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KIHEI DRAINAGE MASTER PLAN ECOLOGICAL ALTERNATIVES ANALYSIS FOR WAIPUILANI AND KULANIHAKOI DISTRICTS

MAUI, HAWAII

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Prepared for:

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I. Background and Basis of Design

This report was developed as a follow-up to the Kihei Drainage Master Plan (2016), (hereafter referred to as the KDMP) in response to requests by community residents and professional organizations in the fields of development, civil engineering, marine ecology, water quality, climate change, and others. The primary goal of this project was to determine if alternatives to the KDMP could, 1) provide ecological benefits/reduce impacts, 2) include water quality improvements for frequent storms, 3) convey the predetermined design flow (100-year storm), 4) meet or reduce the estimated cost of the project within the KDMP, and 5) address community concerns and preferences that were relayed during the course of this assessment. The findings presented are conceptual and more detailed analysis will be required to develop detailed designs and implementation.

Development of the Ecological Alternatives Assessment (EAA) involved gathering historical information from community Kūpuna, site assessments and field verification, conducting outreach to firms and community groups for data sharing, compiling all existing data, and assessing regional and statewide management plans, and other information relevant to the project goals. Draft EAA findings were presented to the community in May of 2019 at the Kihei Community Association (KCA) meeting and through multiple forms of correspondence to date (see Appendix G for a list of community outreach efforts). In addition, staff from the County of Maui and R.M. Towill (RMT) Corporation have also provided in-depth comments. The comments and suggestions received have been incorporated into this ecological assessment, to the best of our ability.

In summary, the existing conditions within the two drainage areas do not safely convey flows during the 100-year storm event and development within the riparian zone would not be permitted under current regulations. Buildings are located within the flood zone and road elevations and culvert sizes do not currently meet existing freeboard requirements. Channel widths and culverts are highly constrained and undersized through most of the study area makai of Piilani Highway. Due to these constraints and the objective of this report, our recommendations are intended to strike a balance between preserving ecological connectivity, minimizing disturbance, improving water quality, maintaining private properties, restoring cultural and ecological features in the area, and considering goals and concerns expressed by both the County of Maui and members of the community. For example, in some instances, meeting current regulatory requirements for open channel flow (e.g., freeboard requirements) given the above constraints, may not be practical. Similarly, providing public access in some areas may not provide a reasonable level of safety at this time. This report documents the options that were evaluated, while also providing the rationale for including or not including those options in the list of solutions that are being recommended moving forward. As requested, all options will safety pass the 100-year storm.

II. Assumptions

The impacts of future development projects on flow rates were not explicitly considered, above the contributions contained within original KDMP report. It was assumed that runoff from future developments would be retained onsite, per Maui County Regulations, and would not be permitted to exceed pre-existing flow conditions. It was also assumed that the current channel capacity, or ability to convey flow, would remain constant in areas where future development projects bisect the channels. Alternative scenarios and cost estimates were developed based on our current understanding and information provided to us.

The scope of this project included conceptual level assessment and design, therefore the recommendations that follow will require additional analysis and detailed design to be executed. Cost estimates may also change as time progresses, but the overall scale should remain the same. We highly recommend continued community feedback be an integral component of the final plan for these areas.

III. Methods

To understand and verify the flow conditions within the two watersheds, a hydraulic model was developed in HEC-RAS software (Army Corps of Engineers) using LIDAR elevation values with refined and field verified input factors such as channel roughness (a factor of vegetative cover), width, and slope. Channel cross sections were "sliced" across multiple elevation surfaces. Channel and over-bank areas were defined. Culvert dimensions were input from the values provided in the Kihei DMP. The 100-year flow values (9.96" over a 24-hour storm) used within the Kihei DMP were cross-referenced with HEC-HMS hydrologic modeling software, using the same input values as RMT.

The HEC-HMS hydrologic model inputs (precipitation depth, channel length and slope, roughness, dimensions) used to calculate the 100-year storm flows were cross-checked using local precipitation records, USGS stream gage records, select field data, and local descriptions of flooding extent after a given storm event. Channel roughness and channel geometry are also important inputs in the hydrologic model for determining the shape of the storm hydrograph and the resulting peak flow values. Therefore, field observations of channel roughness and geometry conditions at numerous locations were conducted throughout both watersheds.

Additional existing data relevant to the Waipuilani and Kulanihakoi Districts (e.g., existing infrastructure, hydrologic in-pipe flows, precipitation, tides, streamflow, climate projections, floodplain maps, historic data, traditional uses, endangered species, invasive species, permits active in area, mauka land-use, etc). was collected and compiled, then field checked where necessary to contribute to the hydrologic model.

A GIS database was then developed to combine existing data, which included landowner information, 1-ft contour data, stormwater infrastructure, watershed boundaries, soils, roads, wetlands, and photographs taken during site visits.

IV. Findings

1. Precipitation and Flow Modelling

A wide range in channel roughness conditions and channel geometry was observed. Sections of each gulch were found to have very high roughness conditions, which would slow down flows and potentially flatten the shape of the hydrograph, reducing peak flows through the project area. A thorough review of all available rainfall data and regional modeling showed that there are minimal active rain gauges in operation in this area. Rainfall depths and frequency were found to be highly variable across the elevation gradient within each watershed during any single rainfall event.

For example, there is one USGS gaging station is located within the project area. The Kulanihakoi Gulch (#16660000) gage is located immediately upstream of the Piilani Highway and drains an area of 15.03 square miles. Annual peak streamflow data is available from 1963 through 2008. The highest recorded

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flow from 1963 to 2008 was 4,460 cfs (Table 1). The largest flow in recent years was 2,340 cfs in 2007. This flow produced significant flooding along South Kihei Road.

Table 1. Highest Peak Flows Measured at The Kulanihakoi Gulch (#16660000) USGS Gauge Station from 1963 through 2008.

Date	Peak Flow (cfs)
1/28/71	4,460
1/10/80	2,750
12/5/07	2,340
12/6/88	1,670
1/23/04	1,380
10/15/02	1,210
1/20/97	398
11/3/00	342
3/17/02	311

Figure 1 shows the total rainfall across the region during the four days preceding the large flooding event in 2007. Over the 4-day period from December 1 to December 5th, 2007, total rainfall depths recorded across the watershed ranged from 3 to 13 inches, averaging 7 inches. The highest recorded daily rainfall was 5.3 inches at a precipitation monitoring station along Kula Highway. The USGS stream gage on Kulanihakoi recorded a flow of 2,340 cfs (Table 1).

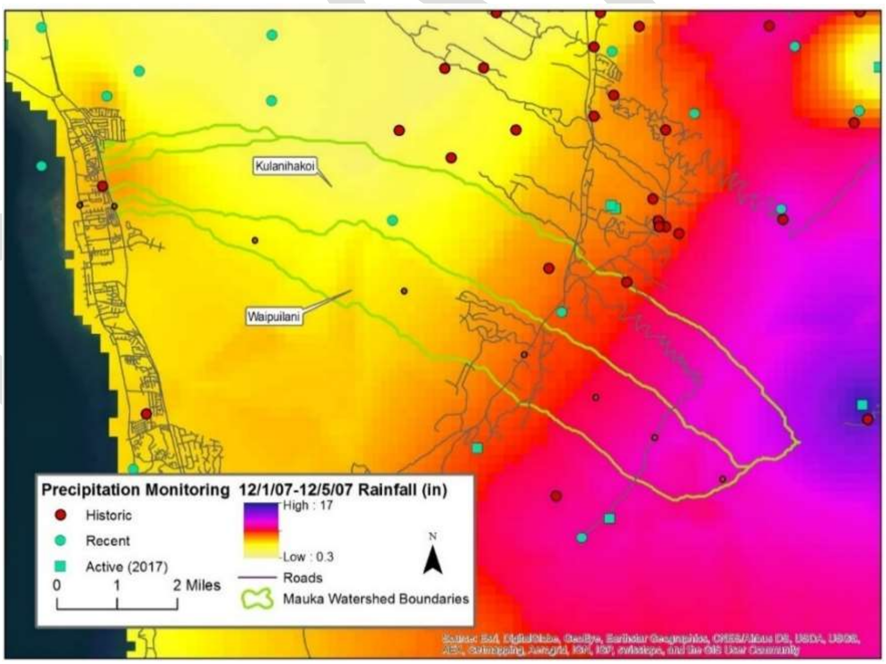

Figure 1. Total Rainfall from 12/1/07 to 12/5/07 within the Kulanihakoi and Waipuilani Basins

Newspaper articles and video from the 2007 rain event show flood depths of 2-4 feet over South Kihei Road (https://www.youtube.com/watch?v=ulRyeZnnTbA). Review of rainfall from this event and from other recent reported floods (12/20/2017, 3/7/2017, and 4/9/2018) indicate that highly variable rainfall distribution within the watershed may result in minor to moderate flooding, primarily along South Kihei Road.

For comparison, the KDMP 100 year-24 hr flows estimated to enter the Kulanihakoi gulch at Kulanihakoi Bridge is 10,086 cfs. If this event were to occur with the existing channel and culvert conditions, the entire project area would be inundated by up to 6 feet of water (Figure 2).

Figure 2. FEMA National Flood Hazard Layer map of the Kihei study area. The existing conditions 100-year flood model (unknown flood discharge) indicates significant flooding along South Kihei Road and overbank flooding along Waipuilani Gulch.

Given the minimal number of active rainfall monitoring stations in these watersheds, characterizing rainfall data for a single storm event (100 yr 24 hr storm) across the entire watershed may not accurately predict flow (the HEC-HMS model in the KDMP used a single rainfall depth of 9.96”).

Local climate change scientists have concurred with this predicament, and often reference a recently published study which calculated daily rainfall totals (1990-2014) at a 250-meter grid for the Hawaiian Islands (Longman et al. 2019). This dataset utilized all available precipitation data from almost 2,400 active and historic monitoring locations and found a wide range in precipitation data collection quality and density. The two drainages in this study have a lower degree of data availability, however the dataset utilizes a weighted interpolation method to fill in data gaps for rainfall estimation.

It is therefore important to understand the limitations inherent in sizing flow conveyance systems for high flows of this nature. It may be prudent to consider a more realistic rainfall value and associated storm flow within these complex watersheds.

Based on this hydrology modeling effort, it appears that the 100-year 24-Hr flow may be closer to 6,000 cfs for Kulanihakoi (as opposed to 10,086 cfs) and 4,500 cfs for Waipuilani (as opposed to 8,089 cfs). Therefore, it is highly recommended that any future modeling efforts incorporate more detail for rainfall depth and distribution across the watershed, as this likely plays an important role in estimating the peak flood discharges, and has a large impact on infrastructure sizing and costs.

In summary, observations of channel roughness and dimensions, and analysis of precipitation and flow records suggest that the previously determined flows for the 100 year 24-hr storm event within these two watersheds are likely overestimated and utilization of these flow values in concert with the current County of Maui freeboard requirements for open channels severely limits options for reasonable flood conveyance.

For the purposes of this report, the original values were used, per the request of the County of Maui, therefore, some options presented do not meet current freeboard requirements, but still safely pass the predicted 100-year 24-hour event. Future studies may warrant that additional scenarios are presented, based on more realistic flow conditions.

2. Assessment of Flow Diversion from Waipuilani to Kulanihakoi

The proposed diversion of 8,719 cfs into a 50’ wide 10’ tall concrete channel from the Waipuilani Gulch into the Kulanihakoi Gulch was the most ecologically impactful component of the KDMP. The first step was to determine if the diversion was essential, and if not, what channel modification would be required to accommodate existing flow and reduce flooding. This channel diversion was estimated to cost approximately $14,359,000. In addition, the increased flow to Kulanihakoi Gulch (10,086 cfs at Kulanihakoi bridge would be increased to 20,200 cfs) required extensive downstream channel improvements, described as a trapezoidal, concrete lined channel with 80’wide bottom, 12’ high sides with 2:1 side slopes, estimated to cost roughly $20,490,000. Flow from the channel would be passed from Piilani Highway to South Kihei Road via a new 130’ wide bridge (although channel constrictions makai of the proposed bridge do not appear to have been addressed). Based on our hydraulic modeling results, the constriction significantly reduces conveyance of flood flows, increasing water surface elevation through much of the study area.

The assessment concluded that it was possible to avoid the diversion, however the narrow channel and undersized culvert within the Waipuilani Channel, from South Kihei Road to the ocean, require significant modifications to safely pass the 100-year flow.

3. Kulanihakoi Existing Conditions

Within Kulanihakoi District, we focused primarily on the area makai of Piilani Highway to the channel outlet at the ocean, within Kula2_1, where the flooding impacts and proposed improvements were the most dramatic (Figure 3).

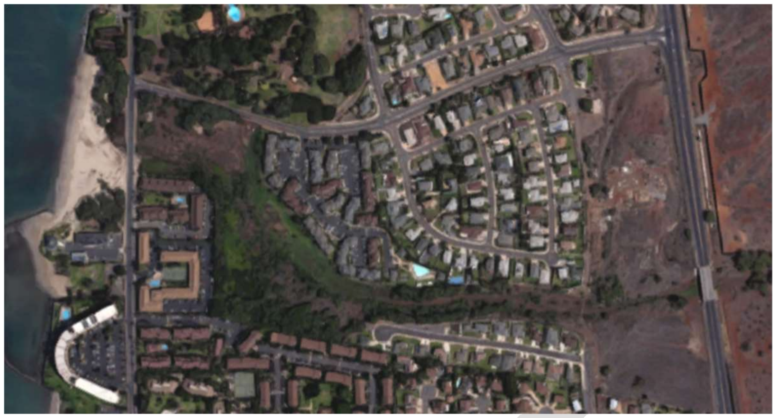
Figure 3. Aerial View of Kulanihakoi Channel from Piilani Highway to the Ocean

Flows at the intersection of the Kulanihakoi channel and the Kulanihakoi Bridge are estimated to be approximately 10,086 cfs (100 yr-24 hr), with a contributing drainage area of 9,576 acres (Kihei Drainage Master Plan, 2016). That contributing drainage area from the mauka lands is comprised of primarily dryland shrubs with an approximately 4-mile wide belt (from 2,000 to 7,000 feet of elevation) of lush vegetation adjacent to the Kula Highway. The watershed extends to the ridge west (makai) of the Haleakala Summit to an elevation over 9,200 feet. Large land holdings account for most of the drainage area between Piilani Highway and Kula Highway. For instance, a portion of the 5,890-acre Kaonoulu Ranch is shown below (Figure 4).


