WAIAKEA-PALAI STREAMS
Hilo, Island of Hawaii, Hawaii

CONTINUING AUTHORITIES PROGRAM SECTION 205
FLOOD RISK MANAGEMENT

Appendix B-2: Hydraulics

MAY 2020

US Army Corps of Engineers
Honolulu District

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Appendix B2 – Hydraulic Analysis

WAIAKEA-PALAI FLOOD RISK MANAGEMENT
FLOOD DAMAGE REDUCTION PROJECT, HILO, HAWAII
MAY 2019

Executive Summary

The Hydraulic Appendix provides details of the hydraulic analysis performed for Waiakea, Palai and portion of Four Mile streams in Wailoa watershed. The report summarizes previous studies conducted for the project area, as well as updated data, information, and modeling used for the tentatively selected plan (TSP). Since 1984, various channel and conveyance improvements have been done to alleviate acute flooding problems in the project area. Similarly, hydrology and hydraulic modeling has been conducted by the Corps of Engineers with partner organizations.

The modeling is based on HEC-RAS model version 5.0.6. Model simulations were done for eight frequency events including the 50%, 20%, 10%, 4%, 2%, 1%, 0.5%, and 0.2% Annual Chance Exceedance (AEP). Inflow hydrographs for the each event were obtained from the Hydrology analysis (Appendix A2) and some based on the field observations.

As a part of the study, nine different alternatives including future without project were assessed to identify the most beneficial alternative for reducing flooding problems in the Waiakea Hilo project area. As indicated in the main report, TSP alternative is a combination of two measures (Kupulau Ditch and Golf Course projects) that produce the most benefits. The TSP simulation is based on the 2% AEP (50-year), as required by plan formulation guidance based on project life. But this report is supplemented with results from all flow events for the purpose of information and future use.

The final intent of the hydraulic analysis is to provide comprehensive floodplain maps, inundation extents, and water elevation profiles in the project area. The project development team will use the hydraulic results to perform the flood damage assessment, risk assessment, and benefit cost analysis.

Consistent with Corps risk informed decision making policy, this report is based on best available information developed over several years by the Corps and its partner agencies. Data sets that underpin the modeling and results have significant uncertainties that cannot be resolved until new terrain data (LiDAR) becomes available. LiDAR data will be available during the design phase of the project and the hydrologic and hydraulic modeling will be updated at that time. The accuracy of the updated modeling is expected to be significantly greater than that used for feasibility level analysis. Model hydraulic output data (flow rates, elevations, depths, inundation) could differ enough from the values presented in this report that modification to the project measures may still be necessary to maintain the same or higher economic benefits of the selected plan.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE. This hydraulic appendix documents the hydraulic modeling, assumptions, analyses, and results used to determine the extent and amount of flood damage resulting from the 50%, 20%, 10%, 4%, 2%, 1%, 0.5%, and 0.2% Annual Chance Exceedence (AEP) storm events in the Waiakea and Palai Streams, and Four Mile Creek drainage areas. This hydraulic analysis is part of Flood Risk Management (FRM) study for the Waiakea-Palai Stream system in Hilo, Hawaii. Results of the hydraulic modeling are presented as water surface elevation profiles and inundation maps for the various stream reaches used in this analysis.

1.2. STUDY AUTHORITY. The Waiakea-Palai Streams Flood Risk Management (FRM) Project investigation is authorized under Section 205 of the Rivers and Harbors Act of 1962, Public Law 87-874, as amended (76 U.S.C. 1197s; hereinafter Section 205). Section 205 is an authority allowing the Secretary of the Army to initiate surveys for flood control and allied purposes.

1.3 STUDY AREA LOCATION AND DESCRIPTION. Waiakea and Palai Streams, and Four Mile Creek, located in Hilo, Hawaii, are part of the Waiakea-Uka district and extend upstream southwest of Hilo Harbor. The island of Hawaii is also known as the Big Island. Waiakea Stream originates in the upper watershed along the slopes of Mauna Loa (elevation 13,653 feet) volcano and flows through the residential community of upper Waiakea-Uka Homesteads before entering the business district in Hilo town in the lower portion of the watershed (Figure 1). Palai Stream and Four Mile Creek originate down slope on Mauna Loa and while Palai stream flows thru the City of Hilo, Four Mile Creek flows away from Hilo through a constructed channel. The other volcanic masses on the island are Mauna Kea Volcano, Kohala Mountains, Hualalai Volcano, and Kilauea Volcano. Mauna Loa and Kilauea Volcano located in the southern half of the island are the only remaining active volcanoes on the island. See Figure 1, the Location Map. A complete description of the study area can be found in the Hydrology Appendix.

1.4 FLOOD PROBLEMS. Stream flow within the Waiakea-Palai Stream and its tributaries is intermittent with flooding occurring during heavy rainfall events. The flood problems within the study area can be attributed to primarily poorly defined channels with inadequate capacity and secondarily to accumulation of debris and vegetation in the channels which cause blockages within the channels and at stream crossings (Figure 2). The channels when crossing perpendicular to the slope are classed as perched or partially perched and when overtopped can cause severe flooding to the surrounding areas. Severe flooding has occurred within the study area in March 1939, March 1953, July 1966, February 1979, March 1980, August 1994, November 2000, January 2002, and February 2008. A complete description of the prior flood events and previous flood studies can be found in the Hydrology Appendix.

