KAWAI NUI STREAM FLOW RESTORATION PROJECT

PRELIMINARY ENGINEERING REPORT

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Prepared For

State of Hawaii, Department of Land and Natural Resources, Engineering Division

Department of Land and Natural Resources
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Prepared By

oceanit

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ACRONYMNS AND ABBREVIATIONS

Alt.	Alternative
CCH	City and County of Honolulu
C&C	City and County
CFS	cubic feet per second
DOT	State of Hawaii Department of Transportation
DLNR	Department of Land and Natural Resources
EA	Environmental Assessment
ft	foot/feet
HDPE	High Density Polyethylene
KWS	Kailua Waterways System
Marsh	Kawai Nui Marsh
MLLW	Mean Lower Low Water – locally established to ocean tides, = -0.30 ft MSL
MSL	Mean Sea Level – established to City's survey base
O&M	Operation and Maintenance
PVC	Polyvinyl chloride
Stream	Kawai Nui Stream
USACE	U.S. Army Corps of Engineers
USGS	United State Geological Society

1 INTRODUCTION

1.1 PROJECT BACKGROUND AND PURPOSE

The project is located in Kailua on the windward side of Oahu. The purpose of the proposed structure is to restore partial water flow from the Kawai Nui Marsh to the Kawai Nui Stream without increasing the flood threat to the area protected by the existing flood control levee. Kawainui Stream is part of the 142 – acre Kailua Waterways System (KWS) that includes the ITT Wetland, Kawai Nui Stream, Hamakua Wetland, Kaelepulu Stream, Kaelepulu Pond, Kaelepulu Wetland and stream mouth to the ocean at Kailua Beach.

Historically, Kawai Nui Stream (Stream) was part of the Kawai Nui Marsh (Marsh) and water from the Marsh flowed into KWS through Kawai Nui and Kaelepulu Streams before discharging into the ocean at the south end of Kailua Bay. Construction of the Oneawa Canal in 1952 and in 1961 the 9,000 – foot long, flood protection levee, which separated Kawai Nui Stream from the Marsh, diverted the water from the Marsh directly to the north end of Kailua Bay. This deprived the KWS of the historical flow from the Marsh, changed the water quality of the system and also adversely impacted the stability of the stream mouth at Kailua Beach.

Currently, the stream mouth is closed most of the time by a sand berm built up by the waves, which effectively blocks water exchange between KWS and the ocean. During dry weather, evaporation lowers the water level elevation of KWS and exposes submerged areas resulting in odor problems from rotting aquatic vegetation. During wet weather, runoff into KWS elevates the water level behind the sand berm causing flooding in low-lying areas. As a flood threat minimization measure, the City and County of Honolulu (City) mechanically opens the sand bar about nine times per year and allows the stream to release excess water to the ocean. This allows the water surface elevation in the KWS to fluctuate with tidal influences until the waves build up the sand berm across the stream mouth to block the flow. In between sand berm openings, the KWS water surface elevation can fall significantly due to evaporation, resulting in negative effects on the ecosystem. The purpose of the project is to divert a sufficient amount of water from the Marsh to offset the volume of evaporation, raise the water surface elevation by about 0.5 ft., and maintain a water surface elevation of 1.7 feet MSL in KWS.

A 3-month temporary flow restoration trial demonstrated that restoration of a small fraction (2 CFS) of the historical inflow from the Marsh to the KWS (11 CFS)

- increased circulation,
- increased stratification,
- enhanced habitat of endangered wetland birds,
- reduced the magnitude of water level variation in KWS,
- improved the efficacy of water exchange through the stream mouth[1],
- minimized low-dissolved oxygen events,
- eliminated fish die-offs,
- eliminated avian botulism outbreaks, and
- eliminated all episodes of foul odors produced from the system in this highly urbanized area.

Based on Siphon Flow Restoration Experiment Report, 2016 data, the KWS and ecosystem will see substantial improvements if the water elevation is maintained at 1.7 feet MSL.

The project proposes to restore partial water flow from the Marsh to Kawai Nui Stream by installing a pipe through, beneath or around the existing Kawai Nui Flood Control Levee. The pipeline is designed to convey 2 cubic feet per second (CFS) of water by gravity. The purpose of this report is to describe the design features, flow calculations, construction methods, and costs estimates for each alternative concept considered and the 30% concept design of final selected alternative.

[1] Based on anecdotal knowledge of the area, prior to the construction of the levee, the water level of the KWS was higher and the sand berm at Kailua Beach was smaller; and therefore, the Kaelapululu Stream would flow out into the ocean on a more frequent basis. The construction of the levee has created a secondary flood threat by causing the KWS to be closed off from the ocean. Therefore, during storm events the runoff water cannot drain until the berm is mechanically lowered by the county.

2 ALTERNATIVE OVERVIEW

2.1 LOCATIONS

The proposed project is located at the eastern edge of the Marsh in the town of Kailua, Koolaupoko District, on the northeast, windward coast of the Island of Oahu within the Hawaiian Islands. The Marsh is located between the Koʻolau mountain range to the west and the town of Kailua to the east. The main purpose of the proposed project is to move up to 2 CFS of water from the Marsh to KWS. Four potential locations for water transfer were identified. Figure 1 shows the locations considered during this study.

Site I (ITT Wetland);

Site II (U.S.G.S Gauge Site);

Site III (North end of the Levee Headwall);

Site IV (Kaha Park) and,

Site V (Kailua Road).

Site I has a typical head differential over 2 feet between the Marsh and KWS, which provides enough pressure so no pump would be required to move the water. However, at this site the water must flow through the ITT wetland before discharging to the Stream. DOFAW manages the ITT wetland to best suit their goals for the wetland ecosystem.

Site II is similar to Site I and typically has about a 2-foot difference in water level between the Marsh and the Stream. This is enough head to create a feasible water flow from the Marsh to the Stream without any pumps or additional operating equipment. A disadvantage of this site is that the portion of the Stream to the north would not receive significant benefits from increased circulation and water flow.

Site III is located on the north east end of the levee, just beyond the end of the concrete levee floodwall. The water level elevation between the Marsh and the Stream is relatively the same at this location. Therefore, a pump would be required to move the water from the Marsh to the Stream. This would incur higher costs, maintenance and noise. However, the advantage of this location is the entire Stream would have increased water flow and the corresponding ecosystem benefits.

Site IV is located near the north end of the levee where the end of Kawai Nui Stream is separated from the Oneawa Canal by the levee. Similar to site III this location would require a pump to transfer water from the Oneawa canal to the Kawai Nui Stream. The water transferred into the Stream would be more brackish when compared to any of the other sites. When the water surface eleveation in KWS exceeds 1.7 ft. MSL, the pump could also be used to move water from KWS to Oneawa Canal.

Site IV is also the location of a potential supplemental project separate and distinct from the flow restoration project. This supplemental project includes an overflow pipe to reduce a previously unrecognized, existing flood threat. Excess water from the KWS will overflow into Oneawa Canal at this location. This overflow facility is designed to be included with one of the water supply alternatives discussed in this report. Secondary benefits of this supplemental project would be that 1. it would provide water circulation to the entire Stream, and 2. it would provide an automatic overflow at 1.7 ft. MSL thereby obviating the need for personnel to stop the inflow of water from the

Marsh once water in KWS reaches this elevation. The conceptual design for the supplemental project is included in this engineering report in Appendix A.

Site V has a typical head differential over 2 feet which provides enough pressure so no pump would be required to move the water. At this location, water would be moved around the levee and not through or under it. This may be preferred by the USACE and require significantly less permitting from the USACE. The pipeline would likely be under the DOT right-of-way so coordination and approval from DOT would be required. Water must flow through the ITT wetland before discharging to the Stream. DOFAW manages the ITT wetland to best suit their goals for the wetland. A disadvantage of this site is that the portion of the Stream to the north would not receive significant benefits from increased circulation and water flow. The preferred Alternative A – 3 is located at Site V.

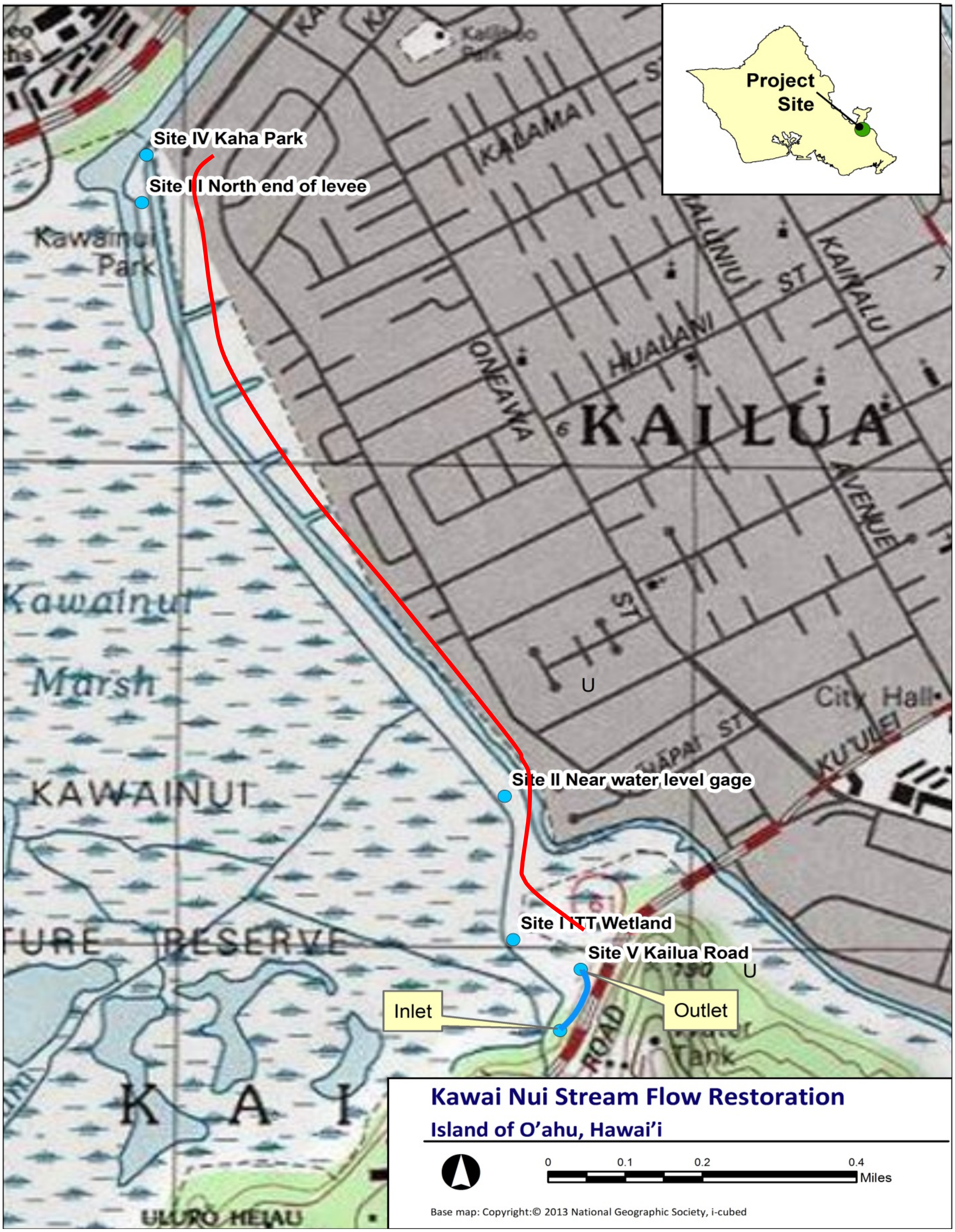

Figure 1. Location Map of the Proposed Project Alternatives along the Kawai Nui levee (red).

2.2 ALTERNATIVES

Alternative concepts considered are described in relation to proposed locations and methods used to transfer the water. The Kawai Nui Stream runs along the entire eastern boundary of the Marsh from the ITT wetland adjacent to the Kailua Road Bridge, to Kaha Park at the head of the Oneawa Canal. The levee wall is stamped with location markers at 100-foot intervals from Kailua Road (0:00) to Kaha Park (83:00) with the levee continuing along the Oneawa Canal to 9,470 feet. Water transfer could occur anywhere along the length of this levee. At the Kaha end of the levee, the water surface elevation of the Marsh varies tidally (~0 to 2 ft. MSL), but at the Kailua Road end, the water surface is typically elevated at about 4.5 ft. mean sea level (MSL). Alternative locations selected along the levee will therefore provide different water head gradients between the Marsh and the Stream.

For each potential location there may be several methods available to transfer the water from the Marsh to the Stream. Where the head difference is sufficient, gravity may be used to push the water from the Marsh to the Stream in a siphon over the levee, a drain pipe through the levee, or a directionally drilled pipe below or around the end of the levee. Pumping the water using electric (or solar electric) pumps would allow water to be transferred at any location.

