West Maui Watershed Study

West Maui, Hawaii

Draft Report
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Prepared for:

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APPENDIX 2

PROPOSED STRUCTURAL MEASURES AND CONCEPTUAL STRUCTURAL ALTERNATIVES

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EXECUTIVE SUMMARY

A management measure is a feature or activity that can be implemented to address one or more planning objectives (e.g. reduction of in-stream erosion). The Project Delivery Team (PDT)'s approach began by focusing on either 1) reducing flow using an upstream feature, 2) implementing a feature mid-stream, or 3) capturing sediment with a downstream feature. Some of these measures were *not recommended* to be carried forward as an alternative after an initial assessment of various criteria (e.g. technical feasibility, environmental impacts, cost of construction). The management measures considered to be feasible were explored in greater detail, before being sited and included in an conceptual plan. These measures include use of lo‘i terraces, construction of new micro basins, and modifying existing detention basins to retain water longer.

Lo‘i terraces are very effective at trapping sediment but are only able to treat a small amount of flow. By themselves, a few lo‘i would not likely have a significant impact on reducing the concentration of sediment in the main channel. Unlike other measures discussed here that target effectiveness against a small flood event, lo‘i terraces are more appropriate at treating daily flows that are typical of the river system (baseflow). Lo‘i are proposed at Honokowai and Honolua, where there was previously extensive use based on historical records. However, this measure would be more effective at Honolua where there is a greater likelihood of continuous flow and no existing mitigation feature to capture sediment.

Micro-basins are another management measure that was carried forward. They have a similar design concept to lo'i, without the consideration of the cultivation of taro. A typical micro-basin covering 1,000 ft^2 in area and depth of 5 ft has a trap efficiency of about 30% for fine sediments.

Modifications to existing detention basins at Kahana, Ka'opala, and Honokowai are also proposed. The first proposal is over-excavation at the Kahana Basin and installation of upstream embankments to regulate flow, as needed, by the dam operator to be able to effectively remove captured sediments from the basin. The second is to install stoplog panels over the open ports of the existing Honokowai riser structure. These would allow for controlled, top-down release of flow. Finally, a replication of the Napili 4-5 outlet modification is proposed to be implemented at the Ka'opala Basin also. These modifications result in increased trap efficiency of 65%, 30%, and 85% for Kahana, Honokowai, and Kaopala, respectively.

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LIST OF ACRONYMS & ABBREVIATIONS

CWRM	Commission on Water Resource Management
DAR	Division of Aquatic Resources
DLNR	Department of Land and Natural Resources
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling Software
LMSL	Local Mean Sea Level
NOAA	National Oceanic and Atmospheric Administration
RAS	River Analysis Software
State	State of Hawaii
USGS	U.S. Geological Survey

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1 Management Measures

This section describes the various management measures that were initially considered and evaluated during the development of conceptual alternatives. A management measure is a feature or activity that can be implemented to address one or more planning objectives (e.g. reduction of in-stream erosion). The Project Delivery Team (PDT)'s approach began by focusing on either 1) reducing flow using an upstream feature, 2) implementing a feature mid-stream, or 3) capturing sediment with a downstream feature. Some of these measures were *not recommended* to be carried forward as an alternative after an initial assessment of various criteria (e.g. technical feasibility, environmental impacts, cost of construction).

1.1 Upstream Alterations to the Flow Regime

This approach was based on altering the flow regime (reducing the flow rate or volume) with an upstream feature to the point that either shear stresses are below the erosion threshold or the depth of water remaining in the channel remains relatively low. However, there is still likely to be some residual bed and bank erosion as even during smaller frequency events (e.g. the 50% AEP flood event), the shear stress along the channel is higher than the critical shear stress required to initiate bank erosion (0.865 Pa).

1.1.1 Upstream Detention Basin / Dam

Not Recommended

This measure features an upstream structure intended to maintain low flow conditions in the channel and thereby minimizing the likelihood of in-stream erosion. Such a feature would likely need to be substantial, triggering the requirement to meet USACE and State of Hawaii dam safety criteria. It would also be challenged by high construction costs, cultural and environmental issues, limited accessibility, and increased requirements for operation and maintenance post-construction. It was not previously presented to the public but is not likely to be well-received by community members who actively promote limited development in the watershed and maintaining flow from *mauka* to *makai* (from the mountains to the ocean).

1.1.2 **Utilization of Existing Irrigation Pipe System**

Not Recommended

This measure focuses on modifying the existing irrigation system (Photo 1-1, Figure 1-1) to route a majority of the flow across multiple watersheds into a single stream during large storm events. The selected stream where all flows are routed to will either include a downstream sediment basin to capture the sediment or be shown through coastal modeling to have minimal impact to the reef based on its location along the shoreline. The challenges with this measure include uncertainty in the existing infrastructure conditions, limited accessibility for rehabilitation, high cost of construction, and potential environmental impacts from altering the flow and sediment regime significantly. This measure also focuses on reducing sediment contributions to the ocean during large storm events (e.g. the 1% [1/100] AEP event) rather than smaller, more frequent flows. Flow diversion has a controversial history in West Maui and this measure was not received well at the August 2018 Public Meeting when initially proposed.

