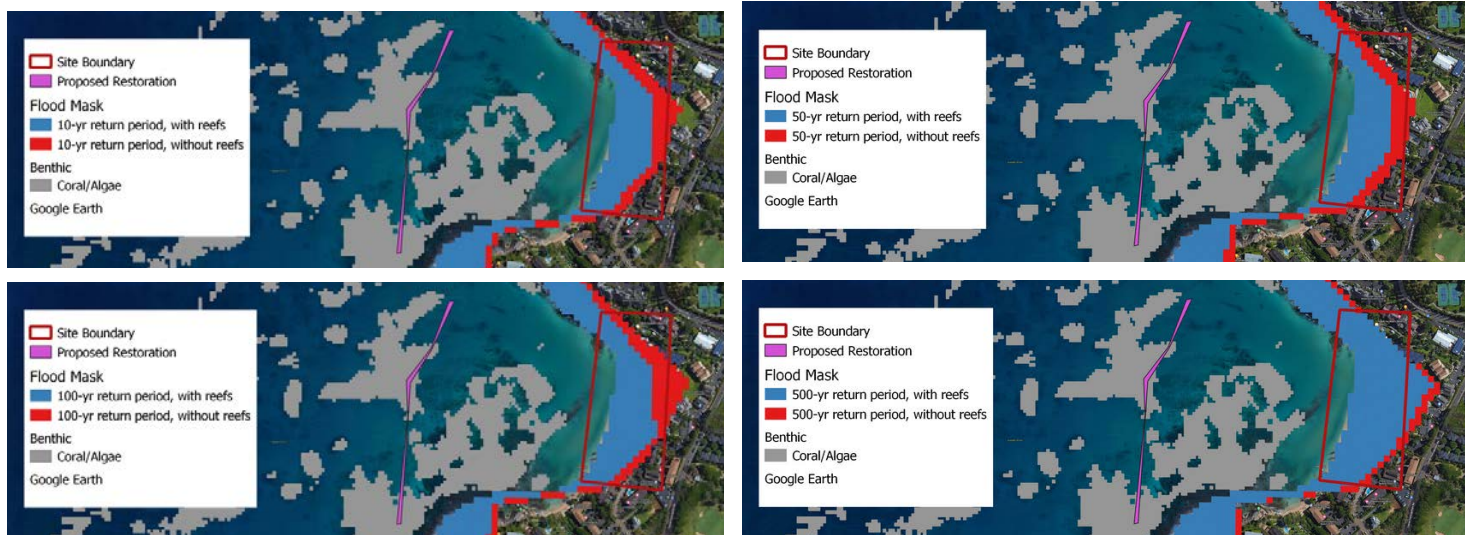


Figure 2I. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Napili Bay site.

REEF CHARACTERISTICS

Reef Condition Assessment

The reefs at the Napili Bay site are within the Kahana watershed, so they are in similar condition to those at Kahana and Kahana Sunset sites. While coral cover is generally low, there is an area of modest coral cover and benthic diversity along the north side of Napili Bay (Minton et al., 2020). A long-term water quality monitoring site at Napili Bay has measured high turbidity levels that impact coral outplant survivability. Further, the coral and hardbottom habitat offshore of Napili Bay is composed mainly of patch reefs rather than the continuous reef that is preferable for a CR4 project.

Reef Profile Assessment: convex or linear

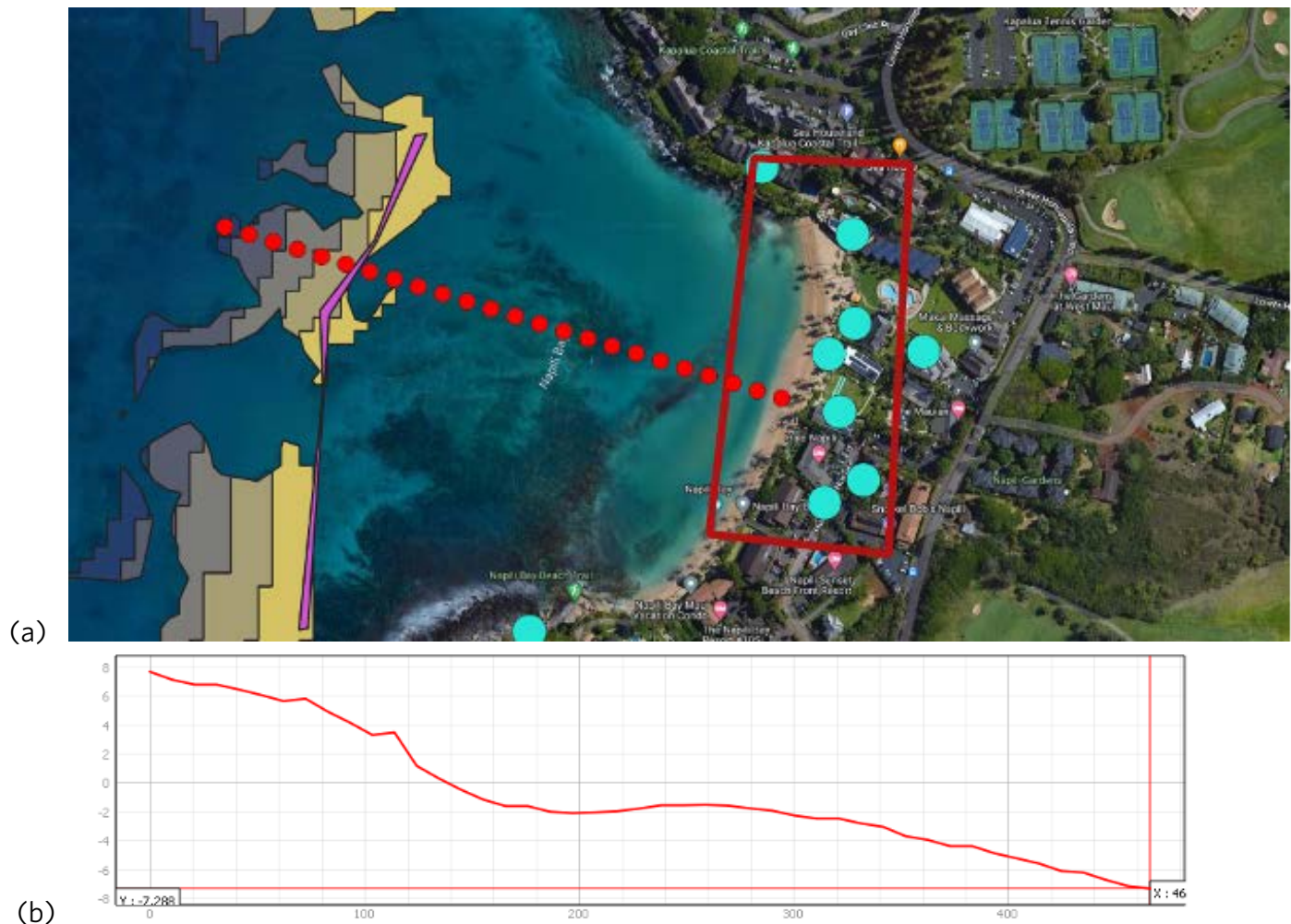


Figure 3I. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 350 value on the x-axis.

