PAS STUDY
FOR
HANAPEPE RIVER AND WAIMEA RIVER
ISLAND OF KAUAI, HAWAII

DEPARTMENT OF THE ARMY

U.S. ARMY CORPS OF ENGINEERS

HONOLULU DISTRICT

FORT SHAFTER, HAWAII

February 2013

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FOR HANAPEPE RIVER AND WAIMEA RIVER
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Executive Summary

STUDY PURPOSE. The purpose of this study is to use an updated HEC-RAS model with new bathymetry data to study improvements that would allow the current levee system to be accredited (meets Federal Emergency Management Agency (FEMA) and U.S. Army Corps of Engineers (USACE) guidance) versus the 1-percent chance flood.

ALTERNATIVES INVESTIGATED. Alternative 1 will raise the levee system to provide three feet of freeboard above the 1% chance flood. Alternative 2 would include dredging the channel to achieve three feet of freeboard above the 1% chance flood; this alternative did not have three feet of freeboard along the entire levee system. Alternative 3 used a combination of dredging the channel and raising the levee system to provide three feet of freeboard above the 1% chance flood. Alternative 4 is a non-structural alternative that would combine purchasing structures and elevating structures adjacent to the rivers. Alternative 5 is a peak flow reduction scenario. A limited interior drainage analysis for adequacy of existing drainage structures was also done for both levee systems. A conceptual design and cost estimate was prepared for a pump station at Waimea.

RECOMMENDED ALTERNATIVES. Alternative 1 – Levee Raise, is the preferred alternative for the Hanapepe River FCP. The estimated cost is the second lowest cost of the five alternatives, Alternative 2 has the lowest cost but it does not provide three feet of freeboard along the entire levee system above the 1% chance flood, therefore, it would not be accredited by FEMA and USACE. This alternative has the lowest risk to life safety. Operations and Maintenance (O&M) cost will be lower than three other alternatives. This alternative provides 98.10 to 99.99% assurance against the 1% chance flood and also provides at least three feet of freeboard above the 1% chance flood along the entire levee system. The construction involved in this alternative will allow this project to be certified by the National Flood Insurance Program (NFIP) Levee System Evaluation. This alternative consists of raising the existing right and left bank levees by 1 ft (feet) to 4.9 ft with an estimated construction cost of $9.4 Million.

Alternative 1 – Levee Raise, is the preferred alternative for the Waimea River FCP. The estimated cost is the lowest cost of the five alternatives. This alternative has the lowest risk to life safety. Operations and Maintenance (O&M) cost will be lower than three other alternatives. This alternative provides 90.00 to 99.99% assurance against the 1% chance flood and provides at least three feet of freeboard above the 1% chance flood along the entire levee system. The construction involved in this alternative will allow this project to be certified by the National Flood Insurance Program (NFIP) Levee System Evaluation. This alternative consists of raising the existing right bank levee by 1 ft to 4 ft along its entire length with an estimated construction cost of $7.3 Million.

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PAS STUDY FOR
HANAPEPE RIVER AND WAIMEA RIVER
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1. INTRODUCTION.

1.1. Purpose. The purpose of this study is to evaluate structural and nonstructural alternatives that would allow the current levee systems at Hanapepe and Waimea to be accredited (meets FEMA and USACE guidance) versus the 1% chance flood. HEC-RAS models for both Hanapepe and Waimea River were updated using new bathymetry data. A levee raise is an obvious alternative to be investigated because this will prevent the levee from overtopping. Sediment deposits have built up in the river over time possibly decreasing the channel capacity which is why a dredging alternative was investigated. A non-structural alternative was evaluated to see if there was another way to provide flood risk reduction without modifying the existing floodplain. A peak flow reduction alternative for flood mitigation was evaluated to see what volume of water would need to be stored to reduce the 1% chance flood water surface elevation to have 3 feet of freeboard. Also, an interior drainage analysis was conducted to determine in greater detail the interior flooding inputs and depths behind the levees. The structural alternatives would allow the levee systems to be accredited by the NFIP Levee System Evaluation as passing the 1% chance flood with 90% assurance.

1.2. Scope. This report describes results from the hydraulic methodologies used to evaluate the Hanapepe River and Waimea River Levee Systems. Structural alternative techniques investigated for flood mitigation consist of a levee raise, channel dredging, combination of a levee raise and channel dredging. Alternative 1 will raise the levee system to provide three feet of freeboard above the 1% chance flood. Alternative 2 would include dredging the channel to achieve three feet of freeboard above the 1% chance flood; this alternative did not have three feet of freeboard along the entire levee system. Alternative 3 used a combination of dredging the channel and raising the levee system to provide three feet of freeboard above the 1% chance flood. Alternative 4 is a non-structural alternative that would combine purchasing structures and elevating structures adjacent to the rivers. Alternative 5 is a peak flow reduction scenario. A limited interior drainage analysis for adequacy of existing drainage structures was also done for both towns. A conceptual design and cost estimate was prepared for a pump station at Waimea.

1.3. Authority. This project was conducted under the Planning Assistance to States (PAS) program following a request by the County of Kauai. The authorization is found in Section 22 of the Water Resources Development Act (WRDA) of 1974 (Public Law 93-251) and Section 319 of the Water Resources Development Act of 1990 (Public Law 101-640).

2. **STUDY AREA**.

2.1. Location. The island of Kauai is the 4th largest in the Hawaiian Island archipelago, and it encompasses 562.3 square miles. The Hanapepe and Waimea Rivers are both on the south side of the island of Kauai.

Hanapepe River and its tributaries drain an area of about 27 square miles of the south central side on the Island of Kauai. The river flows through Hanapepe Town into Hanapepe Bay. The levee system is located on both banks of the Hanapepe River as it flows through town (**Figure 1**). There are over 2,000 people and businesses protected by this levee system.

Waimea River and its tributaries drain an area of about 85 square miles (mi^2) of the south west side on the Island of Kauai. The main tributary to Waimea River is Makeweli River which has a drainage area of 26 mi^2 which joins Waimea River about 1.1 miles upstream from the Waimea River mouth. The river flows through Waimea Town into Waimea Bay. The levee system is located on right bank of the Waimea River as it flows through the town (**Figure 1A**). There are approximately 2,000 people and businesses protected by this levee system.

2.2. Project Features.

2.2.1. Hanapepe River FCP. The components of the authorized project consist of a 2,200-foot long earth levee with floodwall connecting to a 185-foot long concrete floodwall along the left bank commencing at the Kaumualii (formerly known as Belt) Highway Bridge about 1/3 mile upstream of the river mouth and extending to the cliffs at the northeast corner of the town of Hanapepe; and a 4,465-foot long earth fill levee along the right bank, commencing at the old highway bridge (Hana Road) about ½ mile upstream of the river mouth and extending upstream to high ground (**Figure 1**). Improvements on the left and right banks were essentially completed in December 1959 and August 1963 respectively. Construction involving raising the height of the levees and floodwall of the existing project were completed in November 1966. Flood wall designs were cast-in-place reinforced concrete walls except for one segment along the upstream end of the left bank which is much taller and of I-wall type construction. Interior drainage features include three drainage structures in the right bank levee and two drainage structures in the left bank levee.

2.2.2. Waimea River FCP. The authorized project consists of a levee extending 770 ft downstream from the Kaumualii (formerly Belt) Highway Bridge to the coast line area, 335 ft of concrete floodwall between the Kaumualii Highway Bridge and main floodgate, 3,500 ft of concrete rubble masonry (CRM) floodwall on the existing levee in three segments, a 500 ft road raise, levee toe protection extending about 4,600 ft upstream from the Kaumualii Highway Bridge, and three interior drainage structures: two 24 inch diameter concrete pipes with flap gates and another outlet structure with five-60 inch concrete pipes, each with sluice and flap gates (**Figure 1A**).

Prior to the federal project, the County of Kauai and the then Territory (now State) of Hawaii widened the river channel and began construction of an earth-fill levee with the excavated material starting in 1950 and completed in 1954 as a result of the devastating February 1949 flood. This 6,650 ft long levee started about 300 ft upstream of the Kaumualii Highway Bridge. In 1952, more work to the levee was done including a grouted rip-rap lining on the riverside, a 300-ft reinforced concrete retaining wall, and related interior drainage facilities which include eleven gravity drain lines, eight of which were considered abandoned due to poor maintenance in the interior flood design (*U.S. Army Corps of Engineers, 1982*). The other three drainage structures are used for irrigation return flows.

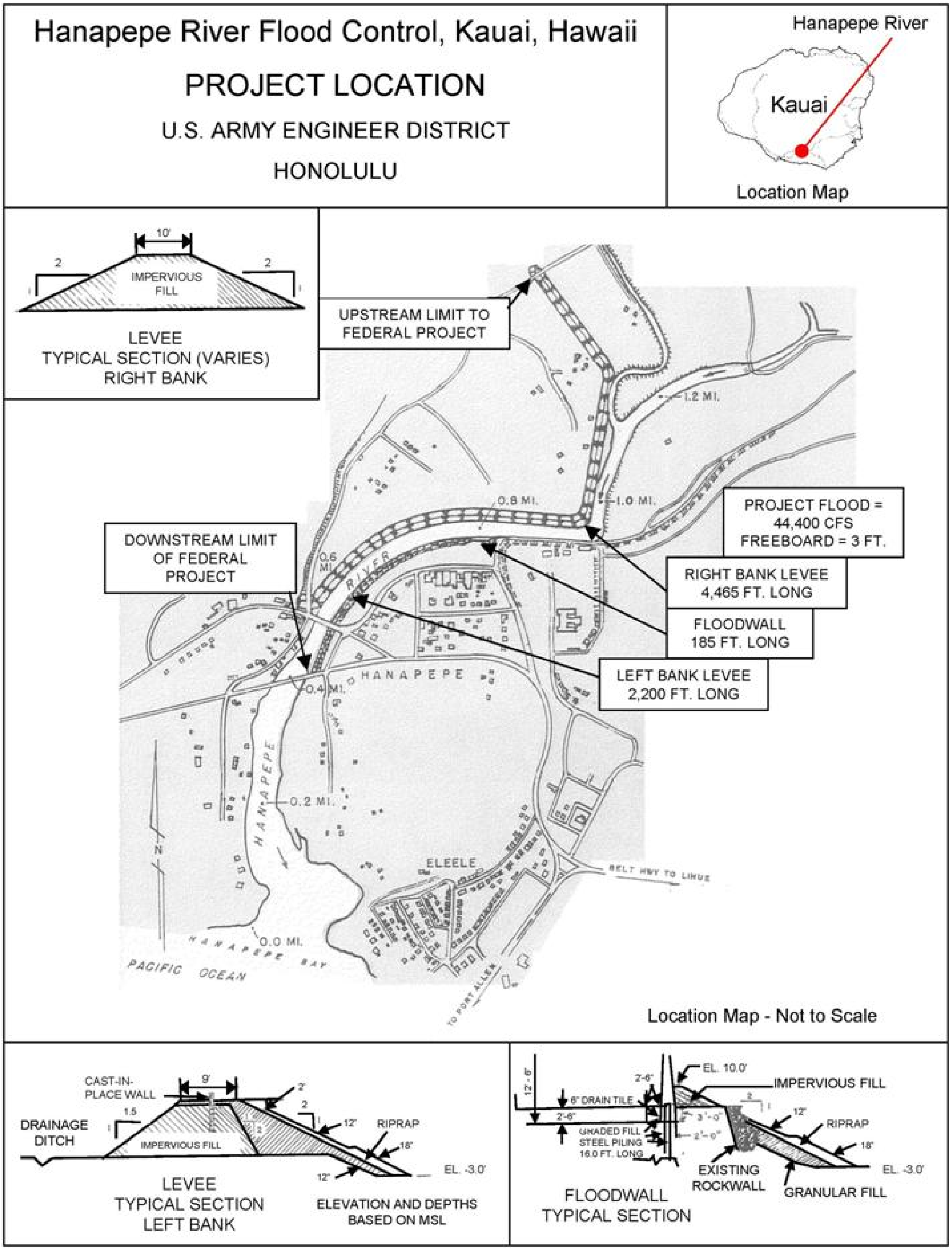


Figure 1. Location Map for Hanapepe River FCP, Hanapepe, Kauai

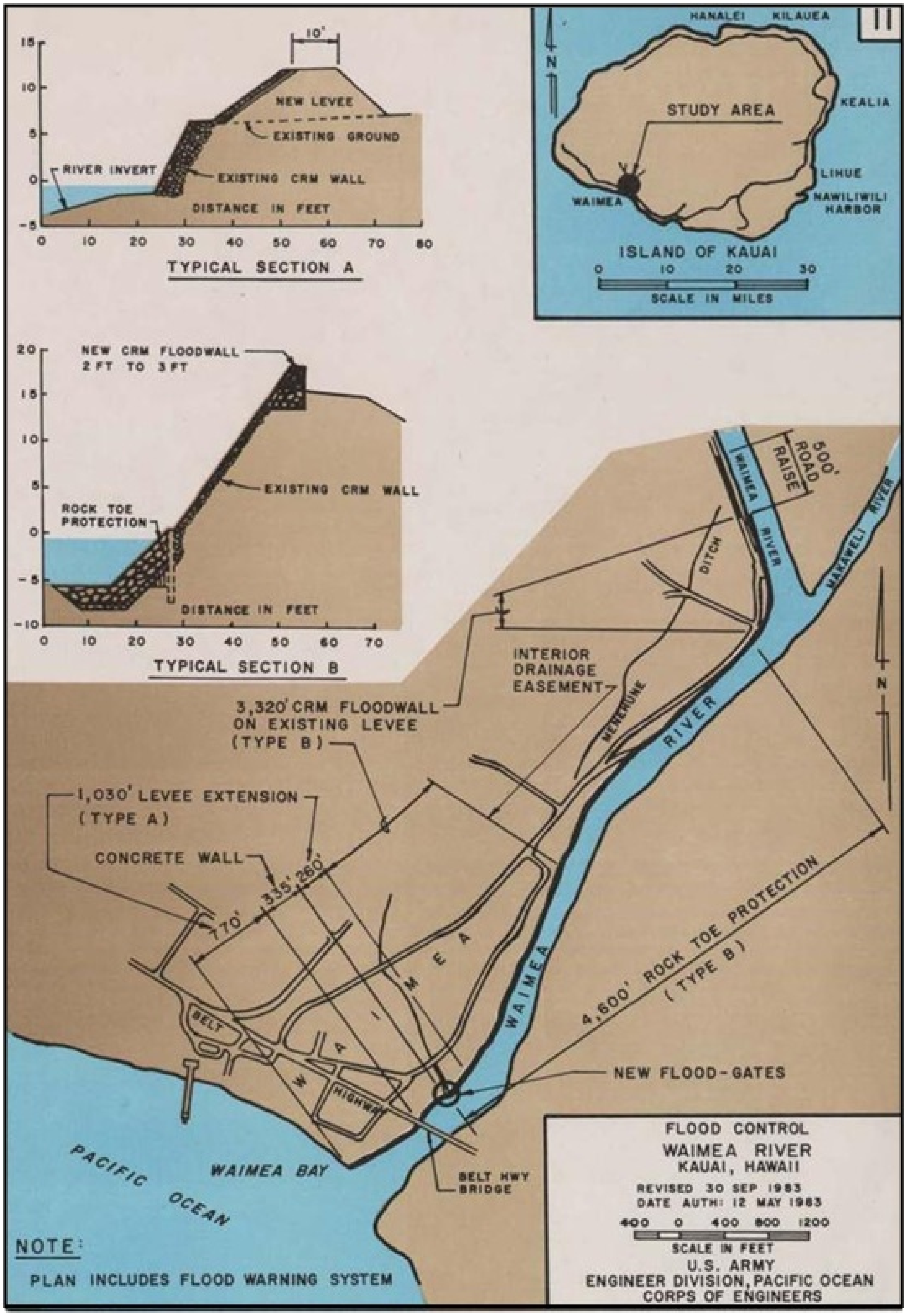


Figure 1a. Location Map for Waimea River FCP, Waimea, Kauai

3. **PREVIOUS STUDIES**.

3.1. Hanapepe River FCP. In April 2004, a re-evaluation study was completed for Hanapepe River based on new channel cross-section survey data collected in May 2003 (*U.S. Army Corps of Engineers, 2004*). A HEC-RAS model was created using this data and the previous data from the 1962 as-built drawings. The existing levee system was built to the project design flood of 25,600 ft^3/s which has a recurrence of a 3.3% (approximately 30 year flood) chance flood. The estimated protection provided by the existing levee system is a 1.25% chance (approximately 80-year) flood event of 34,800 ft^3/s. The re-evaluation study also computed effects of super-elevation of the water-surface at the river bends. If these effects are incorporated the level of protection drops to between a 3.3% to 2% chance (30- to 50-year) flood event. The left bank I-wall was analyzed following USACE guidance (*Department of the Army, 2006)* which was published as a result of I-wall failures in New Orleans due to hurricane Katrina. The results of this analysis indicated that the I-wall may fail when subjected to a 1% chance flood under steady state seepage conditions (*Geolabs, 2007*). USACE guidance on correcting I-wall deficiencies is still forthcoming.

The Hydrologic and Hydraulic Evaluation for Levee Certification Report (*U.S. Army Corps of Engineers, 2010*) stated that the Hanapepe Levee System does not meet either FEMA requirement of three feet of freeboard above the 1% chance flood or 90% assurance against overtopping by the 1% chance flood with two feet of freeboard. The left bank levee elevations do provide at least 90% assurance against the 1.2% chance (83-year) flood. However, the left bank levee also has an I-wall which did not pass the USACE Phase 2 I-wall guidance check versus the 1% chance flood. The right bank levee segment, due to a low elevation section at the downstream bend, can only provide a 65% assurance against the 10% chance flood. The upstream portions of the right bank levee do provide a greater level of assurance, up to the 3% chance flood with 90% assurance. To meet FEMA accreditation requirements, the right bank levee would need to be raised from 2.3 to 7.3 feet and the left bank would need to be raised about 2.1 feet.

3.2. Waimea River FCP. The Hydrologic and Hydraulic Evaluation for Levee Certification Report (*U.S. Army Corps of Engineers, 2010*) stated that the Waimea Levee System does not meet either FEMA requirement of three feet of freeboard above the 1% chance flood or 90% assurance against overtopping by the 1% chance flood with two feet of freeboard. The upstream section of the levee system which consists of a raised road section did not have sufficient height to safely pass the 1% chance flood. The levee system does provide protection against the 3% chance flood with an 87% and higher level of assurance. To meet FEMA accreditation requirements, the levee will need to be raised from 2.2 to 3.0 feet higher than current elevations.

4. **HYDRAULIC EVALUATION.**

4.1. Existing Conditions.

4.1.1. Hydrology Used. The hydrology used for both the Hanapepe River and Waimea River Levee Systems in this report were taken from the Hanapepe River and Waimea River Levee Certification Reports (*U.S. Army corps of Engineers, 2010*).

4.1.2. Hydraulics Updated. This phase of the study consisted of developing the existing conditions of the floodplain using the HEC-RAS version 4.0 model. HEC-RAS (River Analysis System) is a one-dimensional hydraulic model (*U.S. Army Corps of Engineers, 2008a*). The HEC-RAS models from the 2010 Levee Certification Report were used for this hydraulic analysis, newer topographic data was used to update this hydraulic model. During this phase, a steady flow back-water (sub-critical) analysis was conducted using the HEC-RAS computer program to determine the flood elevations and floodplains within the study limits for the 50-, 20-, 10-, 5-, 2-, 1-, 0.5-, and 0.2- percent chance exceedance floods (2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year floods). Selected plots of the water-surface profiles and the floodplains are included and discussed in the following sections of this report. Debris blockage analyses at bridges or channel constrictions were not done as part of this study.

4.1.2.1. Terrain Data. Terrain data was taken from the 2010 Levee Certification Reports. Specific river cross-sections were modified within the stream channel bathymetry using the 2011 topographic data collected by Sam O. Hirota (*2011*) for both the Hanapepe River and the Waimea River. The 2011 bathymetry data for Hanapepe River showed that the invert changed roughly plus or minus 2 feet but overall the cross-sectional areas of the selected cross-sections did not change significantly from the 2010 HEC-RAS model. The 2011 bathymetry data for Waimea River showed that the invert changed roughly plus or minus 2 feet and overall the cross-sectional areas of the selected cross-sections did indicate a reduction in area from the 2010 HEC-RAS model.

4.1.2.2. Floodplain Modeling. The study boundary for the floodplain is defined by high ground on either side of Hanapepe River and Waimea River. **Figure 2** and **Figure 2a** show the locations of selected HEC-RAS cross-sections covering the Hanapepe River and the Waimea River areas. Levee elevations were based on the survey done by Sam 0. Hirota in 2011. The bathymetric portions of the cross-sections were also adjusted from the 2011 survey data. Bridge geometry data was not changed from the 2010 Levee Certification model. The channel and overbank areas were modeled with Manning's n-values (roughness coefficients) from the previous levee certification model, which were 0.025 for the Hanapepe channel and 0.1 for both the left and right overbank areas. The Waimea channel had n-values of 0.03 and 0.025, and a range from 0.04 to 0.08 for the overbank areas. Starting water-surface elevation was 0 ft for all peak flow inputs. The model defaulted to critical depth for all cases. Standard values of 0.1 and 0.3 were used for the contraction and expansion coefficients. Bridge modeling allowed for momentum and pressure flow solutions if necessary.

Results of the Hanapepe modeling show that there are five cross-sections on the right bank levee and five on the left bank levee which are overtopped by the 1% chance exceedance flood. The right bank levee was overtopped at river station 3940 and then overtopped the rest of the way downstream. The left bank levee was overtopped at every cross-section upstream of Old Highway Bridge except at cross-section 3248, the entire levee upstream of the bridge will probably be overtopped during the 1% chance Exceedance flood.

Six cross-sections in the Waimea model are overtopped by the 1% chance exceedance flood. Five of the most upstream cross-sections were overtopped and the last cross-section all the way at the downstream end of the levee was overtopped. This means that majority of the levee system does not get overtopped by the 1% chance Exceedance flood but there is not at least three feet of freeboard along the entire levee.

Section 5.4 of the Hanapepe River Levee Certification Report (*U.S. Army Corps of Engineers, 2010*) and Section 5.4.1 of the Waimea River Levee Certification Report stated the levee height elevations were assumed to have an accuracy of plus or minus 0.25 feet. The Sam O. Hirota survey done in 2011 used the same benchmarks that were used to do the levee height survey for the 2010 Levee Certification Reports. Differences between the 1% chance flood and the height of the levees are shown in **Table 1** and **Table 2**. The 1% chance flood water-surface elevation plots are presented in **Figure 3** and **Figure 3A.**

To determine the sensitivity of the water-surface elevation results, the Manning's n values were increased by 20 percent and decreased by 20 percent. The resulting average difference of water-surface elevation results were 0.69 feet for Hanapepe and 3.06 feet for Waimea which converts to a standard deviation of 0.17 feet for Hanapepe and 0.76 feet for Waimea based on guidance in the Risk-based Analysis for Flood Damage Reduction Studies, EM 1110-2-1619 (*Department of the Army, 1996; page 5-6*). This means that the variation or dispersion of the water-surface elevations are close to the mean for the Hanapepe River HEC-RAS model and further away from the mean for the Waimea River HEC-RAS model. Since both the Hanapepe and Waimea River models had a standard deviation less than one foot both models appear to be sufficient.