Four alternative water transfer methods (A, B, C, and D) were considered at five locations along the levee yielding a total of 11 action alternatives, and the no-action alternative (E):

- Alternative A Gravity Flow Pipe through Levee
    - A-1 Site I Through levee base into ITT wetland
    - A-2 Site II Through levee base in Kawai Nui Stream
    - A-3 Site V Around end of levee into ITT wetland
- Alternative B Inverted Siphon Pipe Directionally Drilled under Levee
    - B-1 Site I Below levee into ITT wetland
    - B-2 Site II Below levee into Kawai Nui Stream
- Alternative C Siphon Pipes Over the Levee
    - C-1 Site I Over levee into ITT wetland
        - C-1a Over headwall
        - C-1b Through base of headwall
    - C-2 Site II Over levee into Kawai Nui Stream
        - C-2a Over headwall
        - C-2b Through base of headwall
- Alternative D Pump Controlled Pipe - Over Levee
    - Alternative D-1 Site IV Pump over levee from Oneawa Canal to Kawai Nui Stream near Kaha park
    - Alternative D-2 Site III Over levee wall to Kawai Nui Stream near Kaha park
- Alternative E: No Action

3 BASIS OF DESIGN – WATER SUPPLY

The water supply pipeline was designed based on the flow requirements, USACE guidelines (Manual No. 1110-2-1913 and 1110-2-2902), and C&C of Honolulu Rules Relating to Storm Drainage Standards, 2000.

3.1 PIPE SIZE

The water supply pipelines were sized to supply approximately 2 CFS of flow to bring the water level in the Kawai Nui Stream up to 1.7 feet MSL. Based on the *Natural History, Hydrology and Water Quality of Enchanted Lake – Kaelepulu Pond, Bourke, 2016* study of the Kawai Nui and Kaelepulu ecosystems, this elevation in water results in improvement to water quality and services ecosystem improvements.

The flow requirements are based on the volume of water supply needed in the Kawai Nui Stream to offset evaporation and elevate and maintain a water surface elevation of 1.7 feet MSL. Based on Siphon Flow Restoration Experiment Report, 2016 data, the KWS and ecosystem will see substantial improvements if the water elevation is maintained at 1.7 feet MSL. The approximate surface area of the entire Kailua Waterways is 142 acres. The table below lists the water bodies in the Kailua waterways and their respective surface area in acres.

Water Bodies	Acres
Kaelepulu Wetland	12.0
Kaelepulu Pond	89.0
Upper Kaelepulu Stream: Keolu to Junction with Kawai Nui Stream	6.0
Lower Kaelepulu Stream: Junction to Ocean, and Kaawakea Bridge to Kaelepulu	15.0
Lower Kawainui Stream: Kailua Rd to Kaawakea Bridge including Hamakua Wetlands	9.7
Upper Kawainui Stream: Kaha to Kailua Rd, and ITT Wetland	10.3
TOTAL	142

Table 3-1 Water Surface Areas in KWS Water Bodies.

Evaporation losses based on *Giambelluca, et. Al, 2014* evaporation maps for this area of Hawaii is 0.25 inches per day and is consistent with the measured fall in water elevation in the absence of rainfall (Bourke, 2016). This is equivalent to 7.5 inches per month over the 142 acres (3,866,000 ft^3). Therefore, the minimum flow rate to offset evaporation is approximately 1.49 CFS. A pilot study was conducted from May-August 2015, during which water was siphoned from the Marsh to the KWS. The average flow rate varied from 0.92 CFS to 2.04 CFS. This pilot study is detailed in *Siphon Flow Restoration Experiment Report, 2016*. The results showed the flow rate of 2 CFS was more than sufficient to offset evaporation losses and raise the water level to the desired elevation. Therefore, this water supply pipeline is designed for 2 CFS of flow.

The calculations for the pipeline size are based on the pipeline's ability to convey the necessary flow capacity. As a cross-check two methods were used to calculate the flow capacity. Two methods were used because each method accounts for different variables. The results are displayed in

Table 3-2. Calculations were not done for frictional losses at bends and joints because the effects on flow are minimal and are not necessary for the conceptual design and comparison between alternatives. The final pipeline design should accommodate for losses at bends and joints. Bentley FlowMaster V8i was used to calculate the flow for each alternative.

The first method uses the Manning's formula. The formulas used in the calculations are shown below.

Manning's Formula:

$$Q = VA$$

$$V = \frac{1.486}{n} \times R^{2/3} \times \sqrt{S}$$

Hydraulic Radius Formula:

$$R = \frac{A}{P}$$

$$A = \pi \left(\frac{D}{2}\right)^2$$

$$P = \pi D$$

Where:

Q = Flow Rate, (ft^3/s)

V = Velocity, (ft./s)

A = Flow Area, (ft^2)

n = Manning's Roughness Coefficient

R = Hydraulic Radius, (ft.)

S = Slope of the hydraulic grade line, (ft./ft.)

P = wetted perimeter (ft.)

D = Pipeline diameter (ft.)

An example is shown below for Alternative A-3 flow (Q) calculations.

D = 1.0 (ft.)

n = 0.010 (Manning's Roughness Coefficient for plastic HDPE pipe)

S = 0.005 (ft/ft.)

$$A = \pi \left(\frac{1.0}{2}\right)^2 = 0.79 \text{ (ft}^2\text{)}$$

$$P = \pi \times 1.0 = 3.14 \text{ (ft.)}$$

$$R = \frac{0.79\ (ft^2)}{3.14\ (ft)} = 0.25 \text{ (ft.)}$$

$$V = \frac{1.486}{0.01} \times 0.25^{2/3} \times \sqrt{.005} = 4.17 \text{ (ft./s)}$$

$$Q = 4.17 \times 0.79 = 3.29 \text{ (ft.}^3\text{/s)}$$

The energy principle was also used calculate the flow for the drain line alternatives (A, B, C and E). This calculation accounts for the pressure head caused by the water elevation differential at the inlet and outlet of the pipelines. Also, friction losses along the length of the pipeline are accounted for in this equation. Bentley FlowMaster V8i was used to calculate the flow for each alternative using the energy principle and manning's formula.

The energy principle is as follows.

$$\frac{p_1}{\gamma} + z_1 + \frac{V_1^2}{2g} + H_G = \frac{p_2}{\gamma} + z_2 + \frac{V_2^2}{2g} + H_L$$

p = pressure (lb./ft.^{2})

γ = specific weight of the fluid (lb./ft.^{3})

z = elevation above a datum (ft.)

V = fluid velocity (ft./s.)

g = gravitational acceleration (ft./s^2)

H_G = head gain, such as from a pump (ft.)

H_L = combined head loss (ft.)

The C&C of Honolulu requires a minimum pipe size of 18 inches for drainage lines in order to perform proper maintenance and inspections. An 18-inch pipe is an over design and this requirement should be further discussed with the C&C during the design phase of the project. The USACE also has minimum size requirements according to the USACE manual EM 1110-2-1913. The justification for such a large minimum requirement is not discussed in the manual. This should be further discussed with the USACE during the design phase. For the purposes of an engineering concept in this phase a 12-inch pipeline diameter was used. An 18-inch pipe can convey almost three times more flow than a 12-inch pipe. The Levee was constructed as a flood threat minimization measure. The additional volume of flow is unnecessary and could potentially increase the flood risk during an emergency situation. In addition, the velocity of the water would be lower and there could potentially be more of a chance of sediment build up in the pipeline.

For the alternatives where the pipelines go over the levee or through the levee wall a smaller diameter pipeline was selected because a 12-inch pipeline would be more likely to break siphon frequently and would also require a significantly larger priming pump. Also, for the alternatives where the pipeline goes through the levee wall the USACE will only allow the trenching up to 12 inches below the surface[1]. There must be a minimum coverage of soil or concrete encasing above the pipeline. Therefore, the maximum pipeline size is 6 inches.

Table 3-2 summarizes the pipe sizes for the various alternatives.

[1] This is based on a response from the Honolulu USACE office via email. All design parameters must be verified with the USACE in the final design of selected alternative.

3.2 PIPE MATERIAL

The water supply and overflow pipeline material must be able to withstand soil pressures and the weight of vehicle traffic. Pipelines placed less than three feet below the surface should be encased in concrete. The drain line alternatives place the pipelines over 10 feet below the top of the levee embankment and access road. This depth will allow the forces from vehicles to be spread and dispersed. The alternatives with the pipeline going over the levee embankment but under the access road and through the buried footing of the Levee flood wall will place the pipelines directly below the access road with three to six inches of coverage. This amount of cover is not sufficient, so for this alternative this section of the pipeline should be concrete encased and able to withstand traffic loadings from maintenance vehicles.

Materials for pipelines through levees are described in the Army Corps EM1110-2-2902. These materials include concrete, reinforced concrete, corrugated metal, plastic, ductile iron and steel. The Army Corps EM1110-2-2902 (section 6-1. General, b. Selection Considerations) prohibits the use of plastic pipes through levees without approval from Head Quarters USACE. As described in the Section 4.8 Construction Methods, the water flowing through the water supply pipeline (alternatives A through D) will be primarily fresh water. Pipeline corrosion could increase the risk for leaks in the pipe potentially leading to piping through the levee embankment. To be conservative, a pipe material resistant to salt water corrosion should be used. Corrugated metal is susceptible to corrosion and the USACE recommends only using this type of pipe on rural levees, where the threat of property damage and loss of life is low, so this material is not an option. In general, steel is not resistant to corrosion. Stainless steel and ductile iron can resist corrosion for long periods of time, but studies have shown that stainless steel and ductile iron can also be highly susceptible to corrosion in brackish water, so they are not an ideal materials.

Concrete, and reinforced concrete are options for pipeline materials of the pipeline through the levee embankment. PVC or HDPE are also options for pipeline alternatives around or over the levee embankment where the use of these materials is not restricted by USACE design guidelines. The reinforcement in the concrete must be corrosion resistant fiberglass or coated steel rebar. Two other pipe materials that may be feasible are fiberglass and vitrified clay. These are not described in the Army Corps manual and would have to be further investigated.

The USACE EM1110-2-2902 details the calculations required for designing pipelines to withstand soil pressures. This should be the primary guidance for the final pipeline design.

Table 3-2 summarizes the alternatives with the number of pipelines, approximate pipeline length and diameter and flow capacity. All of these numbers are based on a conceptual design and will be refined in the final design of the selected alternative.

					# Pipes	Length (Ft.)	Diam. (in.)	Material	Flow[1] (CFS)
Alternative A	Gravity Flow Pipe Thru or Around Levee		A-1	Site I	1	170	12 [4]	Concrete, fiberglass or vitrified clay	3.8
			A-2	Site II	1	170	12 [4]	Concrete, fiberglass or vitrified clay	3.8
			A-3	Site V	1	600	12 [4]	HDPE	2.9
Alternative B	Inverted Syphon Below Levee		B-1	Site I	1	175	12 [4]	HDPE	3.8
			B-2	Site II	1	175	12	HDPE	3.8
Alternative C	Syphon Over Levee	Over Wall	C-1a	Site I	4	185	6 [5]	Concrete, fiberglass or vitrified clay	2.4 [2]
		Thru Wall	C-1b	Site I	4	175	6 [5]	Concrete, fiberglass or vitrified clay	2.4 [3]
		Over Wall	C-2a	Site II	4	185	6 [5]	Concrete, fiberglass or vitrified clay	2.4 [2]
		Thru Wall	C-2b	Site II	4	175	6 [5]	Concrete, fiberglass or vitrified clay	2.4 [3]
Alternative D	Water Pump Over Levee		D-1	Site IV	1	175	12	PVC or USACE approved	2.0 [6]
			D-2	Site III	1	175	12	PVC or USACE approved	2.0 [6]
					1	175	12	PVC or USACE approved	2.0 [6]

1 This is calculated based on an assumption of a 2 foot elevation difference. During flood conditions this would change and the flow will be greater. The flow approximately doubles when the Marsh elevation reaches the top of the levee embankment.

2 Based on limited reliability of the syphon during the pilot project the flow this is likely an over estimate. Also, there frictional losses that are not accounted for at the bends. This will vary depending upon the final design.

3 Same not as note 2. However, there is less lift and bends, therefore the flow would greater for C-1b and C-2b than C-1a and C-2a.

4 This size may change depending upon C&C and USACE requirements.

5 A 12-inch pipe can also be used instead of 4 6-inch pipes. However, one syphon may be less reliable than multiple.

6 This flow can be changed as necessary by increasing the pump capacity.

Table 3-2 Alternative design comparison.

3.3 SLOPE OF PIPELINE

The flow velocity must be an average of 2 feet per second to prevent sediment from building up on the bottom of the pipeline. For concept designs a slope of 0.5% was applied. The final slope will depend on the final alternative selected, the length of the pipeline, bends, pipeline material and head differential.

3.4 INTAKE

The intake structure must be able to filter out floating plant material and debris which could clog the pipeline. The intake must be accessible by the C&C for maintenance, inspections and cleaning.