Photo 1-1: Existing Irrigation Pipe in Wahikuli, West Maui

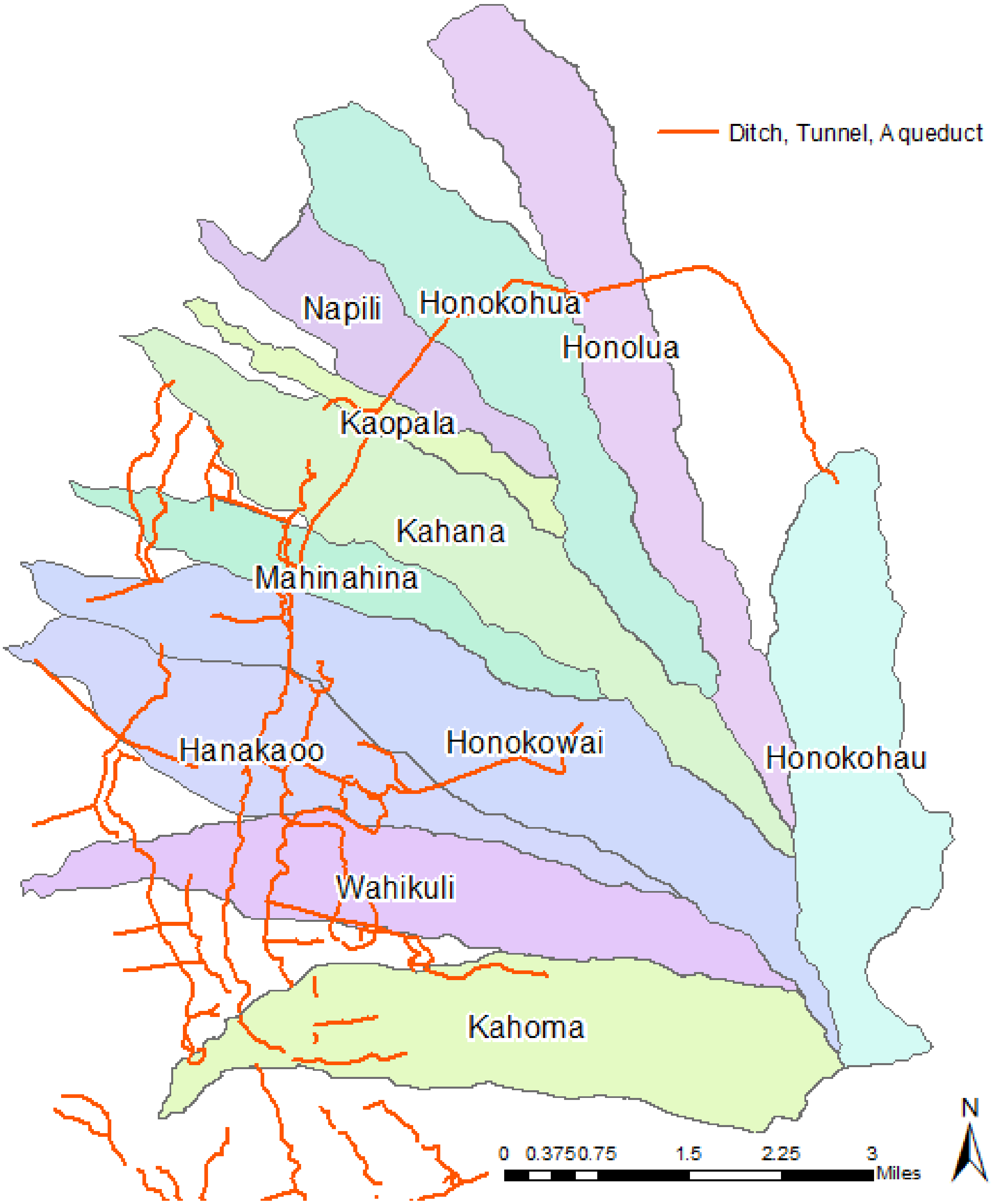


Figure 1-1: Ditches, Tunnels, and Aqueduct Systems in West Maui

1.2 Mid-Stream Structural Measures

These measures address sediment directly at the source or by implementing a measure mid-stream.

1.2.1 Manual Removal by Excavation or Dredging

Not Recommended

This measure focuses on manually removing the highly erodible, fine sediment deposits (*historic fill terraces*) directly from the source. From the 2019 SIR by USGS, "valleys adjacent to or downstream of agricultural fields have sandy silt draped over prehistoric, coarser-grained deposits. These fine-grained deposits form historic fill terraces that are the stream banks along much of the lower channel" (p. 5). Removal would be accomplished by either manually shoveling material out of the banks (excavation) or by using a vacuum (dry land dredging). The effort would be technically challenging, extensive (approximately 154 miles of total impacted stream length estimated by USGS), costly, and time-consuming. Furthermore, while this measure reduces the amount of fine-grained sediment transported to the ocean, there would still be some residual risk of erosion and sediment transport left unaddressed.

1.2.2 Loʻi Terraces

Feasible

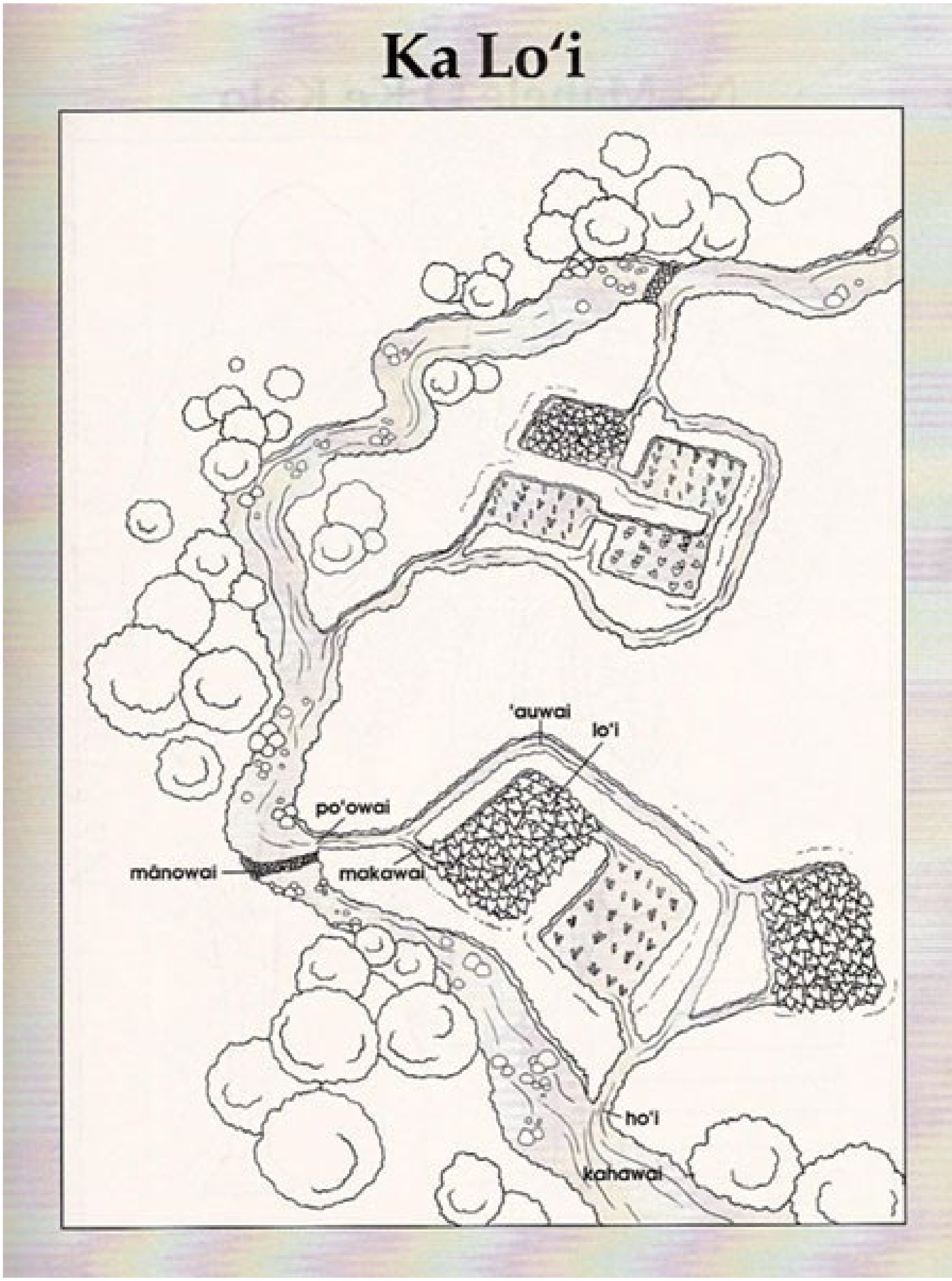
Taro patches (*loʻi*) once filled every valley in Hawaii, but an influx of foreigners in the 19th century brought new crops and opportunities for trade. Several loʻi were converted to rice paddies or left dry as the streams that fed them were siphoned off to nourish pineapple and sugar cane fields (Mishan, 2019). Although taro is no longer the main staple food in Hawaii, the growing and cultivation of taro is still an integral part of the Hawaiian culture. The "Hawaiian Renaissance" in the 1970s renewed interest in Hawaiian culture and taro patch restoration. The decline of the pineapple and sugar industries (and the need to siphon water from streams), along with strong community activism to maintain minimum flows in each river, has restored the opportunity to return taro to former ancestral fields. There is strong community support to restore loʻi terraces at former sites in Honokowai and Honolua, with an opportunity to also use it to capture sediment from daily low flow conditions. It is not likely to be sustainable or effective against higher frequency events, such as the 50% AEP.