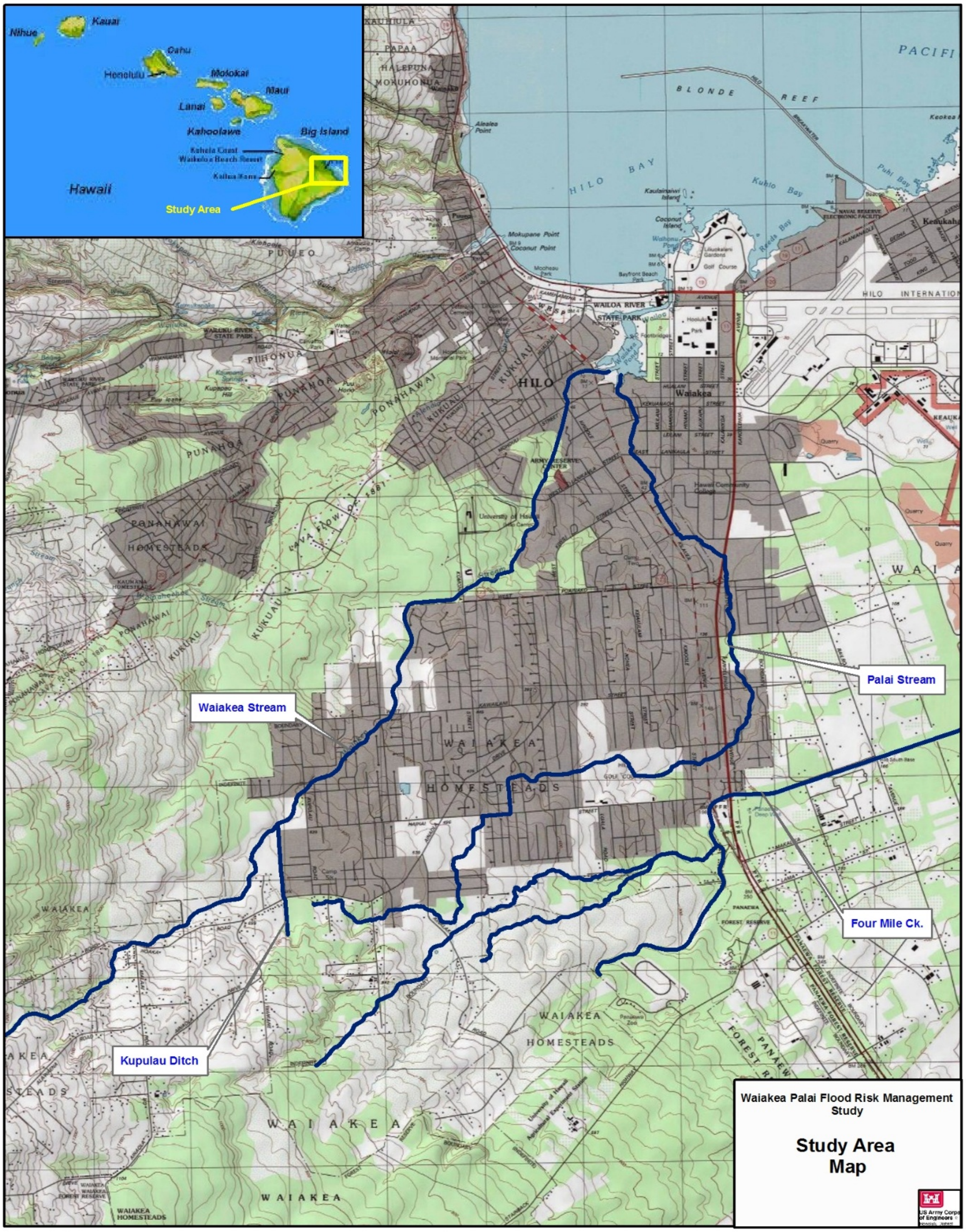


Figure 1. Study Area/Location Map

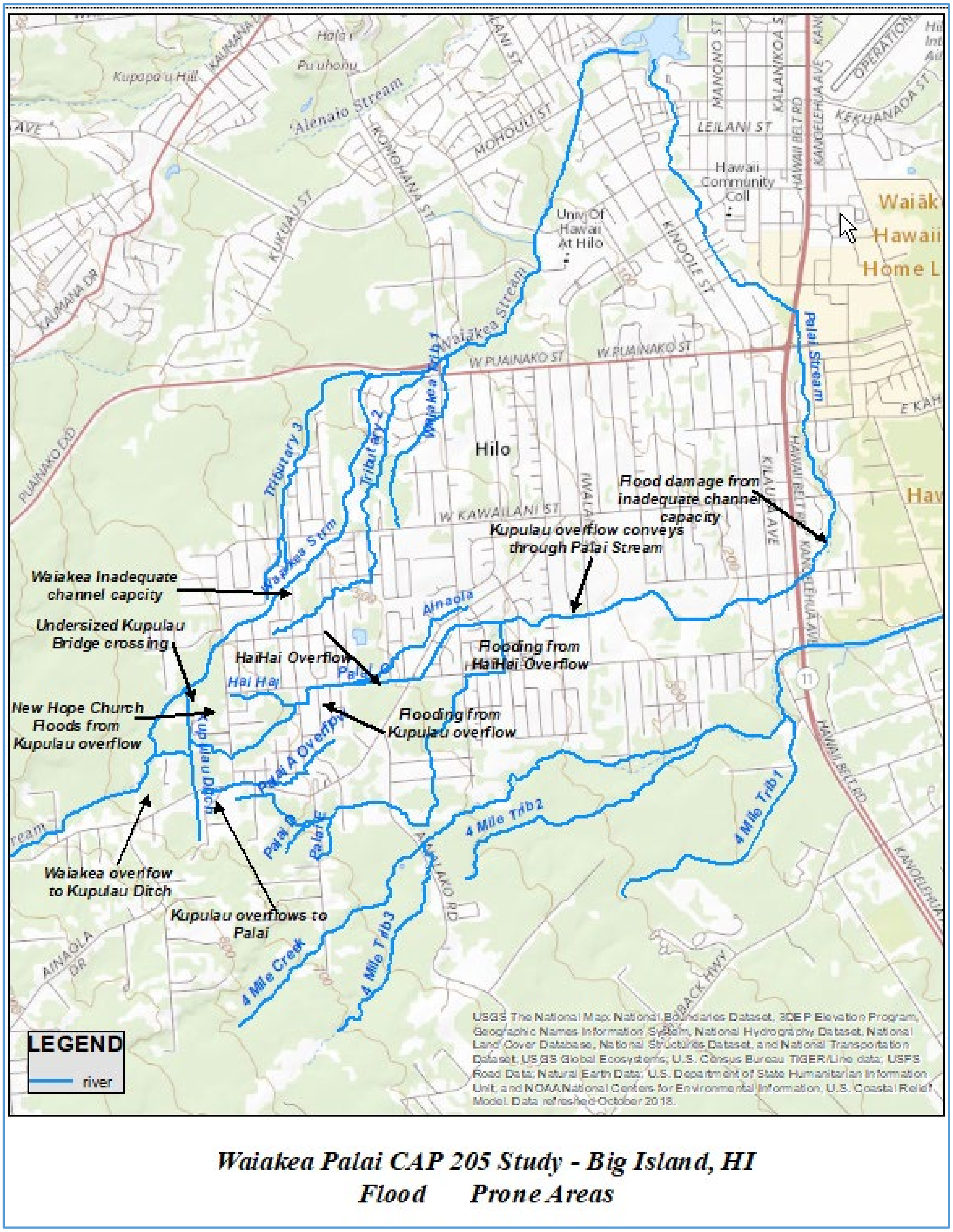


Figure 2. Flood Prone Areas

1.5 FLOOD PROTECTION MEASURES. Downstream in the lower reaches of Waiakea Stream from near The University of Hawaii at Hilo campus to Wailoa Pond (also called Waiakea Pond) at Hilo Bay (Figure 1) the U.S. Army Corps of Engineers (USCAE) built a flood control project in 1965 consisting of channel improvements and levees to protect that portion of Hilo. This project was designed for a flood event of 6,500 cubic feet per second (cfs; ft^3/s) which was determined to have a recurrence interval of 125 years (U.S. Army Engineer District, 1962). Upstream, in the detailed study area, The County of Hawaii constructed the Waiakea Uka channel improvements in 1984. This project consists of 3,460 feet of concrete lined and unlined trapezoidal channel modifications from Komohana Street to near Apono Place. These improvements were designed for a discharge of 4,460 cubic feet per second and were damaged in the November 1-2, 2000 flood. Although not a flood control improvement for Waiakea Stream, The Kupulau Ditch was constructed in 1971 to divert runoff from the Palai Stream drainage basin to Waiakea Stream upstream of the Kupulau Road Bridge. In 2001, after the November 2000 flood, the Kawailani Street Bridge was rebuilt with a new larger clear span structure that to reduce the chance of debris buildup during a rainfall event and repairs were made to the Kupulau Rd. Bridge. No site-specific flood warning system exists for the Waiakea Stream area. Special storm warnings for the Island of Hawaii are broadcast over local radio and television. These warnings are made for broad, extensive areas of the island because of the "flashy" nature of floods and the unpredictability of the precise location of intense storm cells in Hawaii.