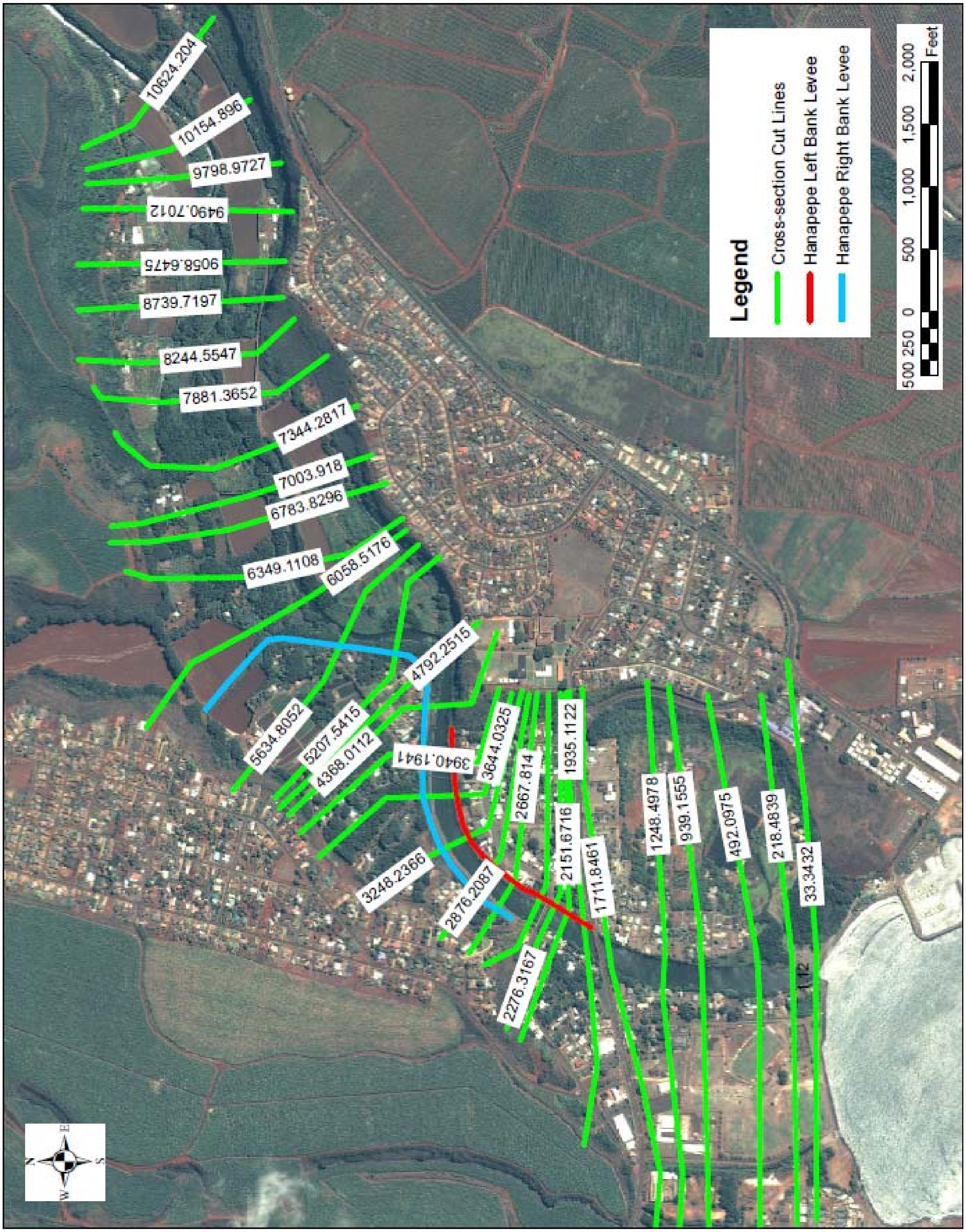


Figure 2. HEC-RAS Model Layout for Hanapepe River

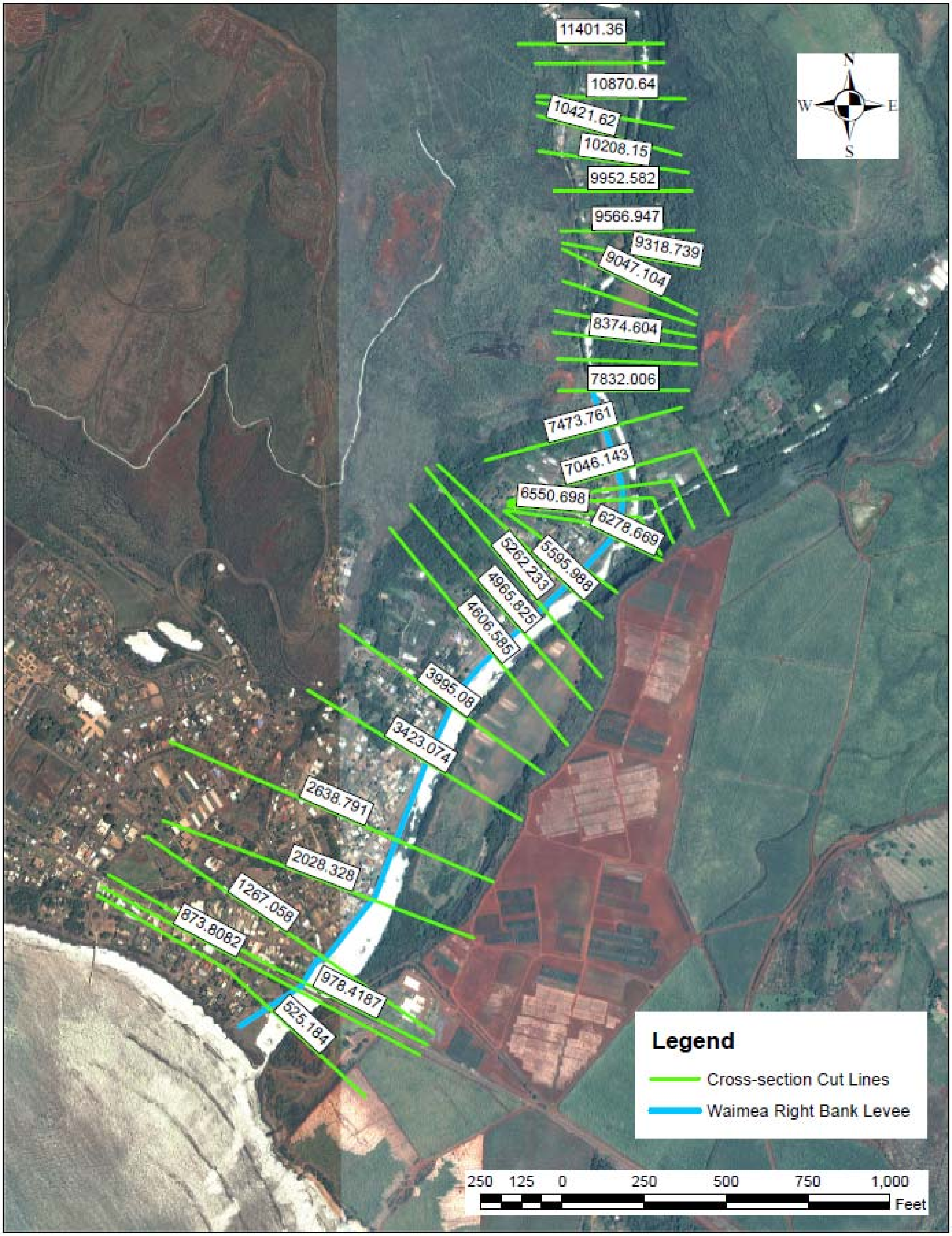


Figure 2a. HEC-RAS Model Layout for Waimea River

Table 1. Existing Levee Heights and Water-Surface Elevations for the 1% Chance Flood Hanapepe Levee System, Kauai, Hawaii

HEC-FDA Index Station	River Station in HEC-RAS Model	Right Bank Levee Height (ft)	Left Bank Levee Height (ft)	1% chance flood (100-year) WSEL (ft)	Difference between Right Bank Levee Height & 1% chance WSEL (ft)	Difference between Left Bank Levee Height & 1% chance WSEL (ft)
RB 1	6058.52	**20.83**	----	19.75	1.08	----
RB 2	5634.81	**19.86**	----	19.84	0.02	----
	5207.54	**19.46**	----	19.36	0.10	----
	4792.25	**18.97**	----	17.94	1.03	----
	4368.01	**17.34**	----	16.64	0.70	----
	3940.19	**15.70**	**16.39**	16.56	-0.86	-0.17
	3644.03	**15.33**	**15.88**	16.61	-1.28	-0.73
RB 3	3248.24	**14.57**	**15.27**	15.73	-1.16	-0.46
	2876.21	**14.64**	**15.16**	15.71	-1.07	-0.55
LB 1	2667.81	**14.14**	**14.93**	15.57	-1.43	-0.64
	2405.24	----	**14.93**	15.42	----	-0.49
	2400	Old Hanapepe Road Bridge				
	2276.32	----	**13.81**	11.18	----	2.63
	2151.67	----	**13.79**	11.51	----	2.28
	1935.11	----	**13.63**	11.95	----	1.68
	1860.69	----	**13.44**	11.53	----	1.91
	1800	Kaumualii Highway Bridge				

WSEL = Water-Surface Elevation

Table 2. Existing Levee Heights and Water-Surface Elevations for the 1% Chance Flood Waimea Levee System, Kauai, Hawaii				
HEC-FDA Index Station	River Station in HEC-RAS Model	Right Bank Levee Height (ft)	1% chance flood (100-year) WSEL (ft)	Difference between Right Bank Levee Height & 1% chance WSEL (ft)
Road	7473.761	**26.43**	26.48	-0.05
	7046.143	**25.13**	26.49	-1.36
	6857.568	**24.72**	26.28	-1.56
	6729.097	**24.59**	25.58	-0.99
Bend	6550.698	**23.67**	25.75	-2.08
	6278.669	**22.88**	19.14	3.74
	5843.995	**22.15**	19.94	2.21
	5595.988	**21.60**	19.59	2.01
	5262.233	**21.21**	17.80	3.41
Middle	4965.825	**20.53**	18.11	2.42
	4786.20*	**20.29**	18.41	1.88
	4606.585	**20.05**	18.35	1.70
	4402.75*	**19.60**	18.28	1.32
	4198.91*	**19.15**	18.21	0.94
	3995.080	**18.70**	18.16	0.54
	3709.07*	**18.53**	18.41	0.12
	3423.074	**18.36**	17.94	0.42
	3161.64*	**18.15**	17.56	0.59
	2900.21*	**17.95**	17.20	0.75
	2638.791	**17.74**	16.79	0.95
	2333.56*	**17.44**	16.58	0.86
Lower	2028.328	**17.14**	16.30	0.84
	1774.57*	**16.51**	14.62	1.89
	1520.81*	**15.87**	14.77	1.10
	1267.058	**15.24**	14.67	0.57
	978.4187	**16.72**	14.42	2.30
	914.8191	**Bridge**	----	----
	873.8082	**13.88**	13.19	0.69
Downstream Bridge	525.184	**10.53**	11.6	-1.07
WSEL = Water-Surface Elevation, * = Interpolated Cross Sections				

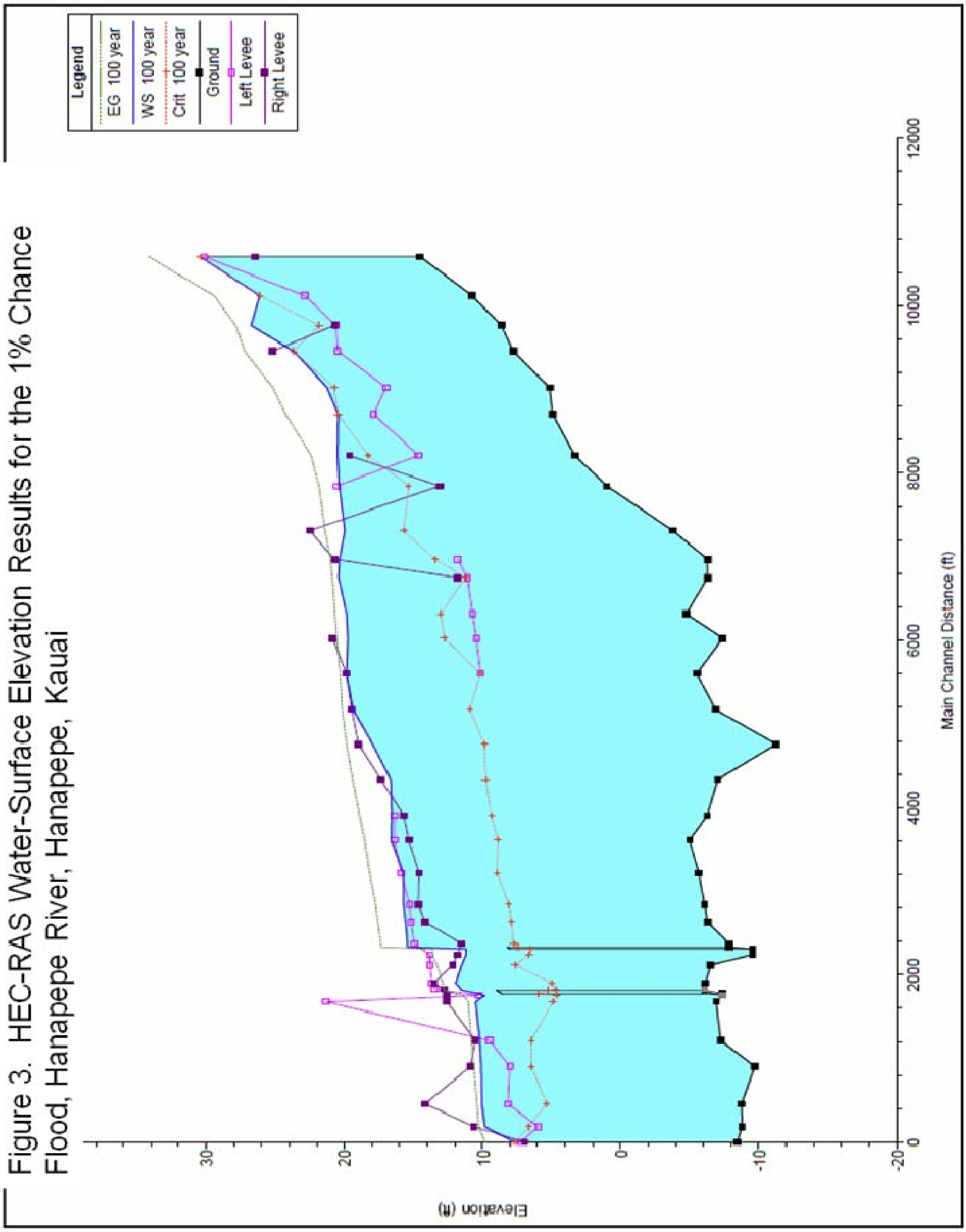
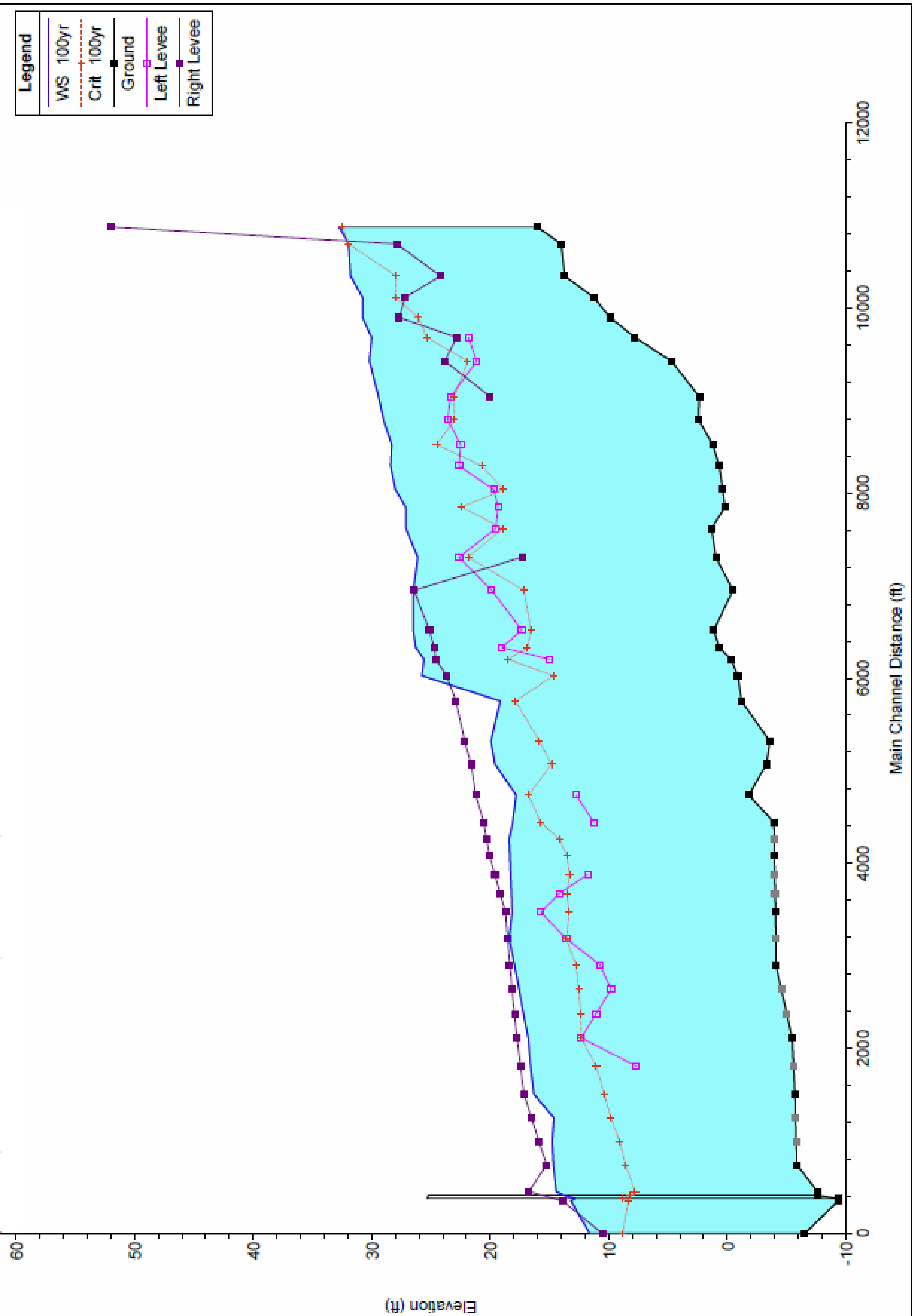


Figure 3. HEC-RAS Water-Surface Elevation Results for the 1% Chance Flood, Hanapepe River, Hanapepe, Kauai

Figure 3a. HEC-RAS Water-Surface Elevation Results for the 1% Chance Flood, Waimea River, Waimea, Kauai



4.2. Alternative 1 - Levee Raise. This levee raise design was based on providing a three foot freeboard above the 1% chance flood event along the entire levee system for both the Hanapepe River FCP and the Waimea River FCP. This alternative design has the lowest life safety risk compared to the other alternatives and there will be little added maintenance required after construction compared to current maintenance requirements. Life safety risk is an assumption based on after the alternative is completed, what the probability of the alternative failing and if it does fail what is the probability distribution of life loss. This report broke it into three categories, low, medium and high. Low meaning that this alternative has a lower probability of life loss compared to the alternative listed as high.

4.2.1. Hanapepe River FCP. This alternative would include raising both the right and left bank levees. See **Figure 2** for the plan view of the levees. This would consist of raising the entire 4,465 linear feet of the right bank levee by 2.0 to 4.9 feet. The right bank levee raise would be raised by constructing a concrete floodwall on top of the existing earthen levee (**Figure 4** and **Figure 5a**). The entire 2,200 linear feet of the earthen left bank levee will also be raised by 1.0 to 4.0 feet (**Figure 4** and **Figure 5b**). The entire 185 linear foot section of the left bank I-Wall will be backfilled on the land side all the way up to the top of the I-Wall with a 10 foot wide crest then sloped down a 2 to 1 sideslope. The river side of the I-Wall will also be backfilled see **Figure 5**. A new concrete floodwall will then be constructed on the earthen levee behind the I-Wall as shown on **Figure 5**. This concrete floodwall will have a height of 2.5 to 3.5 feet. This will establish a 3 foot freeboard above the 1% chance flood event along the entire levee system.

The estimated cost for Alternative 1 for the Hanapepe River FCP is $9.4 million.

4.2.2. Waimea River FCP. This alternative design would include raising the right bank levee. See **Figure 2a** for the plan view of the right bank levee. This would consist of raising the entire 7,620 linear feet of right bank levee by 1 to 4 feet. Majority of the right bank levee raise would consist of constructing a concrete wall on top of the existing earthen levee (**Figure 4a**). Some of the existing earthen levee will have to be raised with a concrete wall constructed in the new earth embankment as shown on **Figure 4b**. A portion of this levee system has an existing concrete flood wall which will have to be raised up to 1 foot (**Figure 4c**). There is also a retaining wall where approximately 100 linear feet should have soil anchors installed every 8 feet for structural stability. The top of this structure will also need to be raised by 3 feet (**Figure 4d**). This alternative will establish a 3 foot freeboard above the 1% chance flood event along the entire levee system.

The estimated cost for Alternative 1 for the Waimea River FCP is $7.3 million.

4.3. Alternative 2 – Channel Dredging. This alternative design would include dredging the channel only. Hydraulic analysis of dredging only alternatives indicate that dredging only does not establish a 3 foot freeboard along the entire levee system for the Hanapepe River FCP and the Waimea River FCP above the 1% chance flood event.

There is some life safety risk because the channels capacity could be affected by sediment and debris buildup which needs to be monitored and dredged again as infilling occurs over time.

4.3.1. Hanapepe River FCP. This alternative design would consist of dredging from station 5207.54 to 1248.50 (see **Figure 2** for plan view of cross-sections) and the change in invert elevation will vary from 0 to 5.8 feet below the existing invert (**Figure 5d** and **Figure 5e**). The river bed cannot be dredged any deeper without impacting the existing levee bank toes. This alternative keeps the 1% chance flood from overtopping any portion of the levee system but it does not provide 3 feet of freeboard along the entire levee system.