This measure focuses only on the cultivation of flooded taro, which requires continuous flow of water and heavy soil capable of impounding water without much loss through percolation. Dry-land taro is essentially rain-fed, supplemented by irrigation, and is not intended to be flooded or to impound water.

Traditionally, a loose wall of rocks (*manowai*) slows down waters in the main channel (*kahawai*) and creates enough headwater (*po'owai*) that some flow is diverted into a rock-lined canal (*'auwai*). From this canal, water flows into each lo'i at its upper corner and out into the next patch from its lower corner, eventually returning to the main channel (Figure 1-2). The water level in each lo'i is controlled at openings in the bank (*makawai*) to keep the base of the plant submerged and maintain continuous flow.

Although primarily intended for agricultural purposes, lo'i have the added benefit of also reducing sediment in the main channel. This measure proposes either lo'i restoration at historical sites or new lo'i strategically placed within the study area. The Honokowai and Honolua watersheds have known sites of former lo'i and community support for implementation. As documented in their 2019 Instream Flow Standard Assessment Report for Honokowai and Honolua, the State of Hawaii's Commission on Water Resource Management (CWRM) conducted a cursory assessment to identify tax map key (TMK) parcels with their associated Land Commission Awards that were likely former lo'i sites. Of particular importance was the presence of terracing and oral testimony that indicated lo'i existed in the middle reaches of Honolua (above and below the current stream diversions) and the middle reaches of Honokowai (approximately 2.35 miles below the current stream diversions).

In 2012, a 7-months long field study by Koshiba et al. demonstrated cultivated taro fields in Palau to trap an average of 90% of the sediment entering into the field. The high sediment trapping efficiency was determined to be the result of water flow management (slowing down flow with vegetation) and water depth management (water entering the fields were maintained at relatively shallow depths – 10 to 50 cm by field observation – as they spread out across the entire width of the field), which allowed fine sediment to fall out of suspension more easily. Effects to the main channel regarding reduced sediment loads were not quantified by this study.



Source: Gregory, 2014

Figure 1-2: Typical Taro Patch System

In 2007, the USGS completed a study to evaluate current water use for commercial wetland taro cultivation in Hawaii. As part of this study, flow and water temperature measurements were collected from individual taro patches (lo‘i) and groups of lo‘i (lo‘i complexes) on four islands – Kauai, Oahu, Maui, and Hawaii (Gingerich, Yeung, Ibarra, & Engott, 2007). A summary of water use calculated for lo‘i and lo‘i complexes under this study is provided in Table 1-1:

Table 1-1: Summary of water use calculated for lo‘i and lo‘i complexes

[gad, gallons per acre day; na, not available]

Island	Lo‘i Complex				Individual Lo‘i			
	Number	Average water use (gad)	Average windward water use (gad)	Average leeward water use (gad)	Number	Average water use (gad)	Average windward water use (gad)	Average leeward water use (gad)
Kauai	6	120,000	97,000	260,000	2	220,000	220,000	na
Oahu	5	310,000	380,000	44,000	4	400,000	460,000	210,000
Maui	6	230,000	230,000	na	na	na	na	na
Hawaii	2	710,000	710,000	na	na	na	na	na
Average		260,000	270,000	150,000		350,000	370,000	210,000
Median		150,000	150,000	150,000		270,000	320,000	210,000

From Table 1-1, the median average water use for a lo‘i complex is 150,000 gallons per acre day (a typical lo‘i is about a fifth of an acre; a lo‘i complex includes several lo‘i). Converting this to flow units, water use is only 0.232 cubic feet per second (ft^3/s) per acre.

From the 2019 Instream Flow Standard Assessment Report on Honokowai by CWRM, the reach segment below the Honokowai diversions (where historical lo‘i were previously sited) the stream is dry for more than 50% of the year. While some flow is diverted to the Kaanapali Coffee Farm and to meet the landscaping demands for the agricultural subdivision (approximately 9 mgd), some flow is also lost through seepage (approximately 1.1 mgd). For this reason, Honokowai is only recommended as a potential site for this management measure if minimum flow standards are established by the State and continuous flow is maintained from *mauka* to *makai*.

At Honolua, surface water may be used for small diversified agriculture and landscape irrigation, but no commercial agriculture is practiced. Honolua Stream and its tributary in Papua Gulch are flowing in the upper watershed but have discontinuous flows below the Honokohau Ditch to the ocean, with most reaches losing surface water due to seepage (approximately 1.3 mgd). While the Honokohau Ditch was originally designed to remove water from the Honolua Stream to supply irrigation water for sugarcane land, the diversion has been inactive since 2003 (CWRM). It was estimated by CWRM that there was continuous stream flow from *mauka* to *makai* about 83% of the time with a mean flow of 7.6 mgd. Differences in discharges between historic and current periods are due to differences in climate from differing years of record. Honolua still has potential for this management measure to be implemented. Its impact in reducing the amount of sediment transported to the ocean, however, would be limited to addressing sediment carried by the base flow (persistent low flow in the stream) rather than the larger, flood-induced flows. Analysis of the effectiveness of this management measure by the Churchill method indicates that it is able to remove approximately 90% of fine silt and clay, but only from a small fraction of the total hydrograph: 0.3 – 0.6 ft^3/s of flow from Honolua and Honokowai, respectively. Typical design assumptions are summarized in Table 1-2. As presented in the Hydrology and Hydraulics Appendix, the 50% AEP (2-yr) peak flow for Honolua and Honokowai are 227 and 646 ft^3/s, respectively.