Figure 4. Aerial View of Kulanihakoi Kaonoulu Ranch Property (Partial)

The Piilani Highway bridge capacity is estimated to be approximately 20,200 cfs and is therefore sufficient to convey the 100-year storm without alteration. Water then flows through a natural earth channel that bisects two private properties currently slotted for development. Ka’Ono Ulu Ph6 Condos (3.10 acres) borders that channel on the north and the Hawaiian Association of Seventh Day Adventists (5.7 acres) appears to contain the main portion of the channel on the south (Figure 5).

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Figure 5. Aerial View Kulanihakoi Makai of Piilani Highway

Flow then crosses the North/South road extension (Figure 6) and enters an engineered trapezoidal channel, with geotextile bottom and boulder lined slopes, with the residential development on both sides (Figure 7).

Figure 6. Aerial View Kulanihakoi North South Road Extension (Yellow)

Figure 7. Aerial View Kulanihakoi Makai of North South Road Extension

The channel has sufficient capacity in this area, with the existing top of bank elevation at approximately 16 feet and the estimated water level elevation during the 100-year event at 13 feet. Following the narrow section makai, the channel widens out and existing vegetative cover is good in this area, however, slope substantially decreases. Low slopes are good from a water quality perspective, for they drop out sediments, but can lead to flooding in adjacent areas, if the channel banks are not high enough to contain the water, as is the case here. In the wider channel section, the existing top of bank elevations are generally 2 to 4.5 feet lower than the projected water level elevation during the 100-year storm event. The channel is owned by multiple landowners, as shown in yellow below (Figure 8), until it crosses South Kihei Road.

Figure 8. Aerial View Kulanihakoi Multiple Property Owners Makai of North South Road Extension

At the intersection of South Kihei Road, there are four 6'x4' box culverts. These culverts are currently severely under sized and can only convey 672 cfs when over 10,000 cfs is estimated for the 100-year storm event. The road is currently at an elevation of 6 feet. The sand dunes on the makai side of South Kihei Road further block water from moving through the area, forcing it to back up and exacerbating flood effects. The dunes are located on approximately 2.5 acres and owned by the County of Maui.

4. Kulanihakoi District Proposed Improvements

The following contains a description of the modifications necessary to protect the north and south properties along the Kulanihakoi channel, while also conveying the 100-year storm flows safely through. For each proposed improvement, recommendations are described moving mauka to makai, referring to the Zone Map with channel cross sections (Figure 9), and Proposed Conditions Map (Figure 10). The existing channel, bank, and water level elevations within each zone are listed in Table 2.

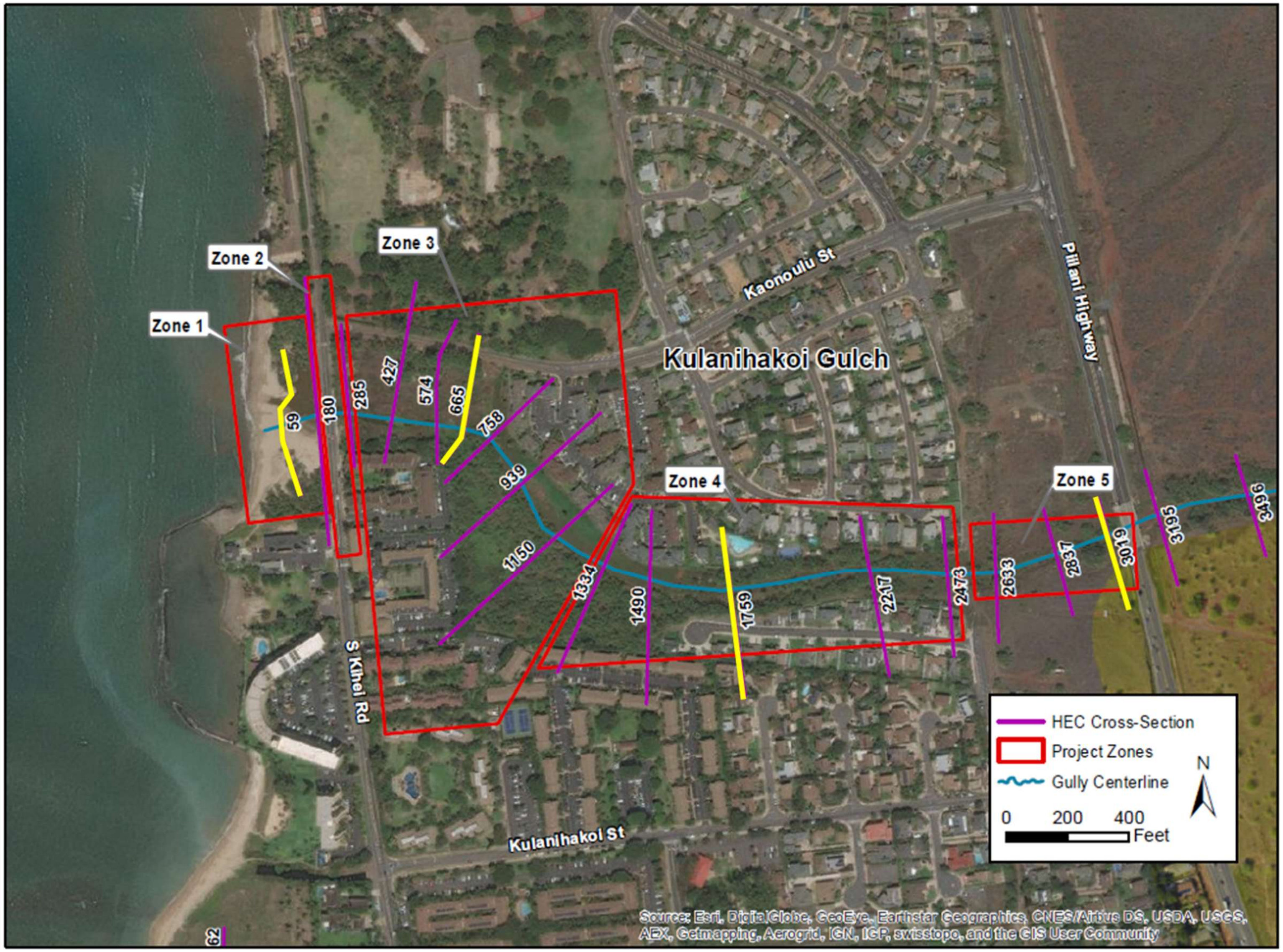

Figure 9. Kulanihakoi Zones Map with Numbered Cross Sections, Detailed Cross Sections Shown in Yellow

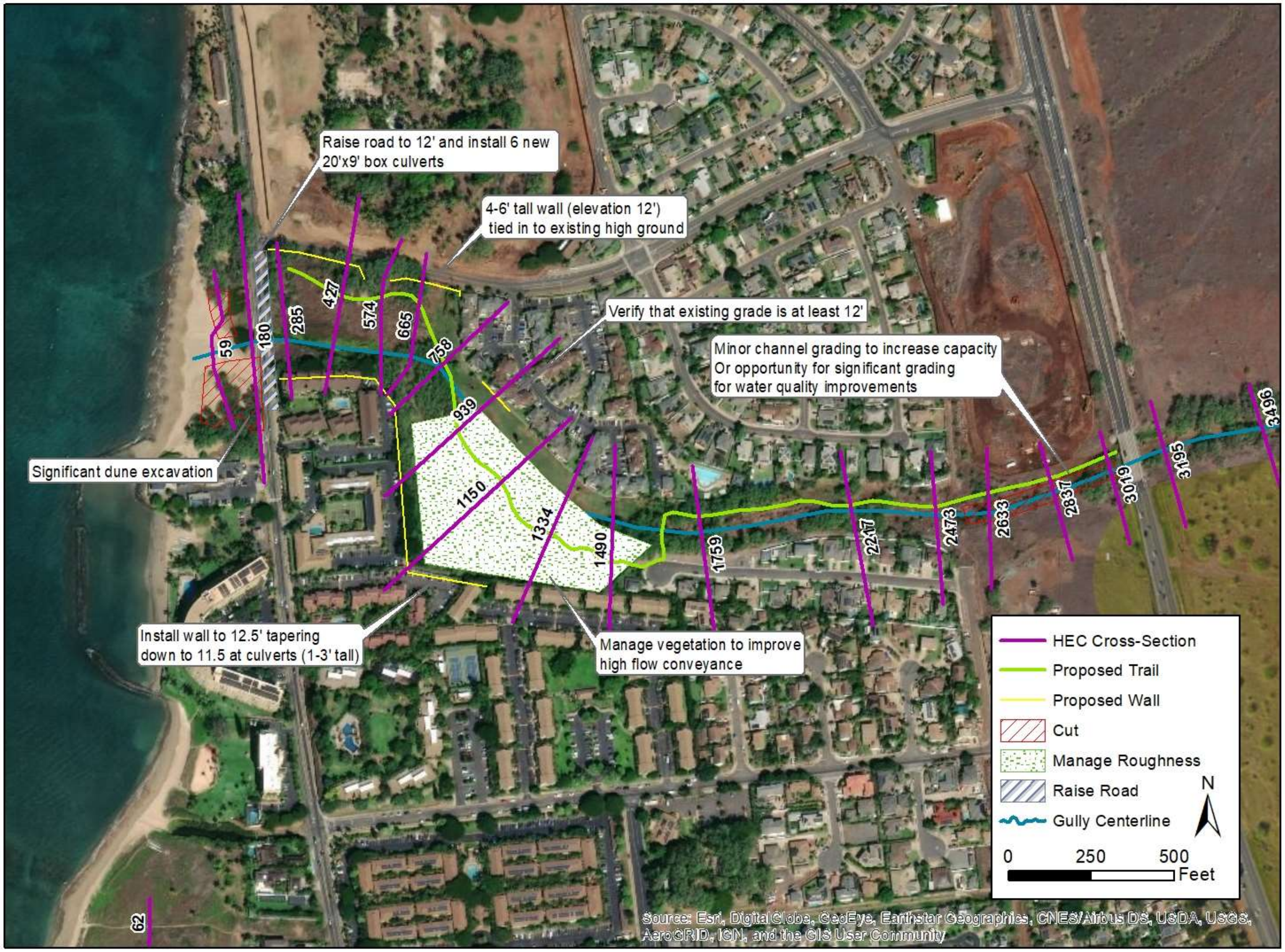

Figure 10. Kulanihakoi Proposed Conditions Map

Table 2. Kulanihakoi Existing Elevations

Zone	Cross Section (#)	Channel Elevation (ft)	Existing Top of Bank (ft)	Q100 Elevation (ft)	Recommendation Summary
1	59	0.5	7	9	Excavate and secure dunes to increase conveyance area makai of South Kihei Rd
2		2	7	11.5	Raise road and install large culverts or bridge
3	665	4	9	12	Install walls up to road elevation, or freeboard if required
4	1759	6	16	13	Install plantings and/or baffles to increase sediment/debris retention
5	3019	12	22	24	Install water quality improvements for smaller storm events, such as regenerative stormwater conveyance approach, while maintaining sufficient conveyance to safely pass large flood events.

A. Water Quality Improvement in Kulanihakoi Basin

Just makai of the Kulanihakoi Bridge (Zone 5, Figure 9), the channel is filled by the 100-year storm with minimal overbank flow, as shown in cross section #3109 (Figure 11). There is an opportunity for minor channel improvements to increase capacity and improve water quality in this area. The Hawaiian Association of Seventh Day Adventists appears to currently own the property (TMK (2) 3-9-001:149).

Figure 11. Kulanihakoi Channel Cross Section #3019 (left) and Key Map (right) showing Cross Section in Yellow

It is important to note that the volume of water estimated to move through the channel during the 100-year event is extremely large, thus many options proposed are focused on conveyance and flood mitigation. Water quality improvements were considered during smaller storm events, where land was available, and where those features could also safely bypass the 100-year storm event.

In general, water quality improvement focused on options within the main channel itself, although improvements to mauka land management may also have a measurable effect on sediment transport during smaller storm events. Water quality improvement can be attained using many options, including:

1. Decrease flow velocity through temporary or long-term ponding (e.g., detention basins, bioretention basins, check dams, weirs)
2. Decrease the incline of the topography, thereby slowing water
3. Increase % vegetative cover, thereby slowing water
4. Replace high velocity vegetation type (e.g., short grass) with low velocity vegetation type (e.g.,tall bunch grass such as pili, shrubs, trees)
5. Replace ground surface with higher friction surface (e.g., manufactured erosion control matting)
6. Add rocks/bounders or other barriers for water to flow around
7. Allow slowed or ponded water to filter through a porous media (e.g., mulch, native soil with minimum 30% sand) to remove sediment and nutrients.

To improve water quality during smaller storm events in this area, a Regenerative Stormwater Conveyance (RSC) approach may be appropriate. This technique includes alternating engineered pools, riffles, rock weirs, and filter materials (Figure 12).

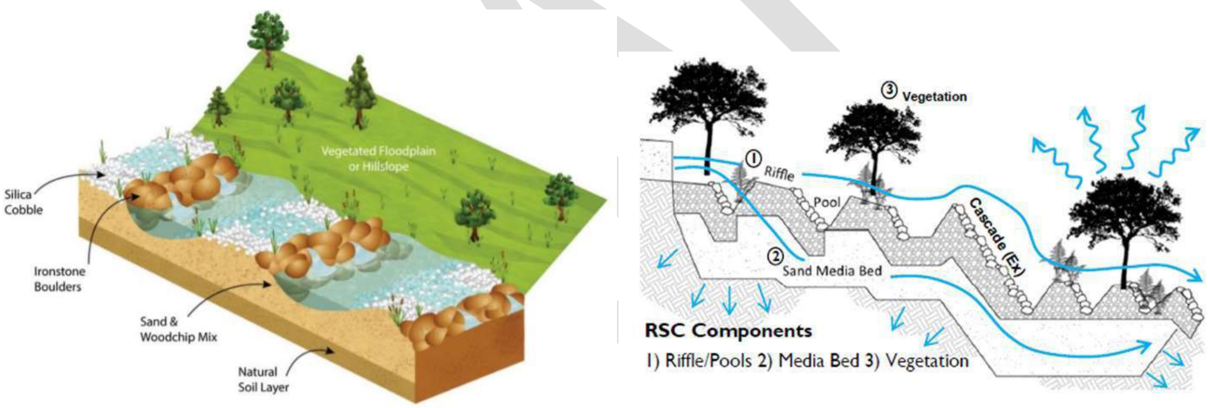

Figure 12. Regenerative Stormwater Conveyance Examples (Image Credit: Williams, M. R., Wessel, B. M., & Filoso, S. (2016))

During a small storm event (e.g., 10 or 50-year), water would move through the engineered treatment area, which is designed to 1) reduce velocity, thereby dropping out sediment, 2) physically filter water via infiltration through a highly porous media, and 3) provide habitat diversity through vegetation restoration. The infiltration areas provide denitrification potential and vegetation can remove metals and other pollutants. Final design for this area would need to allow features to safely bypass high flows during the larger storm events (e.g., greater than 50-year), and all materials (e.g., rocks) should be sized for larger events, so that the erosive potential does not damage the filtration system. Water quality improvements here need not deter public use or access to this area. An appropriately designed trail/boardwalk could be overlaid on top of the water quality improvement features, although the potential liability associated with public access options are too great at this time (as is discussed in further sections).