Additional cost items included for alternatives 2 and 3 included building of a causeway to the dredged area, dewatering of the dredged spoils, water quality permits, BMPs such as silt fences around the dredged areas, pre- and post-dredge surveys, waste characterization of the dredged material, and hauling and disposal of dredged material.

The estimated cost for Alternative 2 for the Hanapepe River FCP is $2.1 million.

4.3.2. Waimea River FCP. This alternative would consist of dredging from station 7473.76 to 525.184, see **Figure 2a** for the plan view of the cross-sections. The change in invert elevation will vary from 0 to 4.88 feet below the existing invert (**Figure 5f**). The river bed cannot be dredged any deeper without impacting the existing levee bank toes. This alternative keeps the 1% chance flood from overtopping any portion of the levee system but it does not provide 3 feet of freeboard along the entire levee system.

Additional cost items included for alternatives 2 and 3 included building a cofferdam using geotubes, dewatering of the dredged spoils, water quality permits, BMPs such as silt fences around the dredged areas, pre- and post-dredge surveys, waste characterization of the dredged material, and hauling and disposal of dredged material.

The estimated cost for Alternative 2 for the Waimea River FCP is $13.6 million.

4.4. Alternative 3 – Combination of Levee Raise and Channel Dredging. This alternative design will require construction along the existing levee systems as well as dredging the channel. This design would establish a 3 foot freeboard above the 1% chance flood event along the entire levee system for both the Hanapepe River FCP and the Waimea River FCP. There is some life safety risk because the channels capacity could be affected by sediment and debris buildup which needs to be monitored and dredged again if infilling occurs.

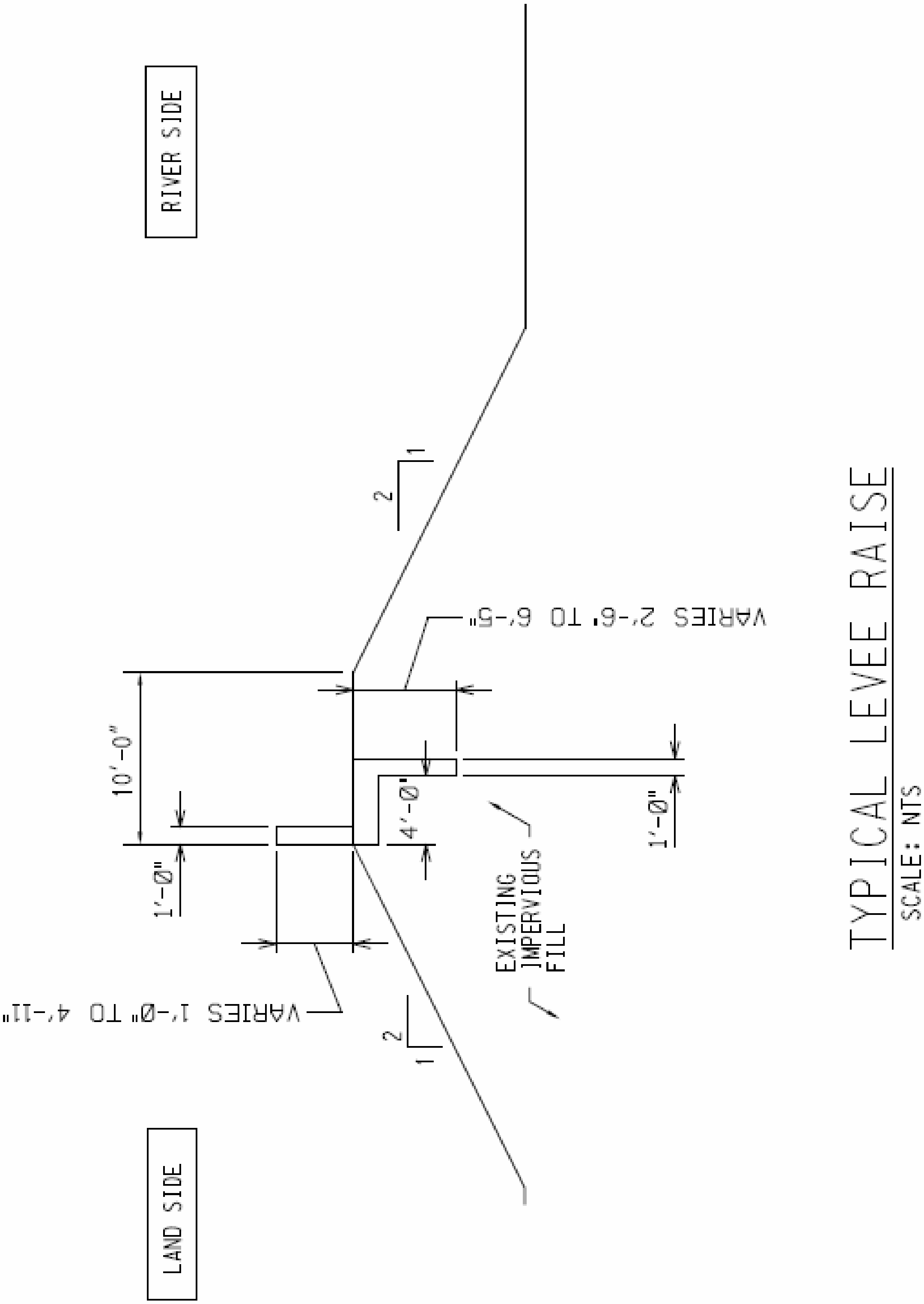
4.4.1. Hanapepe River FCP. This alternative design would include a combination of raising both the right and left bank levees and dredging the channel. This would consist of raising approximately 1,700 linear feet of the right bank levee (station 4368.01 to 2667.81, see **Figure 2**) by 0.5 to 2.9 feet. The right bank levee raise will also use a concrete floodwall (**Figure 4**). The entire 2,200 linear feet of the earthen left bank levee will also be raised by 1 to 2 feet (**Figure 2**, **Figure 4, Figure 5c** and **Figure 5d**). The entire 185 linear foot section of the left bank I-Wall will be backfilled on the land side to the top of the I-Wall with a 10 foot wide crest then sloped down a 2 to 1 side slope. The river side of the I-Wall will also be backfilled see **Figure 5**. A new concrete floodwall will then be constructed on the earthen levee behind the I-Wall as shown in **Figure 5**. This concrete floodwall will have a height of 0.5 to 1.5 feet. The channel will have to be dredged from station 5207.54 to 1248.50 and the change in invert elevation will vary from 0 to 5.8 feet below the existing invert (**Figure 2**, **Figure 5c** and **Figure 5d**). This design will establish a 3 foot freeboard above the 1% chance flood event along the entire levee system.

The estimated cost for Alternative 3 for the Hanapepe River FCP is $10.4 million.

4.4.2. <u>Waimea River FCP</u>. This alternative design would include a combination of raising the right bank levee and dredging the channel. This would consist of raising approximately 3,800 linear feet of the right bank levee (station 7473.76 to 3709.07, see **Figure 2a**) by 1 to 5.5 feet. Majority of the right bank levee raise would consist of constructing a concrete floodwall on top of the existing earthen levee (**Figure 4a**). Some of the existing earthen levee will have to be raised with a concrete floodwall constructed in the new earth embankment as shown on **Figure 4b**. There is also a retaining wall of approximately 100 linear feet that would be modified with soil anchors installed every 8 feet for structural stability. The top of this structure will also need to be raised by 3 feet (**Figure 4d**). The channel will have to be dredged from station 2900.21 to 525.184 and the change in invert elevation will vary from 0 to 3 feet (**Figure 2a** and **Figure 5f**). This design will establish a 3 foot freeboard above the 1% chance flood event along the entire levee system.

The estimated cost for Alternative 3 for the Waimea River FCP is $20.2 million.

Figure 4. Typical Levee Raise Detail, Hanapepe Levee System



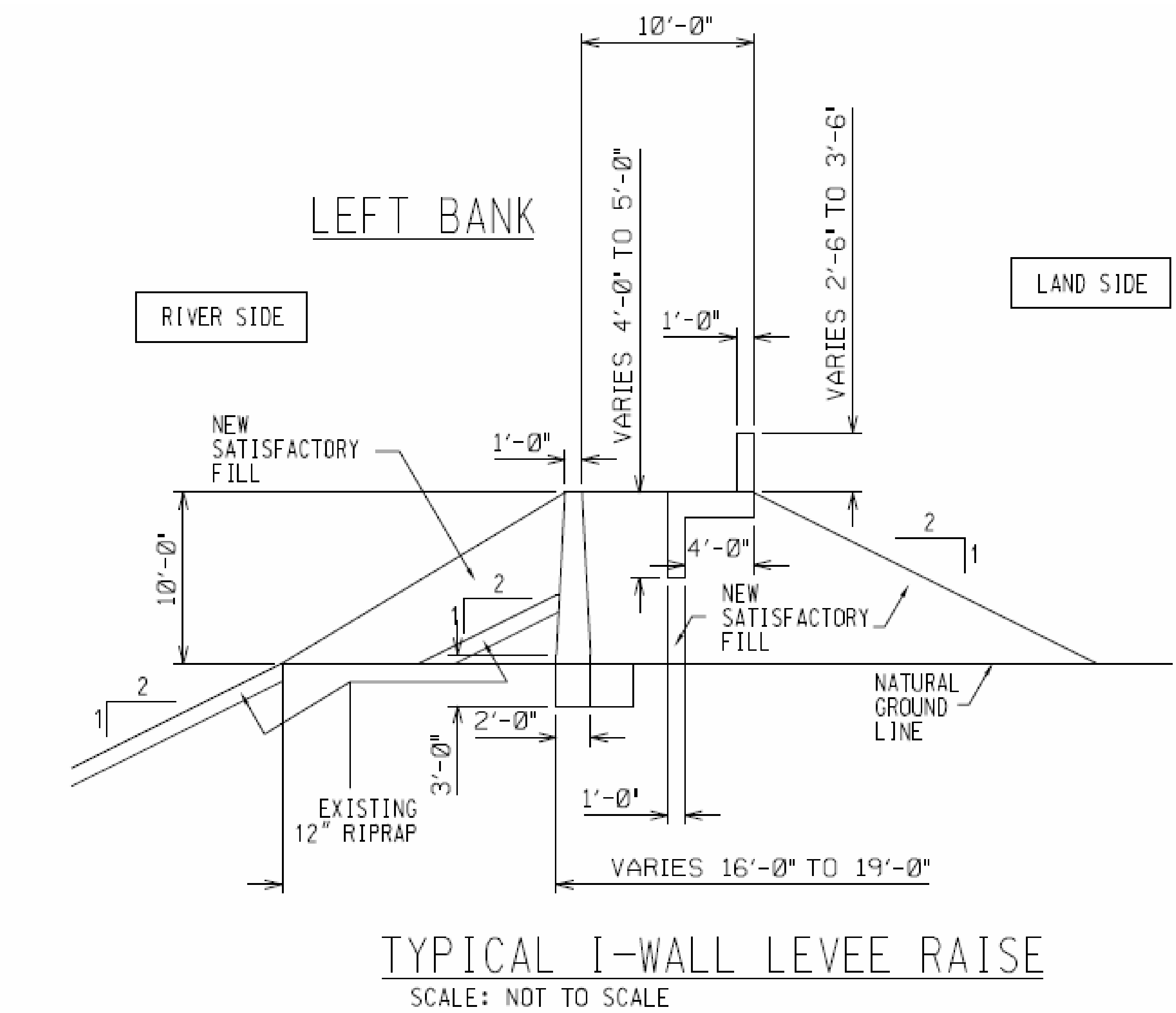
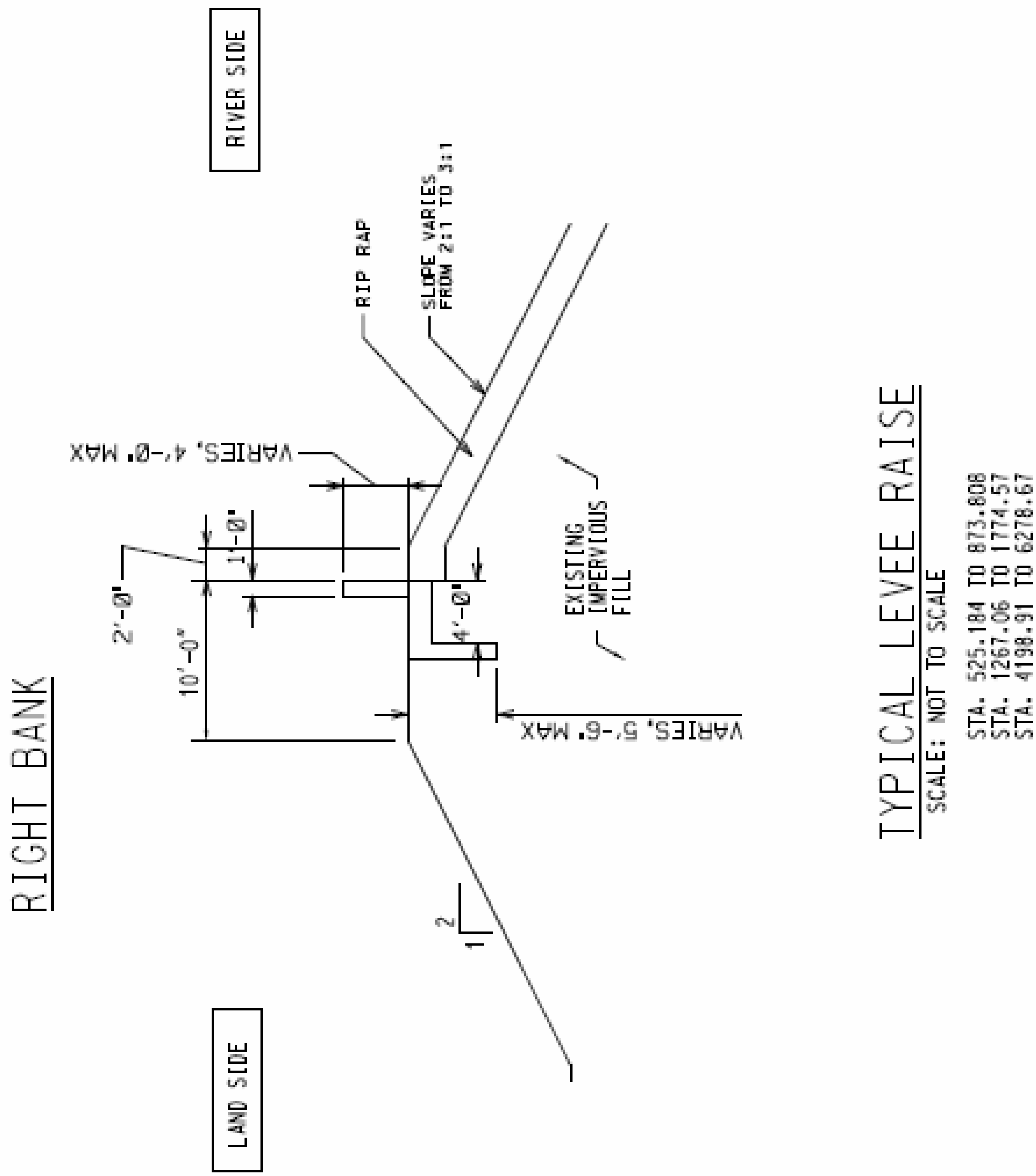


Figure 5. Typical I-Wall Left Bank Levee Raise Detail, Hanapepe Levee System, Hanapepe, Hawaii