One of the implementation challenges with this measure is that building a lo‘i for flooded taro is labor intensive and requires constant maintenance and care. This measure also relies strongly upon community support in actively maintaining the lo‘i once they are constructed.

Table 1-2: Lo'i Design Parameters and Assumptions

	Honokowai	Honolua
Approx. Number of Lo'i	10	5
Surface Area (ac)	2	1
Surface Area (ft^2)	87,120	43,560
Water Depth (ft)	1.25	1.25
Capacity, C (ft^3)	108,900	54,450
Daily Inflow Rate, I (ft^3/s)	0.6	0.3
Mean velocity (ft/s)	0.0008	0.001
Time of Retention, R (s)	181,500	181,500
Time of Retention, R (hr)	50.4	50.4
Sediment Index, SI (s^2/ft)	157,837,184	157,837,184
Percent of Fines Passing (%)	7.7	6.3
Trap Efficiency (%)	92.3	93.7

1.3 Downstream Structural Measures to Capture Sediment

This approach focuses on capturing sediment with a downstream measure before it is transported to the ocean. It allows in-stream erosion to continue as it would through natural processes before being trapped by the measure downstream. These measures would likely require occasional maintenance and periodic removal of the captured sediment.

1.3.1 **Retrofit / Redesign Existing Basins**

This measure proposes modifying existing detention basins to improve their effectiveness in capturing sediment. A brief description of the largest existing basins in the study area are provided in the Hydrology and Hydraulics Appendix. There are three existing basins worth evaluating under this study for a potential modification: Ka'opala Gulch Basin, Kahana Basin, and Honokowai Basin. Mahinahina Basin and the modified Napili 4-5 Basin are two examples of effective, existing desilting basins within the study area.

The primary deficiency with the Ka'opala, Kahana, and Honokowai basins is the inability to control the pool elevation and sediment retention time. The open outlet pipe at Ka'opala allows sediment-laden waters at the bottom of the reservoir pool to be released downstream immediately.

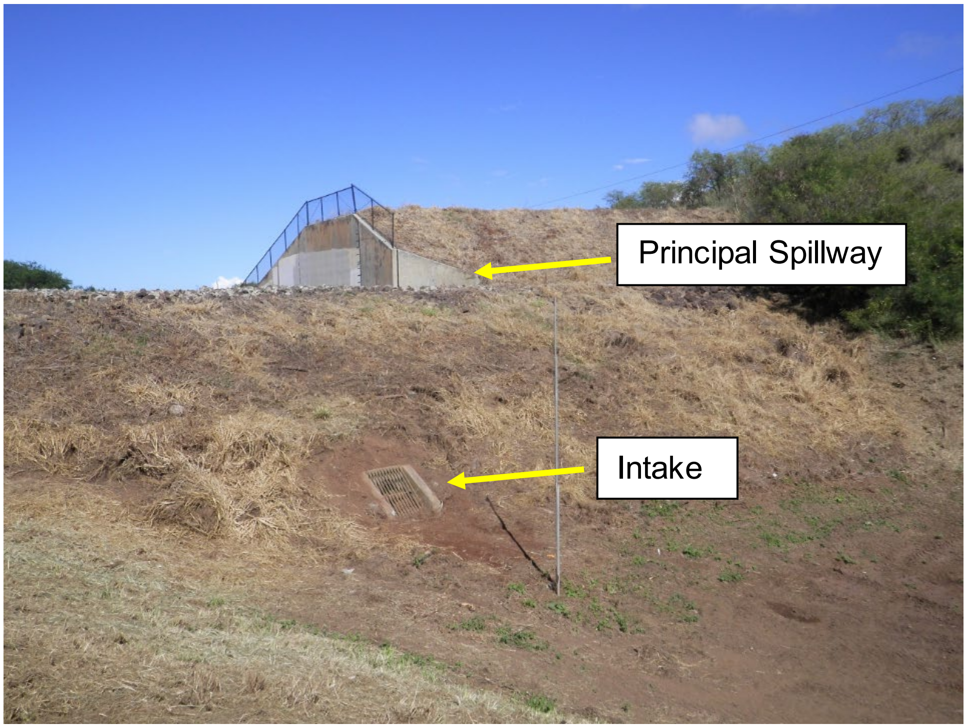


Photo 1-2: Principal Spillway and Intake, Kaopala Dam

Source: State Dam Inventory System, State of Hawaii

Similarly, the open ports on the Honokowai riser structure also allow sediment-laden water to be released immediately. The intake for the Kahana basin was recently uncovered. The modified intake, which was intended to have a sluice gate that opened and closed automatically, was left in the "open" position due to inoperability. Previously, the buried intake prevented the basin from properly draining. While this did significantly increase the retention time for smaller floods, the nonfederal sponsor could not effectively remove these sediments from the basin as it was nearly always saturated. Larger storms likely reactivated these particles, carrying them over the riser structure and downstream.

Photo 1-3: Open ports at the riser structure, Honokowai Dam (2017)

Photo 1-4: Riser structure and saturated conditiosn, Kahana Dam (2017)

Providing dam owners and operators with a means to control the release of water downstream would significantly reduce the amount of sediment transported downstream also. However, controlled release of water comes with the risk of not maintaining flow continuity in the river system and may increase flood risk downstream.

Two examples of an effective detention basin regarding sediment retention are Mahinahina Basin and Napili 4-5 Basin. Mahinahina Basin has a small outlet pipe like Kahana Basin (Photo 1-5). However, it was designed to include a butterfly closure valve and is located halfway up the embankment rather than near the embankment toe. The concentration of sediment at this elevation is less than it would be if the outlet pipe were located at the reservoir bottom.

Photo 1-5: Intake for the outlet pipe, Mahinahina Dam

At Napili 4-5, the outlet modification installed on the embankment provides the dam operator with controlled release of flow from the top-down (Photo 1-6; Figure 1-3). The modification consists of a series of sluice gate panels that are manually opened by the dam operator to allow flow to enter the original, underground outlet pipe.

Photo 1-6: Outlet Modification at Napili 4-5 (2017)

The following sections include proposed modifications for the ineffective basins that are based on these observations and design concepts.