The conceptual design for the intake structure is a 4-foot by 4-foot perforated box structure extending upward from the invert of the pipe to 7 feet MSL. This elevation would typically rise above the average Marsh water surface elevation of about 4.5 feet MSL (site V). The perforated hole openings must provide enough area to allow for a minimum of 2 CFS of water flow into the pipeline. Also, the velocity across the hole openings should not exceed 0.05 feet per second. This intake screen velocity is in line with recommendations from EPA and USFWS for intake structures in sensitive ecosystems. Higher velocities could pull floating vegetation into the openings and create clogs and blockages. The perforations of the conceptual design intake box are 1-inch holes at 80 percent open area, or 50 square feet of perforated surface area during typical flow conditions.

The Marsh bottom substrate consists of soft sediments. Piles, concrete footings or other similar structural supports would be necessary to keep the intake structure from settling and to ensure the structural stability of the access walkway, intake and controls.

The invert for pipeline intake will vary depending upon the alternative. The following considerations are made for the invert design of all the alternatives:

- The invert elevation of the pipe intake should allow for a sufficient slope in the pipeline.
- The invert of the pipelines are above the bottom of the Marsh to prevent sediment build up at the pipe entrance and to stop water flow should drought conditions occur and the Marsh water level falls below 2 feet MSL.
- For alternatives using a siphon or pump (B, C, D) the intake must be at least 2 feet below the typical Marsh water level at that location. This is to prevent air from being suctioned into the pipeline.

The invert elevation of the pipeline should be confirmed with reliable water level data for the final design. Calculations for the concept designs were based off of water level data of the Marsh from USGS Station 16264600 in conjunction with manually collected water level data from Oceanit of Kawai Nui Stream.

3.5 CONTROLS

The USACE EM 1110-2-1913 requires two mechanisms to control the water flow through the pipeline, in the case that one fails. It is also generally required for the controls to be located at the upstream location on all dams and levees so the pipe is under minimal pressure. The conceptual designs include two controls located at the upstream end of levee or pipeline. In addition, the control valves are linked to the water level of the Marsh. When the water level reaches flood conditions, the valve closes, stopping flow through the water supply line.

In the conceptual designs an access walkway is a grade fill path for alternatives on the levee (A-1, A-2, B, and C); and is a walkway bridge and vault box for the alternative around the levee (A-3).

The elevation of this access way is 7 feet MSL. According to USGS water level data for the past 10 years the mean water level is 4.1 feet. The highest water level recorded is approximately 7 feet. Therefore, this is a safe elevation for the access way. Access to the controls should be locked and protected from the public and vandalism. The design of the access way extending off of the embankment versus directly at the top of the embankment is to make locking and protecting the controls easier and keep the controls out of direct reach of the public walkways.

3.6 OUTLET

A concrete, grouted rip-rap or comparable material should be used as an erosion protection apron to prevent scour from the flow through the outlet of the pipeline. A footing at the base of the apron extending below grade is designed to prevent scour and erosion at the edge of the erosion protection apron. The final design should account for maximum velocities at the exit of the pipeline.

3.7 CONSTRUCTION METHODS

There are three main methods of construction considered for the alternatives with a below grade pipeline (Alternative A, and B): directional drilling, microtunneling, and open trench.

The method of directional drilling (DD) would be the least expensive, but the pipe materials are limited to steel, HDPE, PVC, and ductile iron. The USACE guidelines prohibit plastic pipe through levees. Steel is undesirable because of likely corrosion due to the close proximity to the ocean and salt water. The water in the Marsh is fresh, the current salinity in the Stream is about 8 ppt. Therefore, for all alternatives through the levee, ductile iron or stainless steel piping would be required, should the directional drilling construction method be used. However, as described in the Pipe Materials Section, stainless steel and ductile iron may corrode in brackish water and are not recommended. Therefore, the directional drilling method is not feasible for alternatives through the levee, unless the USACE allows the use of a material suitable for DD. For Alternative A-3, a drainline around the levee, HDPE or PVC could also be used as materials since the pipeline is not directly impacting the USACE levee. The benefits of trenchless methods is that minimal disturbances will be made to the surrounding embankment or earthen material.

Microtunneling is a feasible option for Alternatives A, and B. However, the pipeline diameter is relatively small for the microtunneling technology and the mobilization and set up costs most likely make this method too costly to be a viable method. Microtunneling typically requires a minimum of 5 feet of cover or three times the pipe diameter. Therefore, fill would be required at the intake and outlet ends of the pipe to provide proper cover. The pipe materials suitable for microtunneling would be reinforced concrete or fiberglass. The USACE may not allow fiberglass so this may not be suitable for Alternatives A-1, A-2, B-1, and B-2. Microtunneling is a trenchless construction method and therefore would have minimal disturbances to the structure of the existing levee embankment.

The third method is open trenching with shoring. This option does not require any specialized equipment or contractors and could be a viable method. The compaction of the trench must be monitored to ensure quality control and prevent any discontinuity which may jeopardize the stability of the levee or surrounding area. For the alternatives that impact the levee, the compaction of the trench must follow all the USACE guidelines. This method can be used with concrete, steel, ductile iron, fiberglass or vitrified clay pipeline materials.

The construction methods can be left up to the contractor, unless during the permitting process with the USACE or other agency a particular method is required to maintain the integrity of the levee structure or for environmental reasons.

4 COSTS

4.1 DESIGN, PERMITTING AND CONSTRUCTION COSTS

An estimate for each alternative was prepared. Assumptions were made about materials, and construction methods to develop a conceptual cost estimate. The estimate may change based on permitting requirements, and design specifications. The costs were all rated with 0 being the lowest cost and 5 being the highest cost.

Alternative	Construction Costs	Design and Permitting Costs	Total	Cost Rating (0-5)
Alt A1 Site I - Drainline Through Levee	$274,000	$262,000	$536,000	4
Alt A2 Site II Drainline Through Levee	$274,000	$262,000	$536,000	4
Alt A3 Site V Drainline Around Levee	$333,000	$220,000	$552,000	4
Alt B1 Site I –Invert Siphon Under Levee	$276,000	$262,000	$538,000	4
Alt B2 Site II Invert Siphon Under Levee	$276,000	$262,000	$538,000	4
Alt C1a Site I- Siphon Over Levee	$312,000	$257,000	$568,000	4
Alt C1b Site I Siphon Through Levee Wall	$276,000	$260,000	$536,000	4
Alt C2a –Site II Siphon Over Levee	$312,000	$257,000	$568,000	4
Alt C2b Site II Siphon Through Levee Wall	$276,000	$260,000	$536,000	4
Alternative D1 - Pump Over Levee	$374,000	$260,000	$652,000	5
Alternative D2 - Pump Through Levee	$325,000	$272,000	$596,000	5

Table 4-1 Alternative Budgetary Cost Estimates

4.2 OPERATION AND MAINTENANCE COSTS

The various components of the operation and maintenance for each alternative were considered. Operation and maintenance tasks include regular site visits and inspections, cleaning and debris removal from intake and outlet works, cleaning of the water pipeline due to sediment build up and clogging, restarting pumps and siphon, equipment replacement and repair, electricity costs. The operation and maintenance costs were evaluated on a high level for comparison purposes. A detailed operation and maintenance plan should be developed for the selected alternative with the necessary stakeholders. The USACE EM 1110-2-1913 Section 8-2 suggests an agreement be formed with the property owners, USACE, and operation and maintenance agency.

The costs associated with O&M efforts were all rated with 0 being the lowest cost and most desirable and 5 being the highest cost and least desirable.

Alternative	Operation and Maintenance	O&M Rating (0-5)
Alt A1 Site I - Drainline Through Levee	Monthly inspections, Biannual cleaning of intake and outlet works, valve replacement every 5-10 years.	1
Alt A2 Site II Drainline Through Levee	Monthly inspections, Biannual cleaning of intake and outlet works, valve replacement every 5-10 years.	1
Alt A3 Site V Drainline Around Levee	Monthly inspections, Biannual cleaning of intake and outlet works, valve replacement every 5-10 years.	1
Alt B1 Site I –Invert Siphon Under Levee	Monthly inspections, Biannual cleaning of intake and outlet works, Biannual cleaning of pipeline for sediment build-up, valve replacement every 5-10 years.	2
Alt B2 Site II Invert Siphon Under Levee	Monthly inspections, Biannual cleaning of intake and outlet works, Biannual cleaning of pipeline for sediment build-up, valve replacement every 5-10 years.	2
Alt C1a Site I- Siphon Over Levee	Weekly inspections, Biannual cleaning of intake and outlet works, Annual PV panel and pump maintenance, PV panel and pump replacement every 10 years, valve replacement every 5-10 years.	3
Alt C1b Site I Siphon Through Levee Wall	Weekly inspections, Biannual cleaning of intake and outlet works, Annual PV panel and pump maintenance, PV panel and pump replacement every 10 years, valve replacement every 5-10 years.	3
Alt C2a –Site II Siphon Over Levee	Weekly inspections, Biannual cleaning of intake and outlet works, Annual PV panel and pump maintenance, PV panel and pump replacement every 10 years, valve replacement every 5-10 years.	3
Alt C2b Site II Siphon Through Levee Wall	Weekly inspections, Biannual cleaning of intake and outlet works, Annual PV panel and pump maintenance, PV panel and pump replacement every 10 years, valve replacement every 5-10 years.	3
Alternative D1 - Pump Over Levee	Monthly inspections, Biannual cleaning of intake and outlet works, pump maintenance; pump replacement every 10 years, valve replacement every 5-10 years, monthly electricity costs.	5
Alternative D2 - Pump Through Levee	Monthly inspections, Biannual cleaning of intake and outlet works, pump maintenance; pump replacement every 10 years, valve replacement every 5-10 years, monthly electricity costs.	5

Table 4-2 Alternative O&M Budgetary Cost Estimates

An important consideration regarding operation of the siphon alternatives was discovered during the operation of the pilot project. During the pilot project, four 6-inch siphon pipelines moved water from the Marsh to Kawai Nui Stream, the siphons were found to lose their siphon and stop flowing on a regular basis. Keeping the siphons flowing required daily attention. Although this was a pilot project and a permanent solution may use more advanced materials and construction methods, this indicates that a siphon may require frequent priming and may be less reliable in the long term. According to *Morrison-Maierle, 2012* a siphon can typically lift a maximum of 20 feet. The siphon alternative over the levee floodwall would require a lift of about 15 feet. This is reaching the higher limit of what is practical for a siphon to function and may be the reason the siphon flow was frequently disrupted during the pilot project trial.

5 ALTERNATIVE ANALYSIS

5.1 ALTERNATIVE COMPARISON

The alternatives were compared using several criteria. A full alternative analysis is found in the Kawai Nui Stream Flow Restoration Preliminary Environmental Assessment by Oceanit. The alternate methods move to water from the Marsh to Kawai Nui Stream include:

- A, gravity flow pipeline;
- B, inverted siphon under the levee;
- C, siphon pipeline over the levee;
- D, pumped pipeline over the levee, and lastly;

All of the alternatives are feasible from a technical, engineering perspective. Schematic designs of the alternatives are presented in Appendix C. Alternative A uses a gravity drainline and is the simplest technically and therefore is likely to have less long term maintenance or operation costs. Alternative B uses head pressure to move the water and does not require a pump, however, the low point in the pipeline could result in sediment build up and require more maintenance to keep functioning properly. Alternatives C and D use a pump and/or siphon, will require more equipment updates and regular maintenance and electricity costs.

Any of the alternatives that go through the levee have the potential to create a weak point in the levee structure and are therefore not likely to be approved by the USACE due to an increased risk of levee damage or failure. The USACE design manuals offer engineering solutions to strengthen levees at perceived weak points. However, the Honolulu USACE expressed their priority is safety and it is unlikely they would permit a modification to the levee for environmental benefit which could increase the safety risk. The USACE has also expressed they are not in favor of a pipeline running under the levee because similarly, it could be an weak point that could lead to piping and potential levee failure.

The alternatives that are most acceptable to the USACE are: a pipeline going over the levee (C-1a, C-2a, D); or a pipeline going around the levee[1] (A-3). One of the primary guidelines for the pipeline alternative selection and design are the USACE guidance documents. The USACE manual states: “Generally, the only new pipelines allowed to penetrate the foundation or embankment of a levee are gravity drainage lines.” The siphon or pumped pipelines through the levee flood wall would be slightly pressurized, making these alternatives likely more challenging to permit and approve. Alternatives where the pipeline is routed over the levee structure require the most power and maintenance and have the largest visual impact.

A matrix (Table 5-1) was developed to compare the different water supply alternatives. Each alternative was rated 0-5 for each impact. The lower the values in the matrix correspond to the less resistance for that particular impact and alternative. So the lowest totals are the most desirable alternatives.