Figure 4a. Typical Levee Raise Detail, Waimea Levee System



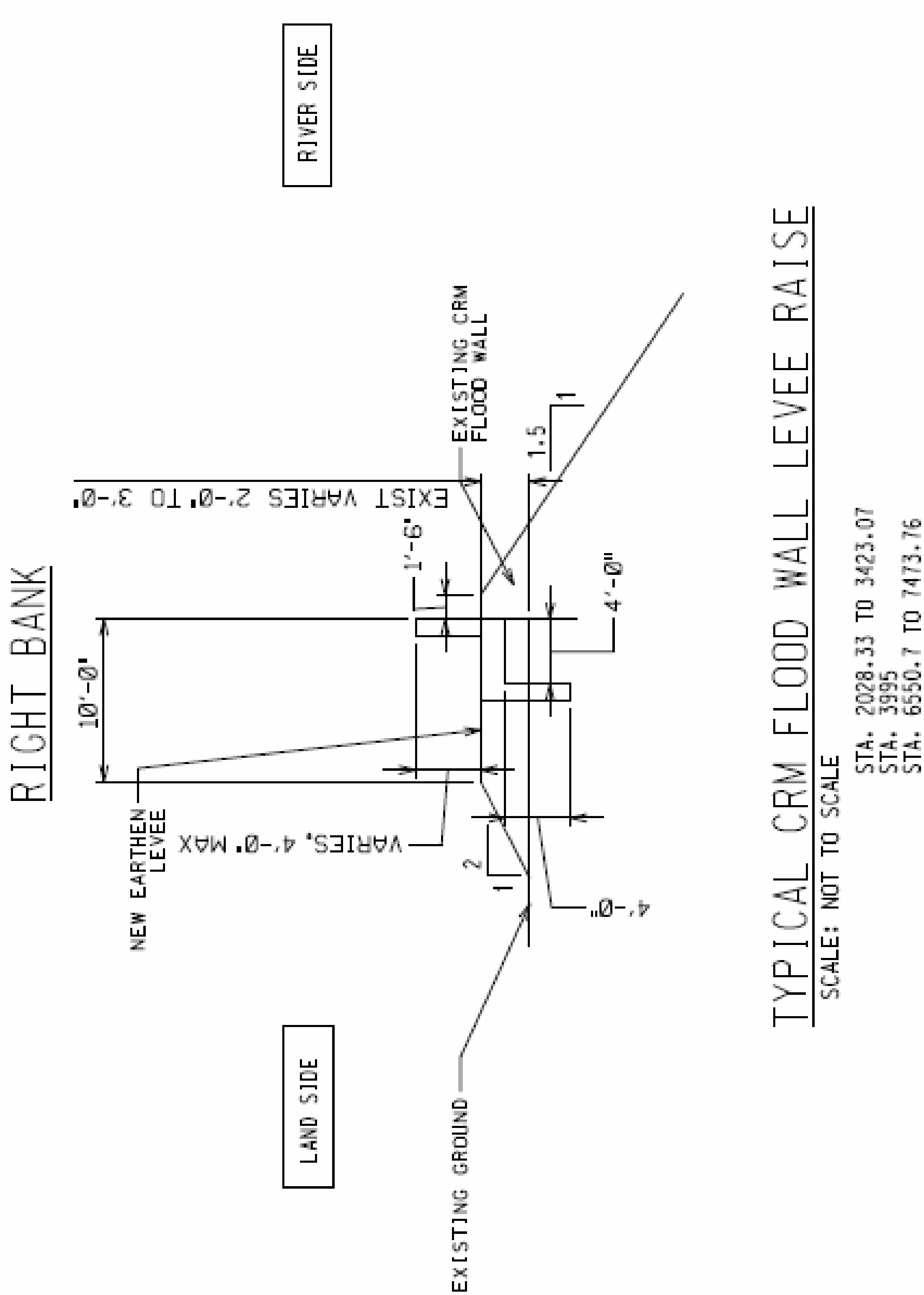


Figure 4b. Typical Earthen Levee and S-Wall Raise Detail, Waimea Levee System

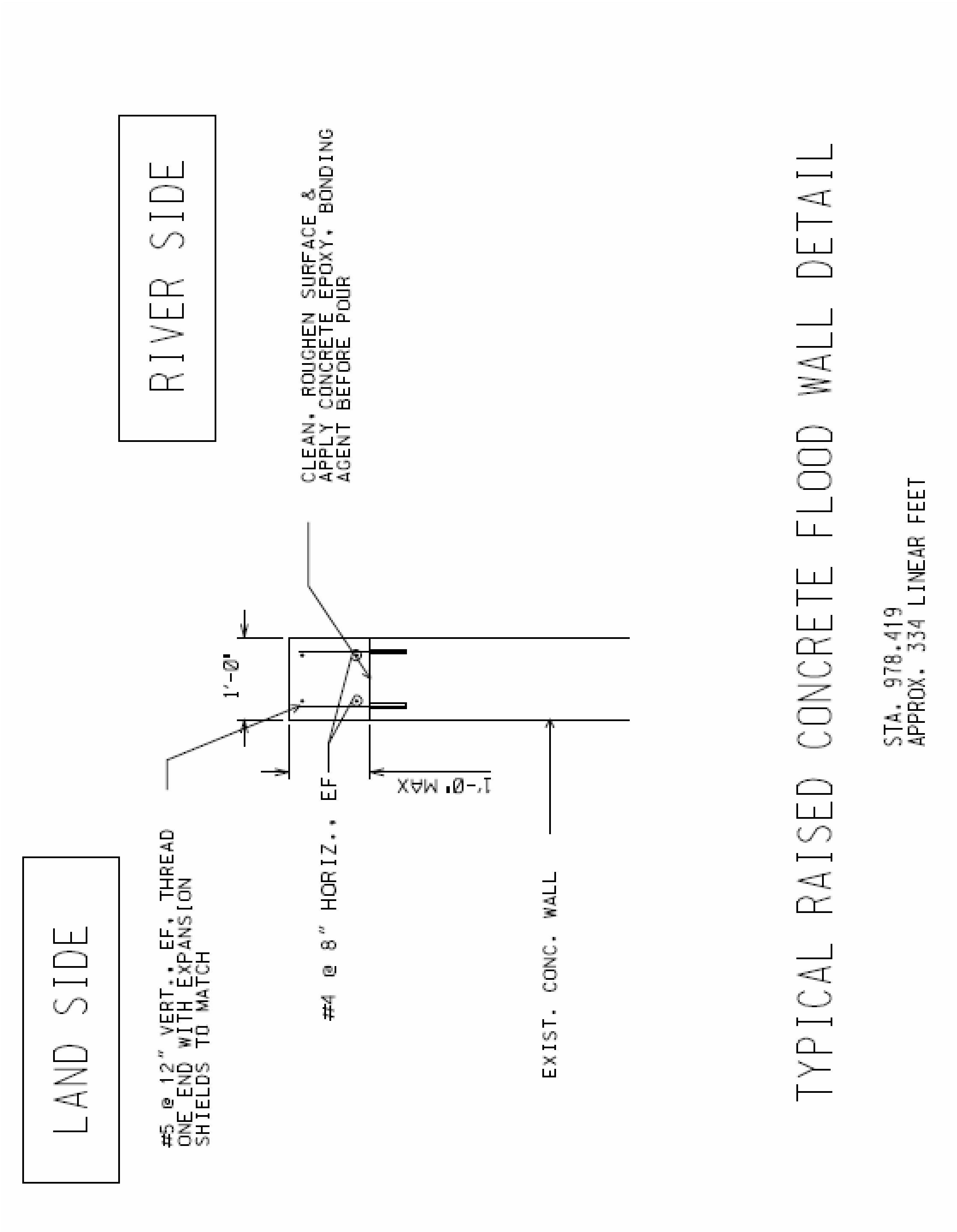
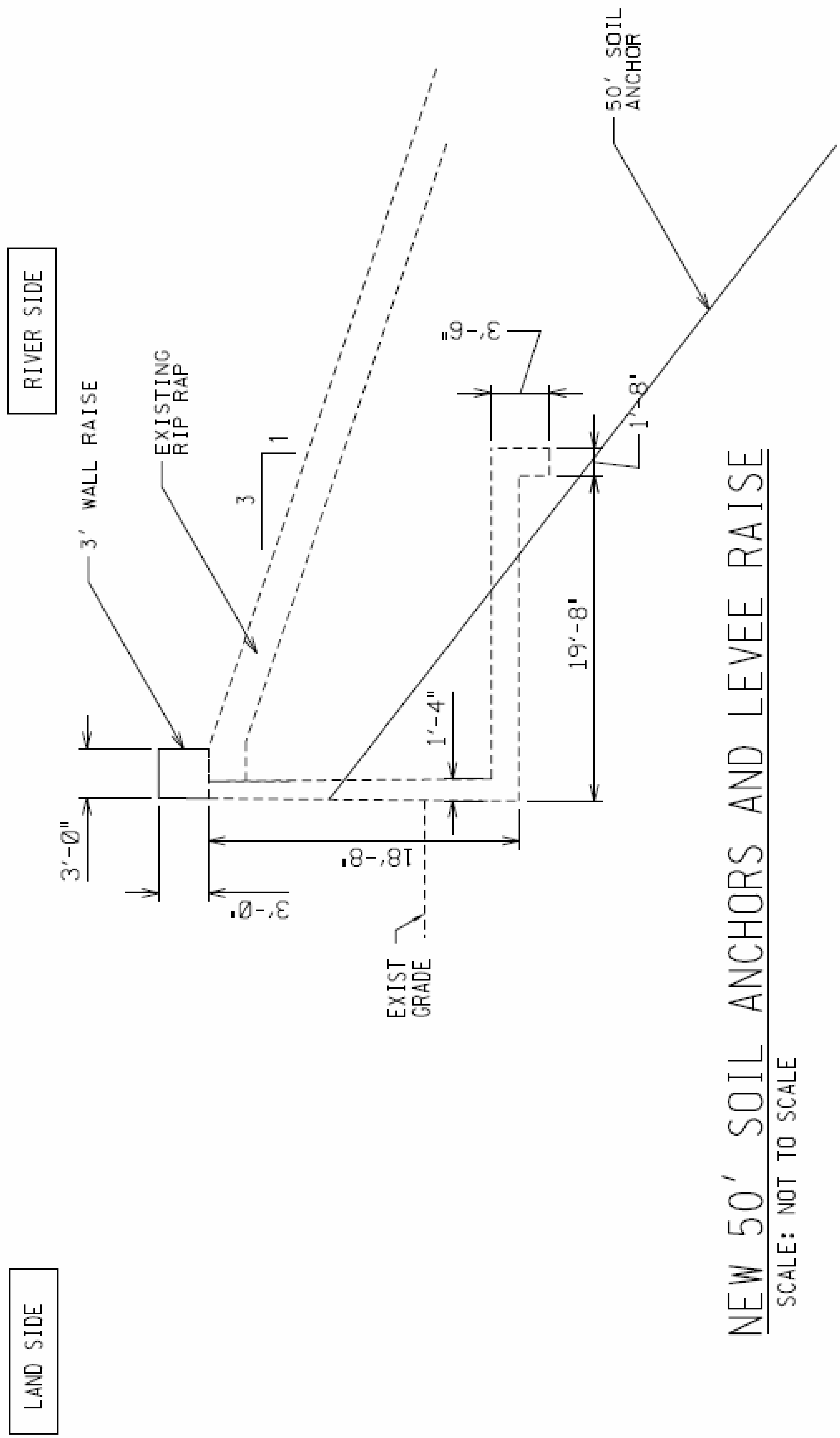


Figure 4c. Typical Raised Concrete Flood Wall Detail, Waimea Levee System

Figure 4d. Typical Levee Raise and Soil Anchor Detail, Waimea Levee System



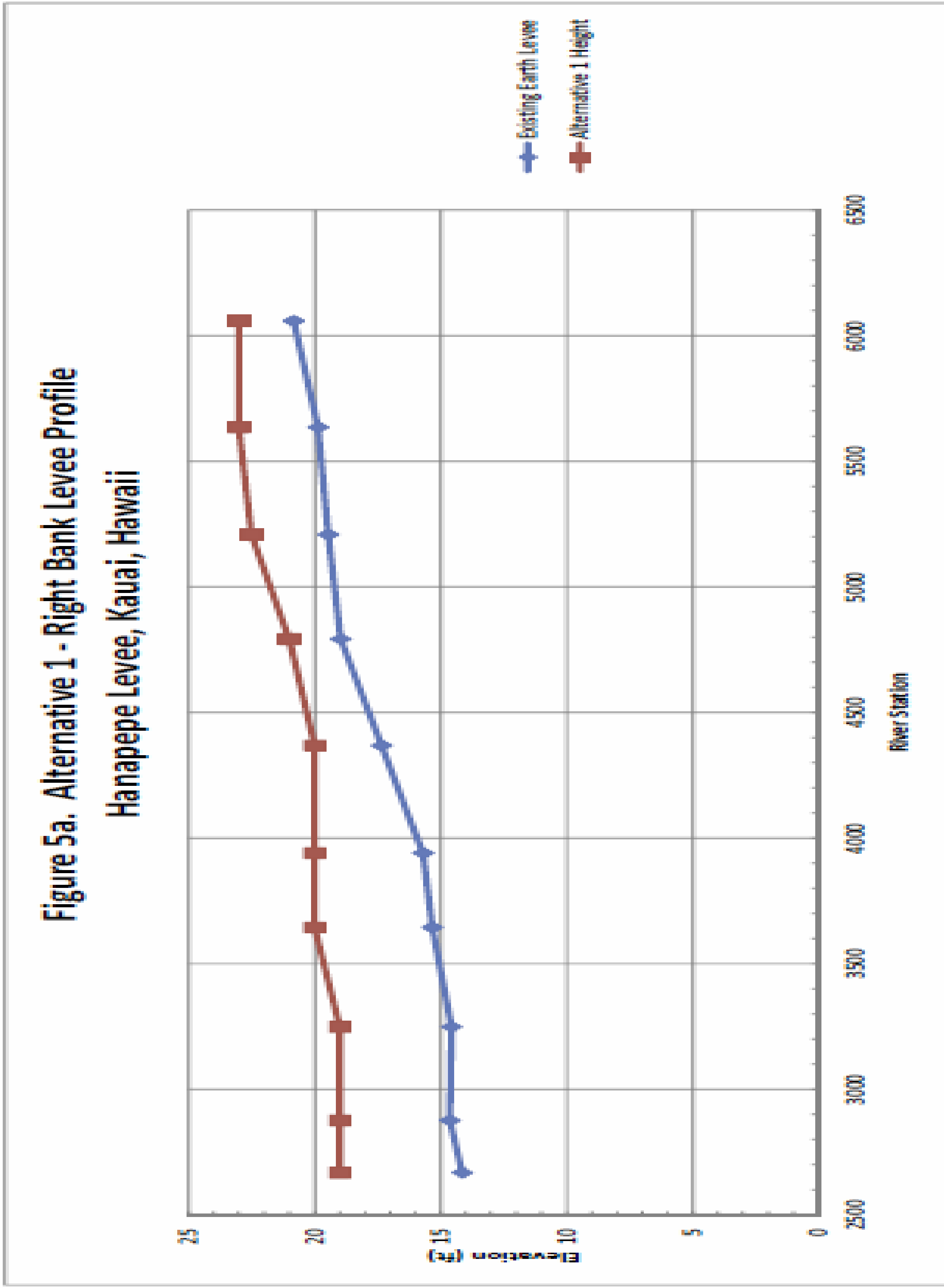


Figure 5a. Alternative 1 - Right Bank Levee Profile
Hanapepe Levee, Kauai, Hawaii
Existing Earth Levee
Alternative 1 Height
Elevation (ft)
River Station
0
5
10
15
20
25
2500
3000
3500
4000
4500
5000
5500
6000
6500

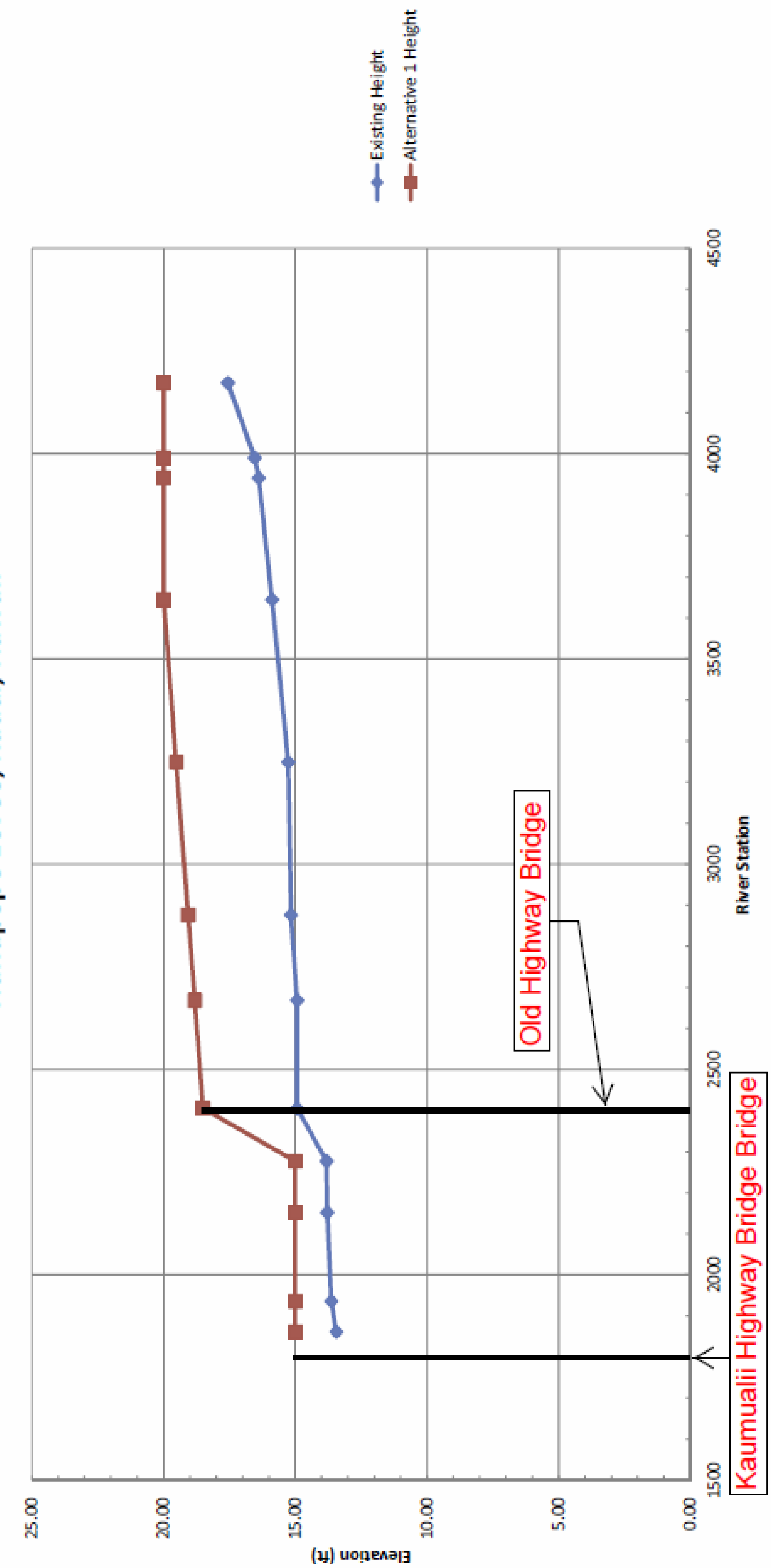


Figure 5b. Alternative 1 - Left Bank Levee Profile
Hanapepe Levee, Kauai, Hawaii

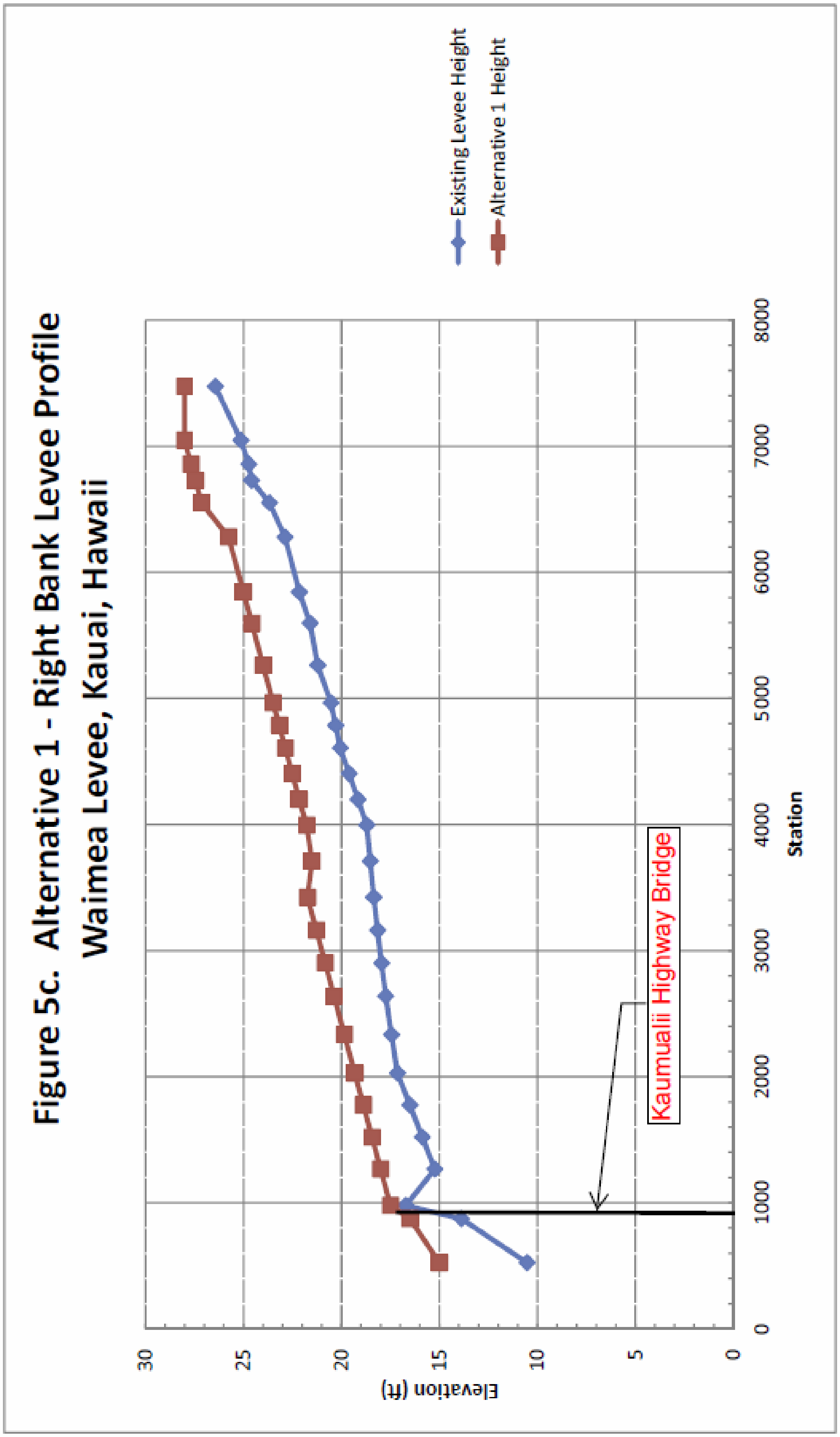


Figure 5c. Alternative 1 - Right Bank Levee Profile
Waimea Levee, Kauai, Hawaii

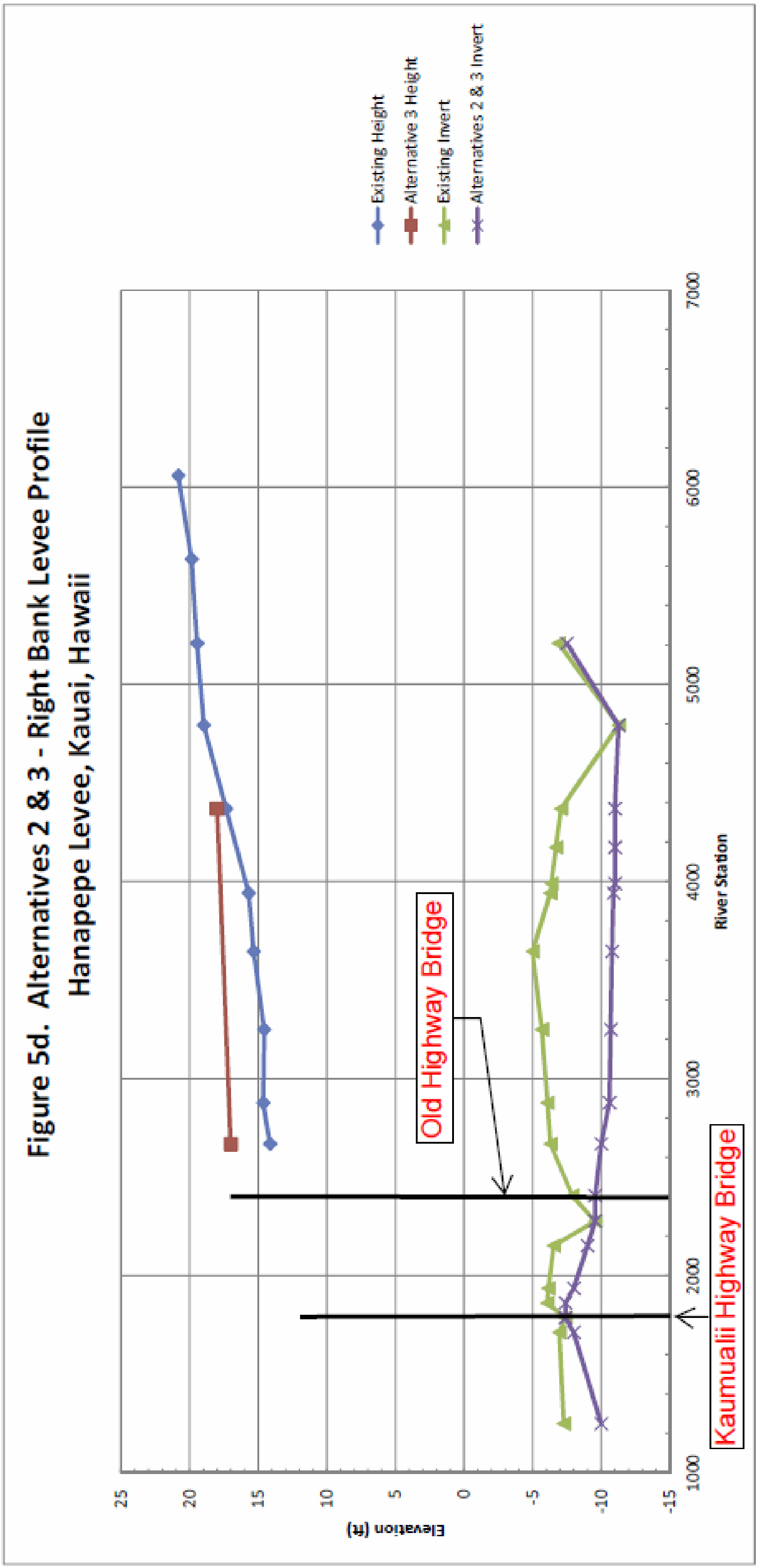


Figure 5d. Alternatives 2 & 3 - Right Bank Levee Profile
Hanapepe Levee, Kauai, Hawaii