PRELIMINARY BCA RESULTS				
RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.4	\$629,796	\$1,272,635	0.49
Hybrid Reef		\$1,724,203	\$1,593,339	1.08

J. Kahanaiki Gulch

Location: 20.9797331° -156.6758976°

PROJECT DESCRIPTION

The Kahanaiki Gulch site is also situated within the Kahana watershed and extends from just north of Hui Drive D on the north to Omaikai Place on the south. This site has a small section of sand within the embayment, and Lower Honoapi'ilani Rd runs alongside the site near the shoreline. This site was selected because of the offshore continuous reef structure and Low Honoapi'ilani Rd proximity to the shoreline. We also wanted to examine the cost-effectiveness of a project protecting a relatively small area with no major condominiums or resorts. There are historic sedimentation issues in this area that could pose a threat to the success of a restoration project offshore.

PROJECT OVERVIEW



Figure 1J. Map showing the Kahanaiki Gulch CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS



Figure 2J. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Kahanaiki Gulch site.

REEF CHARACTERISTICS

Reef Condition Assessment

The reefs in this area are within the Kahana watershed and have similar low coral cover as the reefs at Kahana, Kahana Sunset, and Napili Bay. Sedimentation and runoff in this area could impact coral outplant survivability.

Reef Profile Assessment: convex

COASTAL HAZARD(S) OF CONCERN:

- Sea level rise
- Coastal flooding

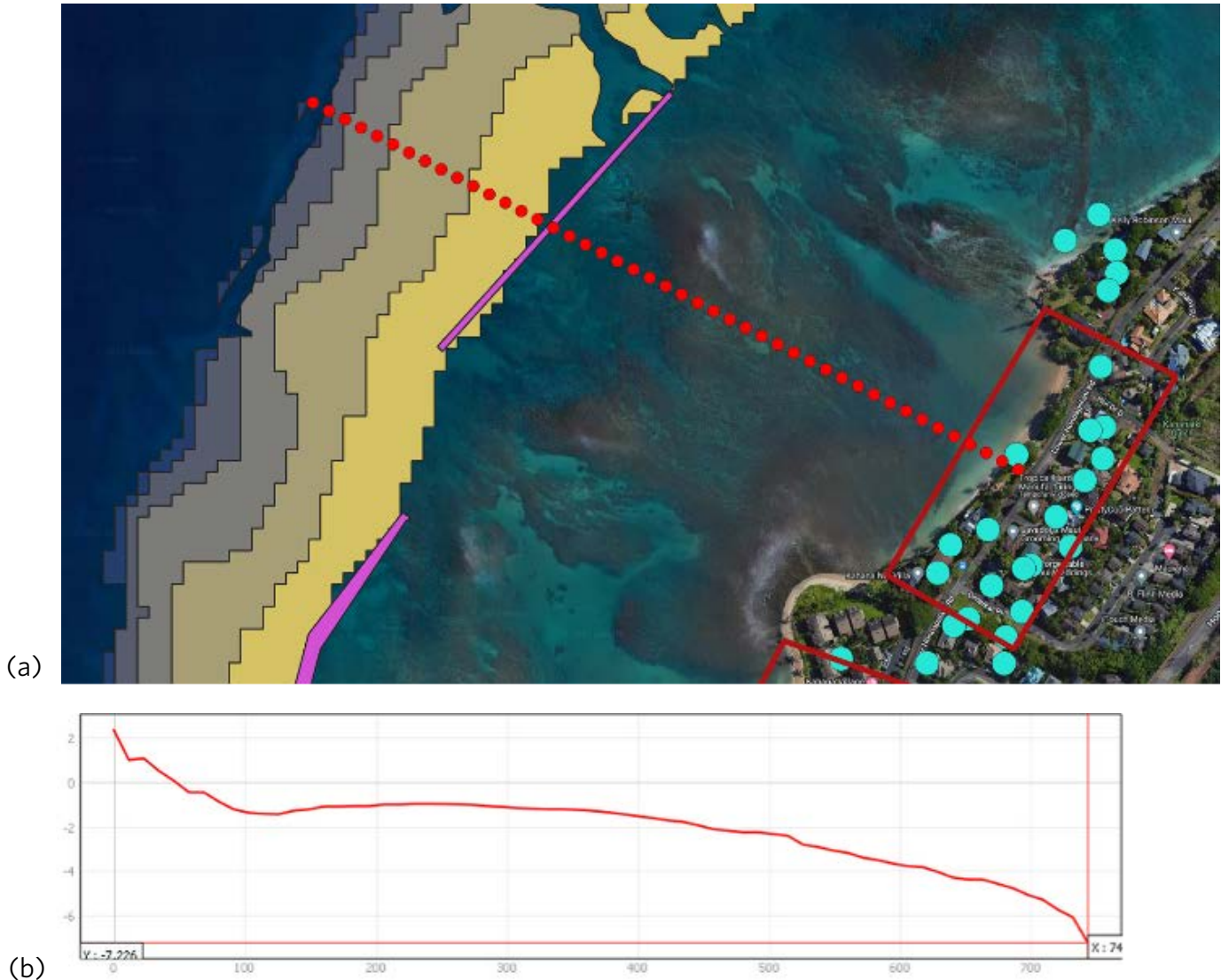


Figure 3J. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 500 value on the x-axis.

PRELIMINARY BCA RESULTS				
RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.37	\$841,266	\$1,177,187	0.71
Hybrid Reef		\$2,333,774	\$1,473,838	1.58

K. Kuleana Resort

Location: 20.9603037° -156.6833982°

PROJECT DESCRIPTION

The Kuleana Resort site encompasses the Kuleana Resort properties. This site was selected as another example of a targeted CR4 project designed to mostly protect the properties of the Kuleana Resort.