Based on the results of this comparison, the most preferred alternative of the alternatives which are acceptable by USACE is the drainline around the levee at site V, Alternative A-3

1 The USACE has anecdotally responded to requests for input about the alternatives. They have not made a formal recommendation and have not reviewed the alternatives in detail. USACE maintains that penetrating the levee with a pipeline is not preferred and is a last resort. Their top priority is human safety and health, not the environment.

	Alternative A			Alternative B		Alternative C				Alternative D	
	Gravity Flow Pipe Thru or Around Levee			Inverted Siphon Below Levee		Siphon Over Levee				Water Pump Over Levee	
						Over Wall	Thru Wall	Over Wall	Thru Wall		
	A-1	A-2	A-3	B-1	B-2	C-1a	C-1b	C-2a	C-2b	D-1	D-2
Impacts	Site I	Site II	Site V	Site I	Site II	Site I	Site I	Site II	Site II	Site IV	Site III
Environmental Resources	3	2	3	3	2	3	3	2	2	1	1
Visual Resources	1	1	0	1	1	2	1	2	1	3	3
Noise	0	0	0	0	0	0	0	0	0	2	2
Water Flows through ITT Wetland	1	0	1	1	0	1	1	0	0	0	0
Total Cost	4	4	4	3	3	2	2	2	2	3	3
Operation and Maintenance	1	1	1	3	3	5	4	5	4	4	4
Constructability	4	4	3	5	5	2	3	2	3	2	2
General Permits	4	4	4	4	4	3	3	3	3	3	3
USACE 408 Permit	5	5	0	4	4	2	3	2	3	1	1
Flood Threat	2	2	2	2	2	1	1	1	1	0	0
TOTALS	25	23	18	26	24	21	21	19	19	19	19
RANK	5	4	1	6	5	3	3	2	2	2	2

Table 5-1 Alternative Comparison Matrix.

5.2 PREFERRED ALTERNATIVE

Alternative A-3 at Site V is selected as the preferred alternative (Figure 2). A 30% conceptual design has been completed for this alternative. The pipeline will be trenched from the Marsh to the directional drilling staging pit as shown on Figure 3 and Figure 4. Then the pipeline will be directionally drilled beneath the DOT State right-of-way under the DOFAW access road and into the ITT wetland.[1] Preliminary research found no buried infrastructure along this alignment. The controls for this pipeline would be directly adjacent to the highway. The primary control would be located inside a vault at the location of the drilling staging pit (Figure 3). The secondary control would be at the intake structure with an access walkway bridge. This would allow ease of access to the controls during all conditions. The pipeline outfall would be in the ITT wetland for this alternative. The water would then flow into the Kawai Nui Stream from the ITT wetland. This will require collaboration with DLNR Department of Forestry and Wildlife (DOFAW), who currently manage the ITT wetland. DOFAW has long term plans to upgrade the ITT wetland. The DOFAW ITT wetland plans should be considered as part of the final design and consultations for this alternative.

The conceptual design of the drainline will be a 12 inch HDPE pipeline, approximately 600 feet long. The invert of the drainline intake in the Marsh will be at 2 feet MSL or about 2.1 feet below the average Marsh water surface elevation. The slope of the pipeline will be 0.5%. The invert of the pipeline outlet will be (-) 1.0 MSL. The invert elevation of the pipeline should be confirmed with reliable water level data for the final design. Calculations for the concept designs were based off of water level data of the Marsh from USGS Station 16264600 in conjunction with manually collected water level data of Kawai Nui Stream by Oceanit.

The intake structure will be a 4-foot by 4-foot perforated box extending upward from the invert of the pipe to 7 feet MSL. The openings must provide enough area to allow for a minimum of 2 CFS of water flow into the pipeline with a flow speed across the screen of less than 0.05 feet per second. The perforations of the conceptual design intake box are 1-inch holes at 80 percent open area or 50 square feet of perforated surface area during typical flow conditions.

The outlet of the drainline shall have a concrete or grouted rip-rap apron to protect against erosion with a footing extending one foot below the ground surface to protect against scour at the pipeline exit.

The conceptual design includes two controls; the primary control is a gate valve located adjacent to the levee access road in a manhole as shown in Figure 4 and Figure 6; the secondary control is a slide gate located at the intake structure of the pipeline. Access to the primary control is in a manhole vault directly adjacent to the levee access road and Kailua Road. Access to the secondary control is a walkway bridge to the intake of the pipeline. Access to the controls should be locked and protected from the public and vandalism. An automatic shut off will be connected to the control valves and the Marsh water level. This will ensure the valves automatically stop flow during flood conditions.

With the drain line fully flowing the flow rate at typical water levels (Marsh at elevation ~4.5 feet and Stream at elevation 2 feet) is approximately 3 CFS. This will increase during conditions where the water level in the Marsh is higher. However, the pipeline flow is controllable with the control valves located both at the intake end of the pipe and within the vault installed at the site of the drilling pit.

1 The exact location of the pipeline intake, directional drilling staging pit and intake valves will be determined based on consultations with State DLNR, Forestry, C&C Honolulu maintenance personal and other primary stakeholders.

Figure 2 . Location Options for Gravity Pipe through or around Levee.

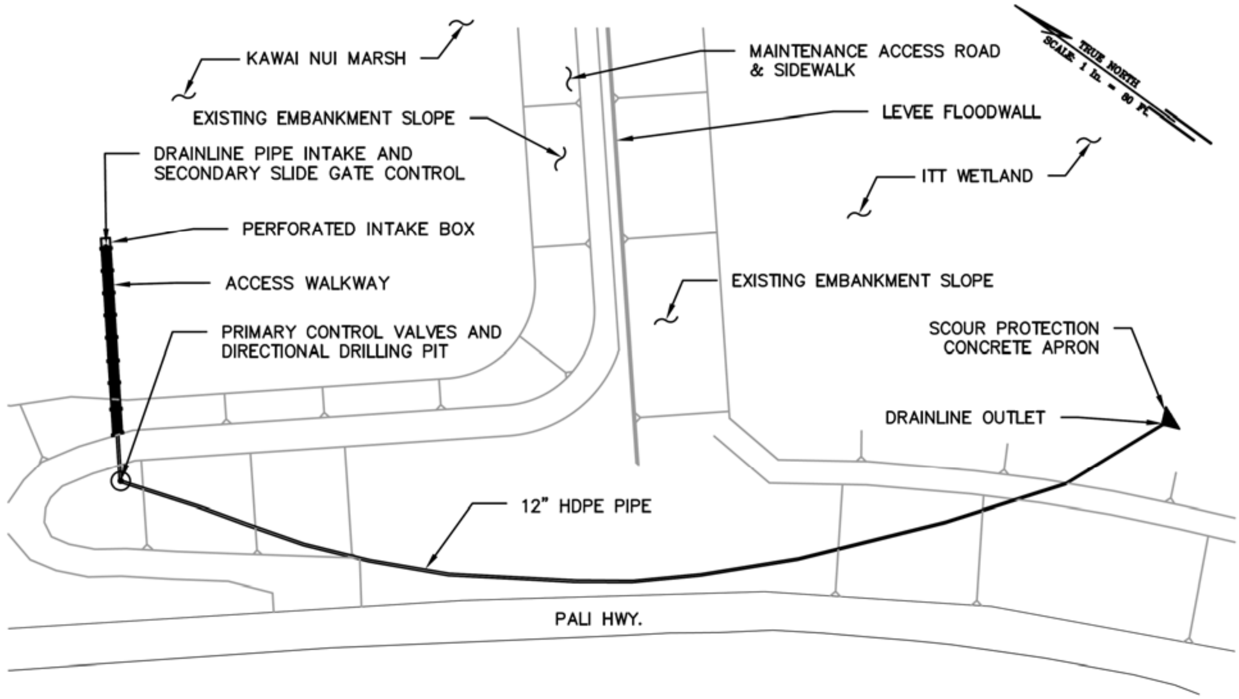

Figure 3. Alternative A3, directional drilling around end of levee within State DOT-highway right-of-way.

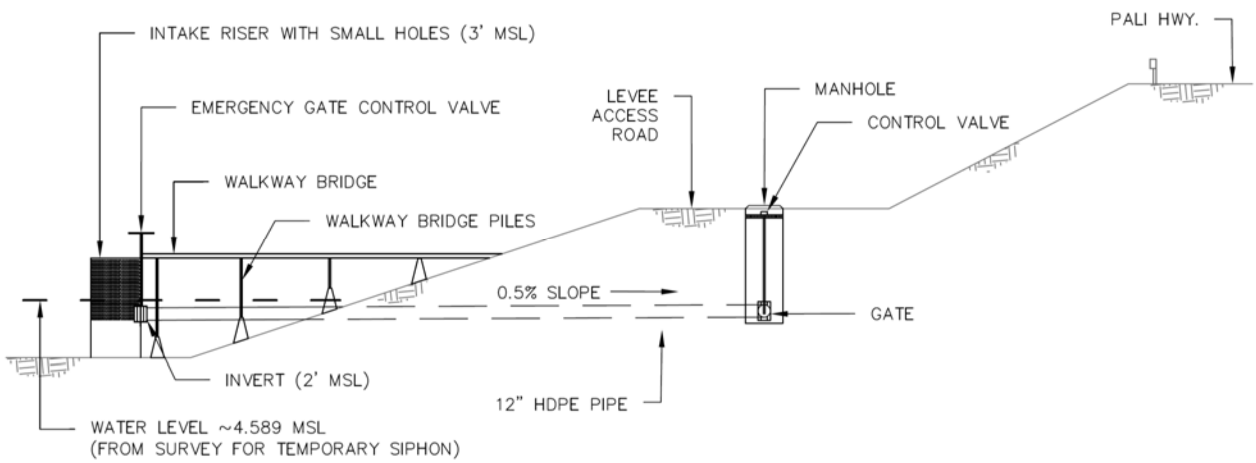

Figure 4. Alternative A3, intake section.

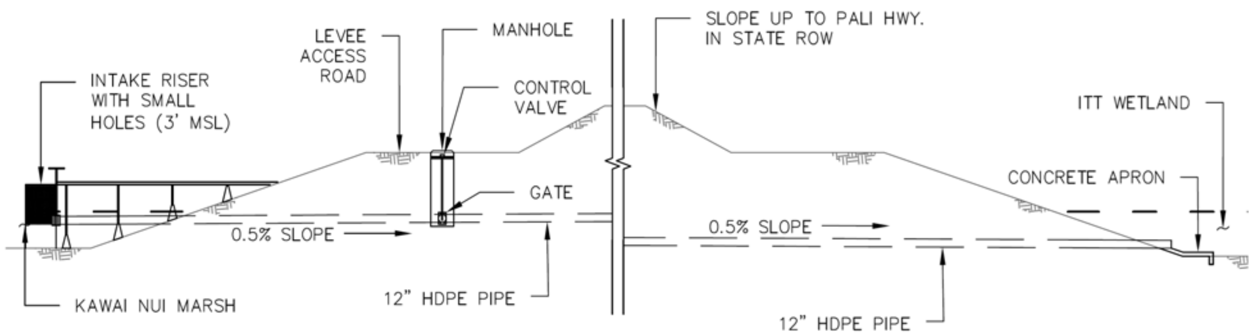

Figure 5. Alternative A3, pipeline alignment section.