1.6 PREVIOUS STUDIES. There have been a number of prior hydraulic studies conducted primarily for the determination of flood insurance rate maps. The Hydrology Appendix describes in greater detail the previous studies undertaken in the Waiakea-Palai watershed. In 2001, in response to the November 2000 flood, POH prepared reconnaissance reports for both Waiakea and Palai Streams under Section 205 of the Flood Control Act of 1946. These reports recommend further studies to identify solutions to the flooding problems.

2. HYDRAULIC ANALYSIS

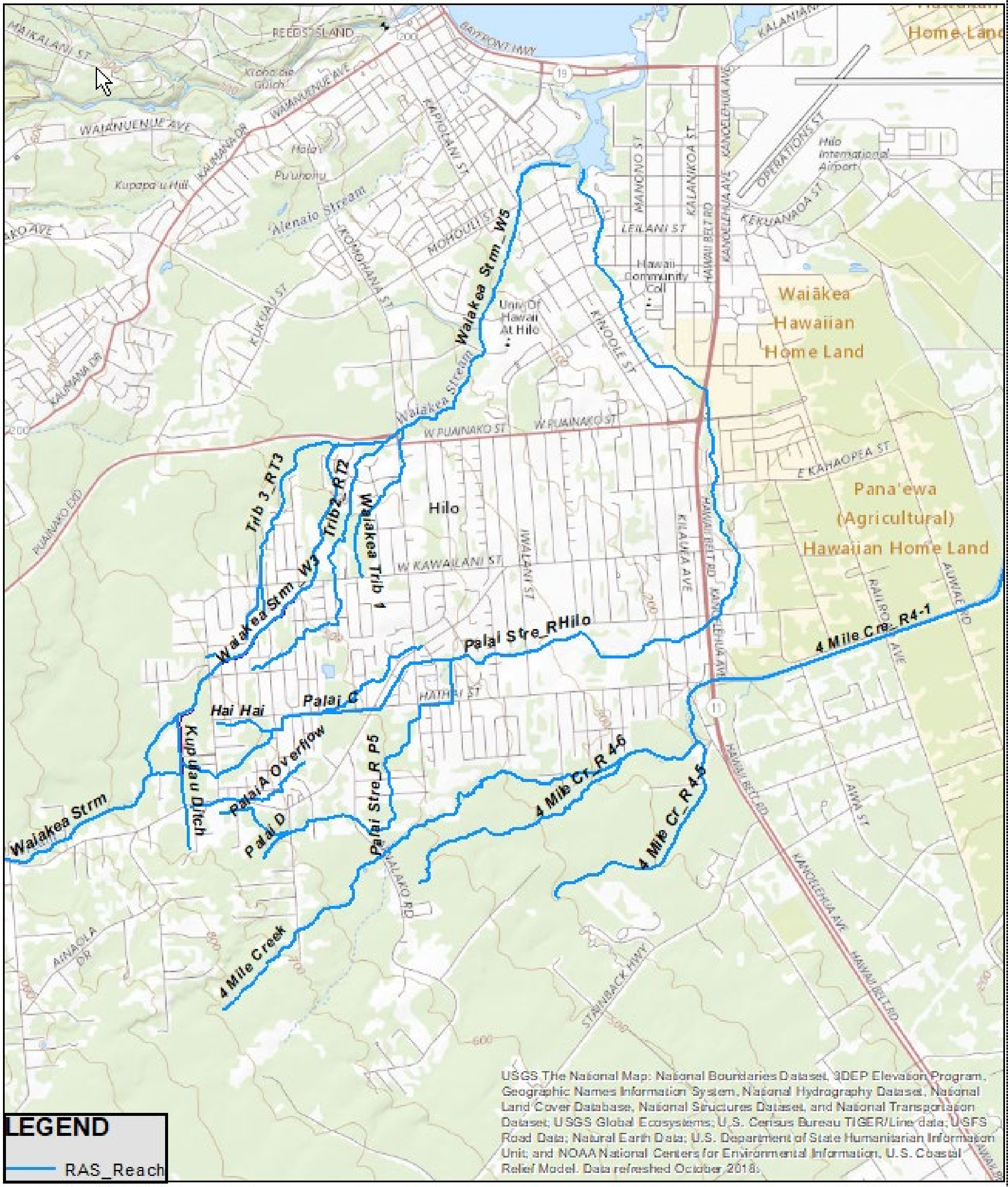
This section discusses the creation of the hydraulic model, modeling assumptions and limitations, and results.

2.1 TOPOGRAPHIC DATA SOURCES. The topographic data used in this study was obtained from several sources. The base topography was obtained by RM Towill Corporation in 2003 via aerial photogrammetric methods (First Palai Stream and Four Mile Creek; then Waiakea Stream through two separate contacts). This basic topographic data has 4-foot contour intervals with 0.1 ft spot elevations accuracy, and a digital elevation model (DEM). The base topo is supplemented by three other sources: 1) LIDAR data from Hawaii County at the Kaumana Road project, covering lower reaches of Waiakea stream; 2) survey data at Ainalako Road diversion area; and, 3) Kapulau Ditch flood insurance study (by Dewberry 2002). The remaining gaps were filled with USGS 10m digital elevation data. Channel, road, bridge, and culvert geometry data was obtained from field measurements, Hawaii State and County Department of Transportation plans, and existing HEC-RAS models created for Flood Insurance Studies.

2.2 MODELING LIMITS. The HEC-RAS modeling limits in this study mirror those of previous studies and are based on flood prone areas. The primary stream network comprises of the channel centerline and stream bank locations of Waiakea and Palai Streams and those tributaries studied in detail. The detailed modeling limits are as follows:

Waiakea Stream was modeled from Waiakea Pond in Hilo, upstream to a point approximately 3,400 feet upstream of its confluence with the Kupulau Flood Ditch for a total distance of about 4.8 miles. Palai Stream was modeled from Waiakea Pond in Hilo, upstream to a point shortly upstream of Ainalako Rd, for a distance of about 6.1 miles. Four Mile Creek was modeled from its mouth at an old quarry upstream to Ainalako Rd for a distance of about 4.4 miles. The Kupulau Ditch was modeled form its confluence with Waiakea Stream upstream to a point just above Ainaola (Hoaka) Road for a distance of about 0.5 miles. Included in the modeling were tributaries to the main study streams. Along Waiakea Stream, tributaries 1, 2, and 3 were modeled for distances of 0.9, 1.8, and 1.2 miles respectively. Along Palai Stream, several of its tributaries were modeled (called A. B. and C which follows the prior FEMA designations). The Palai Stream C stream was modeled from the point where the stream enters the underground storm system at Haihai Street upstream to the point near the New Hope Chapel for a total distance of about 0.8 miles. An overflow reach was labeled as a continuation of Palai Stream from a point where it enters the Kupulau Ditch upstream to a point where it diverts from the Waiakea Stream for a distance of about 0.2 miles.