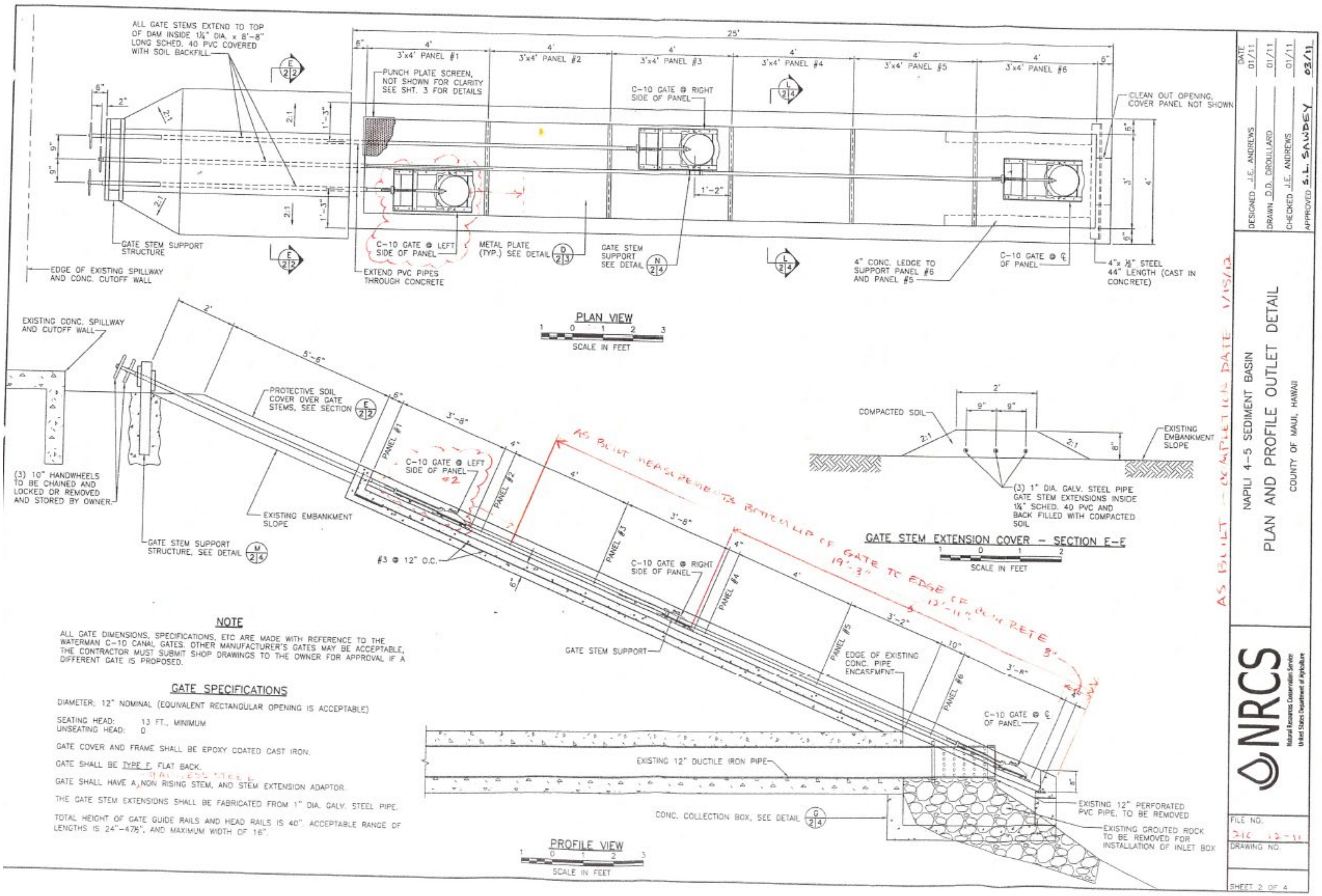


Figure 1-3: Napili 4-5 Outlet Modification Detail

1.3.1.1 Excavate Kahana Basin

In lieu of raising the existing outlet pipe at Kahana Basin, the reservoir bottom can be lowered by over-excavation to achieve a similar function. Runoff volume captured in the excavated area would have a 100% trap efficiency when the runoff volume is less than the excavated volume. However, the amount of excavation required to accommodate the volume produced by the typical plume-triggering event (0.50 AEP flood) would be approximately 89.2 ac-ft. Assuming an approximate basin surface area of 2.00 ac, the additional depth required is about 20 ft. Based on an annual sediment load of 285 metric tons and bulk density of 1,300 kg/m^3, it would take approximately 225 years to fill with captured sediment (excluding extreme events). This also assumes the inoperable outlet works is restored and able to be “closed” by the dam operator. Extreme care would have to be taken to preserve the stability of the existing dam and concrete riser structure.

This modification, however, would likely cause the reservoir to be continuously ponded or saturated. The nonfederal sponsor responsible for maintenance has expressed frustration with continuously saturated conditions as it inhibits their ability to perform maintenance (i.e. excavate captured fine sediments before they are re-activated by a larger storm event). To address this, this measure can be paired with the measure proposed in Section 1.3.1.2 to provide the dam operator with some ability to control flows entering the basin.

1.3.1.2 Flow Regulation Embankments Upstream of Kahana Basin

Two additional embankments are proposed upstream of Kahana Basin to provide the dam operator with some control overflows entering the basin (Figure 1-4). The nonfederal sponsor responsible for maintenance of the dam is unable to effectively remove captured sediments from the basin due to continuously saturated conditions.

Each earthen embankment would have a large 96-inch diameter culvert and sluice gate control structure. Generally, these culverts would be left open until the dam operator wishes to remove captured sediments from the main basin and requires conditions in the main basin to be dry (unsaturated).

While the embankments can be sized within the limitations of being considered "low hazard" by general dam safety standards – less than 25 ft in height, less than 50 ac-ft in storage capacity, and no probable loss of human life as a result of a breach – the State of Hawaii may still consider the two newly constructed basins as part of the larger, regulated Kahana Basin if they are sited too close to each other or are connected by an uncontrolled conduit. General dimensions and characteristics are provided in Table 1-3.