PROJECT OVERVIEW

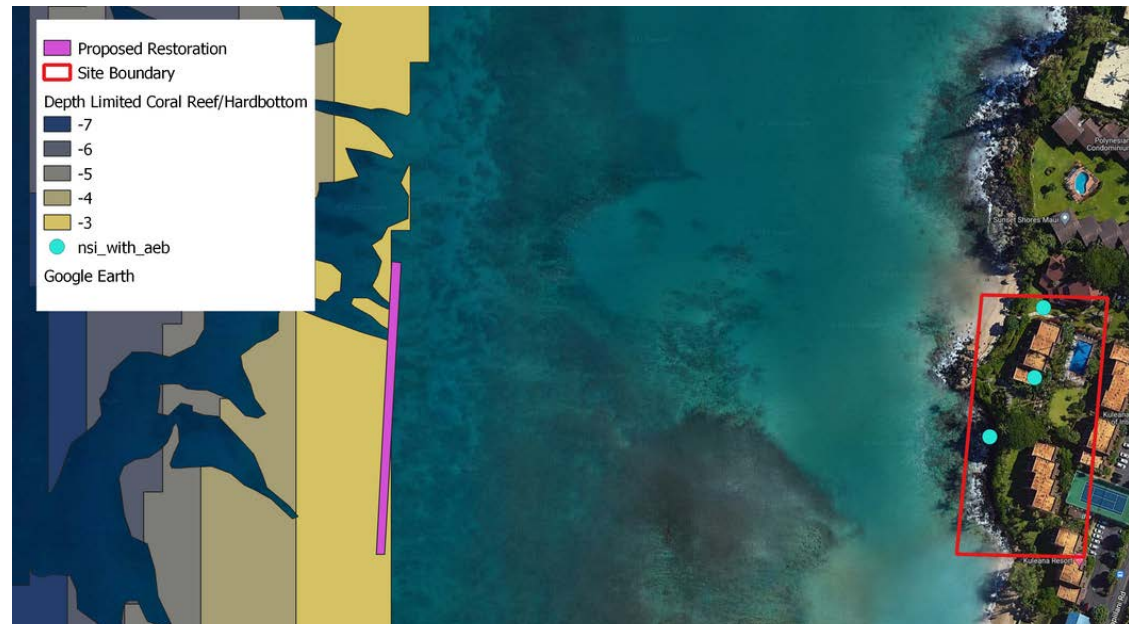


Figure 1K. Map showing the Kuleana Resort CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS



Figure 2K. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Kuleana Resort site.

REEF CHARACTERISTICS

Reef Condition Assessment

The reef tract in this area has high benthic abundance and diversity but extremely low fish biomass. The average coral cover (35%) in this area is higher than the statewide average (16%), but the 2015 bleaching event highly impacted reefs in this area. The most abundant coral species include *Porites lobata*, *Porites compressa*, and *Montipora capitata* (Minton et al., 2020).

Reef Profile Assessment: linear

COASTAL HAZARD(S) OF CONCERN:

- Sea level rise
- Coastal flooding

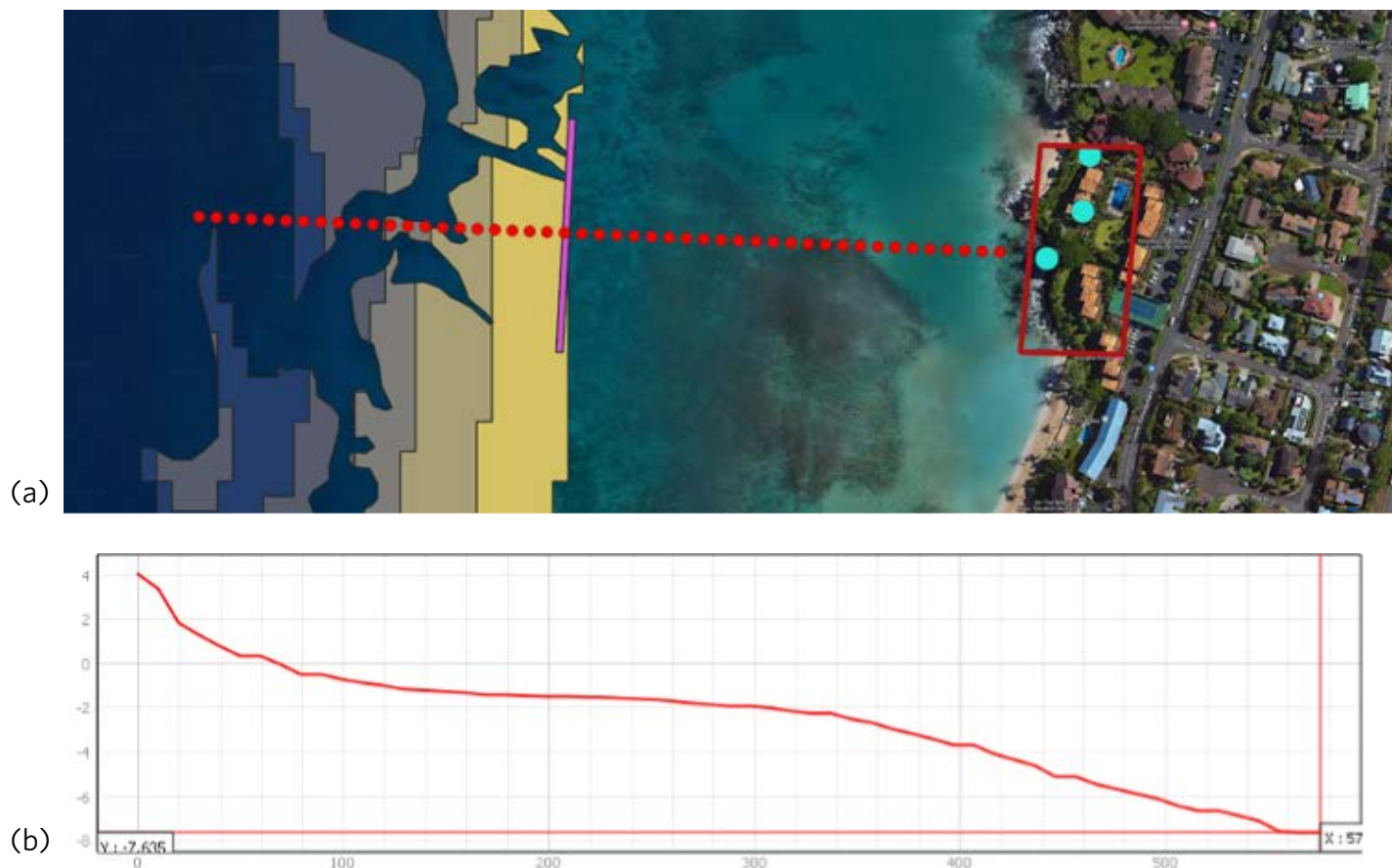


Figure 3K. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 350 value on the x-axis.

PRELIMINARY BCA RESULTS

RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.2	\$607,369	\$636,317	0.95
Hybrid Reef		\$1,697,430	\$796,669	2.13

L. Maui Sands

Location: 20.9528598° -156.6863343°

PROJECT DESCRIPTION

The Maui Sands site is south of Honokowai Beach Park and encompasses the Maui Sands Condos. This site was selected as an example of a site where reefs do not provide an extremely high estimated value of flood protection based on the Storlazzi et al. (2019) flood maps. However, we wanted to represent a hypothetical case study where a resort or condominium association might be interested in a targeted CR4 project to protect their assets regardless of being in one of the high-value reef zones from Storlazzi et al. (2019). This site was also selected to assess what factors most impact cost-effectiveness through our BCA methodology.