Additional overland reaches were modeled to convey overflow leaving the main stream channels. The reach designated as Ainaola runs on the north side of HaiHai St and west side of Ainaola Dr. This reach was modeled from a point about 150 feet downstream of Komohana St to just east of Lei Luaha St for a distance of about 0.5 miles. The reach designated as HaiHai runs along HaiHai St. on its south side. The HaiHai reach runs from Kupulau Rd to just upstream of Hoolaulea St. for a distance of about 0.3 miles. The reach designated as Palai overflow runs from a point just east of Kupulau Road south of Ainaola (Hoaka) Rd downstream to a point just south of Nou Street for a distance of about 0.75 miles. The Puhau St reach runs from the south end of Puhau St downstream to Kawailani St for a distance of about 0.3 miles.



Waiakea Palai CAP 205 Study - Big Island, HI
Hydraulic Model - Study Reaches

Figure 3. Hydraulic Model Boundaries and Reaches

2.3 GIS METHODOLOGY. GIS (Geographic Information System) tools and datasets were used to develop the hydraulic model. These datasets came from various sources. The basic source of elevation data came from a Triangulated Irregular Network (TIN) created from the various elevation sources described in Section 2.1. This dataset was created from Microstation 3D CADD files as part of the aerial photogrammetric data collection. The Microstation files also included a series of 3D “dgn” files. These files contained both topographic and planimetric features. Contour information at 4 foot intervals was provided along with roads, building footprints, bridge and culvert locations, and other ancillary data. Aerial imagery was used in the background to provide location information.

These datasets were used with the Environmental Systems Research Institute (ESRI) software product ArcGIS version 10.1 for processing and data extraction. Upon adding the data layers into ArcGIS, hand-digitizing of the stream centerlines, cross sections, bank locations, flow path lines, and bridge locations was performed.

2.4 INTIAL HEC-RAS MODEL DEVELOPMENT. The Waiakea Palai Stream and Four Mile Creek HEC-RAS hydraulic model was developed to achieve the highest accuracy possible within the limitations of topographic data accuracy, the HEC-RAS model limitations, and the modeling assumptions used. The following sections describe the procedures used to develop the model.

2.4.1 Terrain Data. HEC-GeoRAS (GeoRAS) is a software extension to ArcGIS created by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) in conjunction with ESRI. GeoRAS runs within ArcGIS to prepare an ASCII text file that can be directly imported into HEC-RAS. GeoRAS was used to develop preliminary data that creates a HEC-RAS geometry file that is further processed within the HEC-RAS software.

Input parameters created in GeoRAS for the HEC-RAS model include the primary stream network, channel bank locations, flowpath lengths, and cross section locations. After the HEC-RAS model is created, manual editing is required to input expansion and contraction coefficients, boundary conditions, ineffective flow areas, levees, weirs, roughness coefficients, and stream crossing data to the HEC-RAS model.

All GIS data was projected to a common projection, Hawaii State Plane. The projection parameters are as follows:

Projection:	Hawaii State Plane
Zone:	1
Units:	Feet
Horiz. Datum:	NAD83
Vert. Datum	Mean Sea Level
Spheroid:	GRS80
ZUnits:	Feet
Xshift;	0.0
YShift:	0.0

2.4.2 Detail Study Streams

The primary stream network comprises of the channel centerline and stream bank locations of Waiakea and Palai Streams and those tributaries studied in detail. The stream centerlines and stream banks were hand digitized in GeoRAS using the contour maps and orthophotos as background imagery. The resulting GIS shapefiles are processed in GeoRAS for conversion to HEC-RAS.

The flowpath locations are a measure of the path taken by the flow as it moves across the terrain. It is comprised of three parts; the centerline, left overbank, and right overbank. The overbank flowpaths are typically located at the "center of mass" of the overbank flow. GeoRAS uses this dataset to compute the overbank reach lengths and distance between cross sections.

2.4.3 Cross Section Modeling. Cross sections are oriented from left to right in the downstream direction. For this study, initial cross sections were created at an interval of 200 feet for all streams. Elevation data for the cross sections are extracted from the TIN dataset by GeoRAS.

Stream junctions are used to model where streams join or diverge. Preliminary junction names and lengths in HEC-RAS were created using GeoRAS. The actual distance across the junction was measured along the stream channel from the cross section immediately upstream of the junction to the cross section immediately downstream of the junction. For the tributaries, the distance from the junction to the first upstream cross section was measured and input into the model.

2.4.4 Geometry Update. During the TSP modeling process, a new version of HEC RAS software was used to run the model. RAS Mapper, a new utility within HEC RAS, eliminates the need to use GeoRAS for pre- or post-processing of RAS data and maps. In addition, one can use RAS Mapper and some Geo-processing to recreate the channel geometry based on surveyed cross sections. The recreated channel can be used to compare the terrain and corresponding depth grids. The Mapper utility has been used in the TSP modeling phase to manage DEM inconsistencies and improve inundation accuracies. Potential terrain concerns and a path forward to alleviate them are summarized in the Executive Summary.

The HEC RAS model has been updated using terrain data identified as "applebanana.tif". Previous modeling efforts have used the best available data from state and FEMA. However, it is important to note that the combined data set may have inherent data accuracy issues that may compromise the validity of the hydraulic results but given the circumstances this data would be adequate for ATR.

2.4.4 Bridge and Culvert Modeling. There are 59 bridges and culverts that were modeled in this study. They ranged from small pipe culverts to large bridge structures. The geometry of these hydraulic structures were obtained from field investigations and as-built drawings. The height, width, deck thickness, and pier type and sizes were gathered and input into the model. The bridge modeling approach is decided based on modelers knowledge of the conditions on the ground or what is appropriate based on the model geometry data. In most of the cases, the energy method is used but in some locations it is expanded to include momentum and Yarnell methods to optimize results

2.5 MODEL REFINEMENT. Once processing of the GIS data was accomplished, the resulting ASCII text file was input into HEC-RAS. Further processing of the geometry file was required in order to complete the data that will allow the model to run. Items such as boundary conditions, Manning's "n-values", expansion and contraction coefficients, bridge and culvert geometry, weirs, etc. were incorporated. These additional parameters are described in the following sections.

2.5.1 Stream Roughness. Manning's n-values are a measure of the roughness characteristics of the channel and floodplain and are a very important parameter in open channel flow modeling. High water marks from previous flood events were not available to calibrate the model, therefore the selection of n-values was based on observations from the site visit, theoretical literature, and engineering judgment. Initial estimates of the roughness coefficients were obtained using Jarrett's equation. This equation is applicable due to the steep slopes of the channel bed for the streams in question. Jarrett's equation was developed in 1984 by performing a regression analysis on 75 datasets that were surveyed from 21 different high gradient mountain streams. Jarrett's equation for predicting channel Manning's n-values is as follows:

$$n = 0.39 \times S^{0.38} \times R^{0.16}$$

where:

S = the friction slope of the stream. The average channel invert Slope can be used in place of the actual friction slope

R = the hydraulic radius (area/wetted perimeter) of the flow

The Jarrett equation was used to predict base n-values for the streams along their entire length with the hydraulic radius determined from the 1% AEP (100-yr.) event. Adjustments to the channel n-values were required to account for meandering, irregularity, variation in cross sections, obstructions, and vegetation. These factors are explained in Acrement and Schneider (1989).