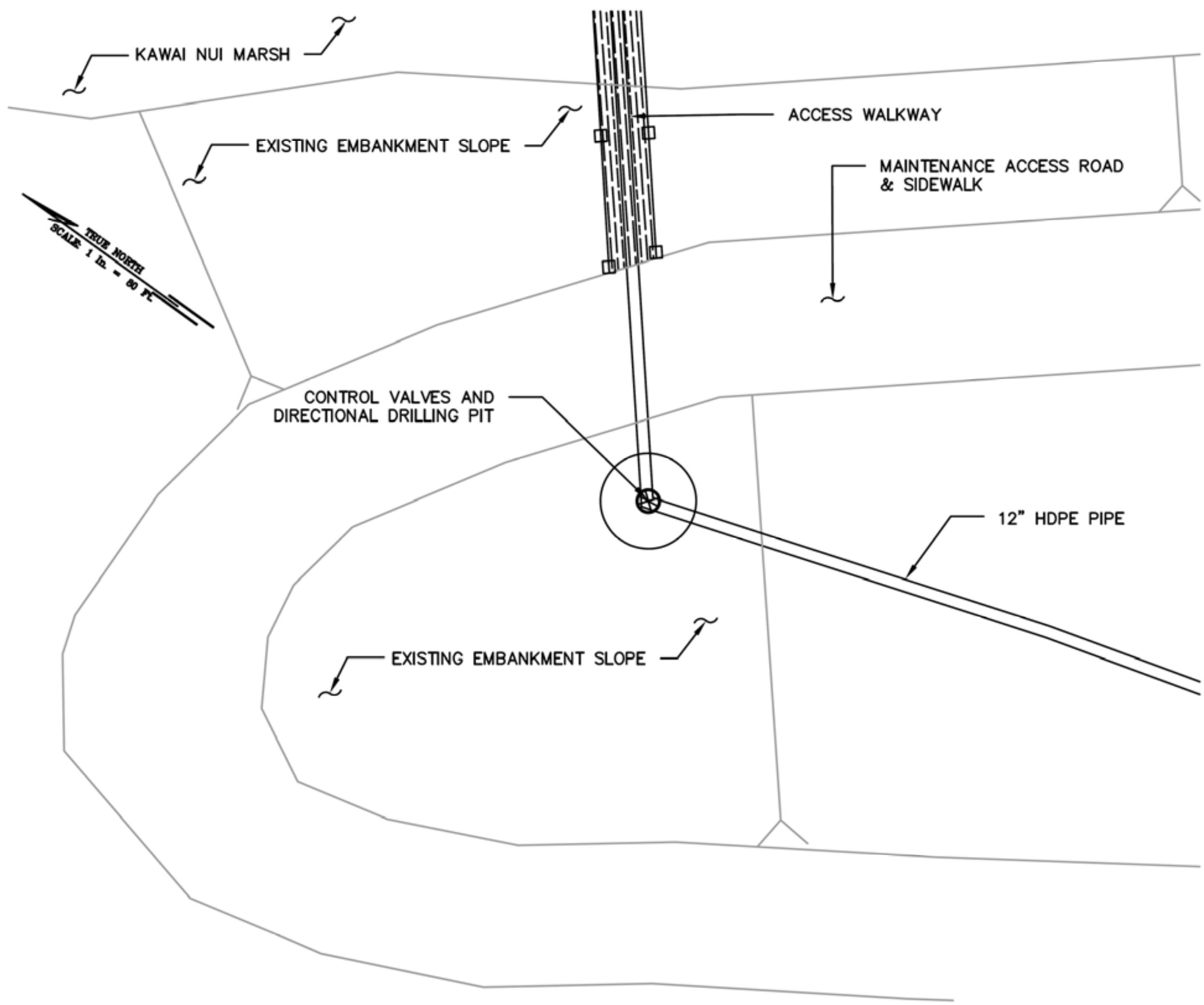

Figure 6. Alternative A3, controls location.

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APPENDIX A

SUPPLEMENTAL PROJECT: OVERFLOW PIPE FROM KAWAI NUI STREAM TO ONEAWA CANAL

SUPPLEMENTAL PROJECT: OVERFLOW PIPE – BASIS OF DESIGN

1.1 DESIGN AND PURPOSE

The Levee blocks 95% of the historical flow through the stream mouth, resulting in insufficient flow to keep the stream mouth open across Kailua Beach. In the absence of this flow the beach berm slowly increases in height, often reaching well above the flood elevation of 3.0 ft. MSL. The sand berm at Kailua Beach blocks water exchange between Kailua Bay and KWS. As a result, the exchange between the ocean and KWS occurs only when the C&C removes the sand berm mechanically. During storm events the runoff water cannot drain from KWS until it either tops this berm or the berm is breached by the C&C using heavy equipment.

The need for a mechanism for water to flow out of the KWS was recognized as data were analyzed from the Kawai Nui Stream Flow Restoration Siphon Flow Experiment in May-August 2015. An existing flood threat was identified. The buildup of sand at the Kailua Stream mouth blocks water from flowing out of the KWS. This creates a closed system. During a storm event sufficient flood storage is needed in this closed system to allow C&C personal time to mechanically remove the sand berm and allow water to flow. The sand berm must be removed before the water surface elevation reaches flood level of 3.0 MSL.

A supplemental project with an overflow pipeline is recommended. The overflow pipeline will provide a means for water to flow out of the Stream into Oneawa Canal. The supplemental project overflow pipeline would allow the KWS to drain to Oneawa Canal to maintain a controlled maximum elevation of 1.7 ft. MSL and provide a 1.3 ft. (8 MCF) flood retention buffer across the 142 acre KWS. While not intended as part of the flow restoration experiment, this project is a potential solution to this flood threat.

The conceptual design for an overflow pipeline has been developed. The primary purpose of the overflow pipeline would be to minimize the existing flood threat by providing an outlet for water from KWS to Oneawa Canal. The project would also result in secondary ecosystem benefits as it would improve water circulation at this dead-end of the stream, and it would obviate the need for personnel to turn off the flow from the Marsh whenever the elevation in KWS reached 1.7 ft. MSL. The ultimate goal of this project is to restore the ecosystem by improving the water quality by increasing the water level of Kailua Waterways to 1.7 feet MSL. However, increasing the water level can reduce the response time during a flood emergency. Flooding begins to occur at an elevation of 3.0 MSL. The supplemental project will provide an outlet for water to flow into Oneawa Canal when the water level in Kawai Nui Stream rises above 1.7 feet MSL, thereby, providing increased response time during flood conditions and a method to reduce flood risk. In addition, during very high tides water will flow from Oneawa Canal into the north end of Kawai Nui Stream, thereby increasing circulation and improving the water quality.

The USACE typically opposes penetrations through the levee. The supplemental project would have to be approved by USACE; further discussion is necessary.

1.2 PIPELINE SIZE

In accordance with C&C of Honolulu standards, the design is for an 18 inch pipeline (

Table 3-2). An 18 inch concrete pipe will allow for sufficient flow to keep the water level elevation at 1.7 feet MSL and offset the water added by the proposed water supply pipeline(s). The drainline flow rate will vary depending upon the head differential between the Kawai Nui Stream and Oneawa Canal.

The design is based on a typical scenario as follows: A 1-year storm (1-inch in 24 hours) will result in the KWS water surface elevation increasing by approximately 16 inches. Therefore, if the normal water elevation of KWS is 1.7 feet MSL, after a 1-year storm the water level will reach 3.0 feet MSL, which is flood elevation. Assuming the sand berm at Kailua Beach is not opened. The 18-inch pipeline will bring the water surface elevation back down to 1.7 feet MSL in approximately 10 days with an average flow rate of 9.17 CFS through the pipeline and 0.25 inches of evaporation per day. 10 days is an estimated time period between storm systems. A 10 day draw down can help to prevent subsequent storms from causing flooding. Without this supplemental project it would take about 62 days for the KWS water elevation to drop back to 1.7 feet MSL (assuming the sand berm is not opened).

1.3 PIPE MATERIAL

The pipeline will be in direct contact with ocean water and therefore the use of corrosion resistant materials is necessary. Since this pipeline also goes through the levee, plastic pipelines will not be allowable by the USACE. Concrete, fiberglass or ductile iron are the recommended materials for the Supplemental Project.

1.4 SLOPE OF PIPE

The proposed drainline from the north end of Kawai Nui Stream to Oneawa Canal is designed with a 0.5% slope towards Oneawa Canal to prevent water stagnation when there is minimal or no flow.

1.5 INTAKE, CONTROLS & OUTLET

The invert of the pipeline is at an elevation of -0.3 MSL. The intake structure at the Kawai Nui Stream end of the pipeline will be an overflow weir. The invert of the weir will be at 1.7 feet MSL. This will allow water to enter the pipeline from KWS once it rises above 2 feet. During high high tides, when the Oneawa Canal water elevation is above 1.7 feet MSL tidal water will flow from Oneawa Canal into KWS from the pipeline. However, due to the elevation of the weir, water will only flow from KWS to Oneawa Canal when the KWS water elevation is above 1.7 feet MSL.

A concrete, grouted rip-rap or comparable material erosion protection apron will be at the Oneawa Canal end of the pipeline. A footing at the base of the apron extending below grade is designed to prevent scour and erosion at the edge of the structure. The final design should account for maximum velocities at the exit of the pipeline.

1.6 CONSTRUCTION METHODS

The most likely method of construction for this pipeline would be open trenching. Directional drilling or other trenchless methods are possible, but since the pipeline is relatively short and there is no levee flood wall, open trench will likely be the most cost effective method. Should the USACE accept HDPE or PVC as a pipeline material, then directional drilling may be the most viable construction method.

1.7 SUPPLEMENTAL PROJECT SUMMARY

			# Pipes	Length (Ft.)	Diam. (in.)	Material	Flow[1] (CFS)
Supplemental Project	Drainline to Oneawa Canal	Site IV	1	100	18	Concrete, fiberglass or vitrified clay	3.8

Table A-1 Supplemental project conceptual design summary

Alternative	Construction Costs	Design and Permitting Costs	Total
Supplemental Project*	$202,000	$100,000	$301,000
*Cost is based on being constructed in combination with another alternative. Should this design be selected alone the costs would increase.			

Table A-2 Supplemental project conceptual design cost estimate

Alternative	Operation and Maintenance
Supplemental Project	Monthly inspections, Biannual cleaning of intake and outlet works, valve replacement every 5-10 years.

Table A-3 Supplemental project operation and maintenance summary

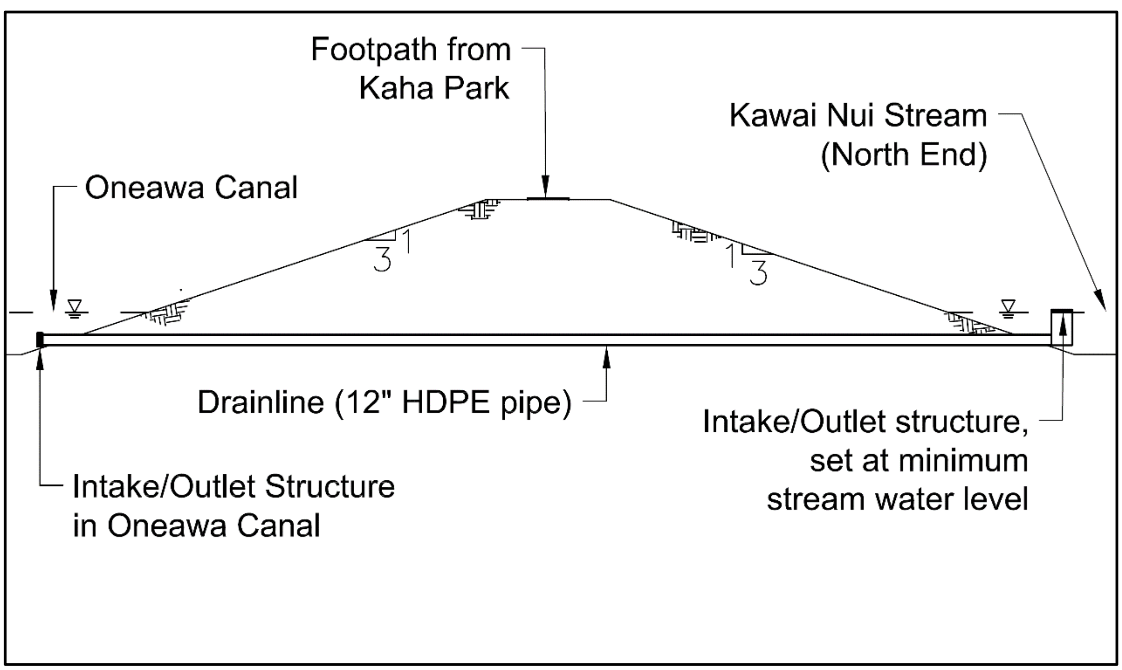

Figure 7. Supplemental project overflow pipeline conceptual cross-section.