PROJECT OVERVIEW

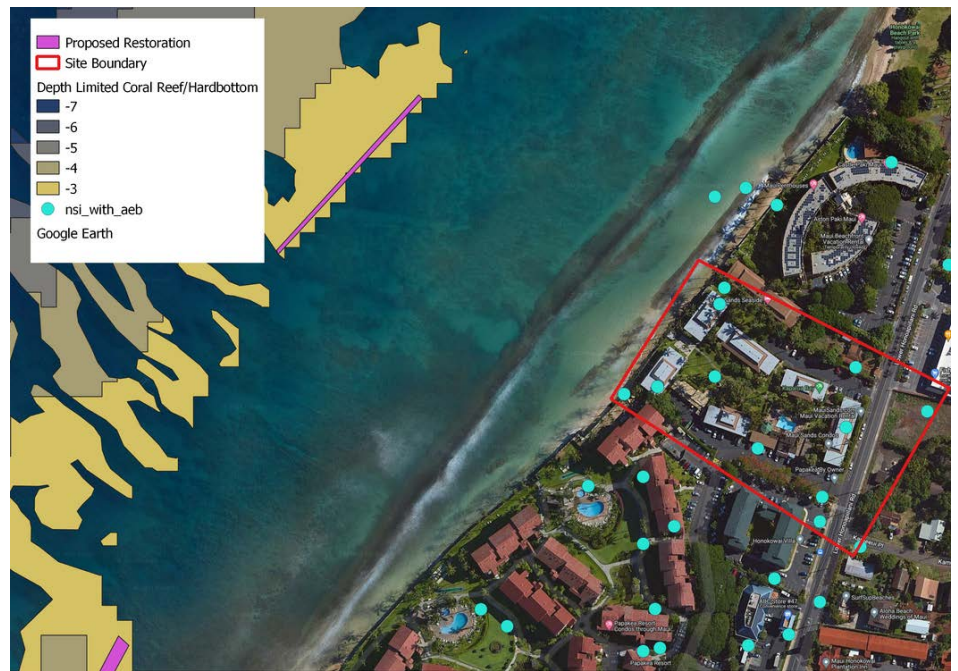


Figure 1L. Map showing the Maui Sands CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS



Figure 2L. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Maui Sands site.

REEF CHARACTERISTICS

Reef Condition Assessment

The reef at the Maui Sands site lies within the Kahekili Herbivore Fisheries Management Area (HFMA). It has a high abundance and diversity of fish and benthic assemblages (Minton et al., 2020). Coral cover in this area is high (35%) compared to the state average (16%), and turf algae cover is only slightly higher than coral cover. The primary coral species include *Porites lobata*, *Porites compressa*, and *Montipora capitata*. In March of 2018, 43% of corals experienced bleaching in this area, suggesting this site has a significant level of extenuating stressors like pollution from runoff and sedimentation (Minton et al., 2020; Maynard et al., 2019).

Reef Profile Assessment: linear

COASTAL HAZARD(S) OF CONCERN:

- Sea level rise
- Coastal flooding
- Storm surge
- Coastal erosion

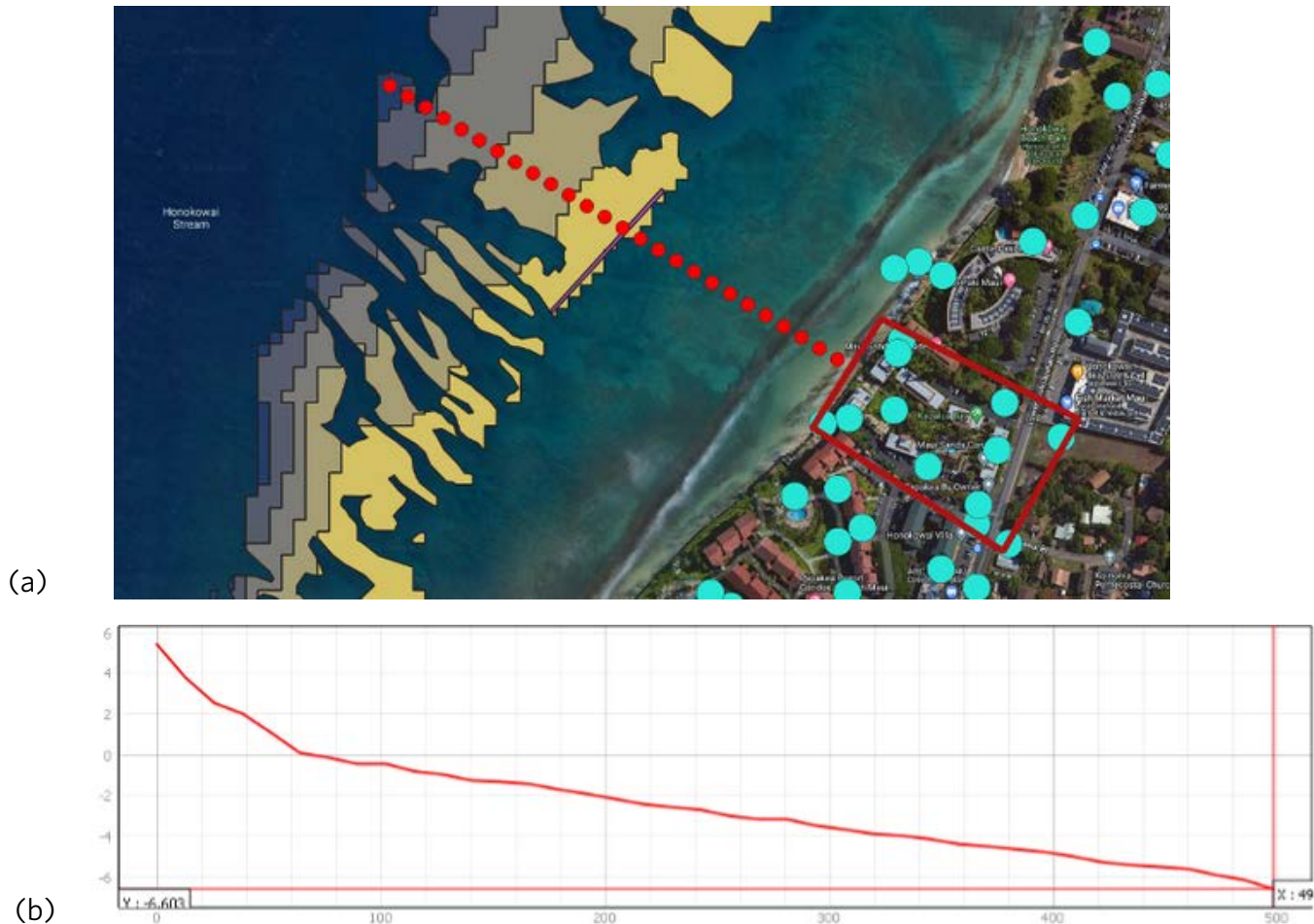


Figure 3L. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 225 value on the x-axis.