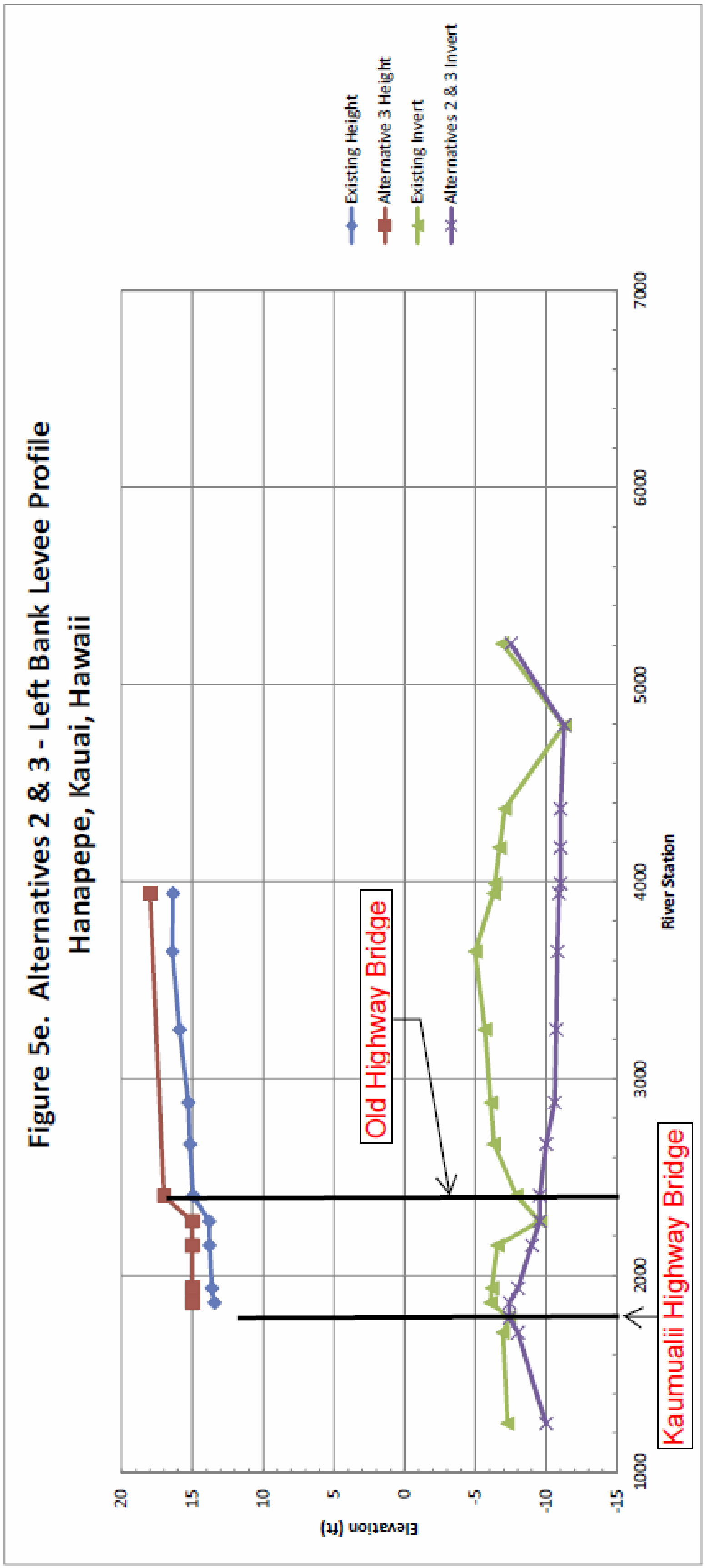


Figure 5e. Alternatives 2 & 3 - Left Bank Levee Profile
Hanapepe, Kauai, Hawaii

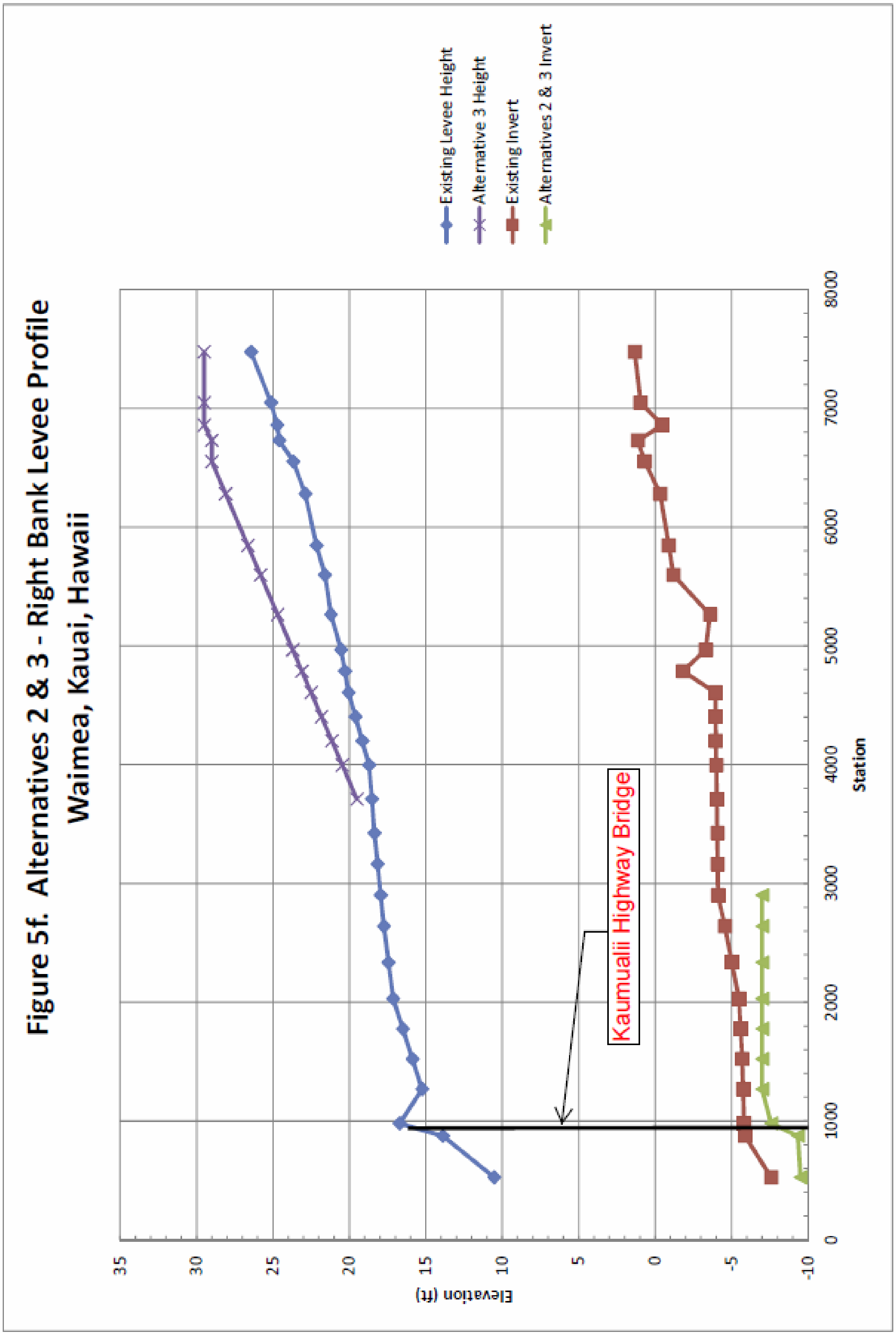


Figure 5f. Alternatives 2 & 3 - Right Bank Levee Profile
Waimea, Kauai, Hawaii
Elevation (ft)
Station
Kaumualii Highway Bridge
Existing Levee Height
Alternative 3 Height
Existing Invert
Alternatives 2 & 3 Invert
35
30
25
20
15
10
5
0
-5
-10
0
1000
2000
3000
4000
5000
6000
7000
8000

4.5. Alternative 4 – Non-Structural Measures. This section explains what constitutes a non-structural measure, what measures could be implemented to protect lives and development in these floodplains, and the estimated costs of these measures.

4.5.1. History & Guidance of USACE Non-structural Measures. Non-structural measures are formulated and evaluated under general guidance applicable to Corps plan formulation, such as Principles and Guidelines (P&G) (*U.S. Water Resource Council, 1983*), ER 1105-2-100 (*U.S. Army Corps of Engineers, 2000*) and ER 1105-2-101 (*U.S. Army Corps of Engineers, 2006*). Specific guidance relating to floodplain evacuation through property acquisition has also been issued. Since 1974, these Engineering Regulations have required non-structural measures or plans be considered along with structural plans for Corps of Engineers flood risk reduction projects. The web-based National Economic Development Procedures Manual for Flood Damage Reduction displays the following chronology of non-structural measures policy as shown in **Table 3**.

Table 3. Policy History of Non-structural Measures

- Flood Control Act 1938--land acquisition authorized
- H.D. 465 (1966)--alternative methods encouraged
- EO 11296 (1966)--flood loss on Federal lands must be considered National Flood Insurance Act (1968)--created NFIP
- EC 1120-2-40 (1968)--treatment of non-structural alternatives
- EC 1120-2-49 (1969)--progress in treatment of non-structural
- ER 1120-2-117 (1970)--alternatives in flood-related planning
- 1973 Flood Disaster Protection Act--required participation in NFIP
- Principles and Standards (P&S 1973)--planning process to include non-structural
- Section 73 WRDA 1974--required consideration of non-structural measures for flood control
- ER 1105-2-351 (1975)--procedures for NED benefits including non-structural
- ER 1105-2-200 (1975)--no multi-objective bias toward structural or non-structural
- EO 11988 (1977)--agency role in floodplain management *II* President's Policy 6/6/78--greater utilization of non-structural
- ER 1105-2-353 (1979)--benefits and costs of evacuation and relocation
- ER 1165-2-26 (1979)--implementation of EO 11988
- Water Resources Council--A Unified National Program for Floodplain Management (1979)
- Policy Guidance Non-Structural Measures (10/15/79)
- Revisions to P&S (1979)--non-structural plan required
- Policy in Land Acquisition for Non-structural (4/12/82)
- P&G (1983)
- IWR Research Report 85-R-1, Assessment of the Economic Benefits from Flood Damage Mitigation by Relocation and Evacuation
- ER 1105-2-100 Planning Guidance Notebook

4.5.2. Types of Non-structural Measures & Descriptions. A non-structural measure generally modifies the characteristics of structures and buildings located in floodplains and the characteristics or behavior of people who live in or have property in floodplains. It does not modify the characteristics of the natural flood; only structural measures do. Non-structural Flood Proofing measures differ from Structural Flood Proofing measures in that they focus on reducing the consequences of flooding instead of focusing on reducing the probability of flooding.

The list below has some of the more common measures:

- Elevation
- Relocation
- Buyout or Purchase
- Dry flood proofing
- Wet flood proofing
- Local berms or floodwalls
- Flood warning & preparedness

Elevation involves raising the buildings in place so that the structure sees a reduction in frequency and/or depth of flooding during high-water events. Elevation can be done on fill, foundation walls, piers, piles, or columns. Selecting the proper elevation method can depend on many building features, as well as flood characteristics such as flood depth or velocity. In some cases, even buildings built slab- on-grade can be elevated, but it tends to be expensive. Rebuilding in place is another approach to elevating flood prone structures. If a structure is too flimsy or of poor quality to withstand elevating, it can be demolished and rebuilt in place with an elevated foundation.

Relocation is moving the structure to another location away from flood hazards. This measure is considered the most dependable method of protection and provides the benefit of use of the evacuated floodplain.

Buyout or purchase is the acquisition and elimination of flood damageable structures, allowing for inhabitants to relocate to locations away from flood hazards. This method also has the potential to transform hazardous flood plain into open space or parkland.

Dry Flood Proofing involves sealing building walls with waterproofing compounds, impermeable sheeting, or other materials to prevent the entry of floodwaters into damageable structures. Dry proofing is applicable in areas of shallow, low velocity flooding.

Wet Flood Proofing measures allow floodwater to enter the structure, while vulnerable items such as utilities are relocated to higher locations or waterproofed. By allowing floodwater to enter the structure, hydrostatic forces on the inside and outside of the structure can be equalized reducing the risk of structural damage.

Local Berms and Floodwalls are freestanding structures located away from the building that prevent the encroachment of floodwaters. Whereas levees may protect entire towns or neighborhoods, these non-structural floodwalls or berms protect only one to several structures.

Flood Warning Systems alert people in flood prone areas of impending high water. Depending on the type of system and advance time, inhabitants have the opportunity to evacuate damageable property and themselves from the flood prone area. The warning message could be disseminated by weather radios, media, sirens, public education, and schools.

4.5.3. Benefits of Non-structural Measures. Non-structural measures can also function as a viable component of an integrated system of flood and coastal storm risk management along with structural measures and ecosystem restoration activities. Non-structural measures offer opportunities for reducing exposure to inundation and storm hazards through managed development in the floodplain, in combination with, or perhaps instead of, structures such as levees and lengthy floodwalls. Included in non-structural measures are activities that precede the threat which could preemptively lessen the potential impact such as with land use restrictions or emergency preparedness. In addition to reducing risk and subsequent damage, non-structural measures promote community resiliency by strengthening critical facilities--hospitals, fire stations, police stations, and similar facilities--that provide services which are essential to the community's well-being and post-event recovery.

Non-structural measures have been required for consideration for Corps of Engineers (Corps) flood risk reduction projects since 1974; however, they have not been fully integrated into the culture of flood plain management and planning. Although they can perform cost effectively for risk reduction, non-structural measures have nontraditional implementation requirements and specific policy guidance which detract from their consideration by planners. Also, the public has traditionally favored structural techniques for risk reduction. However, as the public develops a growing appreciation for ecosystem values coupled with recognition of the limitations of structural measures and the expense involved, it is appropriate that flood plain managers reconsider the role of non-structural measures for risk reduction and review their potential contribution to reducing flood damages.

Not only do non-structural measures reduce risk, they contribute to disaster planning as well as those that provide long-term risk mitigation. Disaster planning deals with preparing for the natural disaster—planning for and implementing actions that individuals and communities can take in advance of a potentially disastrous events to lessen the threat to life, health, and safety. Examples of these activities are evacuation planning, flood warning systems, and emergency preparedness.

4.5.3.1. National Non-structural Flood Proofing Committee Recommendations. According to the U.S. Army Corps of Engineers – National Non-structural Flood Proofing Committee (USACE-NNFPC), there are general guidelines when determining what types of non-structural measures should be used. For below three feet of flooding, flood proofing generally is the answer. From three feet to seven feet elevating the structure should be used. Any flood proofing needed above seven feet should be purchased according to property owner's choice or via eminent domain and condemnation. The problem with buyouts is that they are difficult to execute because communities are generally reluctant or unwilling to uproot.

4.5.4. Possible Non-structural Alternatives for Hanapepe & Waimea. USACE hydraulic engineers have determined that if the existing levees were to overtop, breach or fail; the majority of homes and businesses in the Hanapepe and Waimea floodplains would be inundated with an average depth of approximately 3 feet of water. The approximate 1% chance flood inundation area was created using HEC-RAS and ArcMap. In the cases of Hanapepe and Waimea, the most likely non-structural plan to combat 3 feet of flooding would be elevating the structures more than 3 feet in combination with a purchase. Coincidently, flood proofing is normally only beneficial up to about 3 feet above floor level. Therefore, the option of elevating the structures that are capable of being elevated is the least risky measure. If it were decided to elevate structures higher than 3 feet, say, 7 feet, the incremental cost of elevating the additional height becomes more inconsequential. That is, because most of the cost to elevate a structure is attributed to completing essential tasks and meeting specifications of the job other than height of its foundation.

The choice between elevating a structure or purchasing it would be determined by which is most economically feasible. If a structure is slab on grade, then it is more likely to be purchased because elevating the structure may compromise it structurally and may prove to be more costly if damages occurred while elevating the structure. On the other hand, if a structure is already built on a foundation of posts, piers or blocks, it would not be problematic to raise it a few more feet. However, elevating structures would only be plausible with qualified contractors using proper hydraulic equipment.

In May 2012, floodplain inspections of Hanapepe and Waimea were done to get an estimate on the number of structures that could potentially benefit from non-structural measures. Elevating a structure 3 feet or more can cost upward of $100,000 according to guidance put forth by the USACE-NNFPC. As shown in **Table 4**, if it were practical to elevate every structure behind the Hanapepe and Waimea levee systems, the total cost would exceed $44 million. However, 20 percent of the total structures in both towns cannot be elevated.

The average purchase cost for structures in Hanapepe would be $449,000 and $406,000 for structures in Waimea. Per guidance from the USACE-NNFPC, an acquisition (acq.) multiplier was also included in the calculation for the purchase cost to adjust for the assessed tax value. As shown in **Table 4**, to purchase all the properties protected by the levee system in both towns would cost approximately $147 million.

The general buyout acquisition multipliers and costs used for elevating structures in this analysis represent minimum cost estimates for these measures. Actual costs to elevate structures would depend on many factors including the size and construction type of the structure, regionalized costs of materials and labor, and availability of experienced contractors on Kauai.

Table 4 – Purchasing and Elevating Structures Costs for Hanapepe and Waimea

Total Estimated Cost to Elevate Structures in Hanapepe	$15,551,347
Total Estimated Cost to Elevate Structures in Waimea	$28,692,395
Total Cost to Elevate Structures	$44,243,742
Average Cost to Elevate Structures in Hanapepe	$100,331
Average Cost to Elevate Structures in Waimea	$99,893
*Total Purchase Cost (Land + Structure) in Hanapepe	$53,922,372
*Total Purchase Cost (Land + Structure) in Waimea	$93,344,138
*Total Purchase Cost	$147,266,510
*Average Purchase Cost (Land + Structure) in Hanapepe	$449,353
*Average Purchase Cost (Land + Structure) in Waimea	$405,744

*Buyout Totals have Acq. Multipliers - 1.18 Res., 1.29 Com., 1.235 Mix
Res. = Residential; Com. = Commercial; Mix = Residential and Commercial

A reasonably accurate estimate of the cost to purchase a flood prone structure to remove it from the floodplain begins with the assumption that the tax value for the land and structure is close to the amount of money that the property owner and the local government buyer would settle upon. In addition, there would be legal and administration expenses, demolition costs, and temporary relocation costs for the occupants.

The assumptions made in this analysis may result in cost estimates on the low side; certainly they can only be considered rough or “ballpark” estimates. If a sufficient number of homes were purchased, other land uses such as urban green space producing recreation benefits and opportunities could be implemented. The possibility of creating parkland or other beneficial uses of the flood plain has not been accounted for in this analysis.

4.5.4.1. Non-structural Measures Alternative for Hanapepe. The Hanapepe River is located on the southern coast of the island of Kauai and flows through the town of Hanapepe into Hanapepe Bay. The town consists of small commercial and residential structures, which are fairly old and in some cases rundown. If the levee system overtopped or failed, approximately 155 structures would potentially be damaged. **Table**

5 below shows the breakdown of costs to elevate and purchase structures adjacent to the Hanapepe River. Although the right bank does have some residential properties, the majority of damages would occur on the left bank where approximately 107 structures, both commercial and residential, would need to be purchased or elevated at least 3 feet. Inspections determined that 20% of the commercial and 96% of the residential structures can be elevated, on the left bank. On the right bank, none of the commercial structures can be elevated, but 90% of the residential structures can be. Using the percentages from the May 2012 inspection, the total cost would be about $33 million.

Table 5 – Hanapepe Alternative: Breakdown of the Potential Cost to Raise and Purchase Structures

Project Inspection for Possible Elevation: Right Bank		
Commercial Structures	8	(0% Raisable from observation)
Residential Structures	40	(90% Raisable from observation)
Total Structures	48	
Less: Commercial Structures not raisable	8	
Less: Residential Structures not raisable	4	
Total Possible Elevations	**36**	

Project Inspection for Possible Elevation: Left Bank		
Commercial Structures	43	(20% Raisable from observation)
Residential Structures	64	(96% Raisable from observation)
Total Structures	107	
Less: Commercial Structures not raisable	34	
Less: Residential Structures not raisable	3	
Total Possible Elevations	**70**	

	No.	Average Cost	Total Cost
Residential Structures Elevated (Right Bank)	36	$100,331	$3,612,000
Commercial Structures Elevated (Right Bank)	0	$100,331	$0
Residential Structures Purchased (Right Bank)	4	$449,353	$1,797,000
Commercial Structures Purchased (Right Bank)	8	$449,353	$3,595,000
Residential Structures Elevated (Left Bank)	61	$100,331	$6,120,000
Commercial Structures Elevated (Left Bank)	9	$100,331	$903,000
Residential Structures Purchased (Left Bank)	3	$449,353	$1,348,000
Commercial Structures Purchased (Left Bank)	34	$449,353	$15,278,000
Total Cost for Alternative	**155**		**$32,653,000**

4.5.4.2. Non-structural Measures Alternative for Waimea. The Waimea River is located on the southwest coast of Kauai and is a part of the Waimea community. Most commercial structures are located along the main highway, while the majority of the residential structures are located further in the valley. The majority of commercial structures are slab on grade, while the majority of residential structures are slightly raised. The potential number of residential structures behind the leveed area is 282, as shown in **Table 6**. Approximately 70 percent of these structures (201) are located downstream of the upstream end of the raised concrete wall at approximate station 3425. These structures are tabulated in **Table 6** as “lower” and were individually accounted for in the structure database during a windshield survey inspection in May 2012. The remaining 30 percent of these structures (81), referred to as “upper”, were not surveyed but extrapolated from the 70 percent that were surveyed. The left bank consists of undeveloped land and was included in this analysis. The Waimea inspection showed similar results to Hanapepe’s right bank observations, in which none of the commercial structures can be elevated, while 99% of the residential structures can be elevated. Using the percentages from the inspection, the total cost would be approximately $38 million (**Table 6**).

Table 6 – Waimea Alternative: Breakdown of the Potential Cost to Elevate and Purchase Structures

Project Inspection for Possible Elevation: Lower		
Commercial Structures	26	(0% Raisable from observation)
Residential Structures	175	(99% Raisable from observation)
Total Structures	201	
Less: Commercial Structures not raisable	26	
Less: Residential Structures not raisable	2	
Total Possible Elevations	**173**	
Project Inspection for Possible Elevation: Upper		
Commercial Structures	4	(0% Raisable from observation)
Residential Structures	77	(99% Raisable from observation)
Total Structures	81	
Less: Commercial Structures not raisable	4	
Less: Residential Structures not raisable	1	
Total Possible Elevations	**76**	

	No.	Average Cost	Total Cost
Residential Raise (Lower)	173	$99,893	$17,281,000
Commercial Raise (Lower)	0	$99,893	$0
Residential Buyout (Lower)	2	$405,744	$812,000
Commercial Buyout (Lower)	26	$405,744	$10,549,000
Residential Raise (Upper)	76	$99,893	$7,592,000
Commercial Raise (Upper)	0	$99,893	$0
Residential Buyout (Upper)	1	$405,744	$406,000
Commercial Buyout (Upper)	4	$405,744	$1,623,000
Total Cost for Alternative	**282**		**$38,263,000**

4.5.5. <u>Conclusion</u>. As shown in **Table 5**, the total cost for a non-structural alternative combining purchases and elevating structures adjacent to Hanapepe River would be approximately $32.7 million and would include over 150 structures. As shown in **Table 6** the total cost for a non-structural alternative combining purchases and elevating structures adjacent to Waimea River would be approximately $38.3 million and would include over 280 structures. The combined cost for both the Hanapepe and Waimea areas would be approximately $70.9 million. As expected, this amount is about one-half the total cost of buying out the two floodplains, $147 million. Kauai County decision makers can weigh the approximate cost of this general evaluation of non-structural flood protection alternatives versus the cost of rehabilitating the Hanapepe and Waimea levee systems. This alternative does not establish a 3 foot freeboard above the 1% chance flood event but it does take the flood prone structures out of the floodplain. There weren't a lot of assumptions made for this alternative. The life safety risk is high because the people in the raised structures are still in the floodplain and have to either evacuate or there is a risk that the structure could still collapse if they don't evacuate. There is very little maintenance required for this alternative.

4.6. Alternative 5 – Peak Flow Reduction. This alternative would involve creating upstream storage to store water during the 1% chance flood event. This storage would allow less water down the river and would subsequently lower water surface elevations along the levee system. A storage alternative could be designed to reduce the peak flow to allow for three feet of freeboard above the 1% chance flood event along the existing levee systems. A dam would be needed to store the water. Sizing and design of the storage project is beyond the scope of this study.

For Hanapepe the maximum total flow that would allow three feet of freeboard along majority of the levee with the current levee heights is 18,600 ft^3/s. This means that the existing 1% chance flood event must be reduced by 20,300 ft^3/s.

For Waimea the maximum total flow that would allow three feet of freeboard with the current levee heights is 47,600 ft^3/s. This means that the existing 1% chance flood event must be reduced by 20,400 ft^3/s.

This alternative is likely to be very costly and will have environmental consequences that may not be acceptable. Due to general opposition to dams, no actual cost estimate was completed for this alternative.. The life safety risk for this alternative is a transferred risk. This transferred risk would cause a different type of life safety risk that would be similar to a dam break scenario.