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Moving makai into zone 4, the channel has adequate capacity, as shown in cross section #1759 (Figure 13). No modifications are required for flood conveyance. The excess channel capacity also presents an opportunity for water quality treatment improvements.

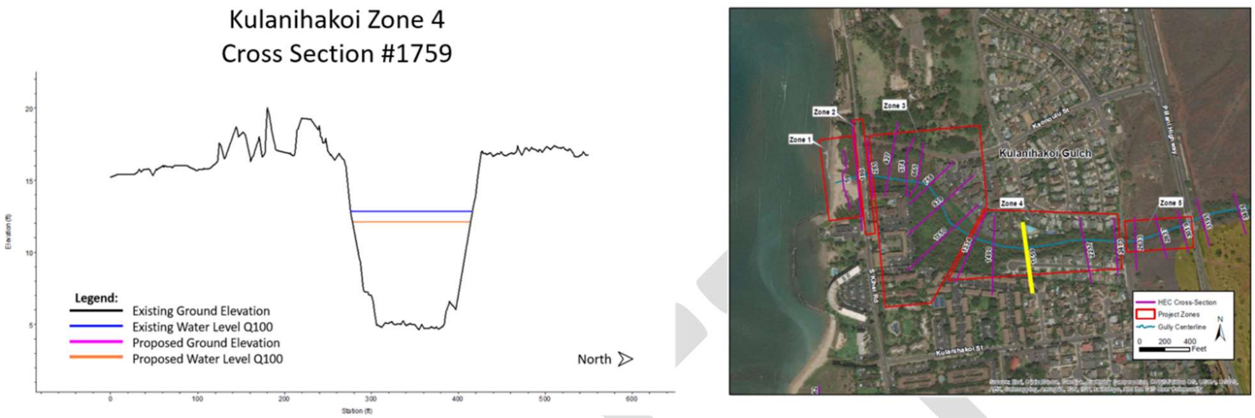

Figure 13. Kulanihakoi Channel Cross Section #1759 (left) and Key Map (right, showing cross section in yellow).

Trash will need to be removed and revegetation efforts should target 100% coverage, where possible. To allow for unimpeded high flow conveyance, native plants that currently thrive in open channels and 'lay down' during storm events or are relatively low lying (i.e., pili grass, robust groundcovers) are highly recommended. Non-native plants such as vetiver grass may also be effective here.

Channel bank stabilization will also improve water quality through decreased erosion. There are many options for slope stabilization, including gabions, vegetated geogrids, rock riprap, and live stakes or fascines (Figure 14).

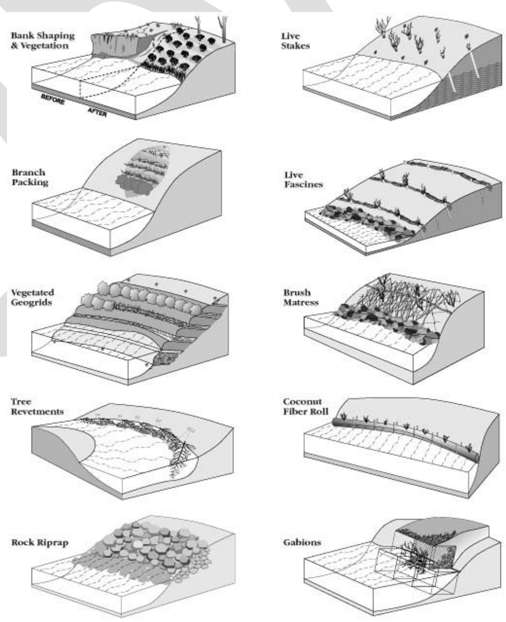

Figure 14. Slope Stability Options (Stream Stabilization Selection: Emelia Brooks, Lizzie Hickman, Leslie Ogar (2015).

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Manufactured slope stabilization techniques such as GEOWEB® or others (Figure 15) are also effective. These systems are designed to be planted and can withstand hydraulic forces between 9 – 30 ft/s.

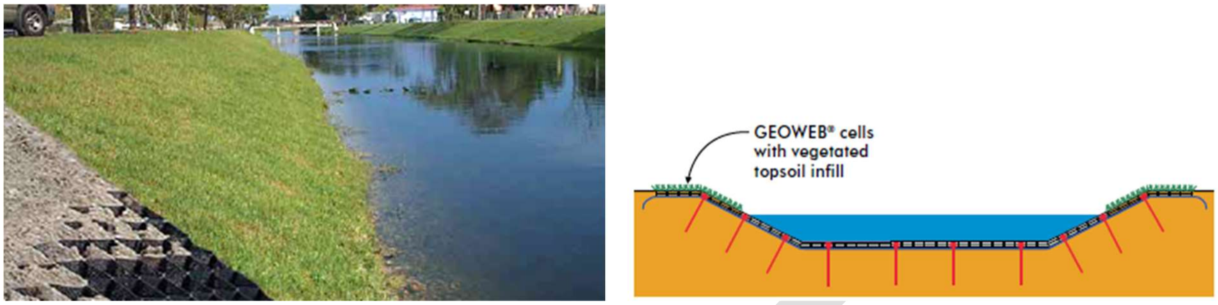

Figure 15. Channel Stability products: a) Geoweb Image (left) and b) Geoweb Profile (right)

The final materials for bank stabilization, erosion control, and appropriate plant selection would be selected during detailed design. It is important to verify that any improvement within the channel can withstand the shearing hydraulic forces expected during the 100-year storm event.

B. Kulanihakoi Flood Walls

Within Zone 3 (Figure 9), the top of the existing channel bank elevation varies from 9 feet to 13 feet and the water level elevation during the 100-yr storm is projected to reach 12 feet, leaving some areas vulnerable to flooding. A floodwall extending to a minimum of 12 feet is recommended in low areas along the north and south bank to contain the 100-year storm event. Flood walls are shown in yellow below (Figure16).

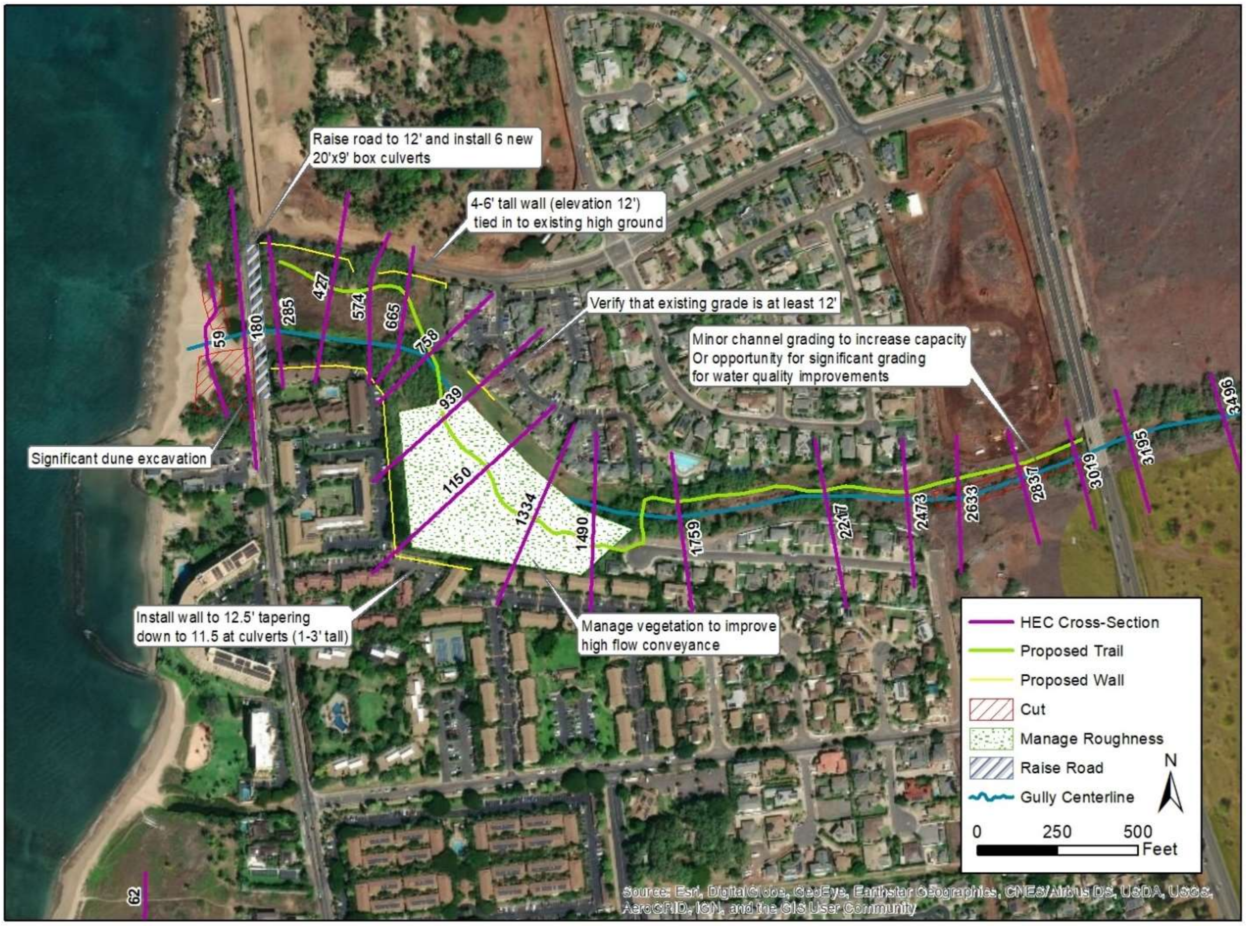

Figure 16. Kulanihakoi Proposed Conditions Map, Proposed Walls Shown in Yellow

The flood walls would act as a levee and freeboard is currently sized to be approximately 1 foot above the peak elevation for the 100-year storm. Additional wall height may be achieved through concrete walls on top of the proposed vegetated walls. Based on the empirical equation for freeboard listed in the Title MC-15 rules, the required freeboard for the 100-year storm event would range from 8 to 20 feet, requiring walls over 20 feet high in many areas. Seeing that the 100-year flow is likely overestimated, and the area under the current conditions would be inundated under 6 feet of water if that flow were to occur, meeting the freeboard requirements in this instance may not be reasonable. Drainage conditions on the landside of any of the proposed flood walls will need to be examined in more detail. Check valves and flow control culverts are suggested from the land side back into the channel.

On the north side of Kulanihakoi channel, at cross section #939 (Figure 9), a 1-2 foot high flood wall would tie into an existing berm along the south-western portion of Villas at Kenolio, until it reaches the intersection with Kaonoulu Street. The structural stability of the existing berm, and its capacity to withstand expected flood flows would need to be confirmed during detailed design.

The flood wall would continue along the south side of Kaonoulu Street’s south side (Figure 16) and tie into existing high ground at approximately 11.9 feet of elevation at cross section #574 (Figure 9), prior to continuing on and ultimately tying into the proposed road improvement project at the South Kihei intersection with Kaonoulu St.

A 3 to 4 foot high flood wall is also needed along the southern bank of the Kulanihakoi channel (Figure 16), along the northern end of the following properties:

1. TMK (2) 3-9-001:149
2. Haleakala Gardens (TMK (2) 3-9-044:041/ (2) 3-9-044:042),
3. Kihei Resort (TMK (2) 3-9-001:136),
4. Kihei Bay Surf (TMK (2) 3-9-001:107)
5. Kihei Bay Vista Condos (TMK (2) 3-9-001:107).

Moving makai down the channel, cross section #665 (Figure 17) shows the existing bank elevation at approximately 8 feet and the water level elevation during the 100-year storm at approximately 13 feet.

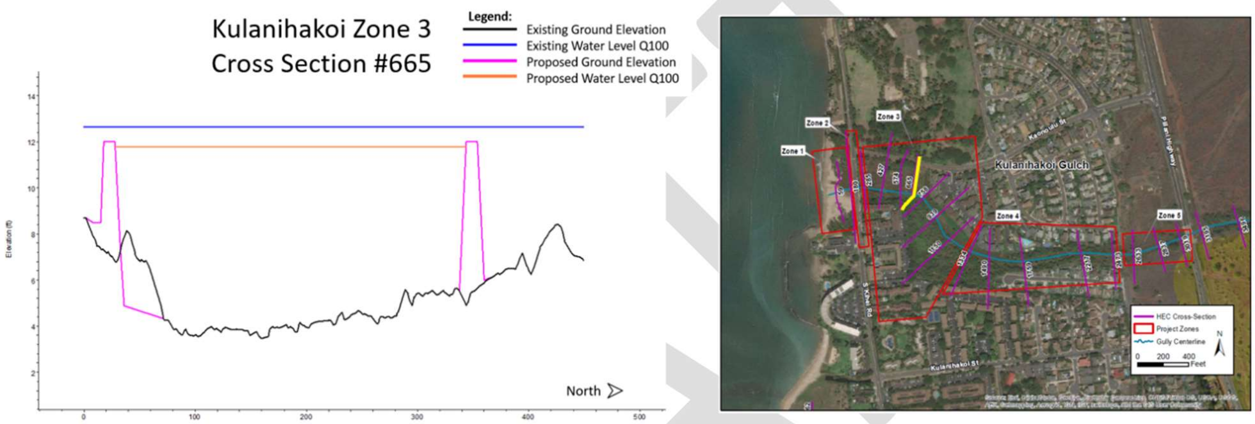

Figure 17. Kulanihakoi Channel Cross Section #665 (left) and Key Map (right, showing cross section in yellow).

The proposed flood wall would thus need to be approximately 4 ft high on the south bank and up to 6 feet high on the north bank, extending to an elevation of 12 feet. Downstream modifications at the South Kihei crossing and the ocean dunes will reduce the flood elevations to approximately 11.5 feet. The flood wall and channel modifications would bring the water level down to approximately 11 feet and contain flooding within that area. This wall would ultimately tie into the road improvements along South Kihei Road.