PRELIMINARY BCA RESULTS

RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.16	\$826,737	\$509,054	1.62
Hybrid Reef		\$2,331,426	\$637,335	3.66

M. Westin Ka'anapali

Location: 20.9413375° -156.6899785°

PROJECT DESCRIPTION

The Westin Ka'anapali encompasses the northern properties owned by the Westin Ka'anapali Ocean Resort. We selected this site because it serves as a comparison to the other sites that encompass high-value resort properties. However, the flood maps from Storlazzi et al. (2019) do not show that the reefs in this area have high flood protection value. This site is just north of Kahekili Beach Park, where contamination from the Lahaina Wastewater Reclamation Facility (LWRF) is particularly prominent in submarine groundwater discharges (Hunt and Rosa, 2009; Glen et al., 2012).

PROJECT OVERVIEW



Figure 1M. Map showing the Westin Ka'anapali CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS

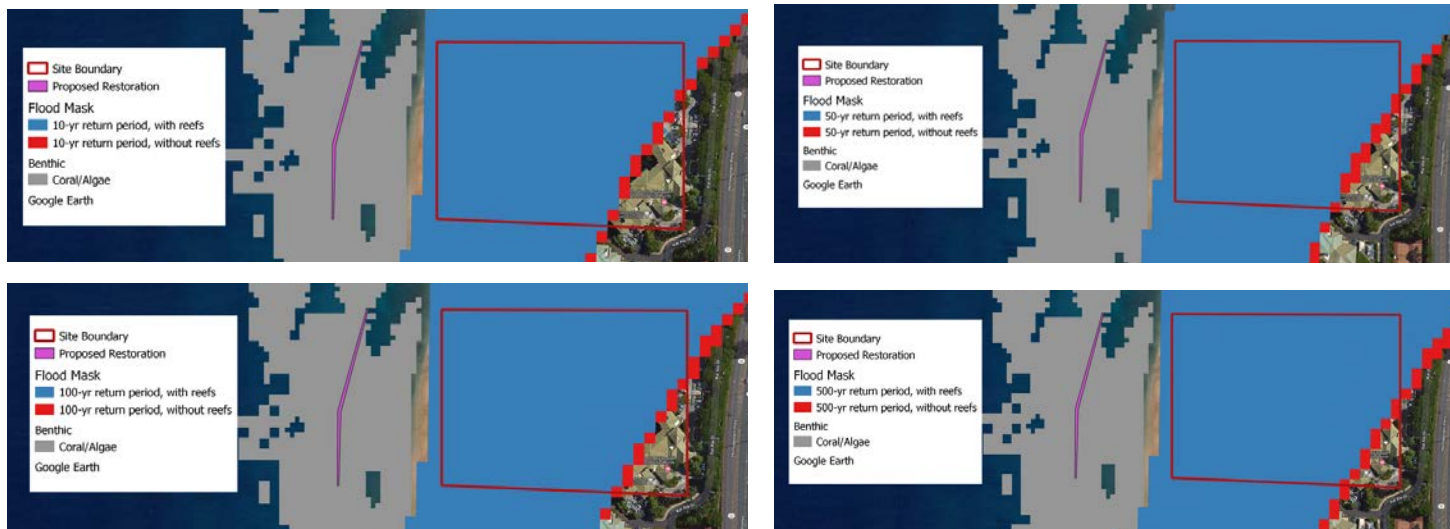


Figure 2M. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Westin Ka'anapali site.

REEF CHARACTERISTICS

Reef Condition Assessment

This site is located within the Kahekili HFMA, and coral cover (28%) is higher than the state average (Minton et al., 2020). Still, impacts from sediment plumes from the LWRF to the north are of particular concern. High levels of phosphorous and nitrate have been measured at the long-term water quality monitoring site near Kahekili Beach Park, which could impact outplant health and survivability.

Reef Profile Assessment: three-slope

COASTAL HAZARD(S) OF CONCERN:

- Sea level rise
- Coastal flooding
- Coastal erosion

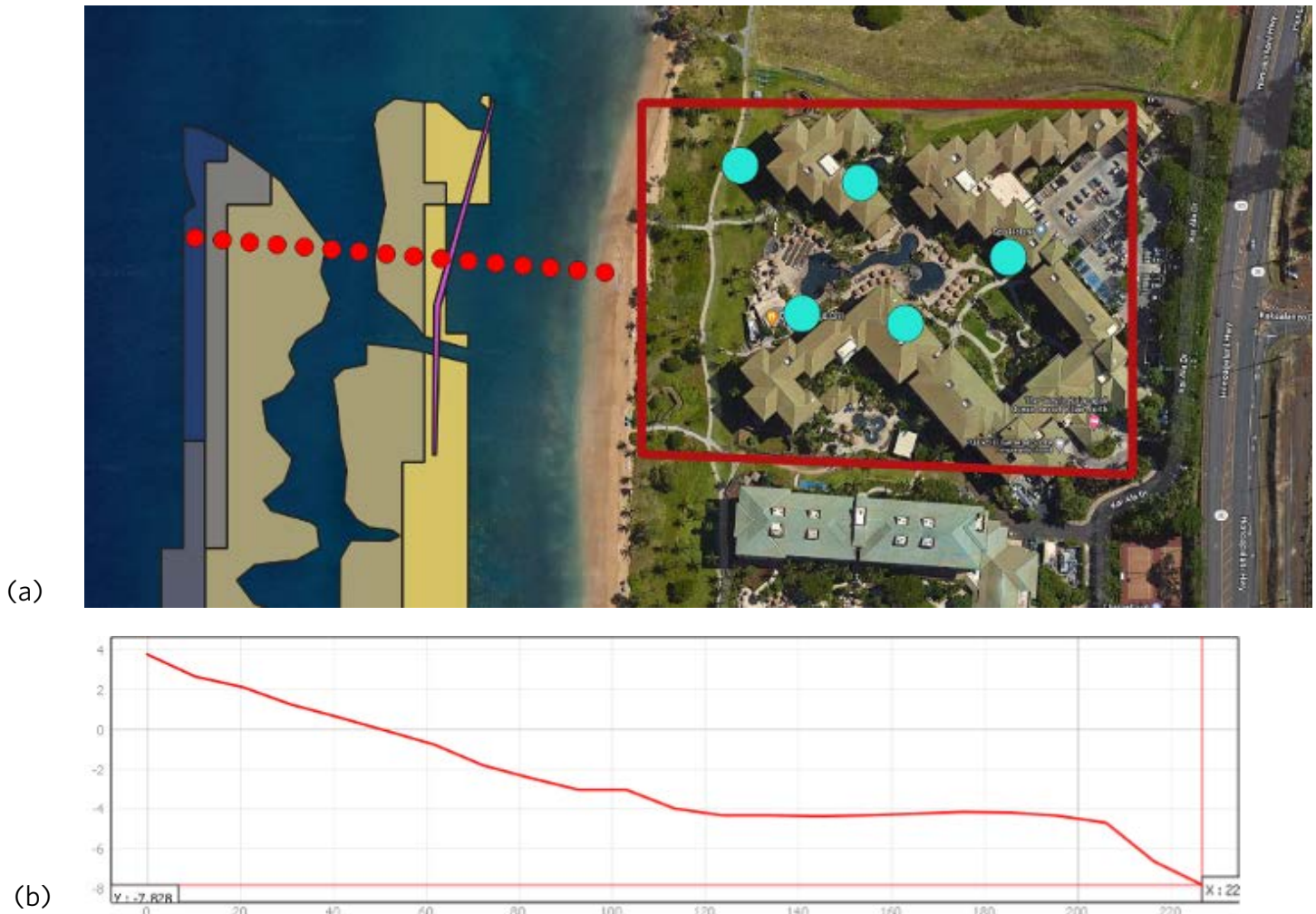


Figure 3M. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 90 value on the x-axis.