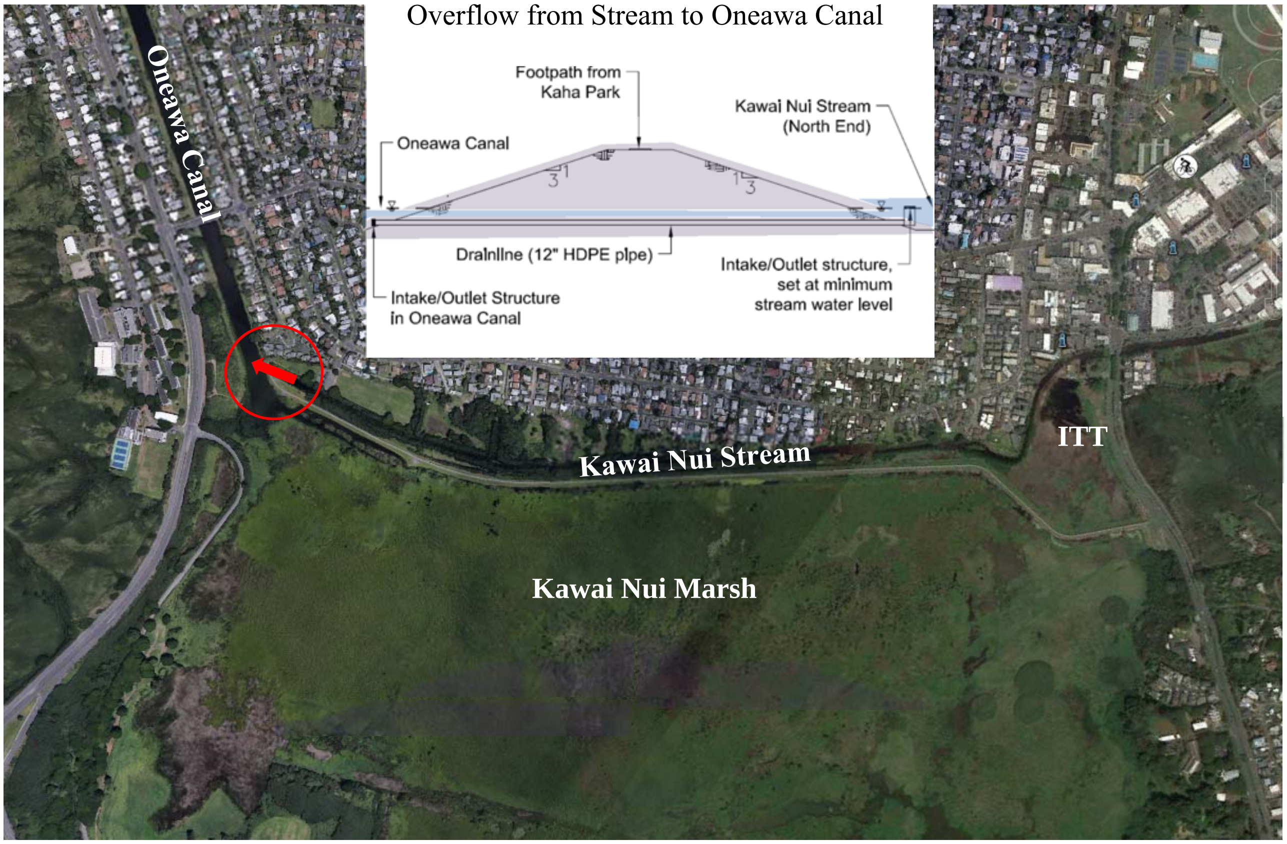

Figure 8. Location of supplemental project from Kawai Nui Stream Oneawa Canal.

Figure 9. Proposed location of supplemental project on Levee: Kawainui Stream (right) from Oneawa Canal (left).

APPENDIX B

COST ESTIMATES

Alternative A-1&2 - Drainline Through Levee
Kawai Nui Marsh Pipe - Cost Estimate

Construction Bid

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Mobilization / demobilization (assumed 8% of the total bid for construction Bid excluding bid price for mobilization)	$ 20,277	$ 20,277
2	1	L.S.	Temporary Erosion & Pollution Control Measures, including installation of silt fencing ; inclusive of all necessary equipment all necessary equipment, maintenance and removal; supplies, and labor; in place complete.	$ 15,000	$ 15,000
3	1	L.S.	Pre and Post construction survey	$ 2,000	$ 2,000
4	1	L.S.	Revegetation	$ 3,000	$ 3,000
5	1	L.S.	30-day maintenance period	$ 15,000	$ 15,000
6	1	L.S.	Water Quality monitoring	$ 36,200	$ 36,200
7	1	L.S.	mobilization and demobilization	$ 50,000	$ 50,000
8	170	LF	12-inch fiberglass or concrete pipe line installed , measured by actual length of pipe installed in place	$ 300	$ 51,000
9	1	LS	Geotechnical borings (2 holes)	$ 15,000	$ 15,000
10	1	EA	Intake structure	$ 19,833	$ 19,833
11	1	EA	Outlet structure	$ 11,900	$ 11,900
12	1	EA	Transport intake and outlet structure	$ 2,800	$ 2,800
13	2	EA	Bridge intake and outlet access structure	$ 8,000	$ 16,000
14	1	EA	Gate valve control	$ 8,430	$ 8,430
15	2	EA	Depth sensor, in place complete.	$ 3,650	$ 7,300
				Total	**$ 273,741**

Design, Permitting and Post Bid Services

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Design & Cost Estimate	$ 45,000	$ 45,000
2	1	L.S.	Specifications & Bid Documents	$ 30,000	$ 30,000
3	1	L.S.	Permits (401, 408, NPDES, Stream Alteration)	$ 45,000	$ 45,000
4	1	L.S.	USACE 404	$ 50,000	$ 50,000
5	1	L.S.	Completed E.A. (arch. survey, socio-econcomic, flora & fauna)	$ 50,000	$ 50,000
6	1	L.S.	Construction Management (13% construction costs)	$ 35,586	$ 35,586
7	1	L.S.	As-builts	$ 6,000	$ 6,000
				Total	**$ 261,586**

Alternative A - 3 - Directional Drill Around Levee
Kawai Nui Marsh Pipe - Cost Estimate

Construction Bid

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Mobilization / demobilization (assumed 8% of the total bid for construction Bid excluding bid price for mobilization)	$ 24,597	$ 24,597
2	1	L.S.	Temporary Erosion & Pollution Control Measures, including installation of silt fencing ; inclusive of all necessary equipment all necessary equipment, maintenance and removal; supplies, and labor; in place complete.	$ 15,000	$ 15,000
3	1	L.S.	Pre and Post construction survey	$ 2,000	$ 2,000
4	1	L.S.	Revegetation	$ 3,000	$ 3,000
5	1	L.S.	30-day maintenance period	$ 15,000	$ 15,000
6	1	L.S.	Water Quality monitoring	$ 36,200	$ 36,200
7	1	L.S.	Driectional Drilling, mobilization and demobilization	$ 50,000	$ 50,000
8	600	LF	12-inch HDPE pipe line installed by Driectional Drilling, measured by actual length of pipe installed in place	$ 175	$ 105,000
9	1	LS	Geotechnical borings (2 holes)	$ 15,000	$ 15,000
10	1	EA	Intake structure	$ 19,833	$ 19,833
11	1	EA	Outlet structure	$ 11,900	$ 11,900
12	1	EA	Transport intake and outlet structure	$ 2,800	$ 2,800
13	2	EA	Bridge intake and outlet access structure	$ 8,000	$ 16,000
14	1	EA	Gate valve control	$ 8,430	$ 8,430
15	2	EA	Depth sensor, in place complete.	$ 3,650	$ 7,300
				Total	**$ 332,061**

Design, Permitting and Post Bid Services

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Design & Cost Estimate	$ 45,000	$ 45,000
2	1	L.S.	Specifications & Bid Documents	$ 30,000	$ 30,000
3	1	L.S.	Permits (401, 404, 408, NPDES, Stream Alteration)	$ 45,000	$ 45,000
4	1	L.S.	Completed E.A. (arch. survey, socio-econcomic, flora & fauna)	$ 50,000	$ 50,000
5	1	L.S.	Construction Management (13% construction costs)	$ 43,168	$ 43,168
6	1	L.S.	As-builts	$ 6,000	$ 6,000
				Total	**$ 219,168**

Alternative B - Directional Drill Under Levee
Kawai Nui Marsh Pipe - Cost Estimate

Construction Bid

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Mobilization / demobilization (assumed 8% of the total bid for construction Bid excluding bid price for mobilization)	$ 20,397	$ 20,397
2	1	L.S.	Temporary Erosion & Pollution Control Measures, including installation of silt fencing ; inclusive of all necessary equipment all necessary equipment, maintenance and removal; supplies, and labor; in place complete.	$ 15,000	$ 15,000
3	1	L.S.	Pre and Post construction survey	$ 2,000	$ 2,000
4	1	L.S.	Revegetation	$ 3,000	$ 3,000
5	1	L.S.	30-day maintenance period	$ 15,000	$ 15,000
6	1	L.S.	Water Quality monitoring	$ 36,200	$ 36,200
7	1	L.S.	mobilization and demobilization	$ 50,000	$ 50,000
8	175	LF	12-inch fiberglass or concrete pipe line installed , measured by actual length of pipe installed in place	$ 300	$ 52,500
9	1	LS	Geotechnical borings (2 holes)	$ 15,000	$ 15,000
10	1	EA	Intake structure	$ 19,833	$ 19,833
11	1	EA	Outlet structure	$ 11,900	$ 11,900
12	1	EA	Transport intake and outlet structure	$ 2,800	$ 2,800
13	2	EA	Bridge intake and outlet access structure	$ 8,000	$ 16,000
14	1	EA	Gate valve control	$ 8,430	$ 8,430
15	2	EA	Depth sensor, in place complete.	$ 3,650	$ 7,300
				Total	**$ 275,361**

Design, Permitting and Post Bid Services

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Design & Cost Estimate	$ 45,000	$ 45,000
2	1	L.S.	Specifications & Bid Documents	$ 30,000	$ 30,000
3	1	L.S.	Permits (401, 404, 408, NPDES, Stream Alteration)	$ 45,000	$ 45,000
4	1	L.S.	USACE 404	$ 50,000	$ 50,000
4	1	L.S.	Completed E.A. (arch. survey, socio-econcomic, flora & fauna)	$ 50,000	$ 50,000
5	1	L.S.	Construction Management (13% construction costs)	$ 35,797	$ 35,797
6	1	L.S.	As-builts	$ 6,000	$ 6,000
				Total	**$ 261,797**

Alternative C - 1&2 a - Siphon Over Floodwall
Kawai Nui Marsh Pipe - Cost Estimate

Construction Bid

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Mobilization / demobilization (assumed 8% of the total bid for construction Bid excluding bid price for mobilization)	$ 23,039	$ 23,039
2	1	L.S.	Temporary Erosion & Pollution Control Measures, including installation of silt fencing ; inclusive of all necessary equipment all necessary equipment, maintenance and removal; supplies, and labor; in place complete.	$ 15,000	$ 15,000
3	1	L.S.	Pre and Post construction survey	$ 3,000	$ 3,000
4	1	L.S.	Revegetation	$ 3,000	$ 3,000
5	1	L.S.	30-day maintenance period	$ 15,000	$ 15,000
6	1	L.S.	Water Quality monitoring	$ 36,200	$ 36,200
7	680	LF	4 6-inch PVC Sch 80, pipe line installed by open trenching, measured by actual length of pipe	$ 68	$ 46,463
8	32	CY	Trench cut & fill	$ 323	$ 10,336
9	110	LF	Reinforced Concrete encasing. 6-inch around	$ 491	$ 54,038
10	1	L.S.	Ramp	$ 15,000	$ 15,000
11	1	EA	Intake structure	$ 19,833	$ 19,833
12	1	EA	Outlet structure	$ 11,900	$ 11,900
13	1	EA	Transport intake and outlet structure	$ 2,800	$ 2,800
14	2	EA	Bridge intake and outlet access structure	$ 8,000	$ 16,000
15	1	EA	Vacuum, self priming pump and controls	$ 13,257	$ 13,257
16	4	EA	Gate valve	$ 1,703	$ 6,813
17	1	EA	Valve box	$ 547	$ 547
18	1	EA	Solar panels, controls, installation, setup	$ 11,500	$ 11,500
19	2	EA	Depth sensor, in place complete.	$ 3,650	$ 7,300
				Total	**$ 311,026**

Design, Permitting and Post Bid Services

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Design & Cost Estimate	$ 55,000	$ 55,000
2	1	L.S.	Specifications & Bid Documents	$ 30,000	$ 30,000
3	1	L.S.	Permits (401, 408)	$ 45,000	$ 45,000
4	1	L.S.	USACE 404	$ 30,000	$ 30,000
5	1	L.S.	Completed E.A. (arch. survey, socio-econcomic, flora & fauna)	$ 50,000	$ 50,000
6	1	L.S.	Construction Management (13% construction costs)	$ 40,433	$ 40,433
7	1	L.S.	As-builts	$ 6,000	$ 6,000
				Total	**$ 256,433**

Alternative C-1&2 b - Siphon Through Floodwall
Kawai Nui Marsh Pipe - Cost Estimate

Construction Bid

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Mobilization / demobilization (assumed 8% of the total bid for construction Bid excluding bid price for mobilization)	$ 20,391	$ 20,391
2	1	L.S.	Temporary Erosion & Pollution Control Measures, including installation of silt fencing ; inclusive of all necessary equipment all necessary equipment, maintenance and removal; supplies, and labor; in place complete.	$ 15,000	$ 15,000
3	1	L.S.	Pre and Post construction survey	$ 3,000	$ 3,000
4	1	L.S.	Revegetation	$ 3,000	$ 3,000
5	1	L.S.	30-day maintenance period	$ 15,000	$ 15,000
6	1	L.S.	Water Quality monitoring	$ 36,200	$ 36,200
7	170	LF	12-inch PVC Sch 80, pipe line installed by open trenching, measured by actual length of pipe	$ 68	$ 11,616
8	35	CY	Trench cut & fill	$ 323	$ 11,305
9	170	LF	Reinforced Concrete encasing. 6-inch around	$ 393	$ 66,810
10	1	L.S.	Core through concrete floodwall	$ 3,656	$ 3,656
11	1	EA	Intake structure	$ 19,833	$ 19,833
12	1	EA	Outlet structure	$ 11,900	$ 11,900
13	1	EA	Transport intake and outlet structure	$ 2,800	$ 2,800
14	2	EA	Bridge intake and outlet access structure	$ 8,000	$ 16,000
15	1	EA	Vacuum, self priming pump and controls	$ 13,257	$ 13,257
16	1	EA	Gate valve & control	$ 6,711	$ 6,711
17	1	EA	Solar panels, controls, installation, setup	$ 11,500	$ 11,500
18	2	EA	Depth sensor, in place complete.	$ 3,650	$ 7,300
				Total	**$ 275,279**