Overbank n-values varied along the streams due to several factors. Areas of residential housing show a mix of low resistance (streets) to areas of no flow (buildings). Areas of vacant land are shown to be pastures or fields with scrub brush or heavily wooded areas. During the development of the model, a decision was made to use averaged "n" values between effective and ineffective flow areas. An n-value table is shown below.

Table 1. Range of Manning's n-Values used in the HEC-RAS Model

Stream Reach	Manning's n-Value Channel	Manning's n-Value Overbank
Waiakea Stream	0.016 - 0.048	0.040 - 0.100
Palai Stream	0.035 - 0.048	0.055 - 0.100
Four Mile Creek	0.042	0.050 - 0.080
Kupulau Ditch	0.041	0.048 - 0.100
Tributary 1	0.035 - 0.070	0.050 - 0.080
Tributary 2	0.035 - 0.010	0.056 - 0.100
Tributary 3	0.048 - 0.053	0.056 - 0.080

Stream Reach	Manning's n-Value Channel	Manning's n-Value Overbank
Palai B	0.048	0.056
Palai C	0.048	0.048 - 0.080
Palai D	0.040	0.080
Palai Overflow	0.048 - 0.052	0.080
Ainaola	0.040 - 0.072	0.050 - 0.080
HaiHai	0.040 - 0.060	0.056 - 0.080
Puhau	0.035	0.090
Four Mile Trib 1	0.042	0.080
Four Mile Trib 2	0.042	0.080

Several channel observations were made during site visits. Waiakea Stream and Kupulau Ditch channel beds are comprised mainly of volcanic rock. While some areas lined up with concrete, other segments of the channels are heavily vegetated, and consist of channel boulders. All of these add complexity and variability of channel friction that change flow regime in the stream. In order to accommodate these variations, a range of n values are selected for a range of flow conditions. On the upper reaches of Waiakea Stream, "n" values were increased by as much as 50% for low flows, 40% on Kupulau Ditch, and as channel fills up "n" value reaches to the normal base.

2.5.2 Expansion and Contraction coefficients. Expansion and contraction coefficients are used to measure the losses in stream energy due to the expansion or contraction of flow. These coefficients are multiplied by the change in velocity head to determine the energy loss. Initial contraction and expansion coefficients were set at 0.1 and 0.3 respectively for the channel sections and 0.3 and 0.5 for the hydraulic structures to account for those losses. During the development of the model, instabilities were encountered due to steep slopes that forced the model to reach critical depth. In order to dampen these instabilities, the expansion and contraction coefficients were reduced to 0.06 and 0.15 in areas where critical depth was attained over several sections. On Waiakea Stream, the Kupulau Road Bridge was assigned values of 0.1 and 0.2, as an example.

2.5.3 Boundary Conditions. Initial model runs were done assuming sub critical flow conditions. Normal depth was used as the boundary condition at the downstream end and is based on a channel bed slope of 0.007 ft/ft for Waiakea stream, 0.0073 ft/ft for Palai Stream, 0.0039 ft/ft for Four Mile Creek, 0.0125 ft/ft for Ainaola reach, and 0.0124 ft/ft for Palai outflow reach. The downstream boundary for the reach named "Debris" was set at critical depth. For the remaining reaches, the downstream boundary was determined by the program at junctions.

In the original modeling for large storm events, flow regime was assumed to be subcritical despite the steepness of some segments. Steep supercritical reaches warrant mixed flow modeling. Some changes were incorporated in the TSP model runs after further examination of the channel conditions and flow patterns.

2.5.4 Lateral Weirs. During the November 2000 flood, it was observed Waiakea stream overtop at upstream and overflow reached Kupulau ditch, then overflow of Kupulau ditch flow travel overland and subsequently reached Palai Stream C. The overflow conditions were modelled using lateral structures feature in the RAS model. The alignment of the lateral structures were determined from digitizing the ground elevation along the overflow path and setting elevation profile

Lateral weirs were incorporated into the model on Waiakea Stream upstream of Kupulau Ditch Reach W2, and at several locations from Kupulau Rd. to Kawailani St. (Reach W3). These weirs control the flow leaving Waiakea Stream and entering Kupulau Ditch, Tributary 2, or Tributary 3. A lateral weir was added along a portion of the right overbank of Kupulau Ditch to allow flow to pass over the bank and eventually into the main stem of the Palai stream in Hilo, passing over HaiHai St. (or Palai C. On Palai C, lateral weirs were inserted on a segment between Waiakea Stream and Kupulau Ditch (Reach P1) and along HaiHai St. where flow overtops the street and enters what was called the Ainaola area (Reach A1).

Weir coefficients were changed to stabilize the water elevation across the structure and Table 2 below shows the final range applicable to each weir.

Table 2.
Final Lateral Weir Coefficients Used in HEC-RAS Model

Reach	Weir Coefficient Range
W2	2.11
W3 (Trib 3)	1.0 - 2.0
W3 (Trib 2)	2.5 - 3.0
KD2 (Palai C)	2.41 - 2.5
KD2 (HaiHai)	1.0 - 1.45
P1	2.0
P3	2.5

There are two stream gage locations in the modeling limits. One is located on Waiakea Stream (USGS 16701300) and the other on Palai Stream (USGS 16701400). USGS Stream gage 16701300 is located approximately 1,580 feet upstream of the Kinoole St Bridge in Reach W5 of the model. USGS Stream gage 16701400 is located approximately 160 feet upstream of Olu St, which is in the Hilo Reach of the model. These two gage stations used to compare model results to observed records for various weir coefficients. The table 3 and Table 4 shows the results of model and observed flows. As can be seen from the tables, at Palai stream gage observed and model flows are fairly lined up but Waiakea gage shows inconsistent results.

Adjustments to the weir coefficients did not improve the results on Waiakea Stream without adversely impacting the results on Palai Stream. Since reach W5 on Waiakea Stream was significantly downstream of the study and anticipated work area, while the Hilo reach on Palai was an integral part of the study objectives, it was decided to use the set of weir coefficients that compared Palai stream favorably. All the subsequent modeling was done using these conclusions and corresponding numerical values.

Table 3.
Flow Comparison at USGS Stream gage 16701400

Event	Model Results		Adopted Flows from Hydrologic Analysis
AEP	Flow (cfs)	Elev. (feet)	Flow (cfs)
50%	497	168.6	476
20%	902	169.3	
10%	1,404	169.9	1,385
4%	1,958	170.3	1,819
2%	2,526	170.7	2,433
1%	2,685	170.8	2,936
0.5%	3,426	171.1	
0.2%	3,928	171.4	4,209
AEP=Annual Exceedance Probability Elev. = elevation cfs = cubic feet per second			

Table 4.
Flow Comparison at USGS Stream gage 16701300

Event	Model Results		Adopted Flows from Hydrologic Analysis
AEP	Flow (cfs)	Elev. (feet)	Flow (cfs)
50%	1,185	64.2	761
20%	1,702	64.7	
10%	2,102	65.1	2,106
4%	3,114	65.9	
2%	3,820	66.5	4,427
1%	5,271	67.3	5,600
0.5%	6,601	67.8	
0.2%	7,438	68.2	9,535
AEP=Annual Exceedance Probability Elev. = elevation cfs = cubic feet per second			

2.5.5 Cross Section Modeling. During the original modeling process, it was observed more cross sections were needed to rectify instabilities in steep stream segments. Therefore, more sections were added at 50ft intervals using the cross section interpolation feature in RAS.