A roundabout at Kaonoulu Road and South Kihei Road intersection has been proposed by members of the Kihei Community Association as an alternative to a traffic light (Figure 18). The roundabout would slow traffic speed while providing a more enjoyable driving experience. This study did not explicitly assess the technical details of the roundabout; however, it does not appear to conflict with the drainage plans recommended here.

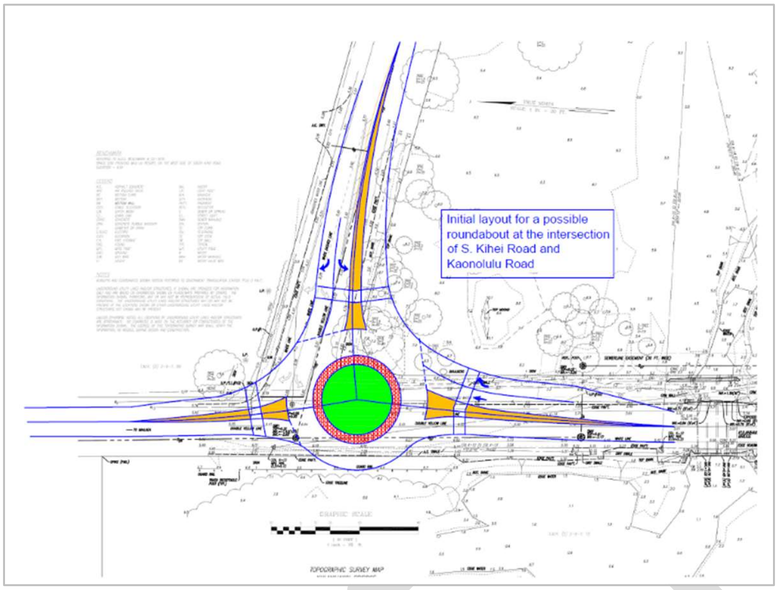

Figure 18. Proposed Roundabout at South Kihei Road and Kaonoulu Street

C. Improvements at South Kihei Road & Kulanihakoi Channel Intersection

At the Kulanihakoi channel intersection with South Kihei Road, the road would need to be raised from an existing elevation of 6 feet to 12 feet, in order to fit the proposed six 9-foot x 20-foot box culverts (minimum) required to pass the 100-year flood flow safely through (Figure 19). Estimated costs for the proposed culvert crossing are in Appendix A.

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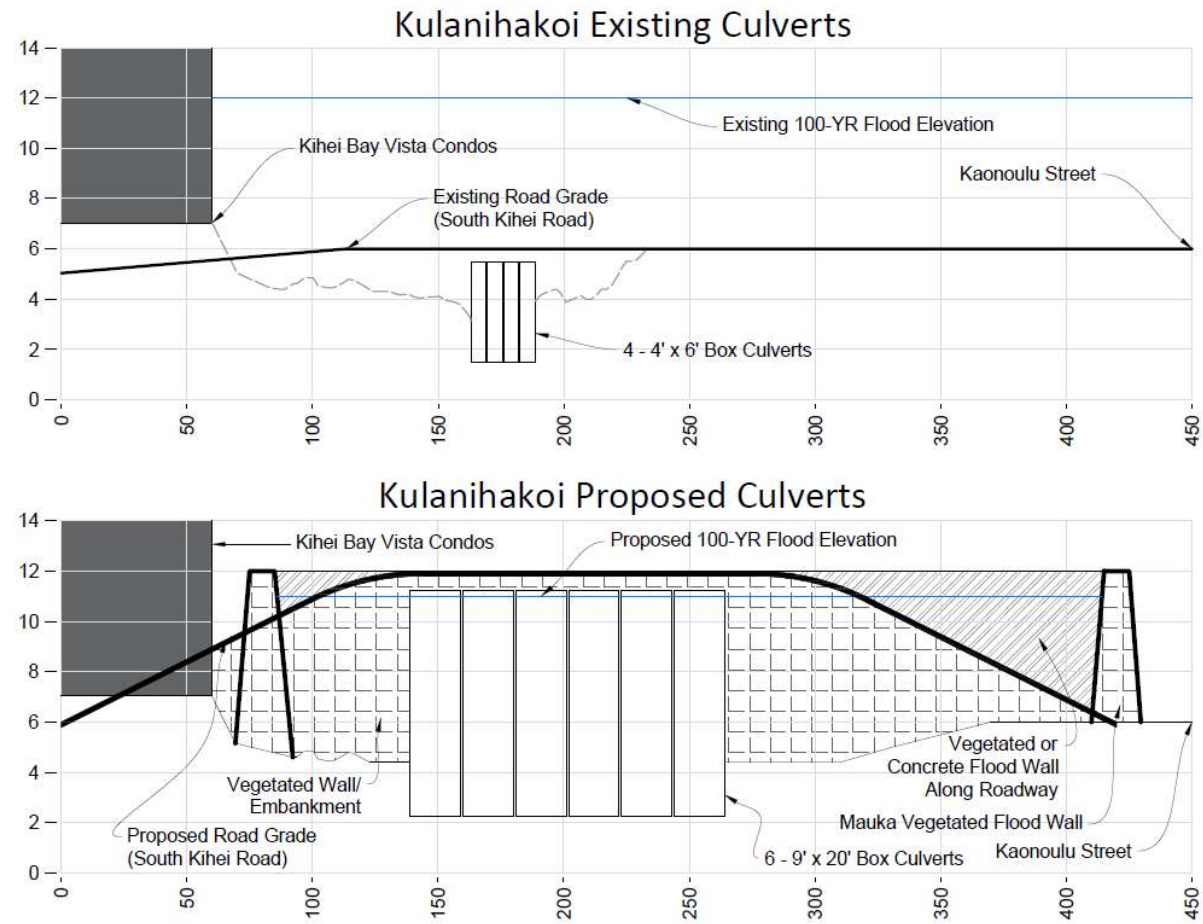

Figure 19. Kulanihakoi Existing and Proposed Culverts at Channel Intersection with South Kihei Road

A flood wall is required along the makai (east) side of the road embankment extending from the culvert to the proposed flood walls along the north and south bank. This will maintain the required flood conveyance and storage area at 12 feet of elevation. As previously mentioned, the storm flows projected for this intersection are greater than 10,000 cfs and the current culvert capacity is 627 cfs. The proposed conveyance infrastructure would have the capacity to pass these flows, but with 0.5-1 foot of freeboard, well below the current freeboard requirements for open channels. If current freeboard requirements for open channels are required in this area, the road would need to be raised to accommodate a much higher structure.

The original drainage master plan proposed a 130’ bridge, estimated to cost approximately $24 million dollars. If that system was designed for the total flows diverted from Waipuilani Gulch (19,642 cfs as opposed to current 10,733 cfs) then a moderate bridge alternative may be possible. The alternative would increase available freeboard but would require raising the road elevation and the floodwall elevations through all of Zone 3. We did not address this alternative in this report.

D. Kulanihakoi Dune Excavation and Stabilization

Dune excavation at the outlet will be required to allow the >10,000 cfs of flow from the 100-yr storm to pass through. As shown in cross section #59 (Figure 20), the southern dune bank is prohibiting water from spreading out, this raising it to an elevation of approximately 10 feet, causing regional flooding. By bringing the southern dune bank down to approximately 5 feet, water level elevation will drop to approximately 6 feet, which will allow the required volume to pass through and out to the ocean.

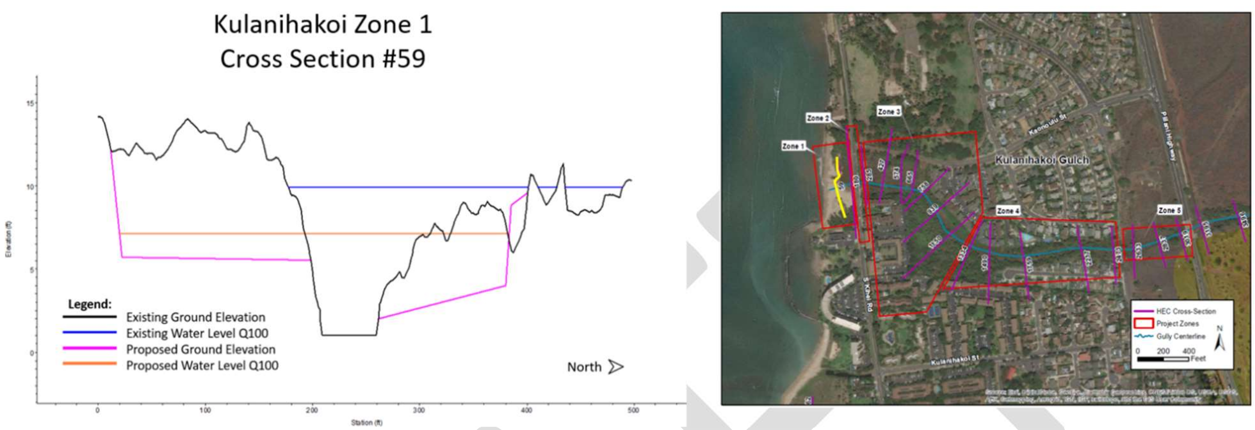

Figure 20. Kulanihakoi Channel Cross Section #59 (left) and Key Map (right, showing cross section in yellow).

Sand dunes are tidally influenced and are built up as the ocean pushed sand landward. The dunes would need to be stabilized to maintain their new position and channel geometry. There are several techniques that could be used, as shown in Figure 21. Final selection and cost estimates would need to be completed during detailed design after evaluating which techniques could withstand the expected flows during the 100-year storm event.

Excavation of the sand dunes needs to carefully consider the history and ecology of the area. According to ‘Ao ‘ao O Na Loko I‘a O Maui, the sand dune area may contain iwi and Hawksbill turtles. Any plans for work in this area need to be carefully developed with cultural and marine ecology experts. This area is currently in an unnatural hydrologic state characterized by impeded flows due to undersized culverts, therefore it is likely that channel clearance and proper culvert sizing would restore the area to a condition which is closer to its pre-development state. We acknowledge that the proposed sand dune alterations will be difficult from both a cultural and permitting standpoint, however the current dune configuration significantly reduces flood conveyance, potentially negating most of the flood mitigation efforts discussed in this report and the KDMP.

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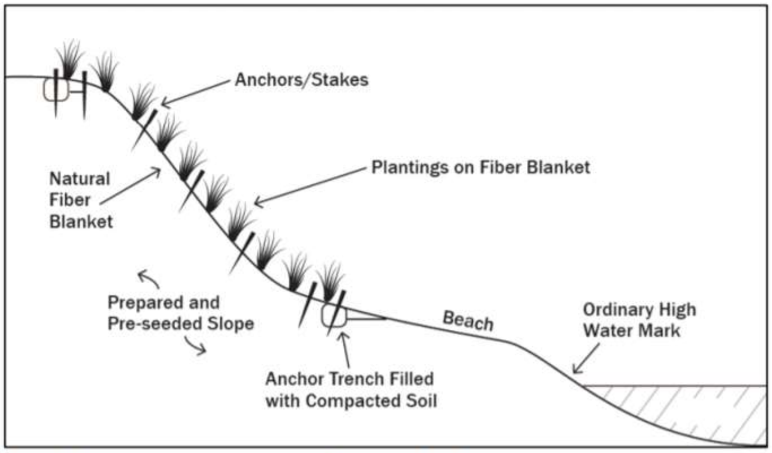

Figure 1. Natural Fiber Blanket Installation Using Anchor Trenches and Planted with Native Grasses. (Adapted from Massachusetts, 2016.)

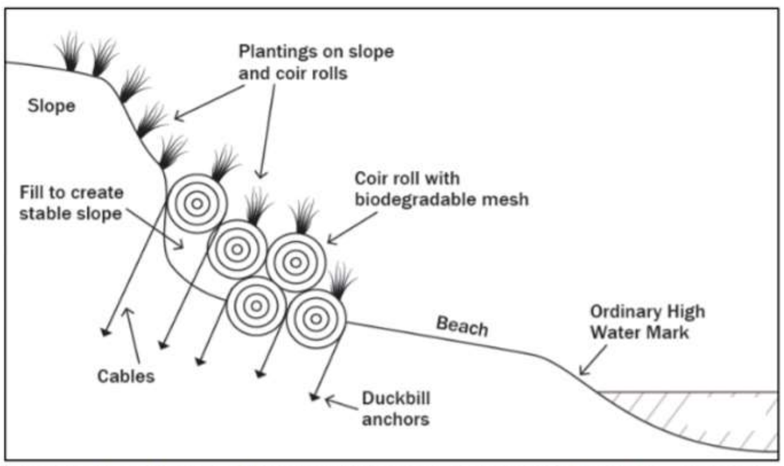

Figure 2. Cross-Section of Bluff/Bank Bioengineering Using Coir Rolls. (Adapted from Massachusetts, 2016.)

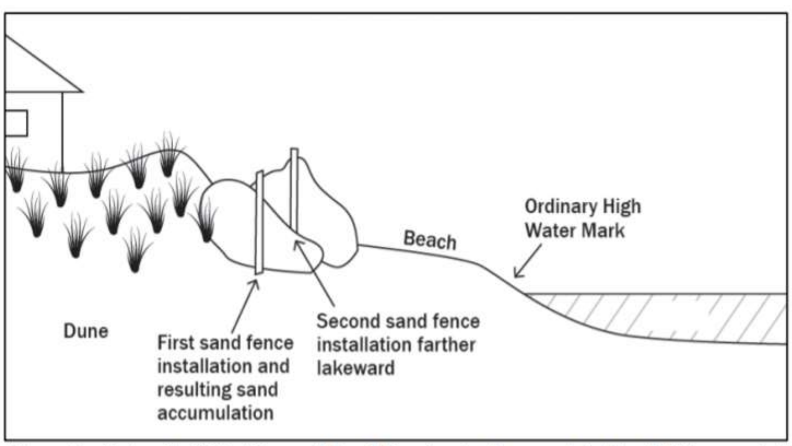

Figure 3. Using Multiple Lines of Sand Fencing to Accumulate Sand Waterward of an Eroded Dune Face. (Adapted from Massachusetts, 2016.)

Figure 21. Channel Stabilization Techniques: a) Fiber Blanket (Top), b) Coir Rolls (Middle), c) Sand Fence (Bottom)

E. Public Access: Assessing Feasibility of Kulanihakoi Multi-Use Trail

A trail concept was proposed by Chris Hart & Partners in 2016, which could theoretically extend from the Kulanihakoi Bridge to South Kihei Road. The proposed trail location is shown below (Figure 22) and on the proposed conditions map (Figure 16). The trail concept is in line with the recommendations contained within the South Maui Watershed Plan, however due to potential public safety concerns, The County of Maui does not pursue this option at this time.