4.7. Comparison of Alternatives. Rough order of magnitude costs were done for alternatives 1 – 3 based on typical details and estimated quantities. The cost is for construction only assuming the subcontractor will be performing the site work and the prime contractor managing the project. The cost includes overhead, profit, bond and tax. Typical Best Management Practices (BMPs) such as silt fences, dust barriers, silt curtains, construction entrances and permits are included in this cost. A topographic survey was included in the cost estimates. Mobilization, demobilization, hauling and disposal to a landfill were included in the costs. The cost does not include contingency or S&A (Supervision and Administration) cost. Excavated levee material excavated for floodwall installation was assumed to be reused as backfill. The performance period for alternatives 1 – 3 is assumed to be 16 months.

Table 7. Comparison of Alternatives for Hanapepe, Kauai, Hawaii

Alternative No.	3 ft freeboard for 1% chance flood	Magnitude of Assumptions	Life Safety Risk	Maintenance	Estimated Cost
1	**Yes**	**Low**	**Low**	**Low**	$9.4 Million
2	No	High	Medium	High	**$2.1 Million**
3	**Yes**	High	Medium	High	$10.4 Million
4	No	**Low**	High	**Lowest**	$32.7 Million
5	**Yes**	Very High	Medium	**Low**	Assumed High

Table 8. Comparison of Alternatives for Waimea, Kauai, Hawaii

Alternative No.	3 ft freeboard for 1% chance flood	Magnitude of Assumptions	Life Safety Risk	Maintenance	Estimated Cost
1	**Yes**	**Low**	**Low**	**Low**	**$7.3 Million**
2	No	High	Medium	High	$13.6 Million
3	**Yes**	High	Medium	High	$20.2 Million
4	No	**Low**	High	**Lowest**	$38.3 Million
5	**Yes**	Very High	Medium	**Low**	Assumed High

4.7.1. <u>Hanapepe River FCP</u>. **Table 7** compares pros and cons for all the alternatives. Alternative 1 (Levee Raise) is the preferred alternative because it will establish 3 feet of freeboard above the 1% chance flood event along the entire levee system, the magnitude of assumptions are low, the life safety risk is the lowest of the 5 alternatives, the maintenance required is low and the estimated cost is the second lowest of the 5 alternatives.

4.7.2. <u>Waimea River FCP</u>. **Table 8** compares pros and cons for all the alternatives. Alternative 1 (Levee Raise) is the preferred alternative because it will establish 3 feet of freeboard above the 1% chance flood event along the entire levee system, the magnitude of assumptions are low, the life safety risk is the lowest and the estimated cost is the lowest of the 5 alternatives.

5. **CAPACITY EXCEEDANCE AND ALTERNATIVES PERFORMANCE.**

The Flood Damage Reduction Analysis (HEC-FDA) program Version 1.2.4 (*U.S. Army Corps of Engineers, 2008d*) was used to determine the levee performance following guidance in Engineering Technical Letter 1110-2-570 (*Department of the Army, 2007*). This program uses Monte Carlo analysis in creating a large number of simulated flood events which are tested against the height of the levee at selected index stations. The resulting hydrologic and hydraulic data with the assigned accuracies are used as input to the Monte Carlo simulations. The HEC-FDA model was only used for levee performance so dummy economic data were entered to allow the HEC-FDA program to work. The HEC-FDA program requires eight frequency values as input but only provides six frequency values as output. The hydrologic data used is based on the entire frequency curve range 50-, 20-, 10-, 5-, 2-, 1-, 0.5-, and 0.2-percent chance exceedance floods (2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year floods). The water-surface elevation data is based on the entire cross-section range of profiles up- and down-stream of the index locations and also cover the frequency range of 50-, 20-, 10-, 5-, 2-, 1-, 0.5-, and 0.2-percent chance exceedance floods with an accuracy of 0.15 ft. A standard deviation of 0.5 was used for both the Hanapepe and Waimea HEC-FDA models based on the sensitivity data.

5.1. Results of Alternatives Performance. Results of the levee performance for the existing condition and alternatives 1-3 are shown in **Tables 9** and **10** and the 1% chance flood results are also shown on **Figures 6** and **7**. Assurance or Conditional Non-Exceedance Probability (CNP) results are based on 52,000 simulations and may be interpreted as explained below.

5.1.2. Hanapepe River FCP. The Hanapepe HEC-FDA model has an accuracy of 60 years equivalent years of record. Four index locations were chosen for the Monte Carlo analysis based upon their location along the levees at bends or lower elevations of the levee. These index locations for the Hanapepe River FCP are shown on **Figure 6**.

For example at Index Station “LB 1” for the existing condition, as providing 29 percent assurance against overtopping by the 1% chance flood event (**Table 9**). Index Station “RB 3” is located on the right bank levee where erosion is occurring and these results further illustrate that this is a weak point in the right bank levee. In **Table 9** the dredged alternative does not meet the 90% assurance against the 1% chance flood at Index Stations “RB 3”.

5.1.3. Waimea River FCP. The Waimea HEC-FDA model has an accuracy of 48 years equivalent years of record. Five index locations were chosen for the Monte Carlo analysis based upon their location along the levee at bends or lower elevations of the levee. These index locations for the Waimea River FCP are shown in **Figure 7**. For example at Index Station “Downstream Bridge” for the existing condition, as providing 18 percent assurance against overtopping by the 1% chance flood event (**Table 10**). In **Table 10,** all three alternatives meet the 90% assurance against the 1% chance flood.

5.2. HEC-FDA Model. The HEC-FDA model was used to check the required levee height at the index stations in order to provide a 90% assurance of passing the 1% chance flood.

5.2.1. Hanapepe River FCP. To provide such assurance, the levee elevations would need to be 23 feet at Index Stations “RB 1” and “RB 2”, and at least 18.5 feet at “RB 3”, and at least 18.6 feet at “LB 1”. Thus, the right bank levee would need to be raised by 2.0 to 4.9 ft and the left bank levee will need to be raised by 1.2 to 4 feet to meet the freeboard requirements. This would result in the levee heights on the right and left bank segments to have a freeboard greater than 3 feet, thus meeting the FEMA hydraulic design criteria.

5.2.2. Waimea River FCP. To provide such assurance, the levee elevations would need to be 28 feet at Index Station “Road”, 27.1 feet at “Bend”, 23.5 feet at “Middle”, 19.4 at “Lower” and 15 feet at “Downstream Bridge”. Thus the right bank levee would need to be raised by 0.8 to 3.5 feet to meet the freeboard requirements. This would result in the levee heights on the right bank segments to have a freeboard greater than 3 feet, thus meeting the FEMA hydraulic design criteria.

Table 9. Conditional Non-Exceedance Probability Values for Hanapepe River Levee at Selected Index Stations computed by Monte Carlo Simulation, Hanapepe, Kauai, Hawaii

Index Station	Levee Elevation (ft)	1% (100-yr) Percent Chance Flood			
		Existing Condition	Alternative 1 Levees Raised	Alternative 2 Dredged	Alternative 3 Combination
RB 1	20.83	0.7342	0.9766	0.9998	0.9997
RB 2	19.86	0.4719	0.9724	0.9801	0.9760
RB 3	14.57	0.0679	0.9999	0.6293	0.9999
LB 1	14.983	0.2943	0.9999	0.8978	0.9999
Uncertainty value used was 60 Equivalent Years of Record for discharge frequency and a standard deviation of 0.50 ft for stage-discharge uncertainty					

Table 10. Conditional Non-Exceedance Probability Values for Waimea River Levee at Selected Index Stations computed by Monte Carlo Simulation, Waimea, Kauai, Hawaii

Index Station	Existing Levee Elevation (ft)	1% (100-yr) Percent Chance Flood			
		Existing Condition	Alternative 1 Levee Raised	Alternative 2 Dredged	Alternative 3 Combination
Road	26.43	0.6113	0.9450	0.9999	0.9140
Bend	23.67	0.2553	0.9552	0.9813	0.9228
Middle	20.53	0.8683	0.9999	0.9999	0.9999
Lower	17.14	0.6293	0.8953	0.9999	0.9999
Downstream Bridge	10.53	0.1836	0.9901	0.9924	0.9929
Uncertainty value used was 48 Equivalent Years of Record for discharge frequency and a standard deviation of 0.50 ft for stage-discharge uncertainty.					

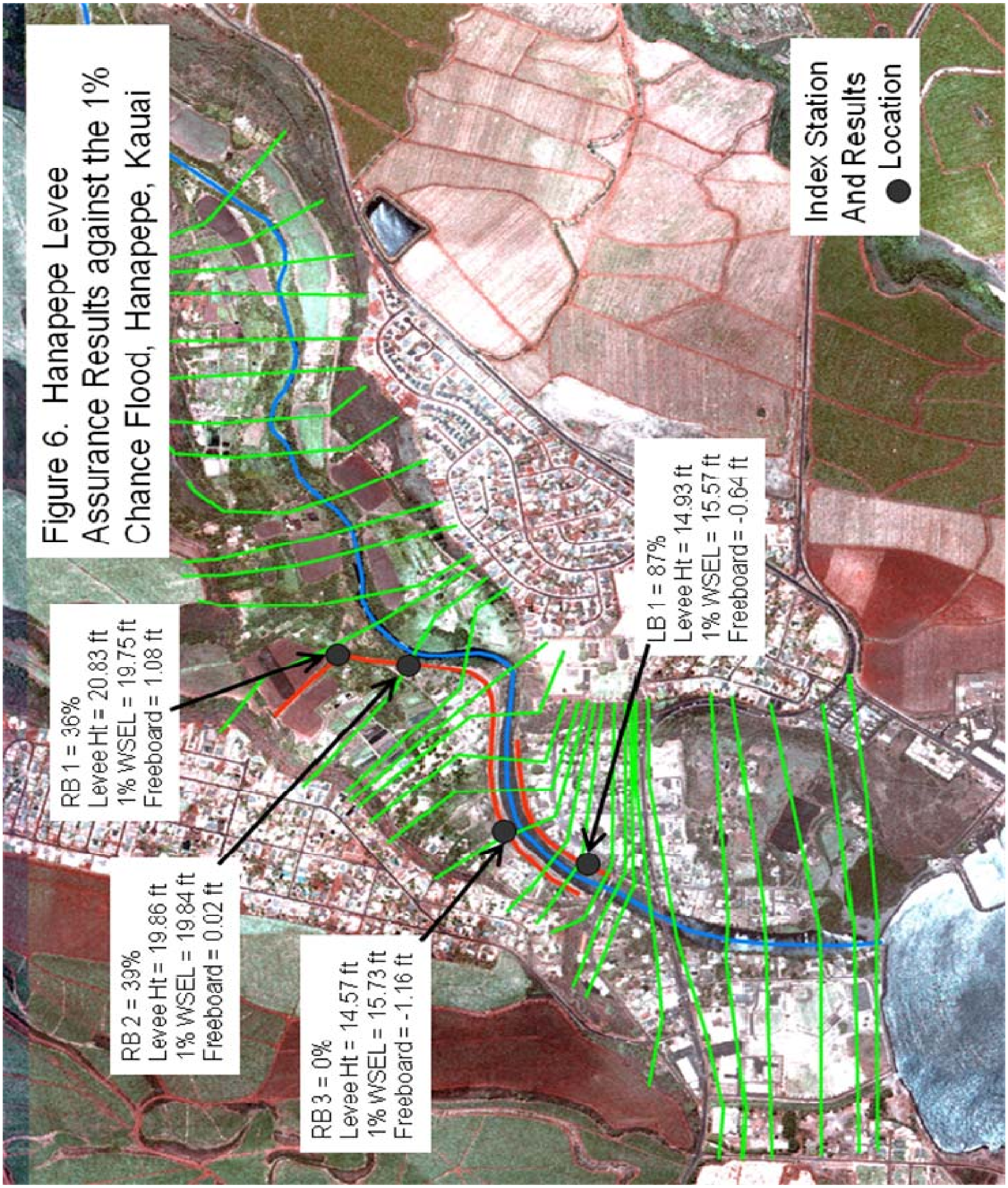


Figure 6. Hanapepe Levee Assurance Results against the 1% Chance Flood, Hanapepe, Kauai

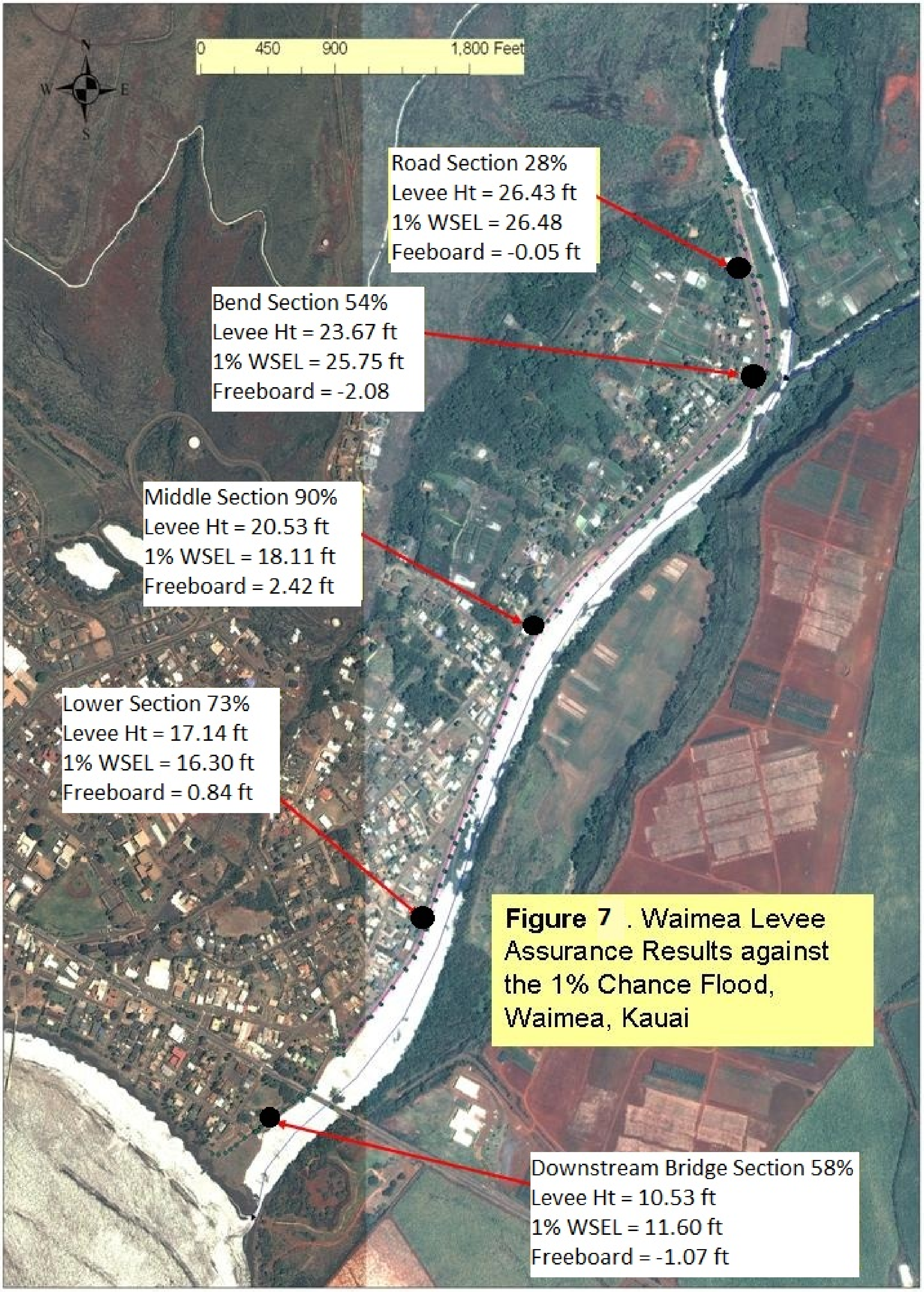


Figure 7 . Waimea Levee Assurance Results against the 1% Chance Flood, Waimea, Kauai

6. **INTERIOR DRAINAGE ANALYSIS**.

6.1. Hanapepe River FCP. Based on the 1962 and the 1965 As-Built drawings there are 9 interior drainage outlets that go through the levee system, six through the right bank levee and three through the left bank levee. There have been changes over time to the structures and landowners behind the levee system. The right bank has one 18-inch, two 24-inch, one 36-inch and two 42-inch drainage outlets. The left bank has two 18-inch and one 24-inch drainage outlets.

This interior drainage analysis is only based on the 1965 as-built condition; the actual flows may be different. A more detailed interior drainage analysis is beyond the scope of this study. Two 18-inch interior drainage outlets through the left bank levee were judged to be inadequate based on an estimated drainage area behind the pipes. In the 1965 As-Built drawings these two 18-inch pipes go through the left bank levee at Station 6+94 and 19+00. These two pipes did not have sufficient capacity for a 10 year storm (10% chance storm). The drainage outlet at Station 19+00 is only slightly under designed. The rest of the culverts along this levee system had sufficient capacity for a 10 year storm flow. Suggest that the two 18-inch outlets on the left bank be changed to bigger diameter pipes or find a way to relieve some of the interior drainage flow to these two outlets.

6.2. Waimea River FCP. Based on the 1983 As-Built drawings there are 19 interior drainage outlets that go through the levee system. The main drainage outlet structure has five 60-inch drainage outlets with flap gates. The rest of the drainage outlets range from 16 to 24-inch diameter pipes.

All the flap gates and gatewells are fully functional. Four outlet structures were found to have sufficient capacity for a 10 year storm event. The rest of the interior drainage outlets did not have sufficient data to do an analysis. However, approximately three feet of water floods Waimea Town during a 10 year storm event and approximately five feet of water during a 100 yr storm event. The problem is a high degree of coincidence between river flooding and interior rainfall. The recommended solution is a pump station to remove interior drainage into the river during high water events.

6.2.1. Waimea River Pump Station. The pump station was designed by trial and error simulations and designed for a 10% chance flood and a 1% chance flood. The HEC-HMS program was used to select a pump based on the existing storm event and the Elevation-Discharge Curve for the pump. See **Appendix A** for more pump information.

Pump stations are required to reduce interior flooding when gravity outlets cannot operate during high water periods. An extra pump should also be installed for backup in the event that a pump should fail. Pump stations should be tested quarterly to maintain assurance that the pumps will be operational during a storm.

6.2.1.1. 10% Chance Flood Pump Design. This pump station design required two (2) propeller pumps. See **Table 11** for pump selection information. A third pump should also be installed for backup in the event that a pump should fail.

Table 11. Pump and System Details for 10% Chance Flood Protection, Waimea, Kauai, Hawaii	
Pump Model (or similar)	Two (2) Fairbanks Morse 8211 Propeller Pumps, 36" diameter, 500 rpm, 1 Stage, Propeller No. A-304-A-4 ¼, 4 vane in Parallel
Single Pump Discharge (gpm)	32,000
Total Discharge Line Length (ft)	60 ft
Discharge Line Diameter (ft)	3 ft
Maximum Static Head (ft)	14 ft
First Pump ON Elevation (ft msl)	4 ft msl
First Pump OFF Elevation (ft msl)	3.5 ft msl
Second Pump ON Elevation (ft msl)	4 ft msl
Second Pump OFF Elevation (ft msl)	3.5 ft msl
gpm = Gallons per minute; msl = Mean Sea Level	

The cost estimates assumed the pump station would be a pre-fabricated metal building. Adequate power was assumed to be nearby therefore no additional transformer cost was included. The cost was based on three EA Fairbanks Morse 8211 36 inch Propeller Pumps costing $430,000.00 including delivery to Hawaii at a lead time of 30 weeks. The performance period to install the pump station and pumps was assumed to be 12 months, including submittals and pump testing.

The estimated cost for the 10% Chance Flood Protection which includes the cost of a pump station and three pumps is $4.5 million.

6.2.1.2. 1% Chance Flood Pump Design. This pump station design required three (3) propeller pumps. See **Table 12** for pump selection information. A fourth pump should also be installed for backup in the event that a pump should fail.

Table 12. Pump and System Details for 1% Chance Flood Protection, Waimea, Kauai, Hawaii	
Pump Model (or similar)	Three (3) Fairbanks Morse 8211 Propeller Pumps, 36" diameter, 500 rpm, 1 Stage, Propeller No. A-304-A-4 ¼, 4 vane in Parallel
Single Pump Discharge (gpm)	32,000
Total Discharge Line Length (ft)	60 ft
Discharge Line Diameter (ft)	3 ft
Maximum Static Head (ft)	14 ft
First Pump ON Elevation (ft msl)	4 ft msl
First Pump OFF Elevation (ft msl)	3.5 ft msl
Second Pump ON Elevation (ft msl)	4 ft msl
Second Pump OFF Elevation (ft msl)	3.5 ft msl
Third Pump ON Elevation (ft msl)	4 ft msl
Third Pump OFF Elevation (ft msl)	3.5 ft msl
gpm = Gallons per minute; msl = Mean Sea Level	

The estimated cost for the 1% Chance Flood Protection which includes the cost of a pump station and four pumps is $5.0 million.

7. **SUMMARY AND CONCLUSION**

7.1. Summary. This report updated the Hydrology and looked at 5 different alternatives for both the Hanapepe River FCP and the Waimea River FCP. The capacity exceedance and levee performance was performed on alternatives 1 – 3 for both projects. A limited interior drainage analysis was also done for both projects.

7.2. Recommendations. Alternative 1 (raising the levees) is the preferred alternative for both the Hanapepe River FCP and the Waimea River FCP due to its cost effectiveness and constructability. The Hanapepe alternative provides 98.10 to 99.99% assurance against the 1% chance flood. The Waimea alternative provides 90.00 to 99.99% assurance against the 1% chance flood. The construction involved in Alternative 1 will allow both projects to be certified by the National Flood Insurance Program (NFIP) Levee System Evaluation.