2.5.6 Blocked Obstructions and Debris. Blocked obstructions were used to model large objects that disrupt the flow of water. On Kupulau Ditch reach, the New Hope Church complex was inserted into the model as a blocked obstruction. At certain bridge locations, partial blockage was used to represent the accumulation of stream bed material under bridges that were observed during the site visits. Clear water flow was assumed in the model, no floating debris functions at bridge locations were used as not many bridge locations had mid-stream piers.

Although it was known that debris played a part in the damage to the Kupulau Road Bridge in November 2000, no debris analysis was conducted, as it was not part of the scope due to the difficulty of accounting for debris impacts on flow conditions. However, in order to accommodate debris effects, manning n value was used as a surrogate with subcritical flow conditions.

3. WITHOUT PROJECT HYDRAULIC ANALYSIS

3.1 Model Calibration and Verification. High water marks from previous flood events were not available to calibrate the model. Model coefficients were adjusted to produce relatively smooth profiles and increase model stability. Floodplains resulting from the original model runs were delineated and were reviewed by other district personnel and Hawaii county representatives for reasonableness and accuracy. The resulting floodplains were judged to be consistent with observations in the field and therefore were considered valid.

3.2 Sensitivity Analysis. Sensitivity analysis was conducted on the lateral weir coefficients since some of the chosen values seemed higher than would be expected for natural ground. Model runs were made with the lateral weir coefficients set lower to 1.0 and 1.5. These runs were compared with the current HEC-RAS model to track the difference in flow. The practical effect of reducing the lateral weir coefficients is to increase flow along Waiakea Stream while decreasing flow in Palai Stream. Reducing the coefficients reduces the amount of flow overtopping Waikea Stream into Kupulau Ditch, and overtopping Kupulau Ditch and entering the Palai Stream system.

On Palai Stream, at USGS Streamgage 16701400, flows are reduced from the current model between 4.7 and 22.7 percent with the average being 15.7 percent when the weir coefficient is reduced to 1.0. When the weir coefficient is set to 1.5, flows are reduced between 1.1 and 10.4 percent with the average being 4.3 percent. Table 5 below shows the comparison at the gage location. The table also contains the water surface elevation at this location. These differences are much closer. The difference in elevation when compared from all runs ranges between 0 and 0.6 feet.

Table 5.
Comparison of Weir Coefficient Runs (Palai Stream)

Recurrence Interval	Weir Coefficient = 1		Weir Coefficient = 1.5		Current Model		Adopted Flows from Hydrologic Analysis
AEP	Flow (cfs)	Elev. (feet)	Flow (cfs)	Elev. (feet)	Flow (cfs)	Elev. (feet)	Flow (cfs)
50%	473	168.6	491	168.6	497	168.6	476
20%	819	169.2	877	169.3	902	169.3	
10%	1,155	169.6	1,312	169.8	1,404	169.9	1,385
4%	1,703	170.1	1,867	170.2	1,958	170.3	1,819
2%	1,974	170.3	2,263	170.5	2,526	170.7	2,433
1%	2,280	170.5	2,620	170.7	2,685	170.8	2,936
0.5%	2,648	170.7	3,270	171.1	3,426	171.1	
0.2%	3,082	171.0	3,855	171.3	3,928	171.4	4,209
AEP=Annual Exceedance Probability Elev. = elevation cfs = cubic feet per second							

On Waiakea Stream, at USGS Stream gage 16701300, flows are increased from the current model between 2.7 and 17.6 percent with the average being 10.6 percent when the weir coefficient is reduced to 1.0. When the weir coefficient is set to 1.5, flows are reduced between -0.3 and 7.2 percent with the average being 2.6 percent. At the 500yr event, the flow is slightly reduced, which resulted in the negative percentage. Table 6 below shows the comparison at the gage location. The table also contains the water surface elevation at this location. These differences are much closer. The difference in elevation when compared from all runs ranges between 0 and 0.7 feet.

Table 6.
Comparison of Weir Coefficient Runs (Waiakea Stream)

Recurrence Interval	Weir Coefficient = 1		Weir Coefficient = 1.5		Current Model		Adopted Flows from Hydrologic Analysis
AEP	Flow (cfs)	Elev. (feet)	Flow (cfs)	Elev. (feet)	Flow (cfs)	Elev. (feet)	Flow (cfs)
2	1,216	64.2	1,192	64.2	1,185	64.2	761
5	1,833	64.8	1,736	64.7	1,702	64.7	
10	2,431	65.4	2,222	65.2	2,102	65.1	2,106
25	3,444	66.1	3,247	66.0	3,114	65.9	
50	4,491	66.9	4,116	66.7	3,820	66.5	4,427
100	5,770	67.5	5,297	67.3	5,271	67.3	5,600
200	7,333	68.1	6,664	67.9	6,601	67.8	
500	8,198	68.9	7,413	68.1	7,438	68.2	9,535
APE=Annual Exceedance Probability Elev. = elevation cfs = cubic feet per second							

Comparing the results of the sensitivity runs shows there is a difference in flows between weir coefficients. However, the difference in water surface elevation appears to be relatively minor. The largest difference occurs at the 0.5% and 0.2% ACE events, and when considering annual flood damages, the difference would have a small effect on the overall damage calculation.

Sensitivity analysis was also done by varying the estimated Manning "n-values" by +/- 20%. This process was used in determining the stage uncertainty values for use in HEC-FDA. See Section 5.3 on risk and uncertainty for more information.

4. Without Project Conditions (Existing Conditions)

This section provides a description and an analysis of the HEC-RAS model results for the various steam reaches in the HEC-RAS model.

4.1 Waiakea Stream. Waiakea Stream above Kupulau Ditch is characterized by poorly-defined channels. It has a nominal slope of 0.01479 ft/ft (1.48%). It has a channel capacity of less than 1,020 cfs, which is comparable to a 50% AEP storm event. The channel bed is a mix of earth and volcanic rock. Excess water leaves the Waiakea Stream by overtopping the right bank at the 50% AEP event and flows overland eastward toward Kupulau Ditch.

Between Kupulau Ditch and the Kupulau Rd Bridge, Waiakea Stream has a nominal slope of 0.02249 ft/ft (2.25%). It has an average channel capacity of about 1,630 cfs, which is comparable to a 20% AEP storm event. Flows greater than the 20% AEP event flood the right and left overbanks, but due to the surrounding topography this flow ultimately makes its way downstream to the bridge.