Figure 22. Aerial Image Depicting Kulanihakoi Gulch Linear Park Exhibit by Kris Hart & Partners

For future reference, the trail or boardwalk could potentially be built into the flood wall (Figure 23), in some locations, but view corridors would need be studied to protect the privacy of private landowners adjacent to the wall. The vegetated floodwalls have steep side slopes and would be difficult to climb in the event of a flash flood. Portions of the floodwall could be installed in a stair step pattern to facilitate emergency egress, with a minimal reduction in floodwater capacity.

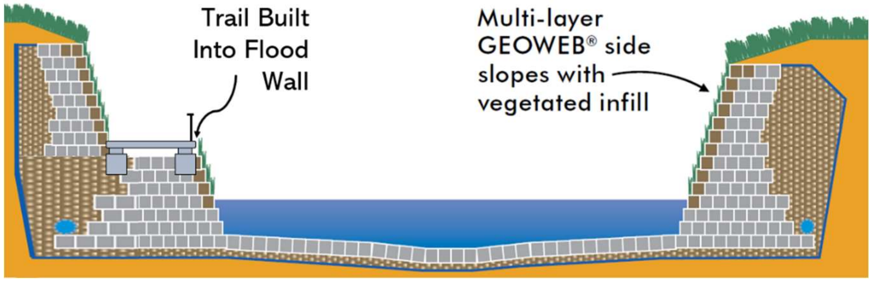

Figure 23. Manufactured Bank Stability Technique with Trail Overlay (Conceptual)

In addition, visitors to the trail would need to be informed of the risks via signage, explaining that water level elevations within the channel can rise quickly during catastrophic storm events (100-year). In smaller storm events, water levels within the channel (given proposed modifications) are only expected to rise 2-4 feet, therefore a raised boardwalk could alternatively be designed to sit along the channel bottom.

Boardwalk materials in the tropics need to be carefully considered, therefore a precast concrete (PermaTrak® or others), composite, or another non-wood alternative is recommended (Figure 24).

Figure 24. Boardwalk Examples (Photo Credits: PermaTrak®)

6. Waipuilani Existing Conditions:

An aerial view of the area studied in the Waipuilani District is shown in Figure 25. Waipuilani Gulch crosses Piilani Highway at Waipuilani Bridge. The bridge capacity is estimated to be 11,200 cfs, and the flows at that point are estimated to be 8,089 cfs for the 100 yr, 24-hr storm event, with a contributing drainage area of 7,259 acres. The bridge has adequate capacity for current flows. Makai of the bridge, water moves through an open area, approximately 3.1 acres, owned by the County of Maui (Figure 26).

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Figure 25. Aerial View Waipuilani Channel from Piilani Highway to the Ocean

Figure 26. Waipuilani County of Maui Land (Left) and Photo Looking Mauka Toward the Waipuilani Bridge (Right).

Approximately 800 feet makai of the bridge is the future Liloa Drive Road extension project (Figure 27), which will construct a road north to south across the channel and will include 2-11'x3' culverts. Current culvert capacity at the Liloa crossing is 392 cfs.

Figure 27. Waipuilani Aerial View Liloa Drive Road

Flows then move into the Waipuilani dry stream channel and the future development parcel for Ho'onani Homes (Figure 28). The development parcel is approximately 12.89 acres. A tall earthen berm located along the southern bank protects houses along Namauu Place, increasing flood risk to the north along Oluea Street.

Figure 28. Waipuilani Aerial View Ho'onani Homes Future Development Property (Approximate)

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The channel then narrows substantially and is bordered by ten private residential parcels on the southern bank of the channel, and one privately owned parcel on the northern bank (Figure 29). This northern parcel is approximately 0.94 acres and assessed at $773,100. A tall earthen berm along the north bank protects the two houses during moderate floods, however the berm reduces channel capacity and increases flood risk to the neighborhood to the south along Ho’onani Street.

Figure 29. Waipuilani Aerial View of 915 South Kihei Road (TMK (2) 3-9-034:027) (Approximate)

There is currently one 10’x2’ culvert at the South Kihei Road crossing, with a capacity of less than 200 cfs. The estimated 100-year flood flows moving through that location are 8,120 cfs. On the makai side of South Kihei Road, the channel narrows to a grassed ditch bordered on both sides by private parking lots, approximately 35 feet apart. Kauhale Makai Condos are on the north and Luana-Kai Condos on the south of the channel (Figure 30).

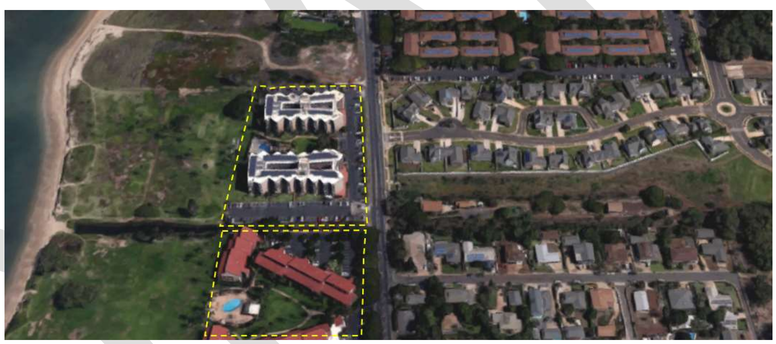

Figure 30. Waipuilani Aerial View of Kauhale Makai Condos (north/top) and Luana-Kai Condos (south/bottom)

The narrow channel then passes through Waipuilani Park, which is currently grassed with tennis courts, prior to discharging to the ocean (Figure 31). The flow at the ocean discharge point during the 100-year event is estimated to be approximately 8,089 cfs.

Figure 31. Waipuilani Aerial View of Waipuilani Park

In the near ocean environment off the shores of the discharge point is a historical fishpond, or loko iʻa (Figure 32).

Figure 32. Waipuilani Aerial View of Historic Fishpond (Loko iʻa)

7. Waipuilani District Proposed Improvements:

The following contains a description of the modifications necessary within the Waipuilani channel to convey the 100-year storm flows safely through. For each proposed improvement, we will describe recommendations moving mauka to makai, referring to the Zone Map with channel cross sections (Figure 33), and Proposed Conditions Map (Figure 34). The existing channel, bank, and water level elevations within each zone are listed in Table 3. There are six major zones in the Waipuilani Channel (Figure 33), with the majority of significant channel and infrastructure modifications required in zones 1 through 4.

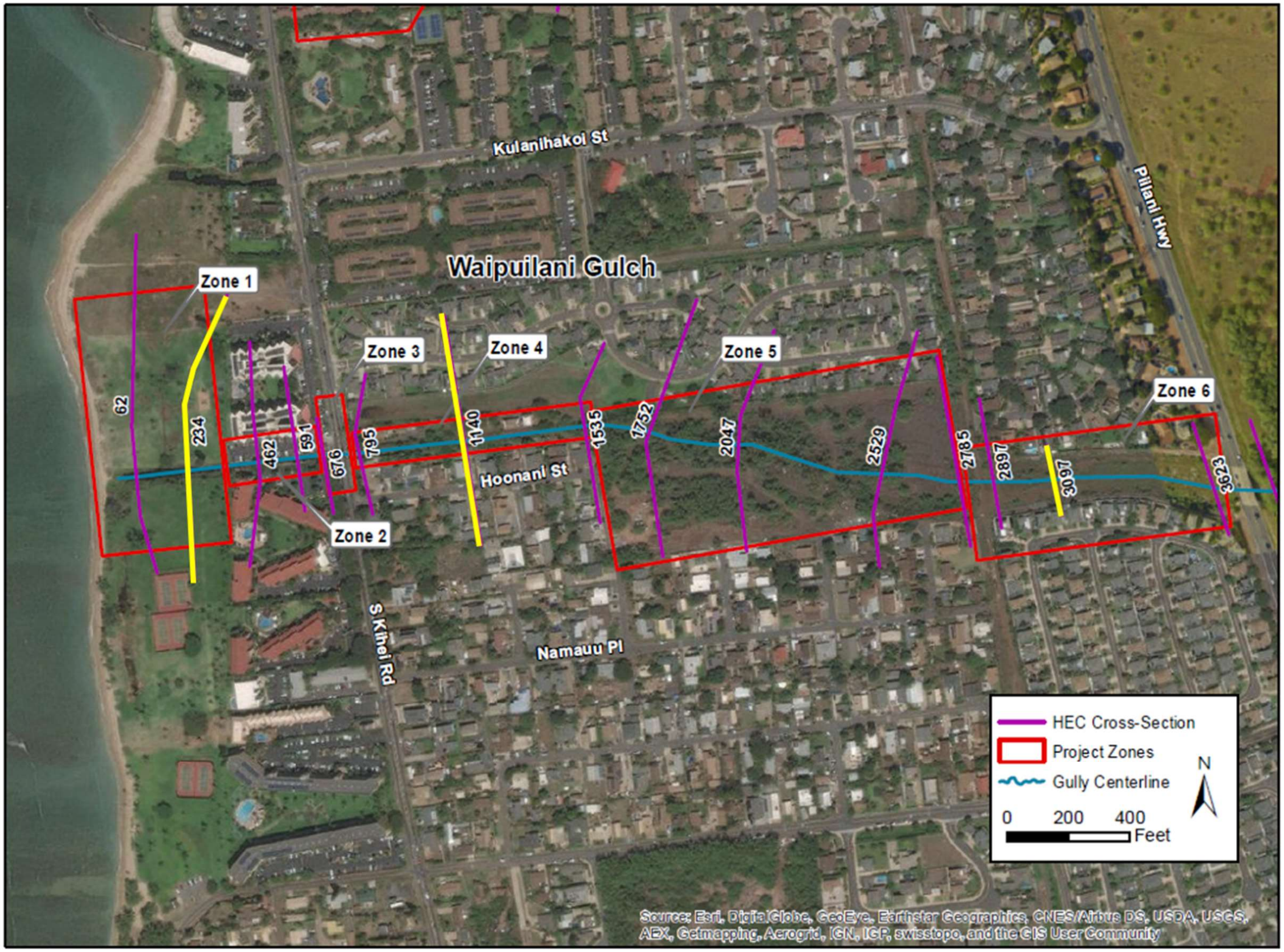

Figure 33. Waipuilani Zones Map with Numbered Cross Sections, Detailed Cross Sections Shown in Yellow

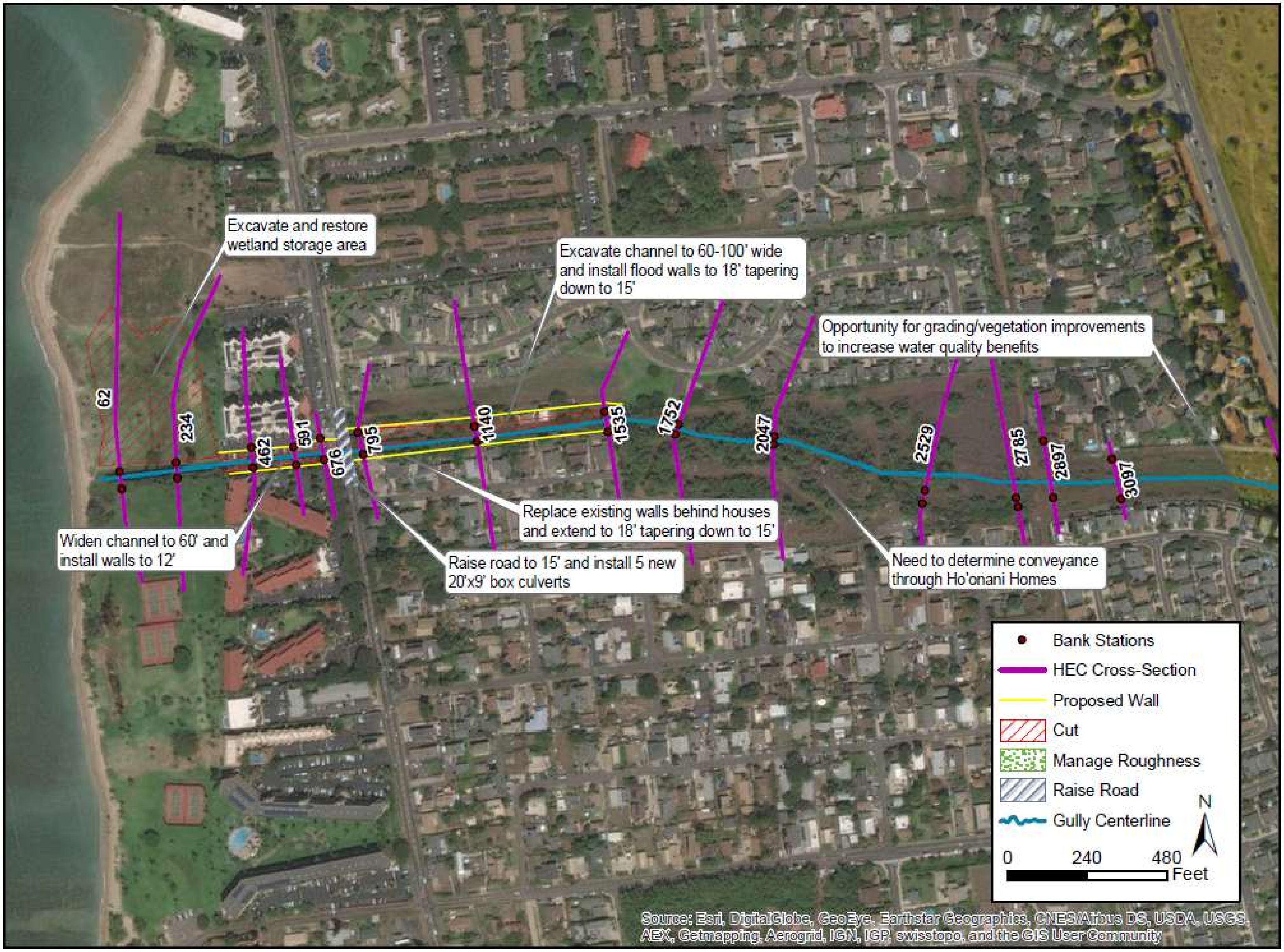

Figure 34. Waipuilani Proposed Conditions Map

On the makai side of the Waipuilani Bridge (Zone 6, Figure 33, there is adequate channel capacity as shown in cross section #3097 (Figure 34), with the existing top of bank at approximately 35 feet and the 100-year water level elevation at approximately 32 feet (Table 3).