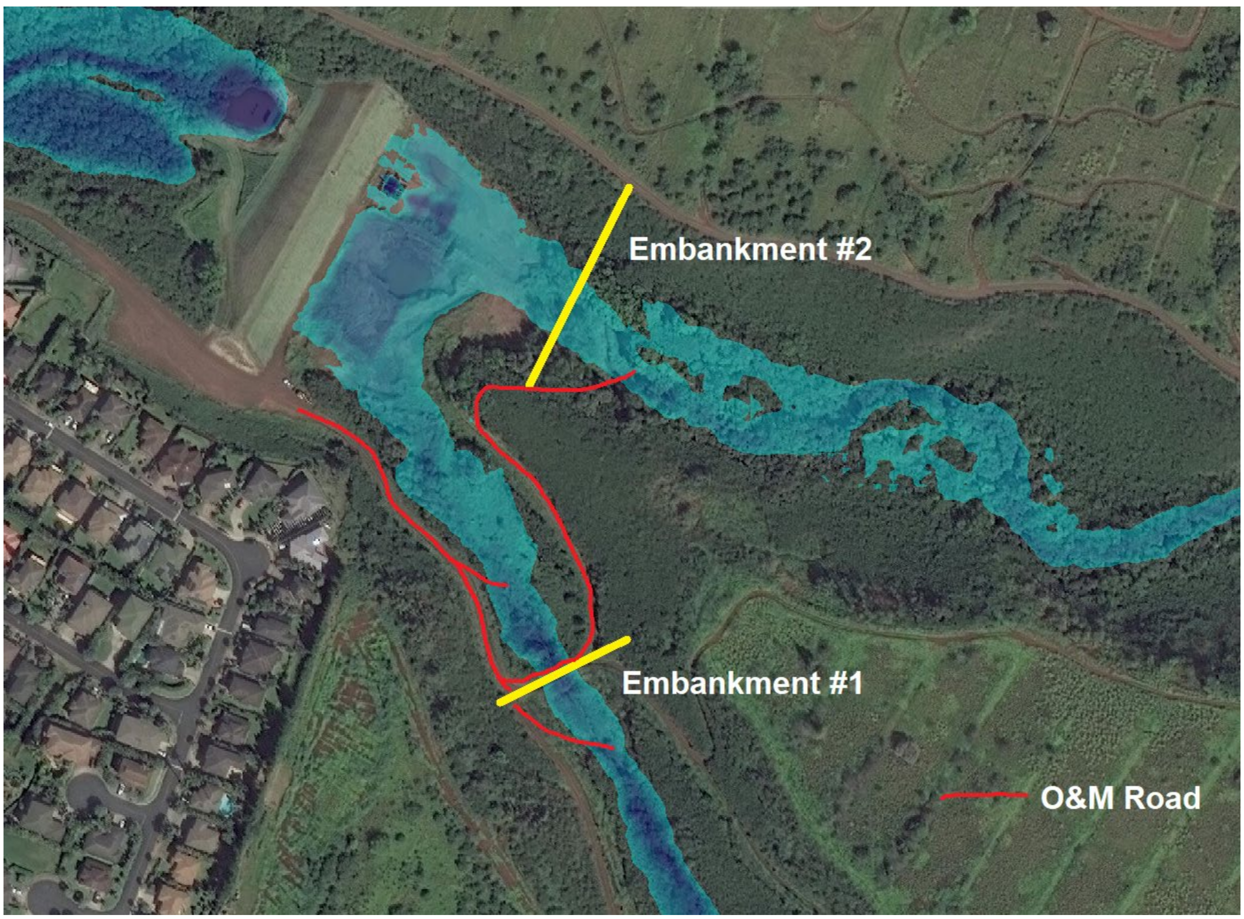


Figure 1-4: Proposed Embankments upstream of Kahana Basin

Table 1-3: Kahana Basin Embankments

	Embankment #1	Embankment #2
Embankment Height	15 ft	15 ft
US Slope	3H:1V	3H:1V
US Cover	Grass	Grass
DS Slope	3H:1V	3H:1V
DS Cover	Grass	Grass

1.3.1.3 Honokowai Riser Structure with StopLog Panels

The existing Honokowai concrete riser could be modified to allow for controlled release of flow from the top-down via stoplog panels (Figure 1-5). These panels could be installed over the existing, open ports. The modification would include eight panels, 4 ft wide by 3 ft high. An elevated work platform would also be necessary to provide operation and maintenance personnel access to the control structure during flooded conditions. As the Honokowai Dam is a regulated dam, any modification would require further evaluation to verify there is no increased flood risk downstream.

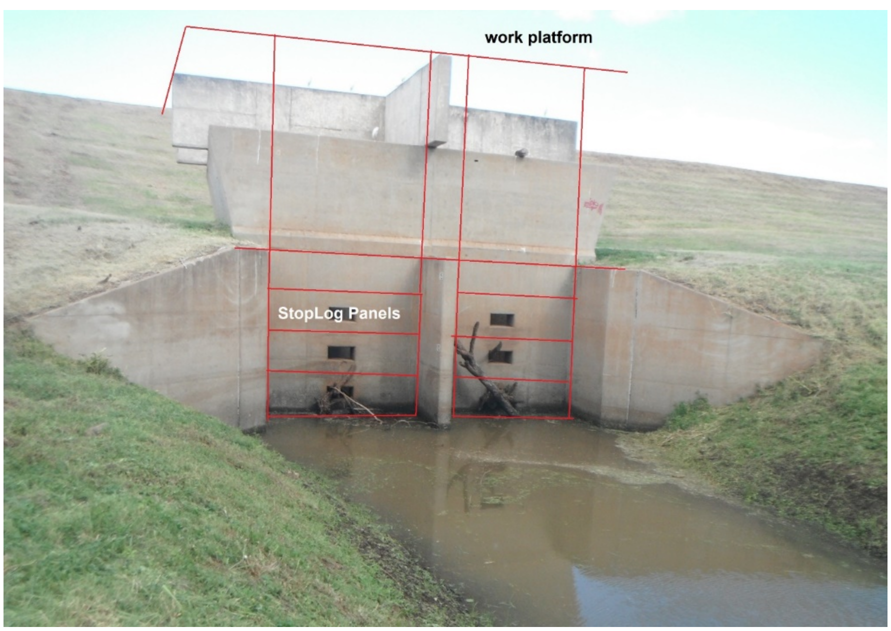


Figure 1-5: StopLog Panels and Work Platform at Honokowai Riser

As introduced in the Hydrology and Hydraulics Appendix, the trap efficiency of a basin to retain sediment during a specific type of flood event (e.g .the 0.50 AEP flood) can be estimated using Camp's [1946] settling velocity equations, which are as follows:

$$TE = \frac{vA}{Q}$$

where TE = trap efficiency

V = settling velocity (ft/s)

A = wetted surface area (ft^2)

Q = discharge rate (ft^3/s)

The settling velocities for the various types of soil separates were also previously computed and are presented in Table 1-4.