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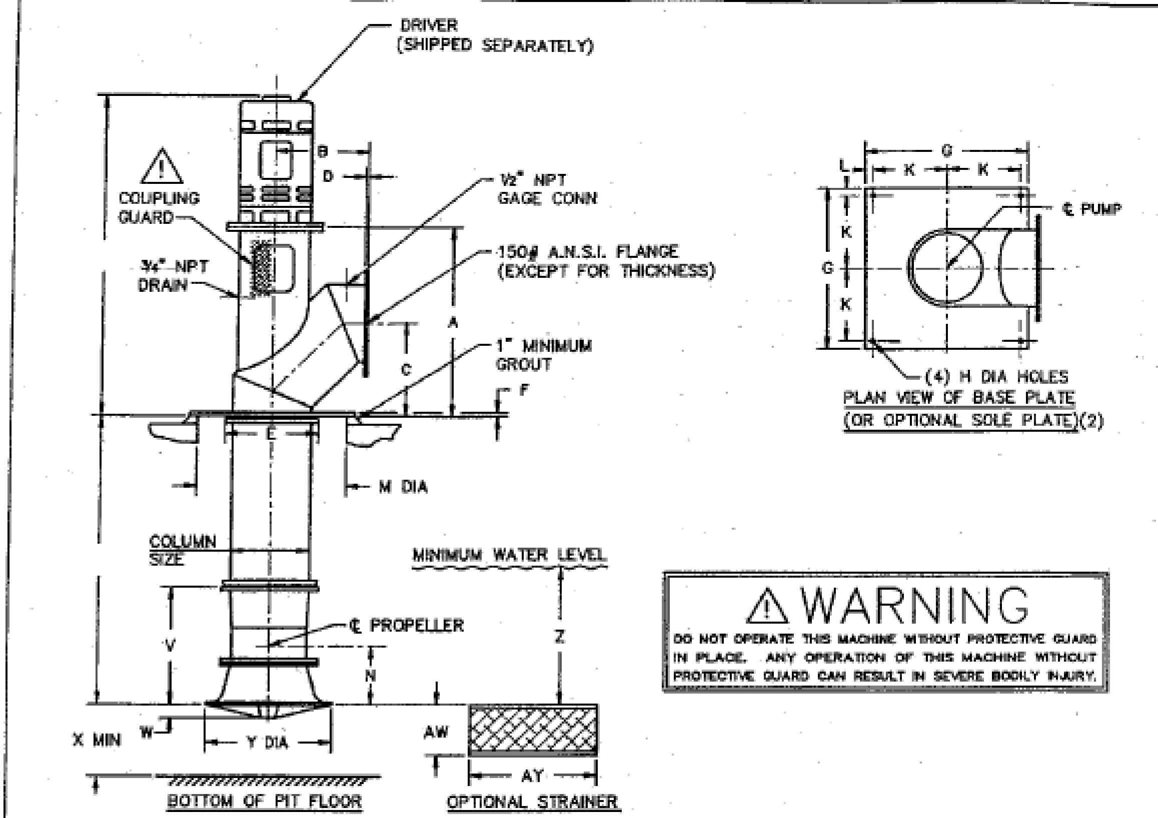
Appendix A: Pump Information

469



DISCHARGE HEAD DIMENSIONS

PUMP SIZE	DISCH SIZE	COL SIZE	A MTR BASE DIA 12	16 1/2	20	24 1/2	30 1/2	B	C	D	E	F	G	H	K	L	M
8	8	8	30	--	--	--	--	11	10	3/4	11 1/2	3/4	21	7/8	8 1/2	2	15
10	10	10	33	--	--	--	--	13	12	3/4	13 3/4	3/4	23	7/8	9 1/2	2	18
12	12	12	35	36	--	--	--	15	15	3/4	16 1/4	1	26	7/8	11	2	21
20	20	20	42	43	49	50	56	24	24	3/4	23 3/4	1	44	1	20	2	38
24	24	24	--	47	53	54	62	29	29	3/4	28	1	50	1	23	2	43
30	30	30	--	--	59	60	68	36	38	3/4	34	1 1/4	54	1 1/8	25	2	45
36	36	36	--	--	65	66	74	43	43	3/4	40	1 1/4	66	1 1/8	31	2	57

PUMP DIMENSIONS

PUMP SIZE	N	V 1 STG	V 2 STG	W	X W/O STR	X WITH STR	Y	STRAINER AW	STRAINER AY	Z
8	6 3/4	13 1/2	21 1/2	2 1/2	5	7	12 3/4	4	13	51
10	8 3/4	16 3/4	26	3 1/2	6	8	15 1/2	5	15 1/2	54
12	10 1/4	19 1/2	30 1/4	3 1/2	7	12	18	9	18	54
20	14 1/2	30 1/2	47	5	11	11	32	6	32	60
24	20 1/4	38	57 1/2	5	12	12	36	7	36	63
30	23	48	73	5	15	15	42	10	42	66
36	24 5/8	54	83	5	18	18	54	9	54	69

1. THIS DRAWING NOT FOR CONSTRUCTION OR INSTALLATION UNLESS CERTIFIED. DIMENSIONS SHOWN ARE TYPICAL AND MAY VARY DUE TO VARIOUS TOLERANCES.
2. BASE PLATE (OR OPTIONAL SOLE PLATE) MUST BE SUPPORTED ON ALL FOUR (4) SIDES.

CUSTOMER | P.O. | RELEASE NUMBER EC2-15054 | REV NO 1

JOB NAME | SERVICE

Fairbanks Morse Pump Corporation

PUMP SIZE & MODEL | STAGES | GPM | TDH | RPM | ROT

MOTOR | HP | FRAME | PHASE | HERTZ | VOLTS | ENCL

CERTIFIED FOR | CERTIFIED BY | DATE

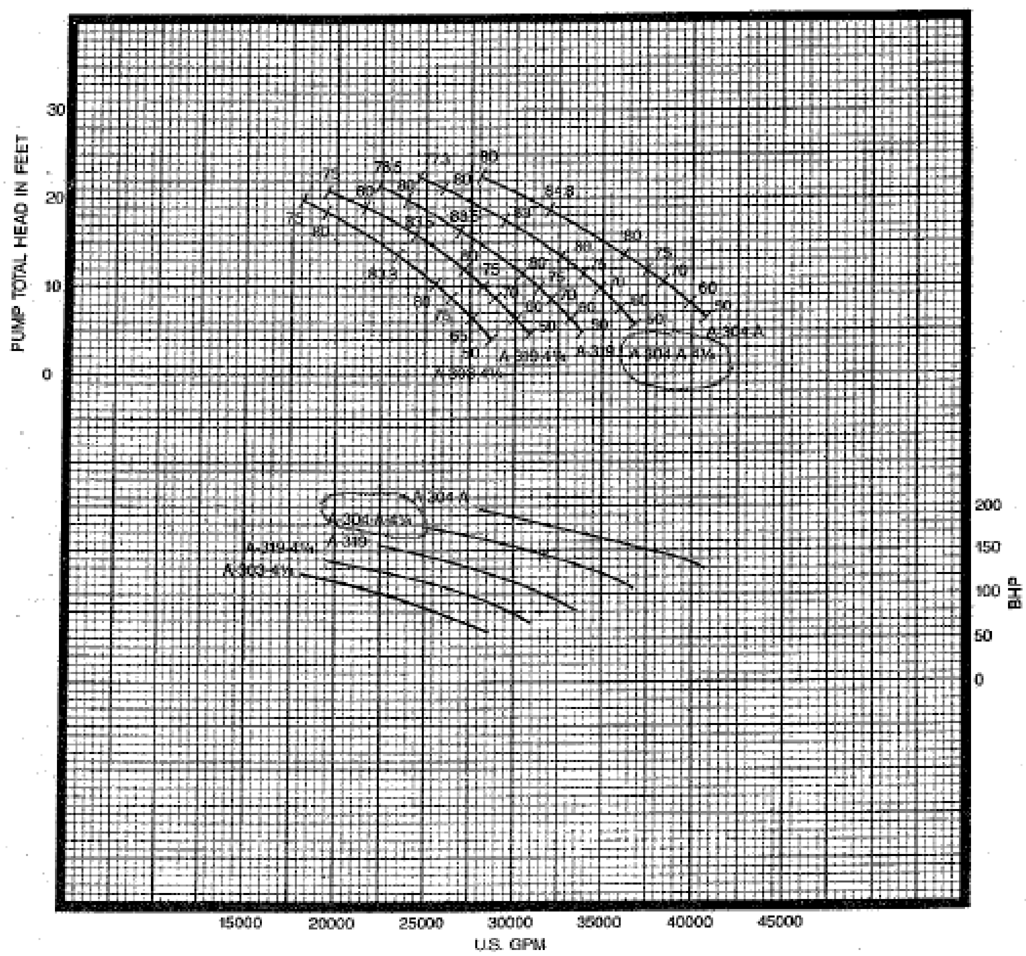
SETTING PLAN
FIGURE 8211
FLANGED DISCHARGE
ABOVEGROUND HEAD

DWG. NO. 24LYA3523A

5/9/00

8000 PROPELLER PUMPS
PUMP PERFORMANCE

339



36″
8211

500
RPM

1
STAGE

36″
COLUMN

36″
FABRICATED
STEEL ELBOW

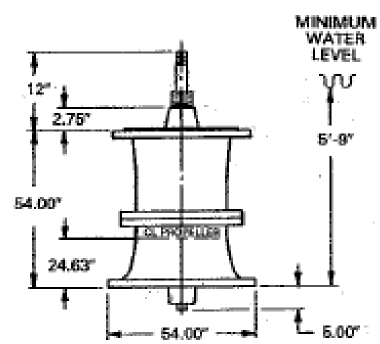
2-7/16″
LINESHAFT

3-1/2
ENCLOSING
TUBE

DATA		VALUE	
PUMP SHAFT DIAMETER		2.9375 IN.	
MAXIMUM SPHERE SIZE		5.00 IN.	
Kt (THRUST FACTOR)		320 LBS./FT.	
Ka (TOTAL ROTOR WEIGHT)		470 LBS.	
Ks (SETTING CONSTANT)		15.9 LBS./FT.	
WK^2		388 LBS.-FT.^{2}	
BOWL ASSEMBLY WEIGHT		3000 LBS.	
EYE AREA:	PROPELLER NO. A-303-4 1/4	537.4 SQ. IN.	3 VANE
	PROPELLER NO. A-319-4 1/4	537.4 SQ. IN.	3 VANE
	PROPELLER NO. A-319	587.5 SQ. IN.	3 VANE
	PROPELLER NO. A-304-A-4 1/4	537.4 SQ. IN.	4 VANE
	PROPELLER NO. A-304-A	587.5 SQ. IN.	4 VANE
	PROPELLER NO.		

HYDRAULIC PERFORMANCE IS CONTINGENT ON FURNISHING THE PUMP WITH SPECIFIED AMOUNT OF CLEAR, FRESH, NON-AERATED WATER NOT TO EXCEED 85° F.

PUMP PERFORMANCE SHOWN IS BOWL ASSEMBLY WITH 10 FEET OF COLUMN INCLUDING A STANDARD ABOVE GROUND DISCHARGE ELBOW. ADDITIONAL COLUMN LOSSES SHOULD BE ADDED WHEN SETTINGS ARE DEEPER THAN 10 FEET AND/OR FOR OTHER DISCHARGE ARRANGEMENTS.



*This value is the minimum submergence required to prevent vortexing only. This value may need to be increased to provide adequate NPSHA.

FAIRBANKS MORSE PUMPS

8000 Propeller Pumps
Material Specifications - Bowl Assemblies

8211

REF. NO.	DESCRIPTION	MATERIAL	SPECIFICATION (1)
27	SNAP RING	STAINLESS STEEL	A564-(632)
28	COLUMN PIPE	STEEL	A53-Gr.B
31	SHAFT COUPLING	STEEL	A108-Gr12L14
32	PUMP SHAFT	416 STAINLESS STEEL	A582-416
33	DISCHARGE BOWL	CAST IRON	A48-CLASS 30
34	DISCHARGE BOWL BEARING	BRONZE	B505-(932)
35	INTERMEDIATE BOWL BEARING	BRONZE	B505-(932)
36	INTERMEDIATE BOWL	CAST IRON	A48-CLASS 30
36A	CAP SCREW	STEEL	SAE BOLT STEEL
36B	NUT	STEEL	SAE BOLT STEEL
38	PROPELLER	BRONZE	B584 (836)
40	SUCTION BELL	CAST IRON	A48-CLASS 30
41	SUCTION BELL BEARING	BRONZE	B505-(932)
44	COMPANION FLANGE	CAST IRON	A48-CLASS 30
44A	CAPSCREW	STEEL	SAE BOLT STEEL
44B	NUT	STEEL	SAE BOLT STEEL
50	CONNECTOR BEARING	BRONZE	B505-(932)
58	SAND CAP	BRONZE	B505-(932)
59	SUCTION BELL PIPE PLUG	CAST IRON	A48-CLASS 30
88	SET SCREW	STEEL	SAE BOLT STEEL
97	PROPELLER KEY	STEEL	AISI-1018
98	BOWL LINER	BRONZE	B505-(932)

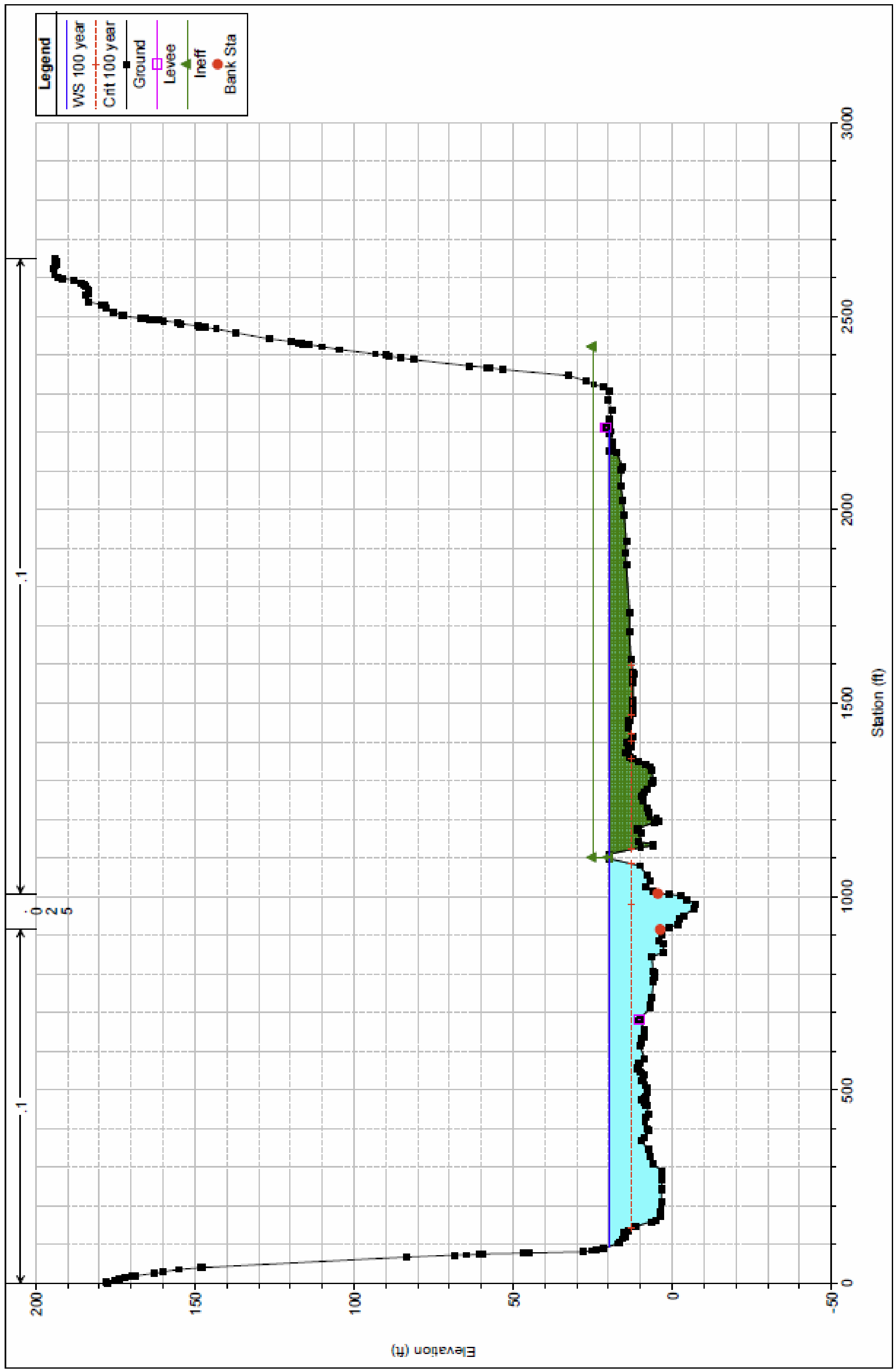
8312

REF. NO.	DESCRIPTION	MATERIAL	SPECIFICATION (1)
24	COLUMN COUPLING	STEEL	A53-Gr.B
30	COLUMN	STEEL	A53-Gr.B
31	SHAFT COUPLING	STEEL	A108-Gr12L14
32	PUMP SHAFT	416 STAINLESS STEEL	A582-416
33	DISCHARGE BOWL	CAST IRON	A48-CLASS 30
34	DISCHARGE BOWL BEARING	BRONZE B584	B505-(932)
35	INTERMEDIATE BOWL BEARING	BRONZE B584	B505-(932)
36	INTERMEDIATE BOWL	CAST IRON	A48-CLASS 30
36A	CAP SCREW	STEEL	SAE BOLT STEEL
37	PROPELLER LOCK NUT	BRONZE	B584 (865)
38	PROPELLER	BRONZE	B584 (836)
39	PROPELLER LOCK COLLET	STEEL	A108-Gr12L14
40	SUCTION BELL	CAST IRON	A48-CLASS 30
41	SUCTION BELL BEARING	BRONZE	B505-(932)
50	CONNECTOR BEARING	BRONZE	B505-(932)
58	SAND CAP	BRONZE	B505-(932)
59	SUCTION BELL PIPE PLUG	CAST IRON	A48-CLASS 30
88	SET SCREW	STEEL	SAE BOLT STEEL
98	BOWL LINER	BRONZE	B505-(932)
99	BOWL SEAT SECTION	CAST IRON	A48-CLASS 30

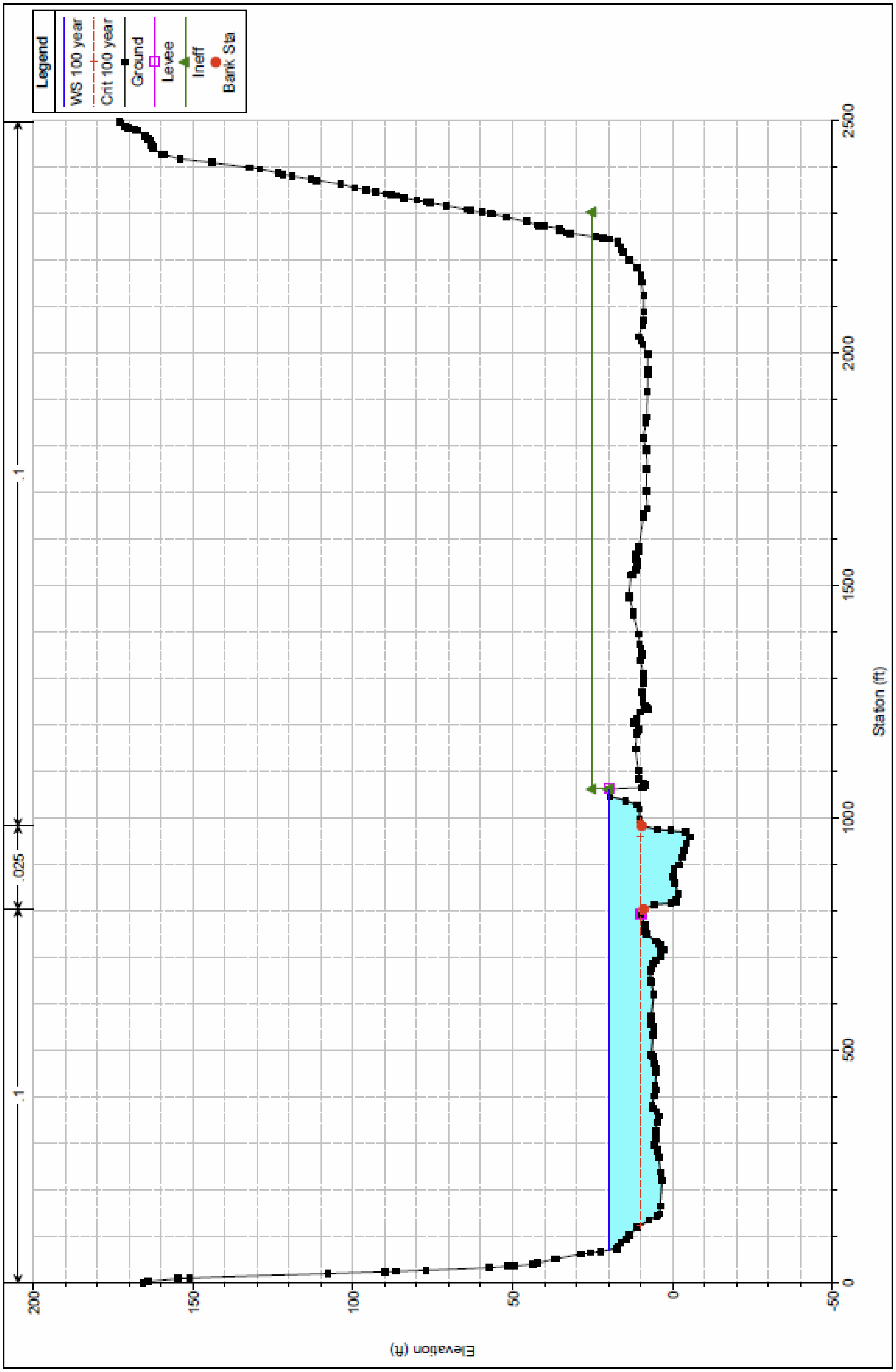
(1) ALL MATERIAL DESIGNATIONS ARE ASTM UNLESS OTHERWISE NOTED, AND ARE FOR DESCRIPTION OF CHEMISTRY ONLY.