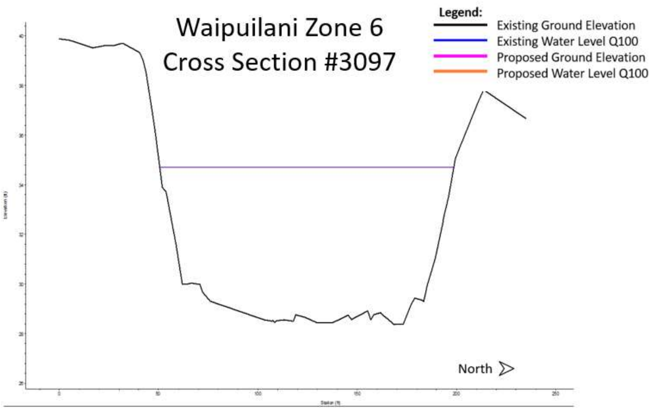

Figure 35. Waipuilani Channel Cross Section #3097 (left) and Key Map (right, showing cross section in yellow).

Table 3. Waipuilani Existing Elevations

Zone	Cross Section (#)	Channel Elevation (ft)	Existing Top of Bank (ft)	Q100 Elevation (ft)	Recommendation Summary
1	234	1.5	5	5.5	Lower north bank, cut terrace to direct flow to dune area
2		4	7.5	12.5	4 alternatives for culvert/bridge configurations
3		5	7.5	13	4 alternatives for channel configuration based on the Zone 2 culvert/bridge
4	1140	7.2	12	15	Remove structures and berm, create large channel 100ft wide and new berm north, wall south (15ft)
5		13	19	21	No proposed modifications
6	3097	27	35	32	Plantings and/or baffles to increase sediment/debris retention

There may be opportunities for grading and vegetative improvement to improve water quality in this area. However, this may not be necessary, depending on the feasibility of water quality treatment at the makai end of the channel, via engineered filtration within the dunes at Waipuilani Park, discussed further on.

At the Liloa Drive road extension (Figure 32), between zones 5 and 6, it is imperative that the culverts installed convey the appropriate flows or that there is an overflow system installed on either side (flumes/chutes) which would allow flood waters to pass through that area unimpeded. Further, conveyance through Ho'onani Homes proposed development project (Zone 5, Figure 32) will need to provide sufficient channel capacity for the 100-year flood.

As flows enter the narrow channel from Zones 4 to 1 (Figure 33), significant channel and surrounding infrastructure modifications are required to safely pass the 100-year storm safely through the area and mitigate current flooding. The main options assessed in this study are described below.

Mauka of the channel intersection with South Kihei Road, the channel needs to be widened up to 100 feet and would require the removal or raising of properties at 915 South Kihei Road (TMK (2) 3-9-034:027), valued at $773,100 (Figure 36).

Figure 36. Properties at 915 South Kihei Road (*TMK (2) 3-9-034:027*) (Approximate)

As shown in cross section #1140 (Figure 37), the property on the northern bank is at an elevation of approximately 9 feet and is protected by a berm at approximately 12 feet.

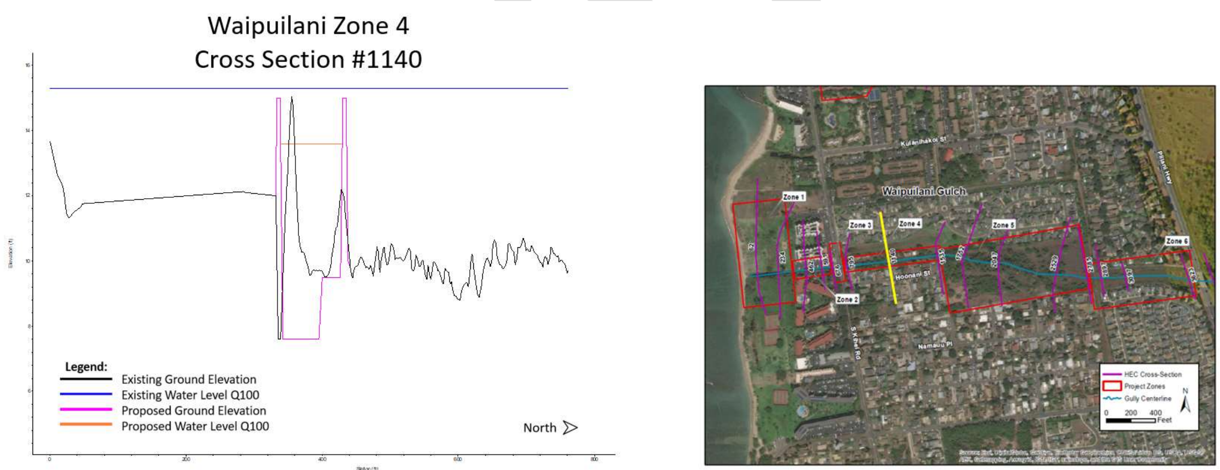

Figure 37. Waipuilani Channel Cross Section #1140 (left) and Key Map (right, showing cross section in yellow).

The houses along the south bank are at an elevation of approximately 12 feet and are protected by a berm with a variable elevation typically at 14-15 feet. The water level during the 100-year storm event is estimated to be over 14 feet at that location. To safely pass the flood flows through this area, flood walls will need to be installed on both the north and south bank (Figure 34). Those walls would need to extend to a minimum elevation of 18 feet (3-5 feet above adjacent grade), tapering down to an elevation of 15 feet to tie into the proposed bridge/culvert improvements at South Kihei Road, described in the next section. Existing conditions on the mauka side of South Kihei Road are shown in Figure 38.

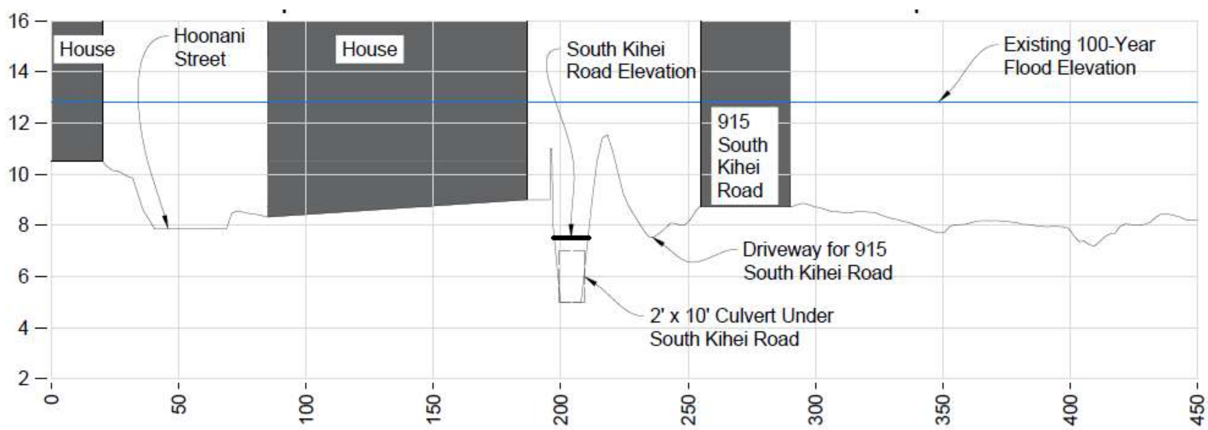

Figure 38. Waipuilani Channel Existing Conditions on Mauka Side of South Kihei Road (Profile Orientation: Left to Right is South to North).

At the Waipuilani channel intersection with South Kihei Road, extending makai through the two private parking lots on the north and south banks (Figure 39), there are several options to convey the 100-year storm flows.

Figure 39. Luana Kai Condominiums (South Bank) and Kauhale Makai Condominiums (North Bank)

The existing conditions makai of South Kihei road are shown in Figure 40.

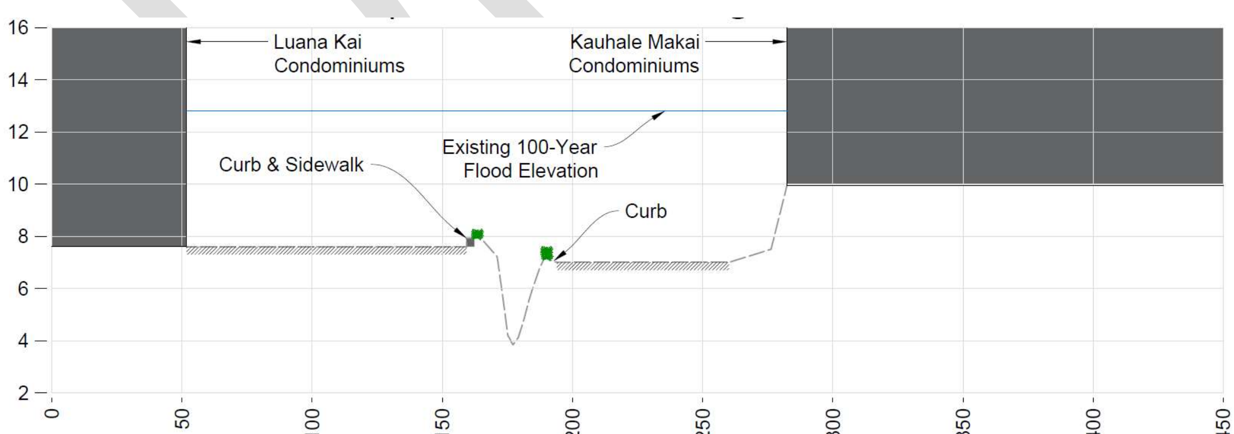

Figure 40. Waipuilani Channel Existing Conditions on Makai Side of South Kihei (Profile Orientation: Left to Right is South to North).

As previously mentioned, walls along the north and south banks of the channel, Mauka of South Kihei Road would need to connect to a wall along the proposed South Kihei Road bridge crossing. This would allow for ponding water to reach up to an elevation of 15 feet, which is necessary to provide sufficient hydraulic head to pass flows through the proposed structures.

A. Alternative Option 1 for Waipuilani Channel Intersection with South Kihei Road

Option 1 includes a 70' wide bridge with approximately 5 feet of clearance to the channel bottom (Figure 41). An 4-8 foot high floodwall extending to an elevation of 15 feet along the east side of the bridge, and to 12 feet on the west side are required to tie into proposed floodwalls makai and mauka of the bridge. The channel makai of the bridge would need to be widened to 70 feet. This option would require removing approximately half of the Kauhale Makai condo parking lot, on the north side adjacent to the channel. It may be feasible to shift some of the channel cut to the Luana Kai Condos parking lot without impacting parking spaces or emergency vehicle access. Flood walls would be installed on both the north and south banks along the parking lots. Concrete walls are recommended to maximize channel capacity within the restricted footprint.

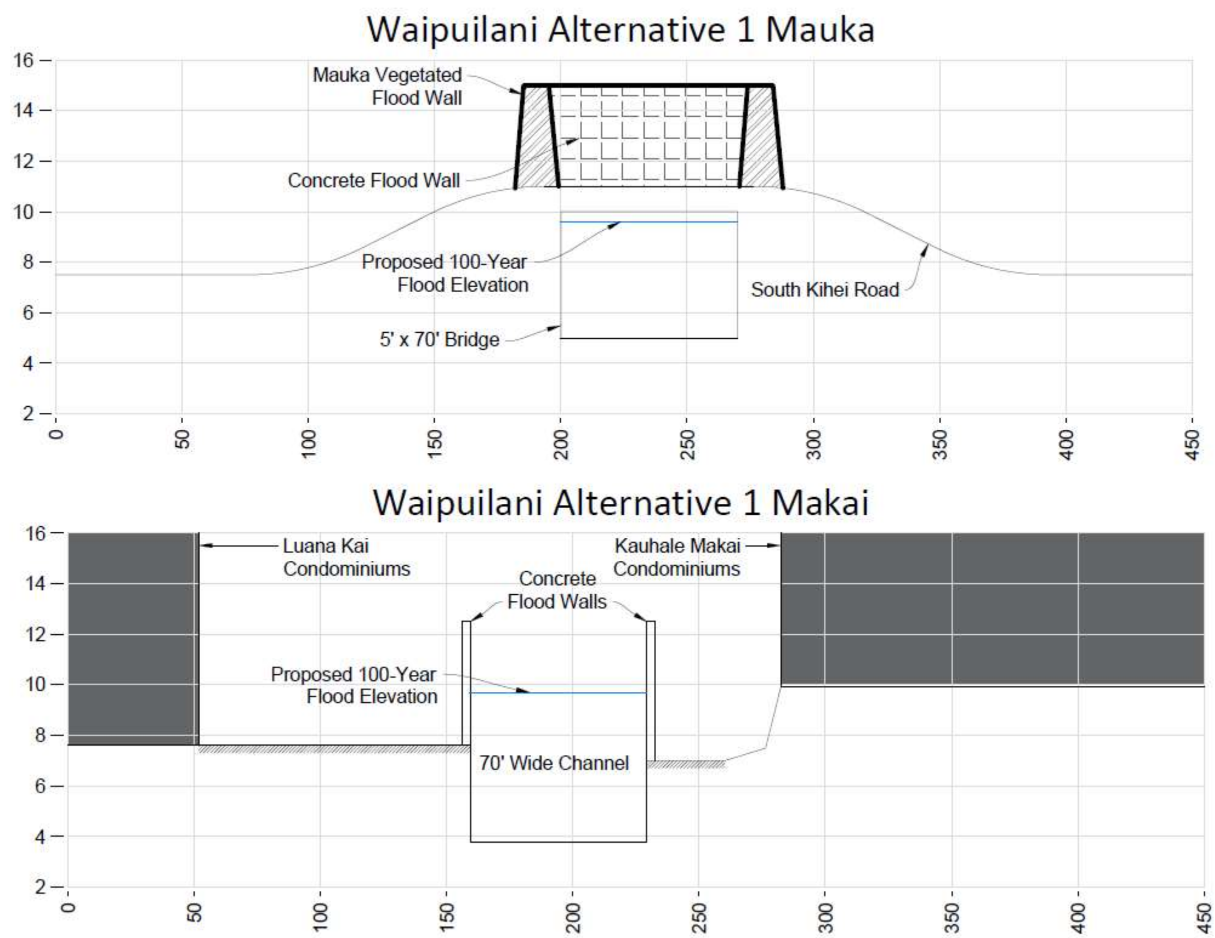

Figure 41. Waipuilani Channel Crossing at South Kihei Road, Proposed Alternative Option 1

B. Alternative Option 2 for Waipuilani Channel Intersection with South Kihei Road

This option includes a 50’ wide bridge with approximately 7 feet of clearance to the channel bottom and two box culverts (each 4’ by 20’) installed under the Kihei Bay Surf condos parking lot (Figure 42). A flood wall extending to 15 feet along the east side of the bridge, and to 12 feet on the west side are required to tie into proposed flood walls makai and mauka of the bridge. The channel makai of the bridge would need to be widened to 45 feet. This option would require the installation of two box culverts under the Kauhale Makai parking lot. This would involve excavation of the parking lot temporarily, with it ultimately being replaced after the culvert installation was complete. Flood walls would be installed on both the north and south banks along the parking lots. Concrete walls are recommended to maximize channel capacity within the restricted footprint.