Table 1-4: Typical Settling Velocities Based on Soil Type

Name of soil separate	Diameter limits (mm)	Equation	Settling velocity, V_s (m/s)	Settling velocity, V_s (ft/s)
Clay	< 0.002	Stoke's Law	8.99E-07	2.95E-06
Silt	0.002 – 0.05	Stoke's Law	6.07E-04	0.002
Very fine sand	0.05 – 0.10	Stoke's Law	5.05E-03	0.017
Fine sand	0.10 – 0.25	Stoke's Law	2.75E-02	0.090
Medium sand	0.25 – 0.50	Ferguson and Church	0.203	0.666
Coarse sand	0.50 – 1.00	Ferguson and Church	0.812	2.66
Very coarse sand	1.00 – 2.00	Ferguson and Church	3.25	10.7

Construction of the stoplog panels would slightly increase the surface area of the reservoir, but most importantly reduce the rate of flow leaving the reservoir. Increased retention time allows for increased settlement and a greater trap efficiency. The original rate of discharge (flow passing through the open ports of the riser structure) during the 0.50 AEP (2-year) flood event is about 215 ft^3/s. This was based on computed outputs in the hydraulic model simulation. When the lower 6 gates are closed by a theoretical stoplog panel, the simulated outflow is 95.73 ft^3/s. The wetted surface area during this type of event is approximately 235,300 ft^2.

Table 1-5: Trap Efficiency for StopLog Panels, Honokowai Basin, 0.50 AEP Flood

Name of soil separate	Diameter limits (mm)	Original Trap Efficiency (%)	New Trap Efficiency (%)
Clay	< 0.002	0.32	0.92
Silt	0.002 – 0.05	> 100	> 100
Very fine sand	0.05 – 0.10	> 100	> 100
Fine sand	0.10 – 0.25	> 100	> 100
Medium sand	0.25 – 0.50	> 100	> 100
Coarse sand	0.50 – 1.00	> 100	> 100
Very coarse sand	1.00 – 2.00	> 100	> 100

1.3.1.4 Outlet Modification at Kaopala Basin

The proposed modification at Kaopala Basin (Photo 1-2) is a replication of the outlet modification that was done at Napili 4-5 (Figure 1-3). Both basins are similar in size. The flow and runoff volume entering both basins are also similar. The outlet pipe at Kaopala Basin currently permits sediment-laden waters to leave the reservoir at a very low elevation (where sediment concentration is the highest).

1.3.2 Micro Basins

This measure proposes the construction of medium-sized detention basins, either in-line with the stream or offset.

Using the estimated peak flow values and settling velocities previously presented in the Hydrology and Hydraulics Appendix, the recommended treatment surface area of the sediment basin can be estimated using the standard equation:

$$S_a = 1.2 * (\frac{Q_{out}}{v_s})$$

where:

S_a = treatment surface area measured at the invert of the lowest outlet of sediment basin (ft^2)

Q_{out} = Peak flow of the detention basin outlet (ft^3/s)

V_s = settling velocity of the solid (ft/s)

1.2 = EPA recommended safety factor

Applying this equation results in the treatment surface areas requirements for addressing the various types of soil with approximately 80% effectiveness (80% reduction of the targeted soil type), which are presented in Table 1-6. These areas assume that the outflow, Q_{out}, is approximately equal to the inflow during the 50% AEP (2-yr), 24-hour design storm.

As shown in Table 1-6, increasing the size (surface area) of the basin alone is not enough to effectively capture the fine sediments affecting the coral reefs (i.e. clays, silts). The outflow must also be limited. Using the same equations with a reduced outflow, provides the results presented in Table 1-7. Even with a baseflow as low as 1 ft^3/s, it is still not practical to capture 80% of the incoming silt without coagulation and flocculation (Section 1.4.1).

Although capturing 80% of the fine material by this measure is not a realistic goal, some sediment captured is still better than none. Engineering judgment was used to site and size practical sediment basins at Ka’opala and Wahikuli. A detention basin that is 5-ft deep, has a 1,000 ft^2 surface area, and outflow of 3 ft^3/s, is approximately 30% effective at trapping fine sediments.

Table 1-6: Treatment Surface Area Requirements for Various Soil Types When $Q_{in} = Q_{out}$

Subbasin ID	Treatment Surface Area (sf)						
	Clay	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand
	0 – 0.002 mm	*0.002 – 0.05 mm*	*0.05 – 0.1 mm*	*0.1 – 0.25 mm*	*0.25 – 0.5 mm*	*0.5 – 1.0 mm*	*1.0 – 2.0 mm*
1A	71,700,000	106,000	12,700	2,340	317	79.3	19.8
1B	366,000,000	542,000	65,100	12,000	1,620	405.0	101.0
1C	174,000,000	257,000	30,900	5,680	769	192.0	48.1
2A	74,100,000	110,000	13,200	2,420	328	82.0	20.5
2B	220,000,000	326,000	39,200	7,190	975	244.0	60.9
3A	78,200,000	116,000	13,900	2,550	346	86.5	21.6
3B	213,000,000	315,000	37,900	6,950	942	236.0	58.9
3C	75,700,000	112,000	13,500	2,470	335	83.8	20.9
3D	123,000,000	182,000	21,900	4,030	546	136.0	34.1
4A	195,000,000	289,000	34,700	6,370	863	216.0	53.9
5A	23,600,000	34,900	4,200	771	104	26.1	6.5
5B	99,800,000	148,000	17,700	3,260	441	110.0	27.6
5C	132,000,000	195,000	23,500	4,310	584	146.0	36.5
6A	79,400,000	117,000	14,100	2,590	351	87.8	22.0
7A	101,000,000	150,000	18,000	3,310	449	112.0	28.0
8A	83,100,000	123,000	14,800	2,710	368	91.9	23.0
8B	70,000,000	104,000	12,500	2,290	310	77.5	19.4
10A	77,000,000	114,000	13,700	2,510	341	85.1	21.3
10B	59,000,000	87,300	10,500	1,930	261	65.3	16.3
10C	60,300,000	89,100	10,700	1,970	267	66.7	16.7
12A	725,000,000	1,070,000	129,000	23,700	3,210	802	200

Red = 1,000 sf or greater

Orange = 500 sf to 1,000 sf

White = < 500 sf

Table 1-7: Treatment Surface Area Requirements for Various Soil Types, Various Outflow Rates