Design, Permitting and Post Bid Services

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Design & Cost Estimate	$ 55,000	$ 55,000
2	1	L.S.	Specifications & Bid Documents	$ 30,000	$ 30,000
3	1	L.S.	Permits (401, 408)	$ 45,000	$ 45,000
4	1	L.S.	USACE 404	$ 38,000	$ 38,000
4	1	L.S.	Completed E.A. (arch. survey, socio-econcomic, flora & fauna)	$ 50,000	$ 50,000
5	1	L.S.	Construction Management (13% construction costs)	$ 35,786	$ 35,786
6	1	L.S.	As-builts	$ 6,000	$ 6,000
				Total	**$ 259,786**

Alternative D 1- Pump Over Floodwall
Kawai Nui Marsh Pipe - Cost Estimate

Construction Bid

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Mobilization / demobilization (assumed 8% of the total bid for construction Bid excluding bid price for mobilization)	$ 27,674	$ 27,674
2	1	L.S.	Temporary Erosion & Pollution Control Measures, including installation of silt fencing ; inclusive of all necessary equipment all necessary equipment, maintenance and removal; supplies, and labor; in place complete.	$ 15,000	$ 15,000
3	1	L.S.	Pre and Post construction survey	$ 3,000	$ 3,000
4	1	L.S.	Revegetation	$ 3,000	$ 3,000
5	1	L.S.	30-day maintenance period	$ 15,000	$ 15,000
6	1	L.S.	Water Quality monitoring	$ 36,200	$ 36,200
7	480	LF	4 6-inch PVC Sch 80, pipe line installed by open trenching, measured by actual length of pipe	$ 68	$ 32,797
8	32	CY	Trench cut & fill	$ 323	$ 10,336
9	110	LF	Reinforced Concrete encasing. 6-inch around	$ 491	$ 54,038
10	1	L.S.	Ramp	$ 15,000	$ 15,000
11	1	EA	Intake structure	$ 19,833	$ 19,833
12	1	EA	Outlet structure	$ 11,900	$ 11,900
13	1	EA	Transport intake and outlet structure	$ 2,800	$ 2,800
14	2	EA	Bridge intake and outlet access structure	$ 8,000	$ 16,000
15	1	EA	Self priming pump and controls	$ 13,257	$ 13,257
16	4	EA	Gate valve	$ 1,703	$ 6,813
17	1	EA	Valve box	$ 547	$ 547
18	1	EA	Solar panels, controls, installation, setup	$ 17,500	$ 17,500
19	2	EA	Depth sensor, in place complete.	$ 3,650	$ 7,300
20	1	L.S.	Electric line installation (electric poles, conduit, conductor, cable, trench, etc.)	$ 65,600	$ 65,600
				Total	**$ 373,596**

Design, Permitting and Post Bid Services

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Design & Cost Estimate	$ 60,000	$ 60,000
2	1	L.S.	Specifications & Bid Documents	$ 30,000	$ 30,000
3	1	L.S.	Permits (401, 404, 408, NPDES, Stream Alteration)	$ 45,000	$ 45,000
4	1	L.S.	USACE 404	$ 38,000	$ 38,000
4	1	L.S.	Completed E.A. (arch. survey, socio-econcomic, flora & fauna)	$ 50,000	$ 50,000
5	1	L.S.	Construction Management (13% construction costs)	$ 48,567	$ 48,567
6	1	L.S.	As-builts	$ 6,000	$ 6,000
				Total	**$ 277,567**

Alternative D-2 - Pump Through Floodwall
Kawai Nui Marsh Pipe - Cost Estimate

Construction Bid

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Mobilization / demobilization (assumed 8% of the total bid for construction Bid excluding bid price for mobilization)	$ 24,042	$ 24,042
2	1	L.S.	Temporary Erosion & Pollution Control Measures, including installation of silt fencing ; inclusive of all necessary equipment all necessary equipment, maintenance and removal; supplies, and labor; in place complete.	$ 15,000	$ 15,000
3	1	L.S.	Pre and Post construction survey	$ 3,000	$ 3,000
4	1	L.S.	Revegetation	$ 3,000	$ 3,000
5	1	L.S.	30-day maintenance period	$ 15,000	$ 15,000
6	1	L.S.	Water Quality monitoring	$ 36,200	$ 36,200
7	110	LF	12-inch PVC Sch 80, pipe line installed by open trenching, measured by actual length of pipe	$ 68	$ 7,516
8	35	CY	Trench cut & fill	$ 323	$ 11,305
9	110	CF	Reinforced Concrete encasing. 6-inch around	$ 393	$ 43,230
10	1	L.S.	Core through concrete floodwall	$ 3,656	$ 3,656
11	1	EA	Intake structure	$ 19,833	$ 19,833
12	1	EA	Outlet structure	$ 11,900	$ 11,900
13	1	EA	Transport intake and outlet structure	$ 2,800	$ 2,800
14	2	EA	Bridge intake and outlet access structure	$ 8,000	$ 16,000
15	1	EA	Self priming pump and controls	$ 13,257	$ 13,257
16	1	EA	Gate valve control	$ 8,430	$ 8,430
17	1	EA	Solar panels, controls, installation, setup	$ 17,500	$ 17,500
18	2	EA	Depth sensor, in place complete.	$ 3,650	$ 7,300
19	1	L.S.	Electric line installation (electric poles, conduit, conductor, cable, trench, etc.)	$ 65,600	$ 65,600
				Total	**$ 324,570**

Design, Permitting and Post Bid Services

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Design & Cost Estimate	$ 60,000	$ 60,000
2	1	L.S.	Specifications & Bid Documents	$ 30,000	$ 30,000
3	1	L.S.	Permits (401, 404, 408, NPDES, Stream Alteration)	$ 45,000	$ 45,000
4	1	L.S.	USACE 404	$ 38,000	$ 38,000
4	1	L.S.	Completed E.A. (arch. survey, socio-econcomic, flora & fauna)	$ 50,000	$ 50,000
5	1	L.S.	Construction Management (13% construction costs)	$ 42,194	$ 42,194
6	1	L.S.	As-builts	$ 6,000	$ 6,000
				Total	**$ 271,194**

Supplemental Alternative - Drainline at North End Kawai Nui Stream
Kawai Nui Marsh Pipe - Cost Estimate

Construction Bid

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Mobilization / demobilization (assumed 8% of the total bid for construction Bid excluding bid price for mobilization)	$ 14,910	$ 14,910
2	1	L.S.	Temporary Erosion & Pollution Control Measures, including installation of silt fencing ; inclusive of all necessary equipment all necessary equipment, maintenance and removal; supplies, and labor; in place complete. Turbidity curtains.	$ 20,000	$ 20,000
3	1	L.S.	Pre and Post construction survey	$ 2,000	$ 2,000
4	1	L.S.	Revegetation	$ 3,000	$ 3,000
5	1	L.S.	30-day maintenance period	$ 15,000	$ 15,000
6	1	L.S.	Water Quality monitoring	$ 36,200	$ 36,200
7	108	CY	Trench excavation	$ 408	$ 44,064
8	100	LF	24" concrete reinforced pipe	$ 116	$ 11,578
9	1	LS	Dewater setup	$ 20,000	$ 20,000
10	1	EA	Intake structure	$ 19,833	$ 19,833
11	1	EA	Outlet structure	$ 11,900	$ 11,900
12	1	EA	Transport intake and outlet structure	$ 2,800	$ 2,800
				Total	**$ 201,286**

Design, Permitting and Post Bid Services

Item No.	Est. Qty	Unit	Description	Unit	Total
1	1	L.S.	Design & Cost Estimate	$ 30,000	$ 30,000
2	1	L.S.	USACE 404	$ 38,000	$ 38,000
3	1	L.S.	Construction Management (13% construction costs)	$ 26,167	$ 26,167
4	1	L.S.	As-builts	$ 5,000	$ 5,000
				Total	**$ 99,167**

APPENDIX C

ALTERNATIVE DESIGNS

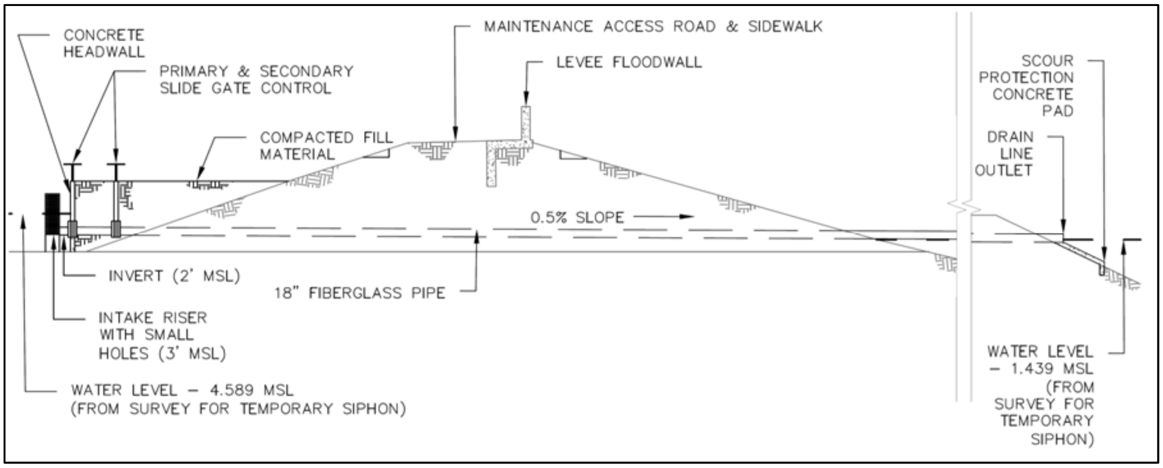

Figure 10. Alternatives A1 or A2. Gravity Pipe Placed through the Levee.

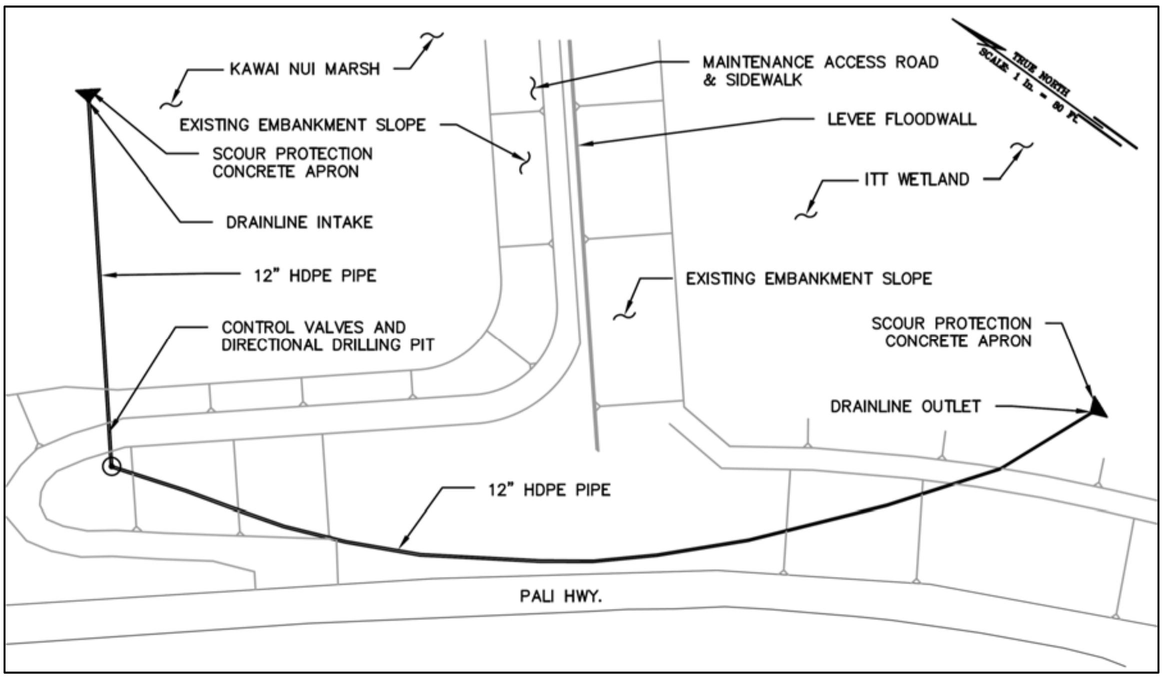

Figure 11. Alternative A3 plan view, gravity line around levee.