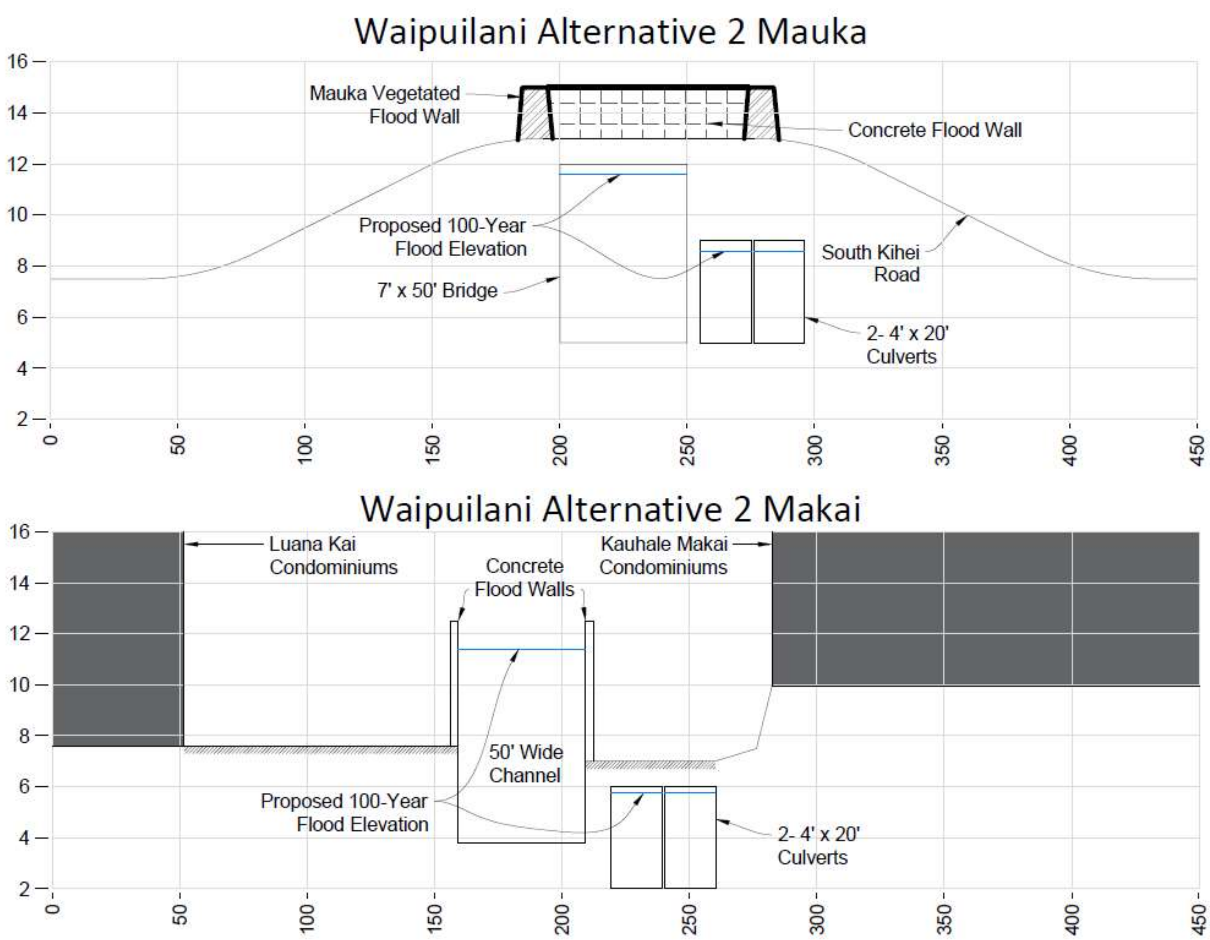

Figure 42. Waipuilani Channel Crossing at South Kihei Road, Proposed Alternative Option 2

C. Alternative Option 3 for Waipuilani Channel Intersection with South Kihei Road

This option involves the installation of a single 8-foot tall 40-foot wide box culvert following the channel from mauka of South Kihei Road to makai of the parking lots (approximately 400 feet long) (Figure 43). A flood wall extending to 15 feet would be required along the east side of South Kihei Road, no wall is required on the west side. The road would need to be raised 2-3 feet. Minimal alteration is required on both parking lots.

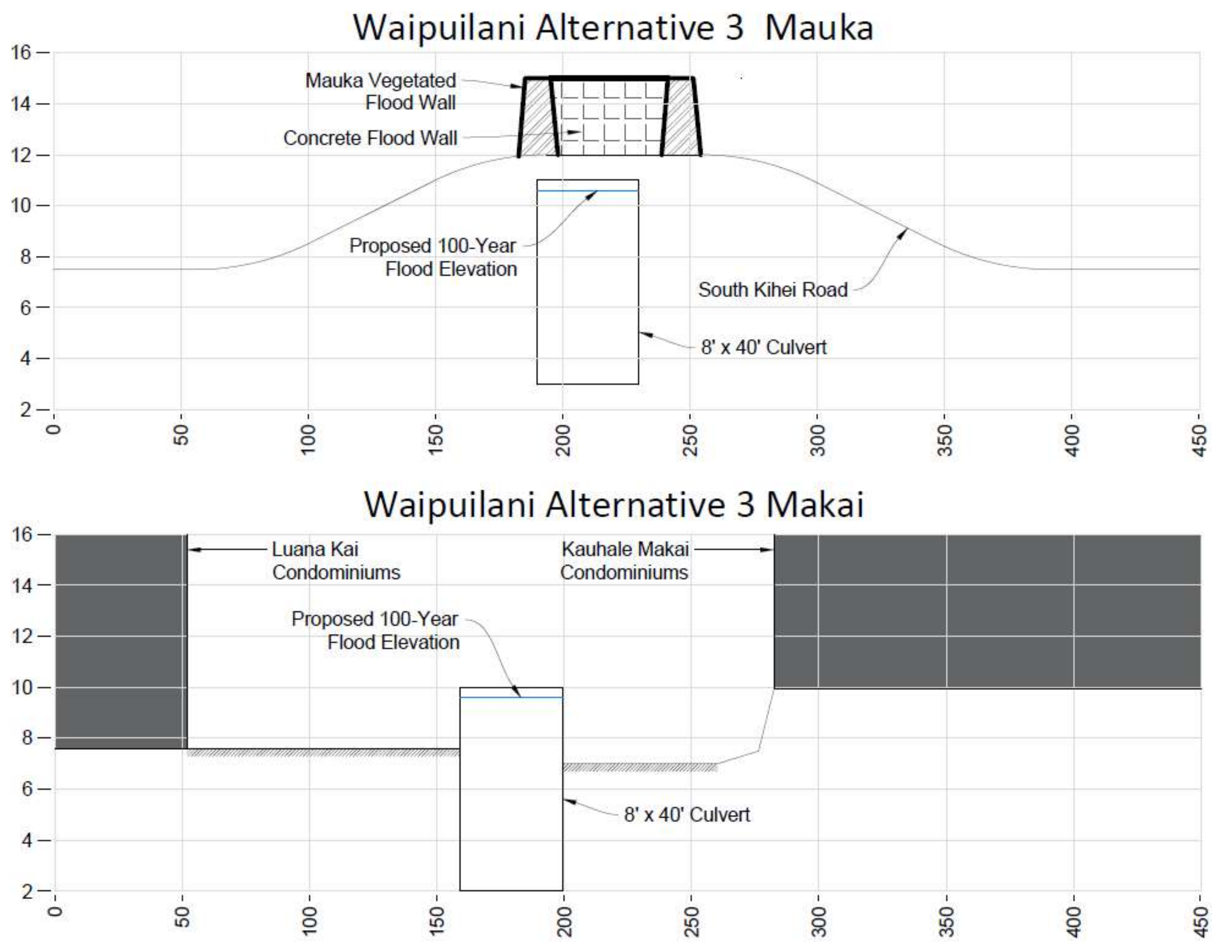

Figure 43. Waipuilani Channel Crossing at South Kihei Road, Proposed Alternative Option 3

D. Alternative Option 4 for Waipuilani Channel Intersection with South Kihei Road

This option involves the installation of a 6-foot tall 40-foot wide box culvert following the channel from mauka of South Kihei Road to makai of the parking lots (approximately 400 feet long) (Figure 44). A flood wall extending to 15 feet would be required along the east side of South Kihei Road, no wall is required on the west side. This option would also require the installation of two 4x20 foot box culverts under the Kauhale Makai condo parking lot. This would involve excavation of the parking lot temporarily, with it ultimately being replaced after the culvert installation was complete.

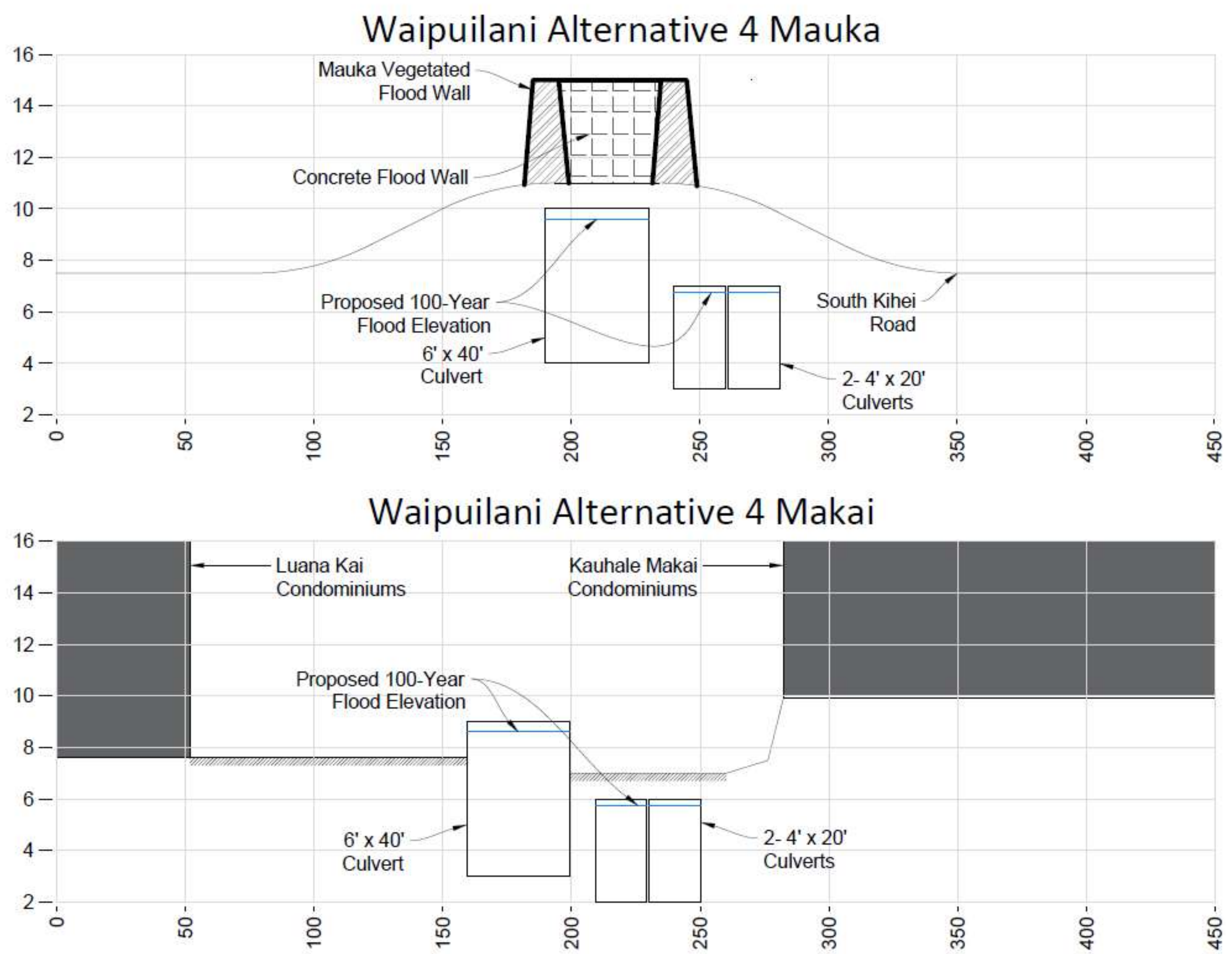

Figure 44. Waipuilani Channel Crossing at South Kihei Road, Proposed Alternative Option 4

E. Water Quality Improvement Options at Waipuilani Park

We recommend that any of the options selected to flood conveyance then hydrologically connect waters to the surrounding Waipuilani Park, for water quality improvement prior to discharging to the ocean. Excavation at the channel edge and within adjacent County owned area will allow channel water to flow into the park (Figure 45), which is classified by the Natural Resource Conservation Service as dune land. These dunes have the potential to provide significant filtration and ecological restoration.

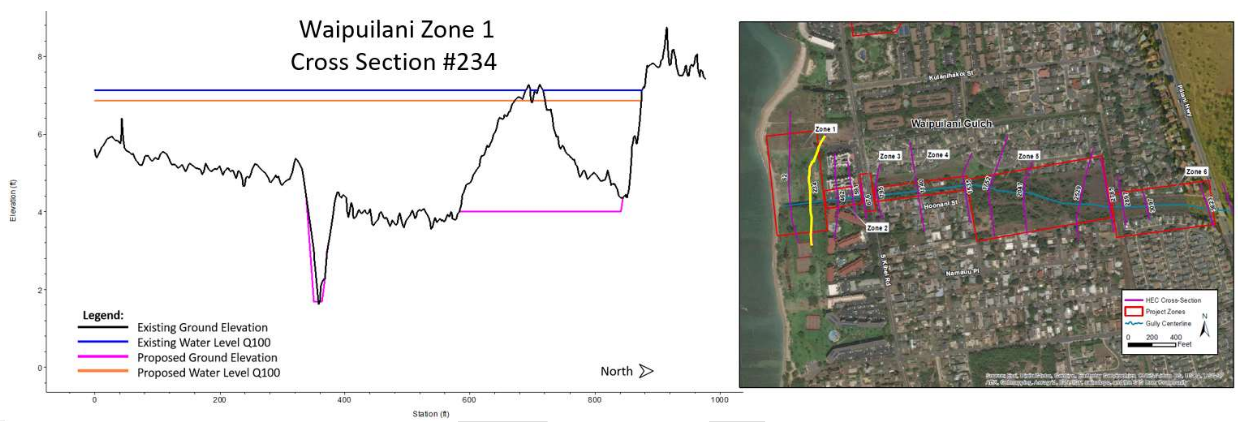

Figure 45. Waipuilani Channel Cross Section #234 (left) and Key Map (right, showing cross section in yellow).