Baseflow (cfs)	Treatment Surface Area (sf)						
	Clay	**Silt**	**Very fine sand**	**Fine sand**	**Medium sand**	**Coarse sand**	**Very coarse sand**
	0 – 0.002 mm	*0.002 – 0.05 mm*	*0.05 – 0.1 mm*	*0.1 – 0.25 mm*	*0.25 – 0.5 mm*	*0.5 – 1.0 mm*	*1.0 – 2.0 mm*
1	406,780	600	71	13	2	0	0
2	813,559	1,200	141	27	4	1	0
5	2,033,898	3,000	353	67	9	2	1
10	4,067,797	6,000	706	133	18	5	1
15	6,101,695	9,000	1,059	200	27	7	2
20	8,135,593	12,000	1,412	267	36	9	2
35	14,237,288	21,000	2,471	467	63	16	4
50	20,338,983	30,000	3,529	667	90	23	6
100	40,677,966	60,000	7,059	1,333	180	45	11

1.3.3 Storm Discharge Pipe

Not Recommended

This measure proposes the construction of a large pipe to convey flow and sediments past nearshore coral reefs. It allows in-stream erosion to continue through natural processes before being captured and diverted into the deep ocean. It does not reduce the sediment load that reaches the ocean but relocates the discharge point so that the impact to nearshore coral reefs is minimized. There are several challenges associated with this measure, including its technical complexity, high cost of construction, requirements for land acquisition or easement rights, potentially significant environmental impacts, extensive permitting requirements, and increased maintenance requirements post-construction. When presented at the August 2018 public meeting, it was strongly opposed by the public.

1.4 Refinements

Refinements are features that can be incorporated into a management measure to improve the efficacy.

1.4.1 Coagulation and Flocculation

Fine sediment, such as clays and fine silts, require a long time to settle. Coarse to medium size silt particles can be realistically targeted for sedimentation but targeting clay and fine silts is generally not practical. However, these fine particles that are suspended in the water can be encouraged to stick together with the help of a coagulant chemical. Flocculation, a gentle mixing stage, further increases the particle size and thereby also reducing the time required for settlement. This measure compliments previously proposed measures that rely upon capturing sediment through detention.

When initially proposed at the public meeting in August 2018, there was some uncertainty regarding the impact that coagulant chemicals would have on the environmental system. Coagulation and flocculation are commonly used in water treatment facilities but has a limited performance history in Hawaii for addressing sedimentation issues in natural river systems. The measure was generally met with hesitancy by the public.

However, since the time of the public meeting, further research has revealed there are sources of biodegradable, natural flocculants that perform on a wide array of soil types and pH ranges; and have demonstrated no harm to aquatic organisms based on toxicity testing at recommended dosages (Dober). One example of this is Chitosan, a natural biopolymer derived from chitin, recycled from the shells of crustaceans like shrimp, crabs, and lobsters.

2 Conceptual Alternative Plans

Based on site visits and investigation of the available data, discussions between the members of the Ridge to Reef partnership yielded an initial array of alternatives for further analysis. The different alternatives, listed and discussed below, are applicable to varying degrees and scales, and do not necessarily apply to all watersheds and locations. None of the listed alternatives are meant to be utilized alone or as perfect solutions, but as part of a larger watershed management plan and sediment mitigation framework.

		Honolua	Kaopala	Kahana	Honokowai	Wahikuli
ALT 1	FWOP					
ALT 2	Microbasin/Instream Detention		X			X
	Lo'i Diversion	X			X	
ALT 3	Microbasin/Instream Detention		X			X
	Lo'i Diversion	X			X	
	Basin Modification		X	X	X	

2.1.1 Conceptual Alternative A: No Action Alternative

Serving as the base alternative, there are no measures proposed within this Alternative. Existing Sediment Basins remain unmodified, and there are no proposed additions to improve this watershed. The goal of this alternative is to provide a basis to compare the other alternatives' sediment flux to the ocean.

Table 2-1: Alternative A Sediment Load, 0.50 AEP Flood

Watershed	Sediment Load (metric tons)
Honolua	20.2
Ka'opala	13.8
Kahana	63.3
Honokowai	13.8
Wahikuli	9.33

2.1.2 **Conceptual Alternative B: Watershed Additions**

Alternative B's goal is to solely add additional features to the watersheds within the study area. The measures included within this watershed include lo'i at Honolua and Honokowai and microbasins at Ka'opala and Wahikuli.

Table 2-2: Alternative B Sediment Load, 0.50 AEP Flood

Watershed	+Trap Efficiency (%)	Sediment Load (metric tons)
Honolua	0.05	20.2
Ka'opala	30.0	9.66
Kahana	0.00	63.3
Honokowai	0.05	13.8
Wahikuli	30.0	6.53

2.1.3 **Conceptual Alternative C: Watershed Additions and Sediment Basin Improvements**

Alternative C's goal is to maximize sediment capture. This is a combination of the measures in Alternative B and improvements to the existing sediment basins. The existing sediment basins are located in located within Wahikuli, Honokowai, and Kahana.

Table 2-3: Alternative B Sediment Load, 0.50 AEP Flood

Watershed	+Trap Efficiency (%)	Sediment Load (metric tons)
Honolua	0.05	20.2
Ka'opala	95.0	0.69
Kahana	30.00	44.3
Honokowai	85.05	2.06
Wahikuli	30.0	6.53

3 Conclusion

The management measures considered to be feasible were explored in greater detail, before being sited and included in an conceptual plan. These measures include use of lo‘i terraces, construction of new micro basins, and modifying existing detention basins to retain water longer.

Lo‘i terraces are very effective at trapping sediment but are only able to treat a small amount of flow. By themselves, a few lo‘i would not likely have a significant impact on reducing the concentration of sediment in the main channel. Unlike other measures discussed here that target effectiveness against a small flood event, lo‘i terraces are more appropriate at treating daily flows that are typical of the river system (baseflow). Lo‘i are proposed at Honokowai and Honolua, where there was previously extensive use based on historical records. However, this measure would be more effective at Honolua where there is a greater likelihood of continuous flow and no existing mitigation feature to capture sediment.

Micro-basins are another management measure that was carried forward. They have a similar design concept to lo'i, without the consideration of the cultivation of taro. A typical micro-basin covering 1,000 ft^2 in area and depth of 5 ft has a trap efficiency of about 30% for fine sediments.

Modifications to existing detention basins at Kahana, Ka'opala, and Honokowai are also proposed. The first proposal is over-excavation at the Kahana Basin and installation of upstream embankments to regulate flow, as needed, by the dam operator to be able to effectively remove captured sediments from the basin. The second is to install stoplog panels over the open ports of the existing Honokowai riser structure. These would allow for controlled, top-down release of flow. Finally, a replication of the Napili 4-5 outlet modification is proposed to be implemented at the Ka'opala Basin also. These modifications result in increased trap efficiency of 65%, 30%, and 85% for Kahana, Honokowai, and Kaopala, respectively.

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