The Waiakea Stream reach between Kupulau Rd and Kawailani St drops in elevation about 129 feet over a 4,000 foot length for a nominal slope of 0.03242 ft/ft (3.24%). It has a minimum channel capacity of about 2,400 cfs which is comparable to a 10% AEP storm with some areas capable of containing a 4% AEP event. The channel bed is primarily volcanic rock and at its upstream and downstream ends incorporates improvements due to bridge construction as a result of the November 2000 flood. Flows in excess of the channel capacities leave the channel and flood the residential properties along Hookano St, Hoaloha St, Kuleana Loop, Kuleana Place, among others on the right overbank. On the left overbank, water leaves the channel and floods residential properties along Puhau St, Auahi Place where the flow enters the drainage area of Tributary 3. Downstream of Tributary 3 floodwaters impact properties south of Kawailani St before it is eventually contained in the improved channel upstream of the new Kawailani St Bridge.

Downstream of Kawailani St, the stream is characterized by the Waiakea-Uka Flood Control channel. The channel was constructed in 1984 by the County of Hawaii. It consists of a concrete lined and unlined trapezoidal channel and has a design discharge of 4,460 cfs. The channel bed is primarily grouted lava rock. It begins at the Komahana St Bridge and continues upstream to a point parallel to Apono St for a distance of about 3,460 feet. Figures 3 to 20 illustrate the channel conditions of Waiakea Stream.

Figure 3.
Waiakea Stream looking upstream from its confluence with Kupulau Flood Ditch

Figure 4.
Waiakea Stream looking downstream from just downstream of the confluence with Kupulau Flood Ditch

Figure 5.
Waiakea Stream looking upstream from Kupulau Rd Bridge

Figure 6.
Waiakea Stream looking downstream from Kupulau Rd Bridge

Figure 7.
Waiakea Stream looking downstream from Kupulau Rd Bridge at Station 20+219.90

Figure 8.
Waiakea Stream looking upstream from rock outcropping Approximate Stream Station 17+001.00

Figure 9.
Waiakea Stream looking downstream from rock outcropping
Approximate Stream Station 17+001.00

Figure 10.
Waiakea Stream looking upstream from the end of the channel lining near Kawailani St

Figure 11.
Waiakea Stream looking downstream from the end of the channel lining towards Kawailani St

Figure 12.
Waiakea Stream looking upstream at Station 14+592.73

Figure 13.
Waiakea Stream looking downstream at the upstream end of the Waiakea-Uka Channel

Figure 14.
Waiakea Stream looking upstream from the upstream end of Waiakea-Uka channel

Figure 15.
Waiakea Stream looking at the upstream end of Waiakea-Uka Channel

Figure 16.
Waiakea Stream looking downstream at the upstream face of the T. Shiroma Bridge (Note channel restriction)

Figure 17.
Waiakea Stream looking downstream from the T. Shiroma Bridge

Figure 18.
Waiakea Stream looking upstream at Waiakea-Uka channel from Station 18+00
Note scour damage repair on right bank.

Figure 19.
Waiakea Stream looking downstream at upstream face of Puainako St Bridge

Figure 20.
Waiakea Stream looking at downstream face of Komohana St Bridge

4.2 Kupulau Flood Ditch. Kupulau Ditch is a non-federal channel constructed in 1971 to divert runoff from the Palai Stream drainage basin into Waiakea Stream. It consists of an unlined trapezoidal channel with an upstream bottom width of about 8 ft, and widening to a bottom width of 15 feet for the lower 1,600 feet until it meets Waiakea Stream. The channel begins at the Waiakea Stream and ends just upstream of Ainaola Street for a total distance of about 2,710 feet. It has a channel capacity of about 1,000 cfs which is comparable to a 2% AEP storm event. However, the ditch is subject to significant backwater from Waiakea Stream which reduces the effective channel capacity to approximately a 20% AEP event.

Water overtopping the right bank of Waiakea Stream is received by Kupulau Ditch in the vicinity of the New Hope Church. The flow quickly exceeds the capacity of the ditch and overtops the banks where it again flows to the east overtopping Kupulau Rd and flows overland in two pathways; along the south side of HaiHai St and the Palai Stream C tributary south of the New Hope Church. These two paths merge at Hoolaulea St and eventually enter Palai Stream.

Figure 21.
Kupulau Ditch looking upstream at downstream face of Ainaola Dr.

Figure 22.
Kupulau Ditch looking downstream from point approx. 500 ft downstream of Ainaola Dr.

Figure 23.
Kupulau Ditch looking downstream from Pedestrian Bridge at park

4.3 HaiHai Street Reach. Floodwaters that overtop Kupulau Road flow overland along the south side of HaiHai St. This area does not contain a defined channel which causes damage to the residential structures located along the street. Water flows eastward following the topography until it joins with the second pathway from Kupulau Ditch and enters a 4 ft diameter culvert on the south side of HaiHai St.

4.4 Palai Stream C. The Palai Stream C drainage receives excess water from Kupulau Ditch that overtops Kupulau Rd and routes it downstream through a swale where it joins with the flow from the HaiHai St Reach and enters a 4 ft diameter culvert. This culvert, about 320 ft in length, conveys flow through the residential structures along Hoolaulea St where it then enters an open ditch that collects local drainage from the subdivision. This flow enters another 4 foot diameter conduit about 1,060 feet in length along the south side of HaiHai St, and discharges into a concrete lined open channel flowing east until it reaches Ainaola Dr. At Ainaola Dr, the channel transitions into a series of 5 ft diameter conduits that travel through the development and exits to an open channel east of Keone St. Finally, Palai Stream C joins the main stem of Palai Stream at the Hilo Municipal Golf Course.

Figure 24.
Palai Stream C looking upstream at drainage ditch

Figure 25.
Palai Stream C looking upstream at stormwater ditch on HaiHai St.

Figure 26.
Palai Stream C looking at stormwater ditch inlet along HaiHai St.

4.5 Ainaola Reach. This reach begins on the north side of HaiHai Street just east of Lei Lehua St. where it receives floodwaters from Palai C which overtop HaiHai St. These waters flow overland and follow the topography impacting residential structures along Hoomalu St., Ahe St., and Ainaola Dr. At Ainaola Dr., flow overtops the street and enters the Palai C reach drainage impacting the structures there.

4.6 Waiakea Tributary 2 Reach. The Waiakea Tributary 2 stream flows primarily east of Waiakea Stream beginning just upstream of Komohana St and ends just upstream of Kawailani St for a distance of about 5,890 feet. It has a nominal slope of 0.02491 ft/ft (2.49%). The lower end of the stream forms a defined channel for about 2,800 feet, and flows through a residential subdivision. Upstream of the subdivision the stream transitions to overland flow and continues upstream to Kawailani St. Floodwaters overtop the Waiakea Stream channel and enter the tributary flooding residential structures along its length until it joins with Waiakea Stream upstream of Puainako St.

Figure 27.
Waiakea Tributary 2 Stream looking at the tributary outlet to Waiakea Stream

4.7 Waiakea Tributary 3. Waiakea Tributary 3 stream begins at an open channel collecting drainage from residential structures located along both Puhau and Auahi Streets. The stream crosses Kawailani St and transitions to overland flow following the topography to the west of Launa St, continuing downstream west of Olhana St. impacting pockets of residential structures. The stream continues overland where it finally joins the Waiakea Stream approximately 2,000 ft upstream of Puainako St. The total length of the stream is about 6,230 feet and has a nominal slope of 0.02330 ft/ft (2.33%). The channelized portion of the stream has a capacity of about 230 cfs, which is comparable to a 10% AEP storm. The overland portion of the stream results in flood depths of 1 to 4 feet.