PRELIMINARY BCA RESULTS

RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.2	\$164,482	\$636,317	0.26
Hybrid Reef		\$432,495	\$796,669	0.54

N. Kauaula Stream

Location: 20.860855° -156.6696767°

PROJECT DESCRIPTION

The Kauaula Stream site extends from Aholo Rd on the north to Pualoke Place on the south. The site encompasses shoreline properties on the southern end of Front Street, including several business and residential or vacation homes. This site was selected because the reefs in this area provide moderate to high coastal flood protection value and the reef offshore is relatively continuous.

PROJECT OVERVIEW



Figure 1N. Map showing the Kauaula Stream CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS

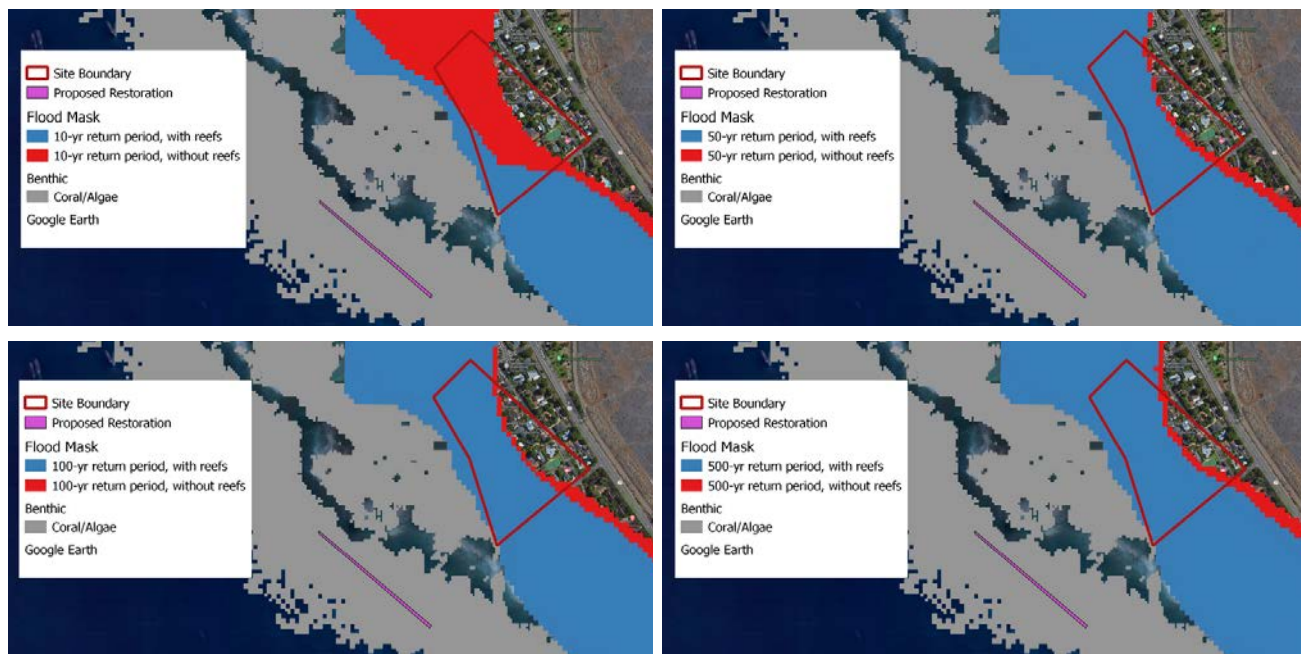


Figure 2N. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Kauaula Stream site.

REEF CHARACTERISTICS

Reef Condition Assessment

Reef Condition Assessment: According to Minton et al. (2020), the reefs offshore of the Kauaula Stream site have low to average coral cover (11%) and low benthic diversity compared to the rest of the West Maui region. However, reefs in this area have medium to medium-high fish biomass. Reefs in this area experience significant runoff impacts from poor current and historical upland land management. Runoff impacts include elevated levels of phosphate, nitrate, and turbidity (Minton et al., 2020). The dominant coral species include *Porites lobata* and *Porites compressa*. This site was assessed with relatively low potential resilience due to the high prevalence of disease, which impacts coral cover (Maynard et al., 2019).

Reef Profile Assessment: convex or linear

COASTAL HAZARD(S) OF CONCERN:

- Sea level rise
- Coastal flooding
- Coastal erosion

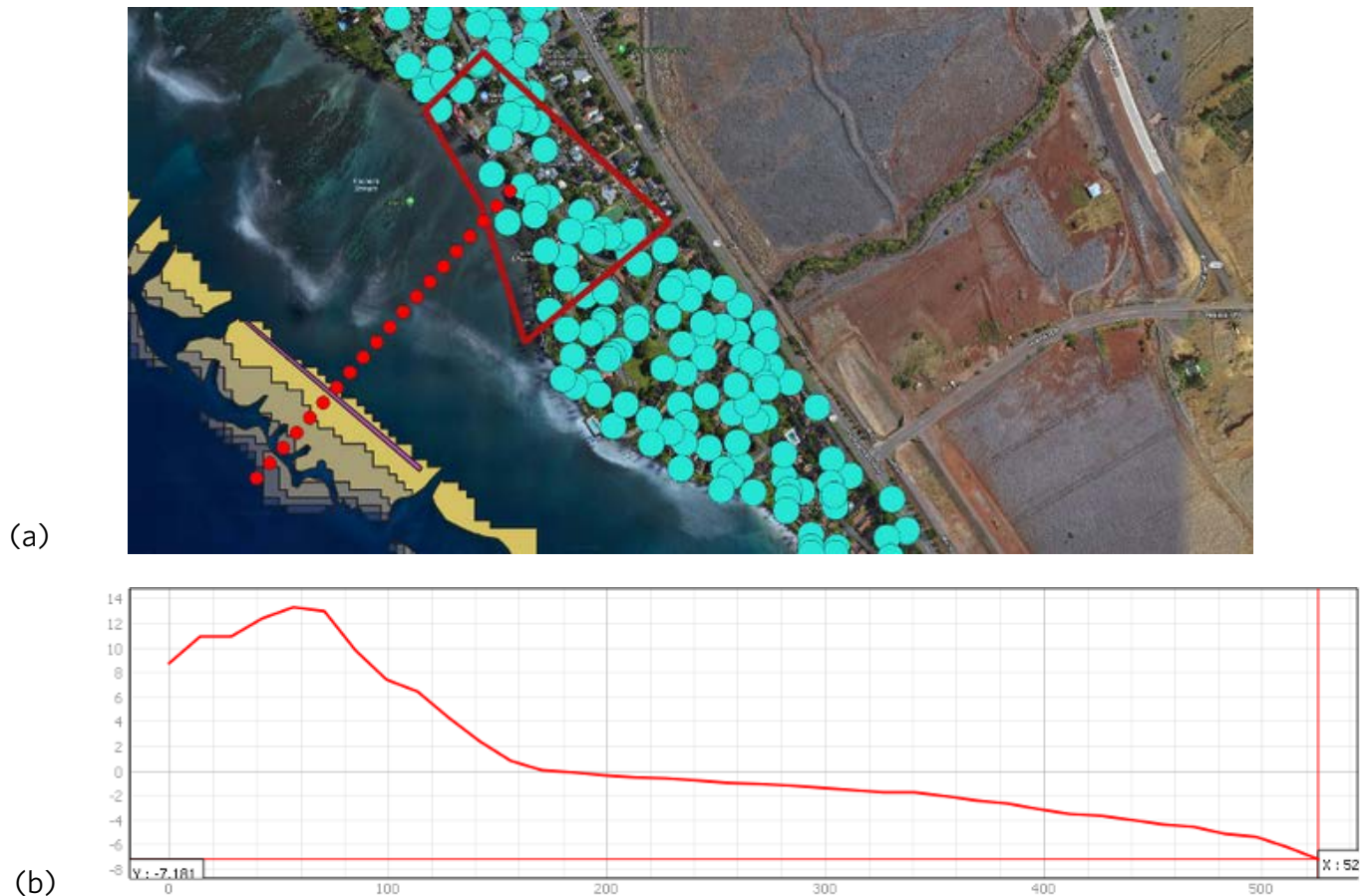


Figure 3N. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 350 value on the x-axis.

PRELIMINARY BCA RESULTS				
RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.39	\$1,989,424	\$1,240,819	1.60
Hybrid Reef		\$5,609,309	\$1,553,505	3.61

O. Olowalu Beach

Location: 20.8078232° -156.6125579°

PROJECT DESCRIPTION

Olowalu is a site where reef restoration could have significant flood risk reduction benefits to this critical roadway and the existing and future Olowalu community. The Olowalu area is a priority site for implementing nature-based solutions because of the Honoapiʻilani Highway (Route 30), which lies adjacent to the Olowalu reef tract and is prone to coastal overwash and inundation (see Fig. 4 & 5). During large wind and swell events, portions of Route 30 are consistently flooded, causing disruptive closures to this critical roadway (see Fig. 5).



Figure 10. A preliminary figure from HI DOT showing the proposed realignment of the Honoapiʻilani Highway (Route 30).

As a result, Maui County and the Department of Transportation have plans to relocate the existing highway about 12 feet inland at the cost of \$4 million (see Fig. 1). Ideally, this realignment would move the majority of this critical highway out of the 3.2 ft sea level rise exposure area. Still, Olowalu is a small, rural community with a handful of residential properties at risk of increased flood risk with the loss of 1 m in reef height as modeled by Storlazzi et al. (2019) (see Fig. 3). We did not include the benefit value of reduced flooding to the critical Honoapiʻilani Highway in our benefit valuation methodology. However, this value could be included in future FEMA BCA calculations to potentially increase the BCR of a CR4 project at this site.

PROJECT OVERVIEW

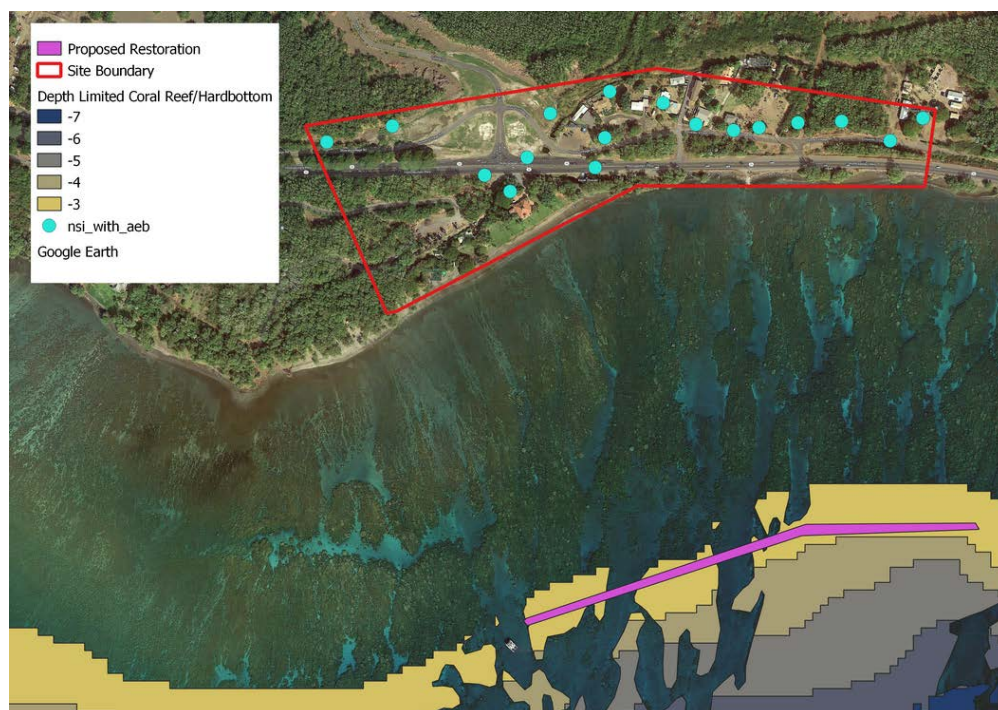


Figure 20. Map showing the Olowalu CR4 project site. The area predicted to receive the most risk reduction benefits from the restoration project is outlined in red. The individual structure annual expected benefit provided by the addition of 1m in reef height is summarized by the teal dots. The isolated area considered feasible for restoration based on depth from 2 m to 7 m and existing coral reef or hardbottom benthos is represented in shades of yellow to blue. The proposed restoration project site is represented in purple.