Appendix B: HEC-RAS Cross-section Plots at Index Stations

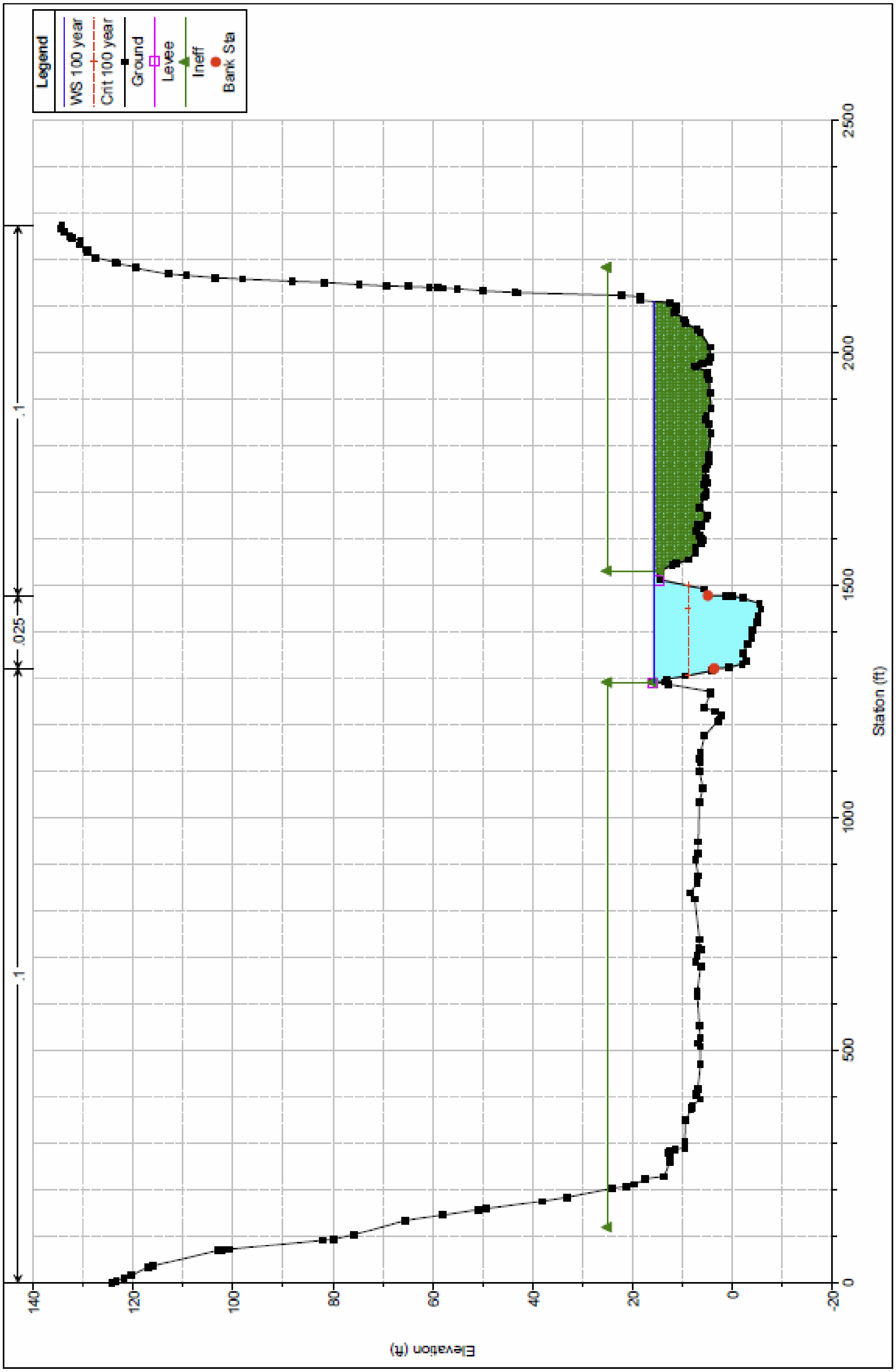
Index Station RB 1, Cross-section 6058.517, 1-percent Chance Flood, Hanapepe River, Hanapepe, Kauai, Hawaii



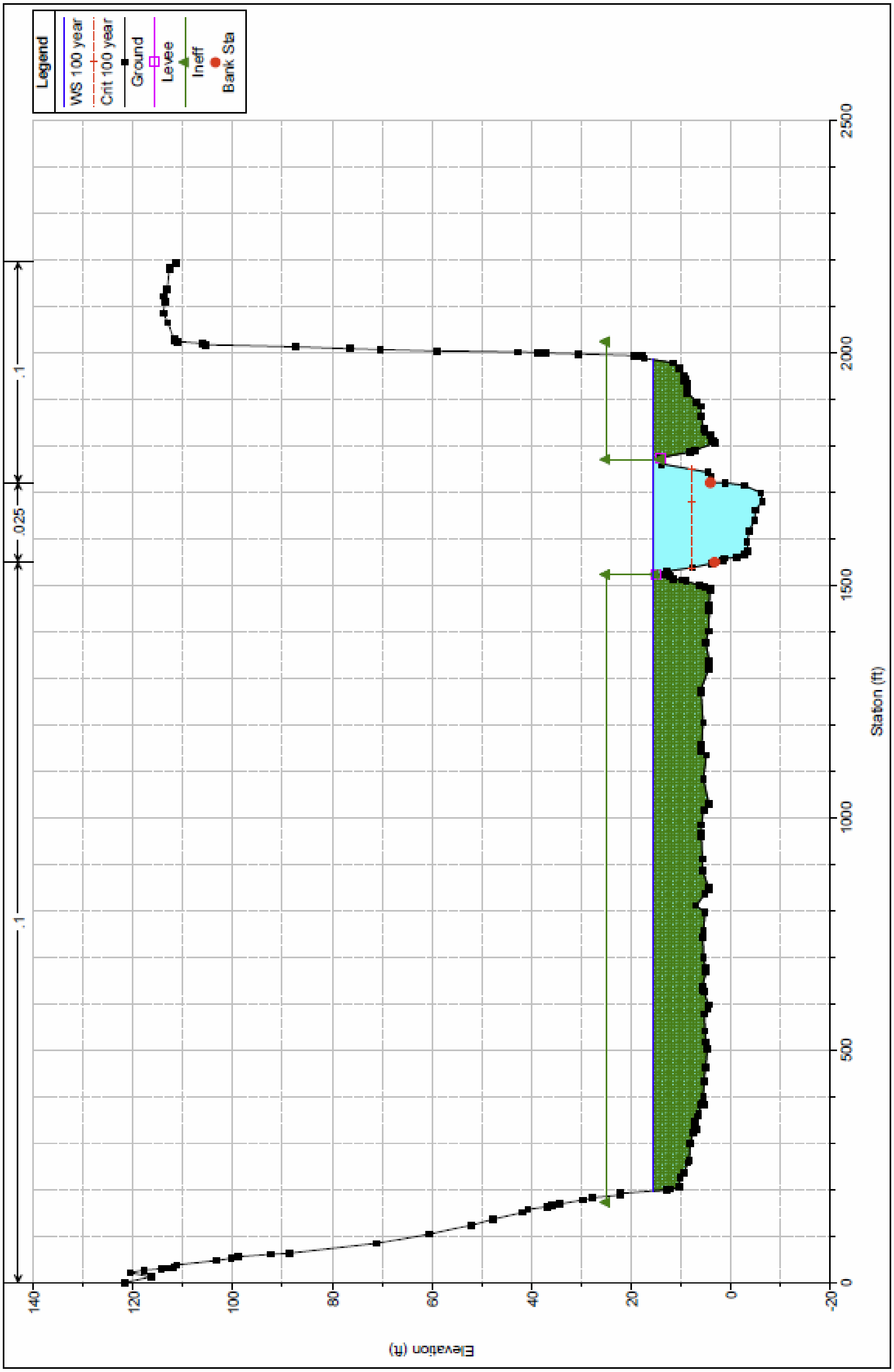
Index Station RB 2, Cross-section 5634.805, 1-percent Chance Flood, Hanapepe, Hanapepe River, Kauai, Hawaii



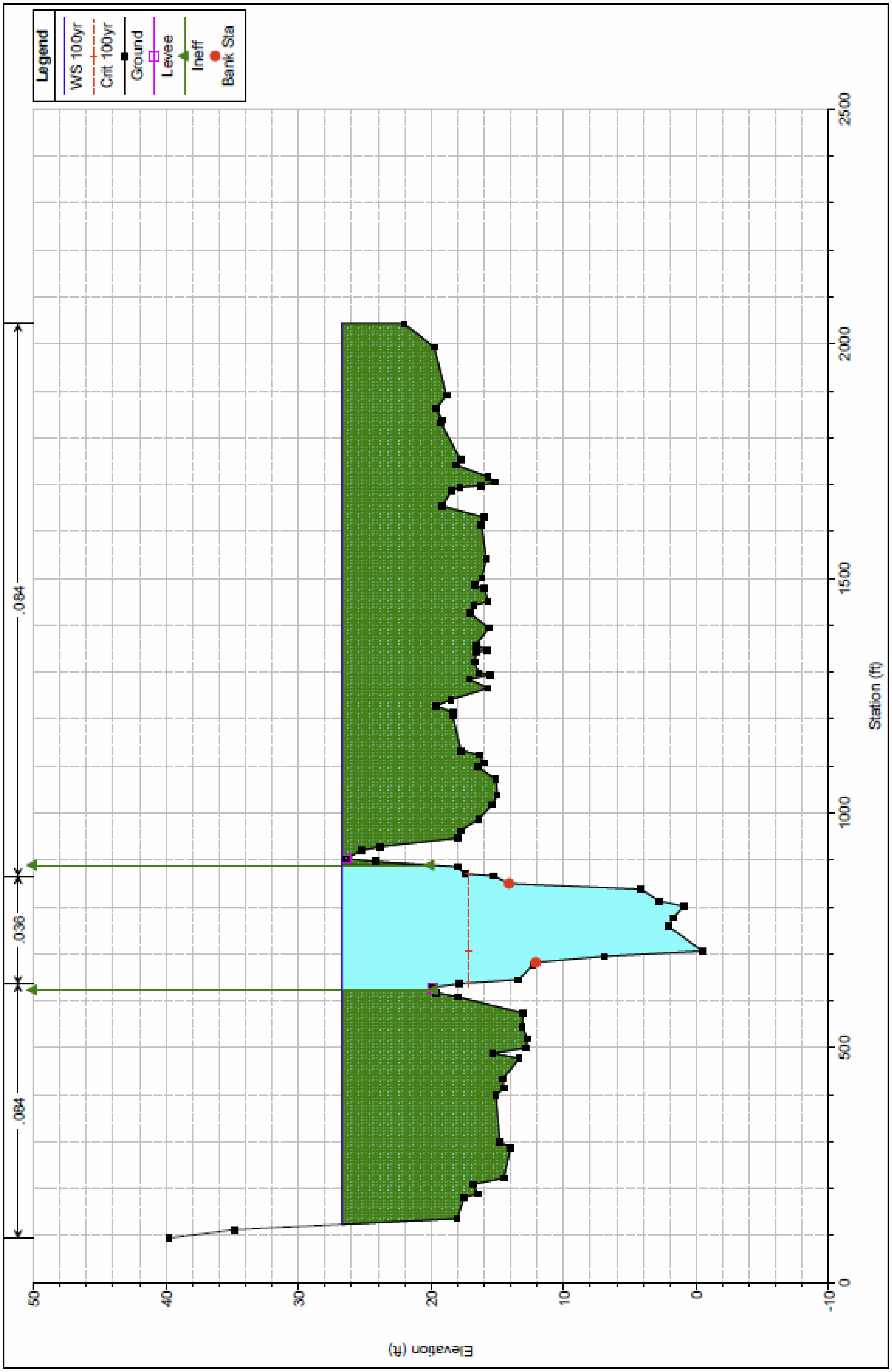
Index Station RB 3, Cross-section 3248.236, 1-percent Chance Flood, Hanapepe River, Hanapepe, Kauai, Hawaii



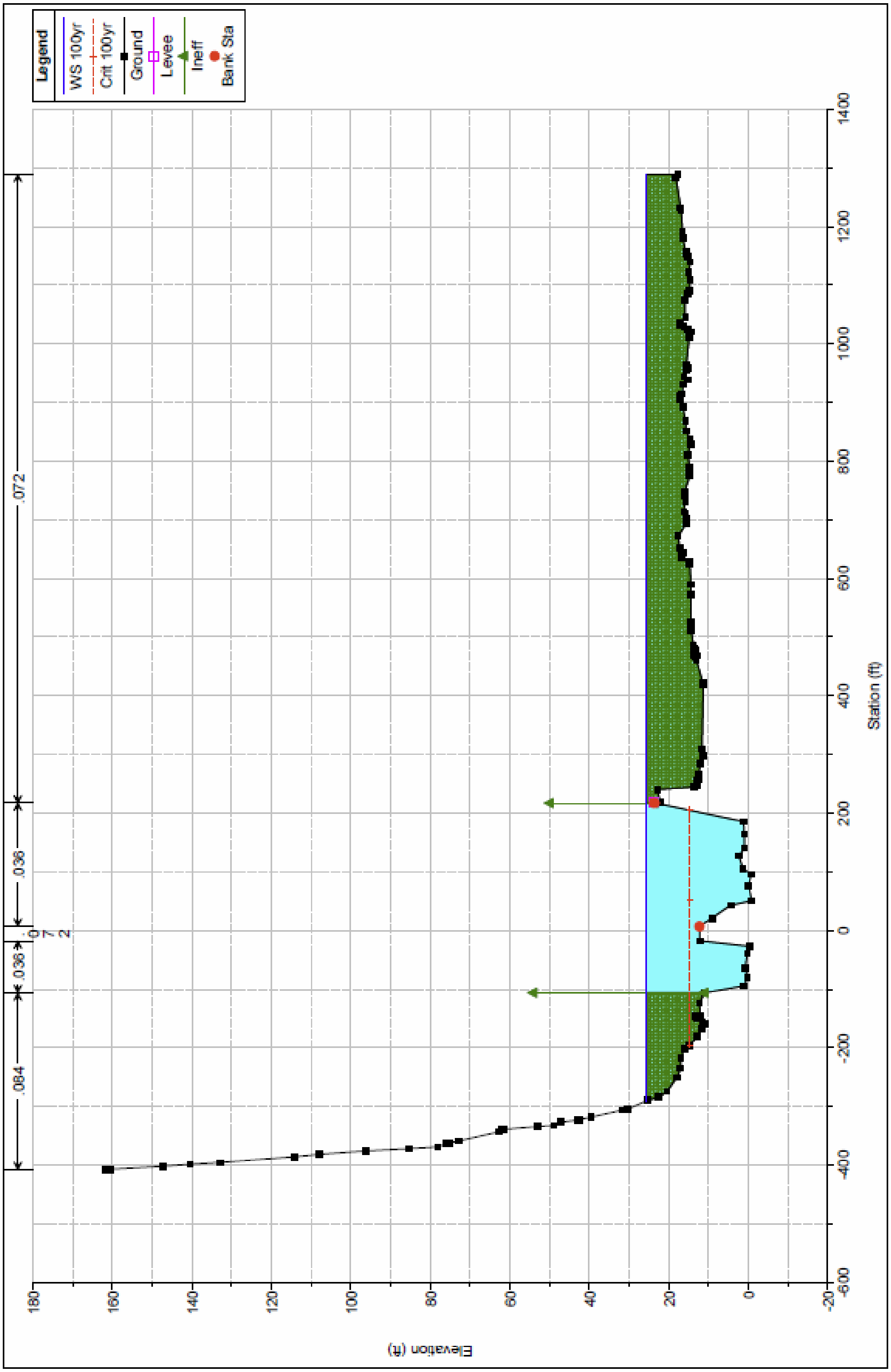
Index Station LB 1, Cross-section 2667.813, 1-percent Chance Flood, Hanapepe River, Hanapepe, Kauai, Hawaii



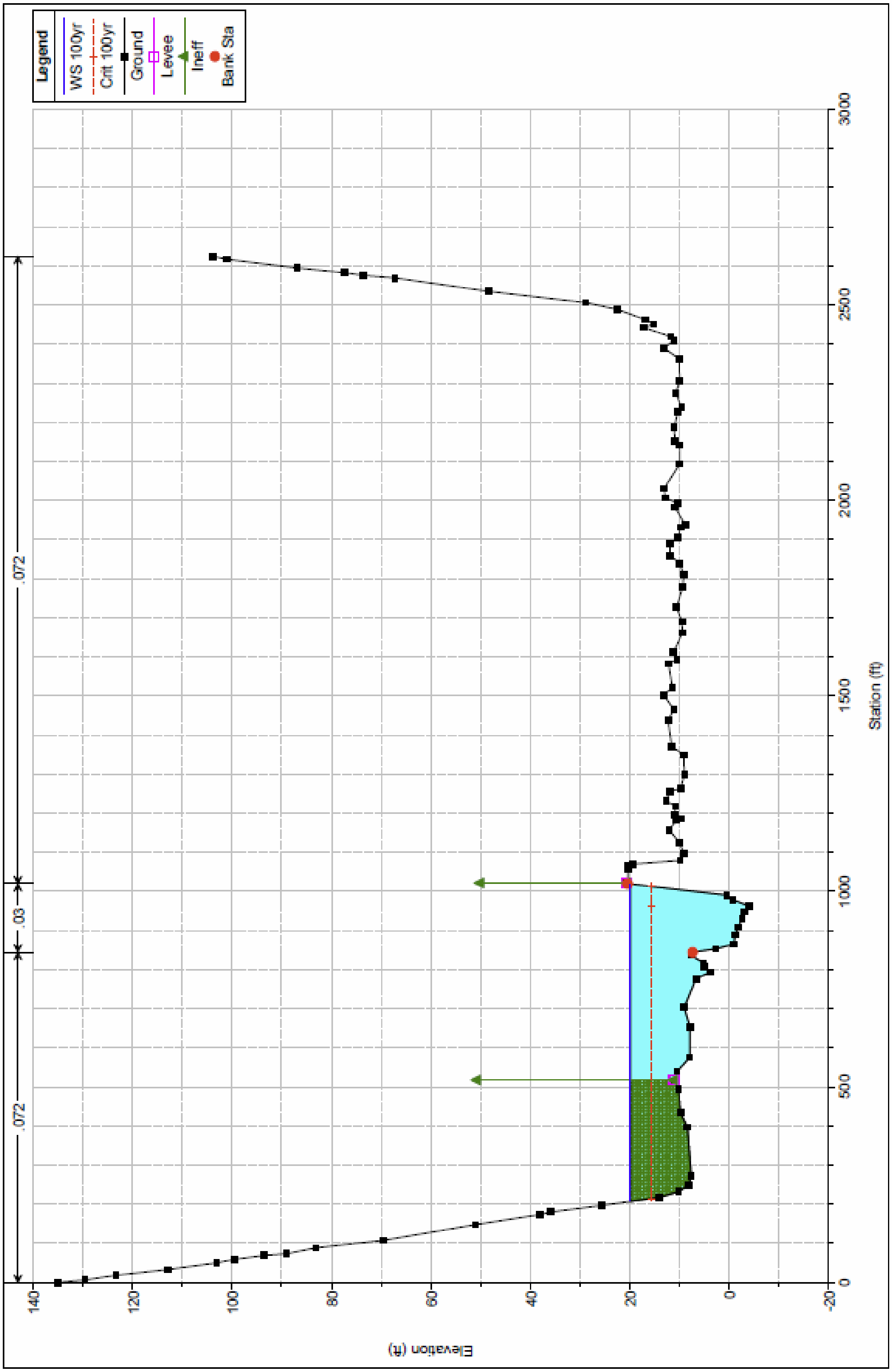
Index Station Road, Cross-section 7473.761, 1-percent Chance Flood, Waimea River, Waimea, Kauai, Hawaii



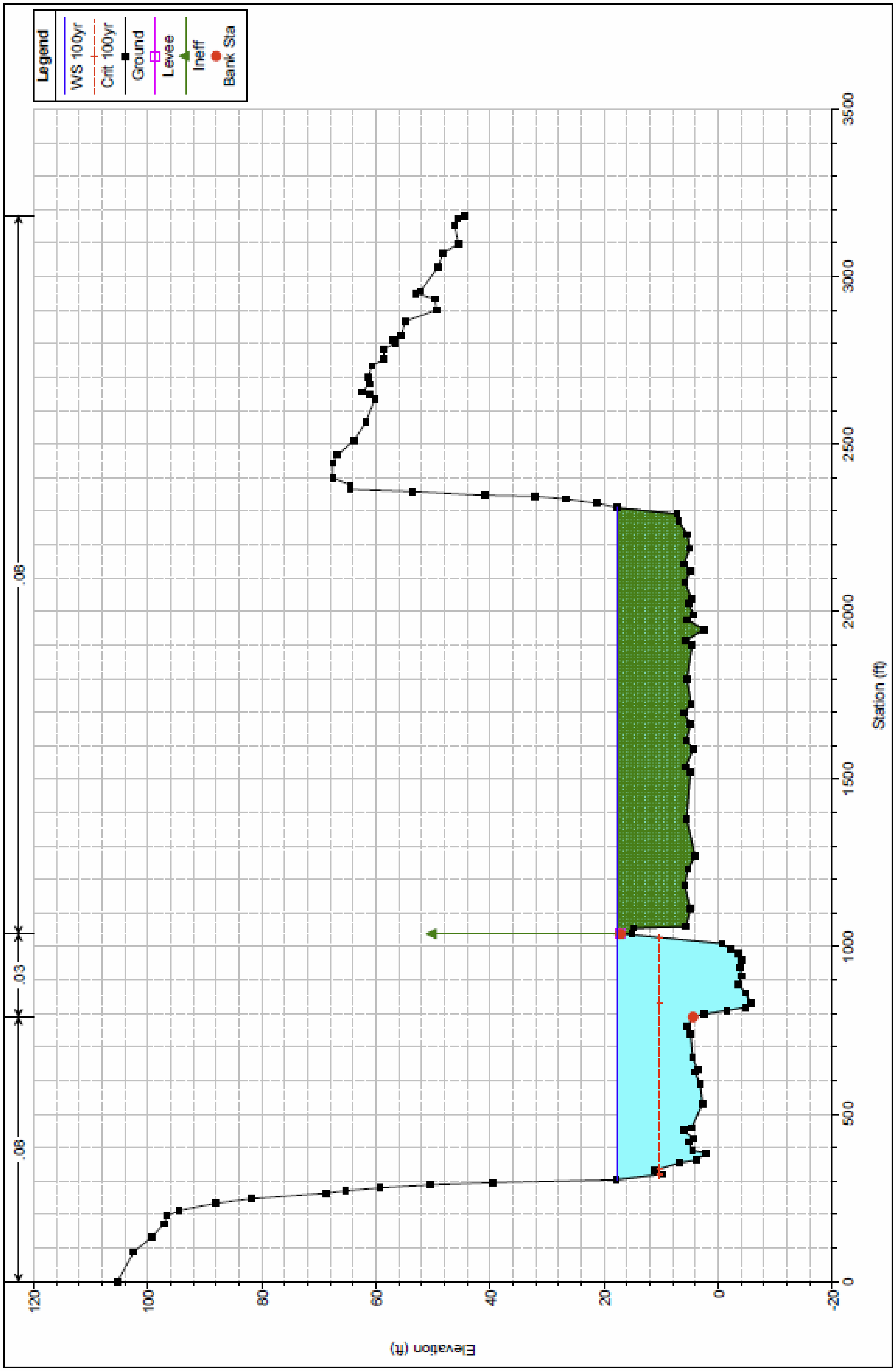
Index Station Bend, Cross-section 6550.698, 1-percent Chance Flood, Waimea River, Waimea, Kauai, Hawaii



Index Station Middle, Cross-section 4965.825, 1-percent Chance Flood, Waimea River, Waimea, Kauai, Hawaii



Index Station Lower, Cross-section 2028.328, 1-percent Chance Flood, Waimea, Waimea River, Waimea, Kauai, Hawaii



Index Station Downstream Bridge, Cross-section 7473.761, 1-percent Chance Flood, Waimea River, Waimea, Kauai, Hawaii