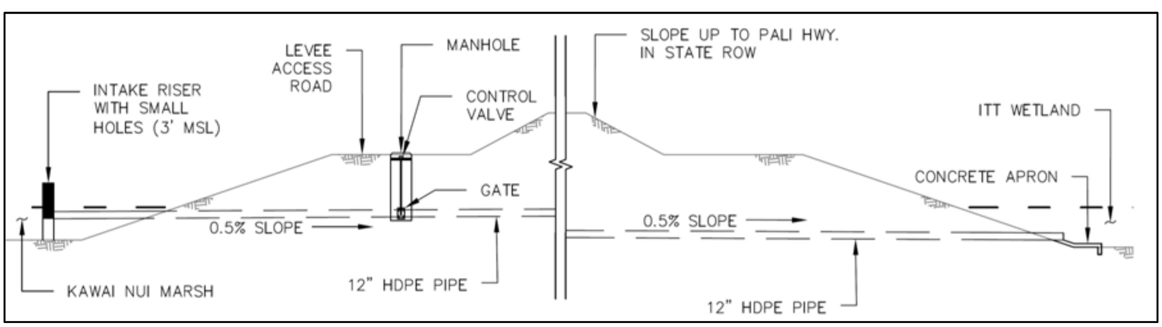

Figure 12. Alternative A3, alignment section of gravity line around end of levee.

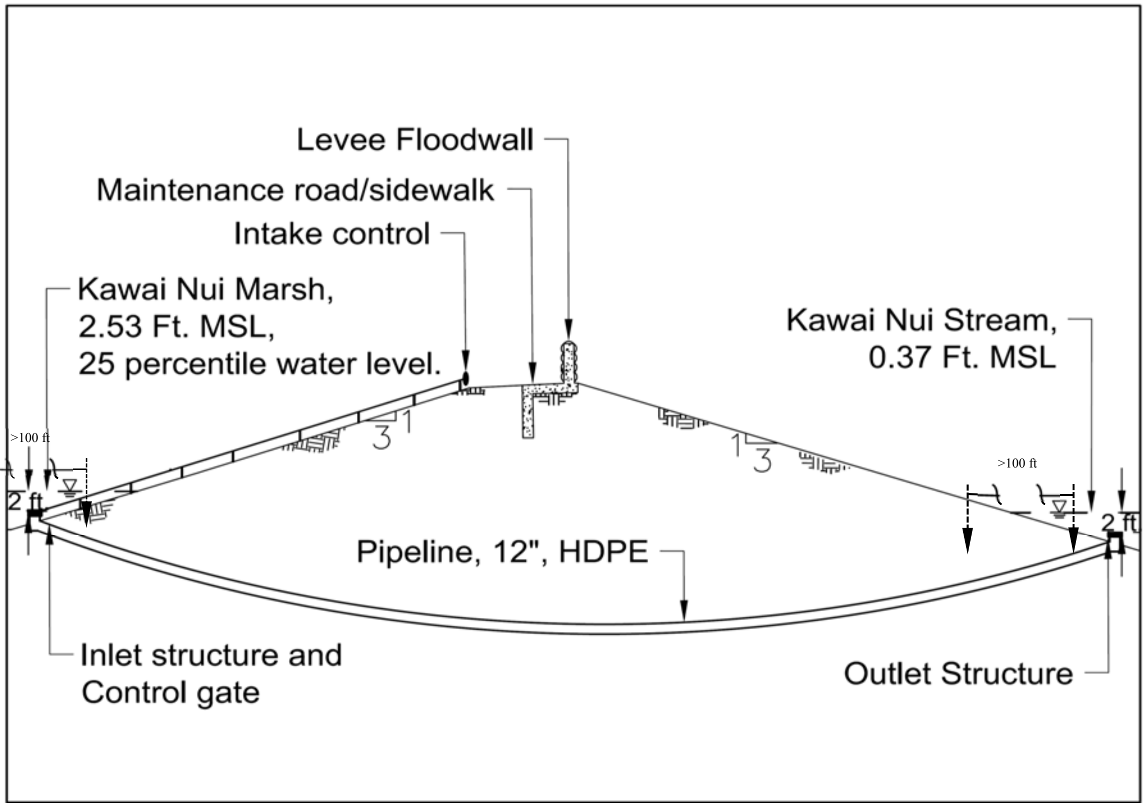

Figure 13. Alternative B-1 or B-2: inverted siphon pipeline under the Levee. Drawing not to scale: intake and outflow ends of pipe would need to be 50-100 feet away from the base of the levee.

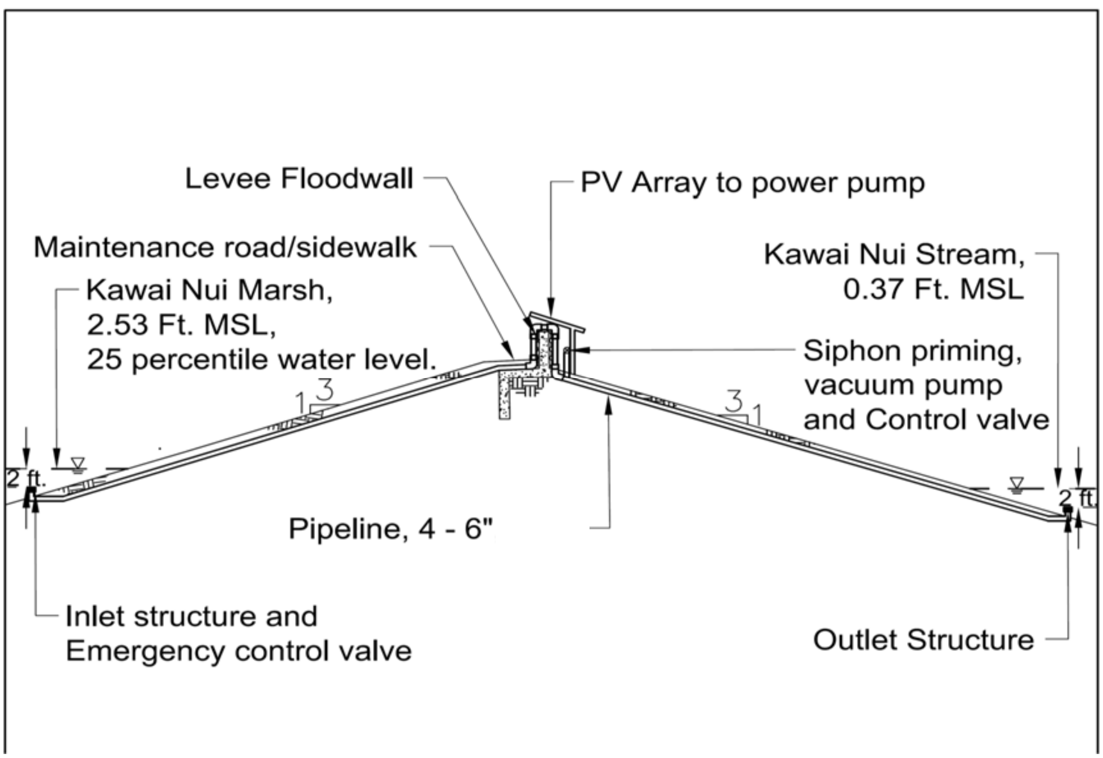

Figure 14. Alternative C-1a or C-2a: siphon pipeline over the Levee

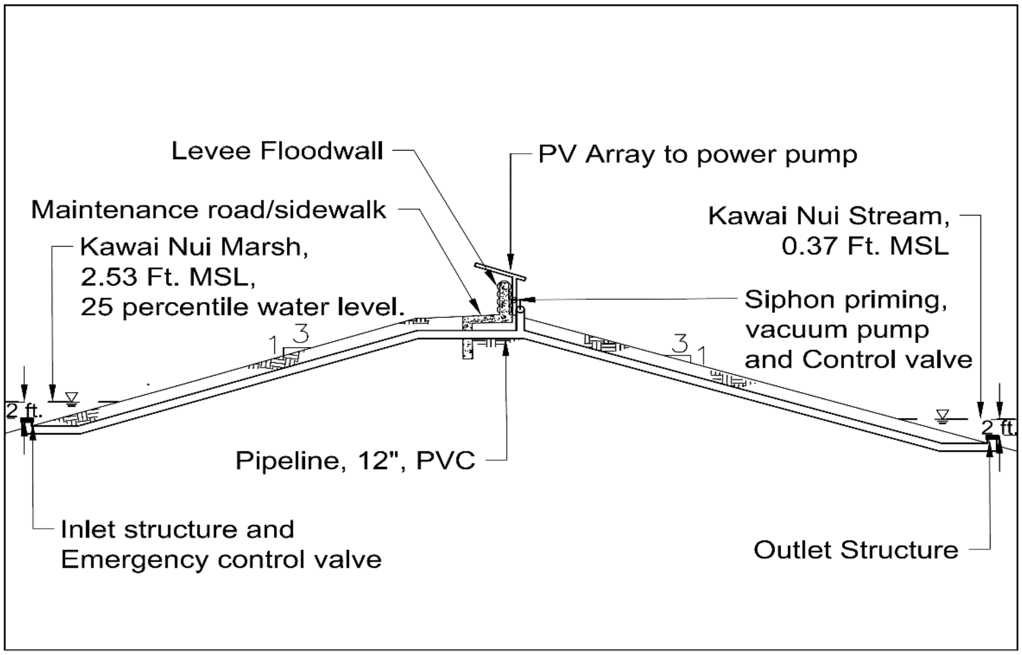

Figure 15 Alternative C-1b or C-2b: siphon pipeline through Levee floodwall

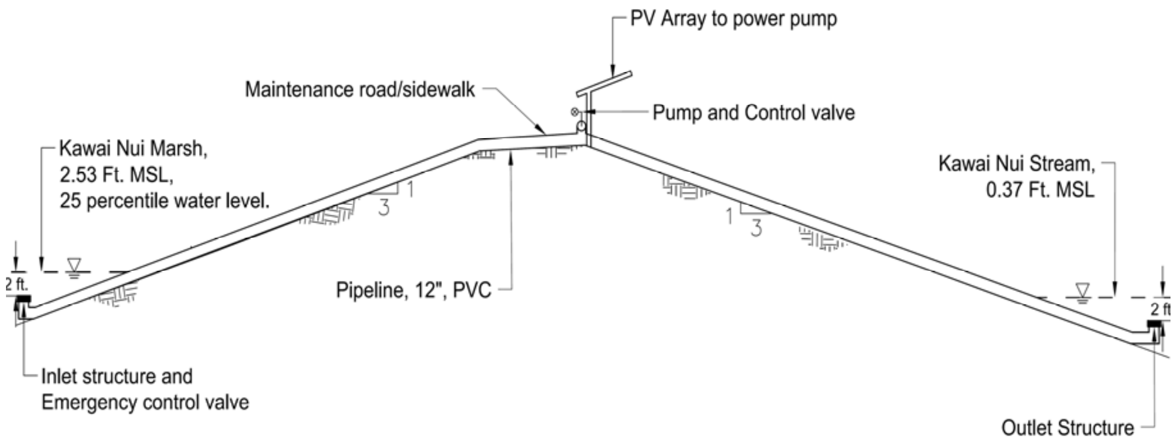

Figure 16. Alternative D-1, pump controlled pipe over the Levee.

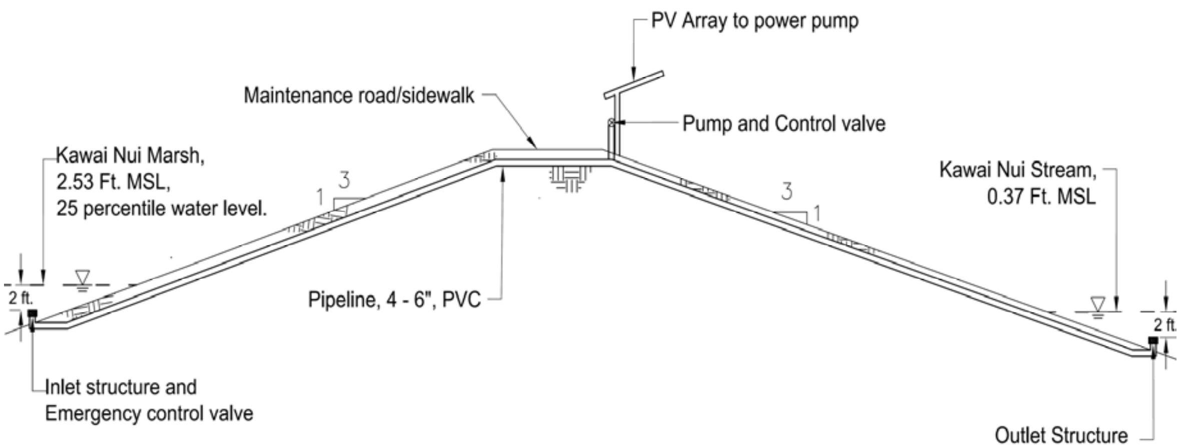

Figure 17 Alternative D-2, pump controlled pipe through Levee floodwall.