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Areas on the north and south edge of the park would need to be bermed to approximate elevation of 6 feet, respectively, to contain the water during a storm event, without increasing flood risk to the Kauhale Makai or Luana Kai condos. These sandy soils will likely drain within 6-12 hours of a flood event; however, soil borings would need to be conducted prior to detailed design.

A micro-topography plan for the area could provide low and high points for both aesthetics and to increase ecological diversity. A boardwalk or trail along the high points could be incorporated and link back to the main trail system proposed, depending on the final design. The topography around the dunes must be such that the water remains within the restoration boundaries (impounded) but allow for high flows to return to the ocean to prevent flooding. This can be achieved through the creation of low outlet points on the makai side

The dunes will have an upstream sediment source as water from storm events flows into this area and settles. This will provide natural enrichment and fertilization to the plant communities that become established. Any open water areas can be designed to remain for a given amount of time, based on the planting needs and soil surveys once that level of detail is established. The dune impoundment berms or walls could be visually tied into the fishpond walls if this important historic feature is restored (Figure 46). Vegetation can be established through seeding and transplanting. Native dryland plants are listed in Table 4.

Figure 46. Waipuilani Aerial View, Historic Fish Pond Wall and Water Quality Dune Filtration Area Proposed Boundaries (Approximate)

Table 4. Hawaiian Native Plants Well Suited for Dry Conditions

Hawaiian Name	***Scientific Name***	**Growth**
Ihi	*Portulaca villosa*	Groundcover
Pā'ūohi'iaka	*Jacuemontia ovalifolia*	Vine
Pōhuehue	*Ipomea pes-caprae*	Vine
Kāwelu	*Eragrostis Variabilis*	Bunching Grass
'Āhinahina	*Artemisia mauiensis*	Low Shrub
'Ilima	*Sida fallax*	Low Shrub
Maiapilo	*Capparis sandwichiana*	Low Shrub
Naio papa	*Myoporun sandsicenses*	Low Shrub
'Ohai	*Sesbania Tomentosa*	Low Shrub
Pōhinahina	*Vitex rotundifolia*	Low Shrub
Beach Naupaka	*Scaevola taccada*	Shrub
Āweoweo	*Chenopodium oahuensis*	Shrub
Kulu'ī	*Nototrichium humile sandwcense*	Shrub
'A'ali'i	*Dodonaea viscosa*	Bush
'Akoko	*Chamaesyce celastroides*	Bush
Hinahina ewa	*Achyranthes splendens rotunda*	Bush
Pili	*Heteropogon contortus*	Tufted Grass

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Appendix A. Cost Estimate Kulanihakoi Watershed

Kulanihakoi Watershed					
Item	Qty	Unit	Unit Price	Total	Comments
9'x20'x40' Concrete Box Culvert	6	EA	$687,000.00	$4,122,000	Includes Labor, Materials and 25% Contingency
Presto Geoweb Green Wall (up to 6')	2,100	LF	$235.00	$493,500	Includes Labor, Materials and 25% Contingency
Concrete Retaining Wall (up to 4')	400	LF	$287.50	$115,000	Includes Labor, Materials and 25% Contingency
NAG Vmax C350 Channel Armor	500,000	SQ-FT	$1.50	$750,000	Includes Labor, Materials and 25% Contingency
Dune Stabilization	1	LS	$100,000.00	$100,000	Includes Labor, Materials and 25% Contingency
			Subtotal =	$5,580,500	
Demolition of Existing Culverts	300	LF	$200.00	$60,000	6 Culverts, Each 50 LF
Roadway Repair and Reconstruction	700	LF	$500.00	$350,000	Approach to and roadway across new culverts
Utility Reconstruction and Repair	1	LS	$300,000.00	$300,000	Assumed. No detailed estimate conducted
			Subtotal =	$710,000	
			25% Contingency =	$177,500.00	
			Total =	$887,500.00	
			Total Project Cost Opinion =	**$6,468,000.00**	

Appendix B. Cost Estimate Waipuilani Watershed Option 1

Waipuilani Watershed Option #1					
Item	Qty	Unit	Unit Price	Total	Comments
5'x70'x40' Concrete Box Culvert	1	EA	$4,062,025.00	$4,062,025	Includes Labor, Materials and 25% Contingency
Presto Geoweb Green Wall (up to 6')	1,000	LF	$235.00	$235,000	Includes Labor, Materials and 25% Contingency
Presto Geoweb Green Wall (6' to 10')	500	LF	$330.00	$165,000	Includes Labor, Materials and 25% Contingency
Concrete Retaining Wall (up to 4')	600	LF	$287.50	$172,500	Includes Labor, Materials and 25% Contingency
Concrete Retaining Wall (4' to 10')	100	LF	$375.00	$37,500	Includes Labor, Materials and 25% Contingency
NAG Vmax C350 Channel Armor	100,000	SQ-FT	$1.50	$150,000	Includes Labor, Materials and 25% Contingency
Wetland Storage Area	1	LS	$150,000.00	$150,000	Includes Labor, Materials and 25% Contingency
			Subtotal =	$4,972,025	
Demolition of Existing Culverts	100	LF	$200.00	$20,000	2 Culverts, Each 50 LF
Roadway Repair and Reconstruction	700	LF	$500.00	$350,000	Approach to and roadway across new culverts
Utility Reconstruction and Repair	1	LS	$300,000.00	$300,000	Assumed. No detailed estimate conducted
			Subtotal =	$670,000	
			25% Contingency =	$167,500.00	
			Total =	$837,500.00	
			Total Project Cost Opinion =	**$5,809,525.00**	

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Appendix C. Cost Estimate Waipuilani Watershed Option 2

Waipuilani Watershed Option #2					
Item	Qty	Unit	Unit Price	Total	Comments
8'x50'x40' Concrete Box Culvert	1	EA	$1,291,755.00	$1,291,755	Includes Labor, Materials and 25% Contingency
4'x20'x40' Concrete Box Culvert	2	EA	$874,206.25	$1,748,413	Includes Labor, Materials and 25% Contingency
Presto Geoweb Green Wall (up to 6')	1,000	LF	$235.00	$235,000	Includes Labor, Materials and 25% Contingency
Presto Geoweb Green Wall (6' to 10')	500	LF	$330.00	$165,000	Includes Labor, Materials and 25% Contingency
Concrete Retaining Wall (up to 4')	600	LF	$287.50	$172,500	Includes Labor, Materials and 25% Contingency
Concrete Retaining Wall (4' to 10')	100	LF	$375.00	$37,500	Includes Labor, Materials and 25% Contingency
NAG Vmax C350 Channel Armor	100,000	SQ-FT	$1.50	$150,000	Includes Labor, Materials and 25% Contingency
Wetland Storage Area	1	LS	$150,000.00	$150,000	Includes Labor, Materials and 25% Contingency
			Subtotal =	$3,950,168	
Demolition of Existing Culverts	100	LF	$200.00	$20,000	2 Culverts, Each 50 LF
Roadway Repair and Reconstruction	700	LF	$500.00	$350,000	Approach to and roadway across new culverts
Utility Reconstruction and Repair	1	LS	$300,000.00	$300,000	Assumed. No detailed estimate conducted
			Subtotal =	$670,000	
			25% Contingency =	$167,500.00	
			Total =	$837,500.00	
			Total Project Cost Opinion =	**$4,787,667.50**	

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Appendix D. Cost Estimate Waipuilani Watershed Option 3

Waipuilani Watershed Option #3					
Item	Qty	Unit	Unit Price	Total	Comments
8'x40'x400' Concrete Box Culvert	1	EA	$10,680,227.50	$10,680,228	Includes Labor, Materials and 25% Contingency
Presto Geoweb Green Wall (up to 6')	1,000	LF	$235.00	$235,000	Includes Labor, Materials and 25% Contingency
Presto Geoweb Green Wall (6' to 10')	500	LF	$330.00	$165,000	Includes Labor, Materials and 25% Contingency
Concrete Retaining Wall (up to 4')	0	LF	$287.50	$0	Includes Labor, Materials and 25% Contingency
Concrete Retaining Wall (4' to 10')	0	LF	$375.00	$0	Includes Labor, Materials and 25% Contingency
NAG Vmax C350 Channel Armor	75,000	SQ-FT	$1.50	$112,500	Includes Labor, Materials and 25% Contingency
Wetland Storage Area	1	LS	$150,000.00	$150,000	Includes Labor, Materials and 25% Contingency
			Subtotal =	$11,342,728	
Demolition of Existing Culverts	100	LF	$200.00	$20,000	2 Culverts, Each 50 LF
Roadway Repair and Reconstruction	700	LF	$500.00	$350,000	Approach to and roadway across new culverts
Utility Reconstruction and Repair	1	LS	$300,000.00	$300,000	Assumed. No detailed estimate conducted
			Subtotal =	$670,000	
			25% Contingency =	$167,500.00	
			Total =	$837,500.00	
			Total Project Cost Opinion =	**$12,180,227.50**	

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Appendix E. Cost Estimate Waipuilani Watershed Option 4

Waipuilani Watershed Option #4					
Item	Qty	Unit	Unit Price	Total	Comments
6'x40'x400' Concrete Box Culvert	1	EA	$8,844,682.50	$8,844,683	Includes Labor, Materials and 25% Contingency
Presto Geoweb Green Wall (up to 6')	1,000	LF	$235.00	$235,000	Includes Labor, Materials and 25% Contingency
Presto Geoweb Green Wall (6' to 10')	500	LF	$330.00	$165,000	Includes Labor, Materials and 25% Contingency
Concrete Retaining Wall (up to 4')	0	LF	$287.50	$0	Includes Labor, Materials and 25% Contingency
Concrete Retaining Wall (4' to 10')	0	LF	$375.00	$0	Includes Labor, Materials and 25% Contingency
NAG Vmax C350 Channel Armor	75,000	SQ-FT	$1.50	$112,500	Includes Labor, Materials and 25% Contingency
Wetland Storage Area	1	LS	$150,000.00	$150,000	Includes Labor, Materials and 25% Contingency
			Subtotal =	$9,507,183	
Demolition of Existing Culverts	100	LF	$200.00	$20,000	2 Culverts, Each 50 LF
Roadway Repair and Reconstruction	700	LF	$500.00	$350,000	Approach to and roadway across new culverts
Utility Reconstruction and Repair	1	LS	$300,000.00	$300,000	Assumed. No detailed estimate conducted
			Subtotal =	$670,000	
			25% Contingency =	$167,500.00	
			Total =	$837,500.00	
			Total Project Cost Opinion =	**$10,344,682.50**	

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Appendix F. Cost Estimates Dune Stabilization

Technique	Relative Costs				
	Design and Permitting	Construction	Expected Maintenance Frequency[1]	Average Annual Maintenance Costs[2]	Average Annual Mitigation Costs[3]
Artificial Dunes & Dune Nourishment	Low	Low	1-5 years	Low	None
Controlling Overland Runoff	Low	Low	5-20 years	Low	None
Planting Vegetation	Low	Low	1-3 years	Low	None
Bioengineering - Coir Rolls on Coastal Banks	Low-Medium	Medium-High	1-3 years	Low-Medium	Low
Bioengineering - Natural Fiber Blankets on Coastal Banks	Low	Low	1-3 years	Low	None
Sand Fencing	Low	Low	3-5 years	Low	None
Beach Nourishment	Medium	Low-Medium	5-10 years	Low	Low
Rock Revetments - Toe Protection	High	High	10-20 years	Low	Low- Medium
Rock Revetments - Full Height (up to predicted flood zone elevation)	Very High	Very High	20-25 years	Low	Medium
Seawall	High-Very High	Very High	25-40 years	Low	Medium-High

COST ESTIMATES *(average cost per linear foot of shoreline)*
Low: <$200
Medium: $200-500
High: >$500-1,000
Very High: >$1,000

[1]The frequency of required maintenance is highly dependent on storm severity and frequency and shoreline exposure. See StormSmart Properties fact sheets for details on maximizing longevity.
[2]Estimated, annual costs averaged over the life of the project to maintain project components, assuming the project is designed and installed properly.
[3]Estimated, annual costs averaged over the life of the project to compensate for the technique's adverse effects.

Appendix G. Outreach Log

Name	Organization/Affiliation	Method	Approximate date
Lucienne de Nae	Maui Tomorrow	In person	2/4/2019
Amy Hodges	Maui Nui Resource Council (MNRC)	Call; in-person	2/13/2019
Jennifer Vander Veur	Coral Reef Alliance,	In person	3/3/2019
Joylyn Paman	Director; \`Ao\`ao O Na Loko I\`a O Maui (Ko\`ie\`ie Fishpond)	Call	3/06/2019
Roderick Fong	General Partner, Waiohuli Parnters, Ho'onani Homes	Phone/Email	3/20/2019
Raymond Cabebe	Vice President, Land Planner Chris Hart & Partners	Email/Call	3/21/2019
Michael Reyes	Associate Director Central Maui Soil and Water Conservation District	Call; In person	4/4/2019
Tova Calender	Kihei resident & Watershed Coordinator West Maui Ridge to Reef Initiative	Call; In person	4/11/2019
Uncle Kimokeo Kapahulehua	\`Ao\`ao O Na Loko I\`a O Maui (Ko\`ie\`ie Fishpond)	In person	4/11/2019
Vernon Kalanikau	Kula Makai Aha Moku	In person	4/2019
Rob Weltman	Sierra Club	In person	5/4/2019
Kelly King	County Councilmember	Presentation	5/2019
Mike Moran	Kihei Community Association (KCA)	Presentation	5/2019
Uncle Vene	\`Ao\`ao O Na Loko I\`a O Maui (Ko\`ie\`ie Fishpond)	Call; in person	6/12/2019
Rowena Dagdag-Andaya	County Public Works Director	Presentation	6/2019

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