FLOOD MAPS

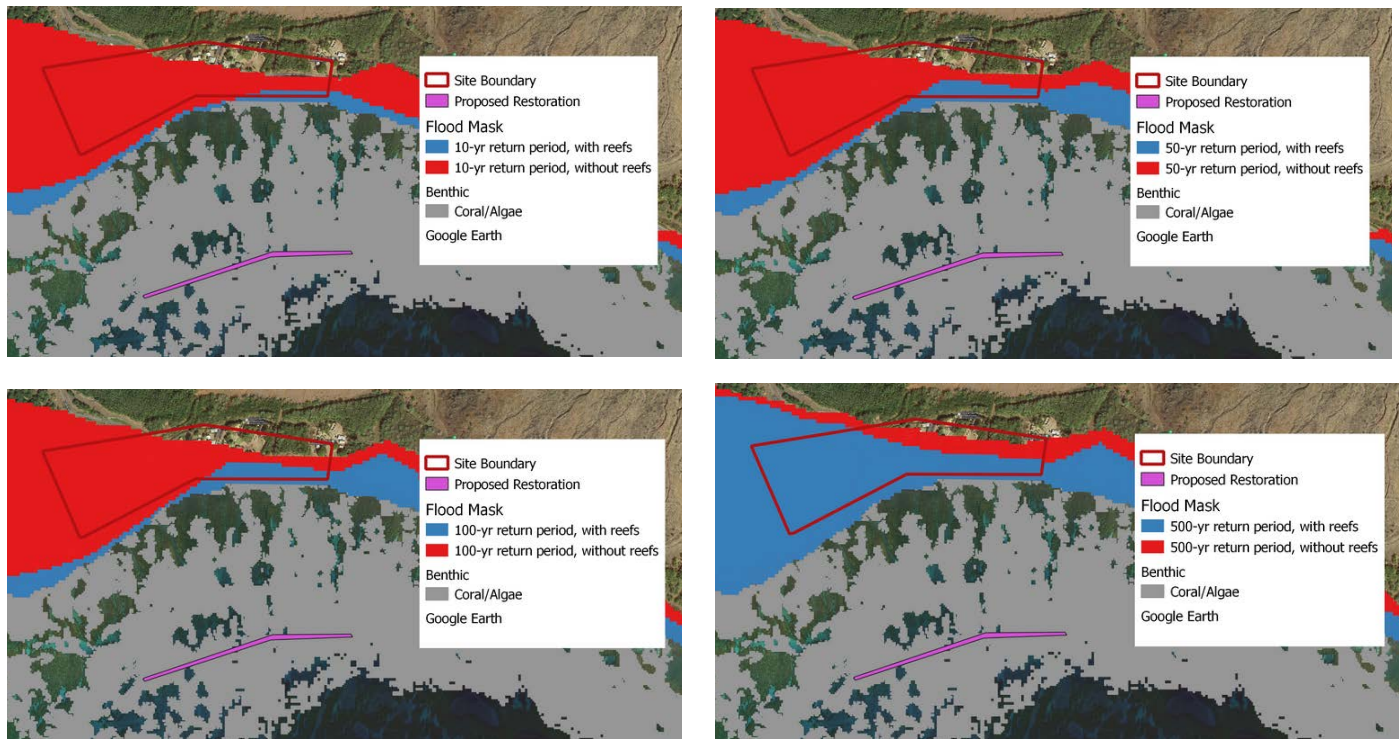


Figure 30. Maps showing the extent of flooding from multiple storm return periods for the with reefs (blue) and without reefs (red) scenarios at the Olowalu site.

COASTAL HAZARD(S) OF CONCERN:

- Coastal flooding
- Coastal erosion
- Sea level rise
- Disruption of access to critical highway



Figure 40. Photo from a The Maui News article showing high wave energy impacting a portion of the Honoapi'ilani Highway at Olowalu.



Figure 50. Image from the HI DOT Climate Resilience Action Plan Exposure Assessment showing vulnerable roadways to inundation due to coastal flooding events like hurricanes.

REEF CHARACTERISTICS

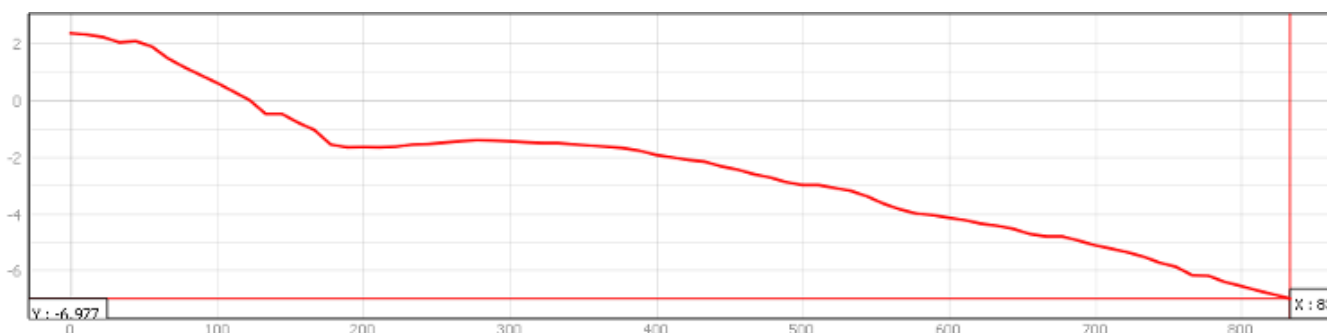


(a)

Reef Condition Assessment

The reef tract at Olowalu represents one of the most important reef areas in Maui, with exceedingly high coral cover and benthic diversity (Minton et al., 2020). The average coral cover for the Olowalu reef tract is 30%. Prominent coral species include *Montipora capitata* and *Montipora patula*. There is a storm drain just under the Honoapi'ilani Highway at this site which may cause pollution or sedimentation events that negatively impact the reef. A 2018 assessment of reef resilience conducted by The Nature Conservancy determined the reefs in this area to have medium-low potential reef resilience. Still, Olowalu has been identified as a priority reef restoration site in the Hawaii coral restoration action plan. There are active plans to install a demonstration coral nursery at Olowalu as Maui restoration practitioners develop their restoration capacity.

Reef Profile Assessment: convex or linear



(b)

Figure 6O. (a) A screenshot of the approximate cross-shore transect examined using the profile tool in QGIS to evaluate the general reef profile within the 2-7 m depth range. (b) A view of the cross-shore reef profile from the beach out to the end of the 7m depth range. The y-axis is approximate depth in meters. The reef profile between 2-7 m depth starts at the 450 value on the x-axis.

PRELIMINARY BCA RESULTS

RESTORATION APPROACH	RESTORATION AREA (ACRES)	PV OF BENEFITS (avoided damages and ecological)	PV OF COSTS	BCR
Coral Gardening	0.7	\$503,642	\$2,227,111	0.23
Hybrid Reef		\$1,307,971	\$2,788,344	0.47

APPENDIX REFERENCES

Maynard, J., Conklin, E., Minton, D., Williams, G. J., Tracey, D., Amimoto, R., Carr, R., Fielding, E., Lynch, H., Rose, J., Sparks, R., Sylva, R., & White, D. (n.d.). Assessing the Resilience of Leeward Maui Reefs to Help Design a Resilient Managed Area Network. 39.

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