4.8 Palai Stream A (Overflow). Palai Stream A begins just east of Kupulau Ditch south of Ainaola Drive. It does not have a well-defined channel and travels overland where it crosses Ainaola Dr in the vicinity of Kupulau Rd. It continues eastward where, after crossing Kaulike St it turns northeast and continues overland following the topography. The modeling of this stream ends at a point south of Nou St for a total distance of about 4,020 feet. The modeled portion of the stream has a nominal slope of 0.01763 ft/ft (1.76%). The stream is dry up to the 0.2% AEP event where it receives flow that overtops the right bank of Kupulau Ditch. At the 0.2% AEP event flood depths are 1-2 feet.

4.9 Palai Stream. Palai Stream is characterized by poorly defined channels. In Hilo Town, the stream has a nominal slope of about 0.00727 ft/ft (0.73%) between Waiakea Pond and Kawailani St. Upstream of Kawailani St, the stream slope increases to 0.02624 ft/ft (2.62%) through the Hilo Municipal Golf Course. The stream mainly travels overland through the city with pockets of flooding occurring at numerous locations. Upstream of the Hilo Municipal Golf Course the stream begins to split into several tributaries. The main stem of the stream turns south and flows towards a residential area near HaiHai St. Between HaiHai St and Ainalako Rd, the stream has a nominal slope of about 0.01831 ft/ft (1.83%), and crosses residential properties at Leimamo and Malia Streets. Above Ainalako Rd the stream flows through mainly open land.

Figure 28.
Palai Stream looking downstream through Hilo Municipal Golf Course

Figure 29.
Palai stream looking at HaiHai St culvert

Figure 30.
Palai Stream looking downstream from Heahea St Bridge

Figure 31.
Palai stream looking downstream from Kinoole Ave Bridge

Figure 32.
Palai Stream looking downstream from Kilauea Ave Bridge

Figure 33.
Palai Stream looking upstream from Palai St

Figure 34.
Palai Stream looking downstream on Kawili St, stream crosses road here and flow around to right of building

4.10 Four Mile Creek. Four Mile Creek empties into an old quarry on the east side of Hilo (Figures 35 to 37). Leading into the quarry is an unlined flood control channel constructed by the Hawaii County.

This channel begins at the Kanoelehua St Bridge and is about 10,000 feet in length. The nominal slope of the channel is about 0.00764 ft/ft (0.76%). Upstream of this point the stream flows mainly through open land with some scattered pocket of mixed residential structures and farmland.

Figure 35.
Four Mile Creek looking downstream from Ainalako Rd

Figure 36.
Four Mile Creek looking downstream from Awa St Bridge

Figure 37.
Four Mile Creek looking upstream from Railroad Ave Bridge

5. WITHOUT PROJECT MODEL RESULTS

5.1 Flood Inundation Maps. Figures 38 and 39 show the computed 1% and 0.2% AEP flood inundation areas for the Waiakea-Palai Study without project conditions. The maps are created by plotting the water surface elevations onto a digital elevation model. The areas where the water surface elevations are greater than the ground elevations are shown as flooded.

5.2 Without Project Water Surface Profiles. The without project water surface for the 0.5%, and 0.2% AEP events are shown in figures 40-42.

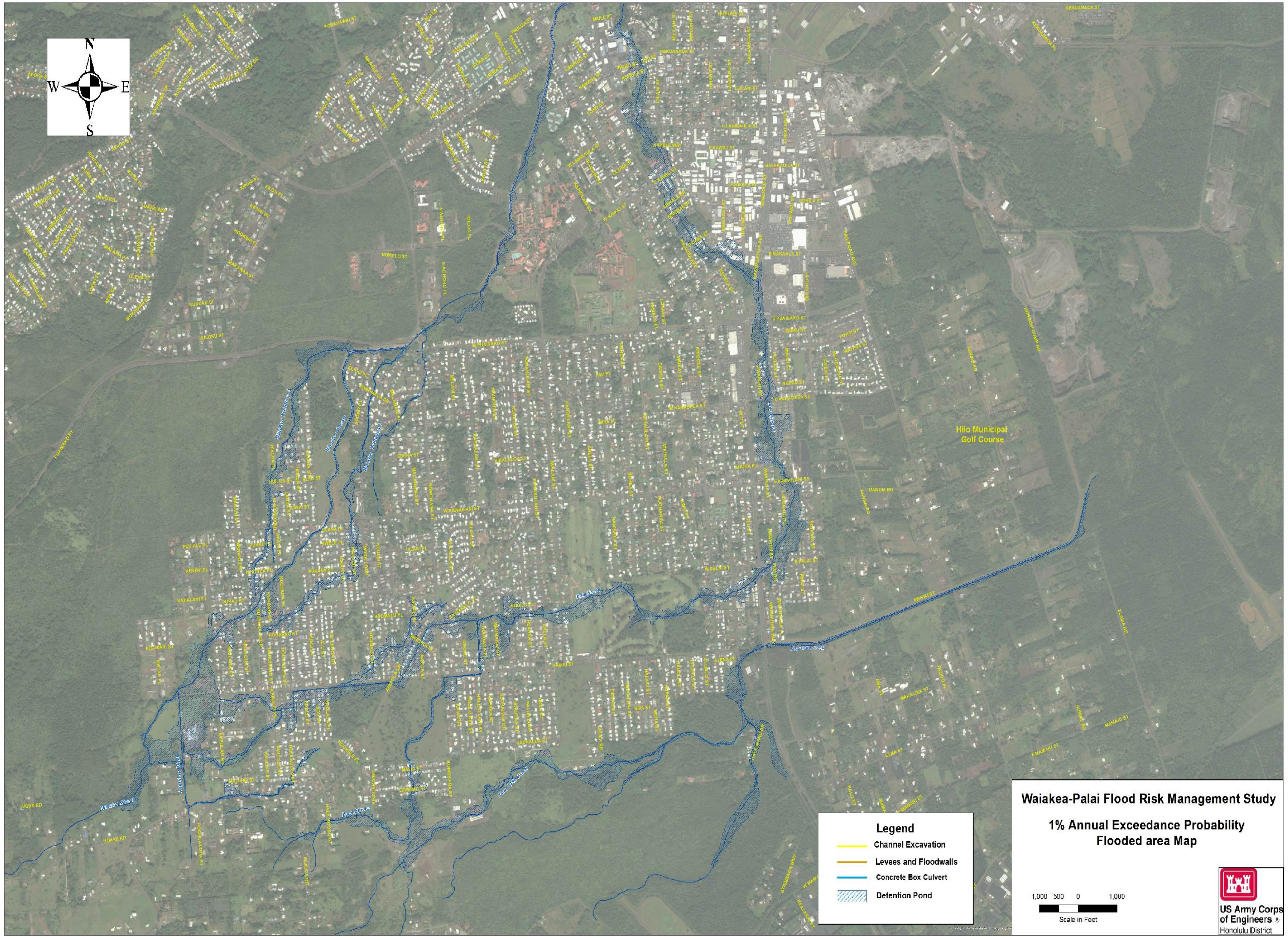


Figure 38. 1% AEP Without Project Flooded Area Map

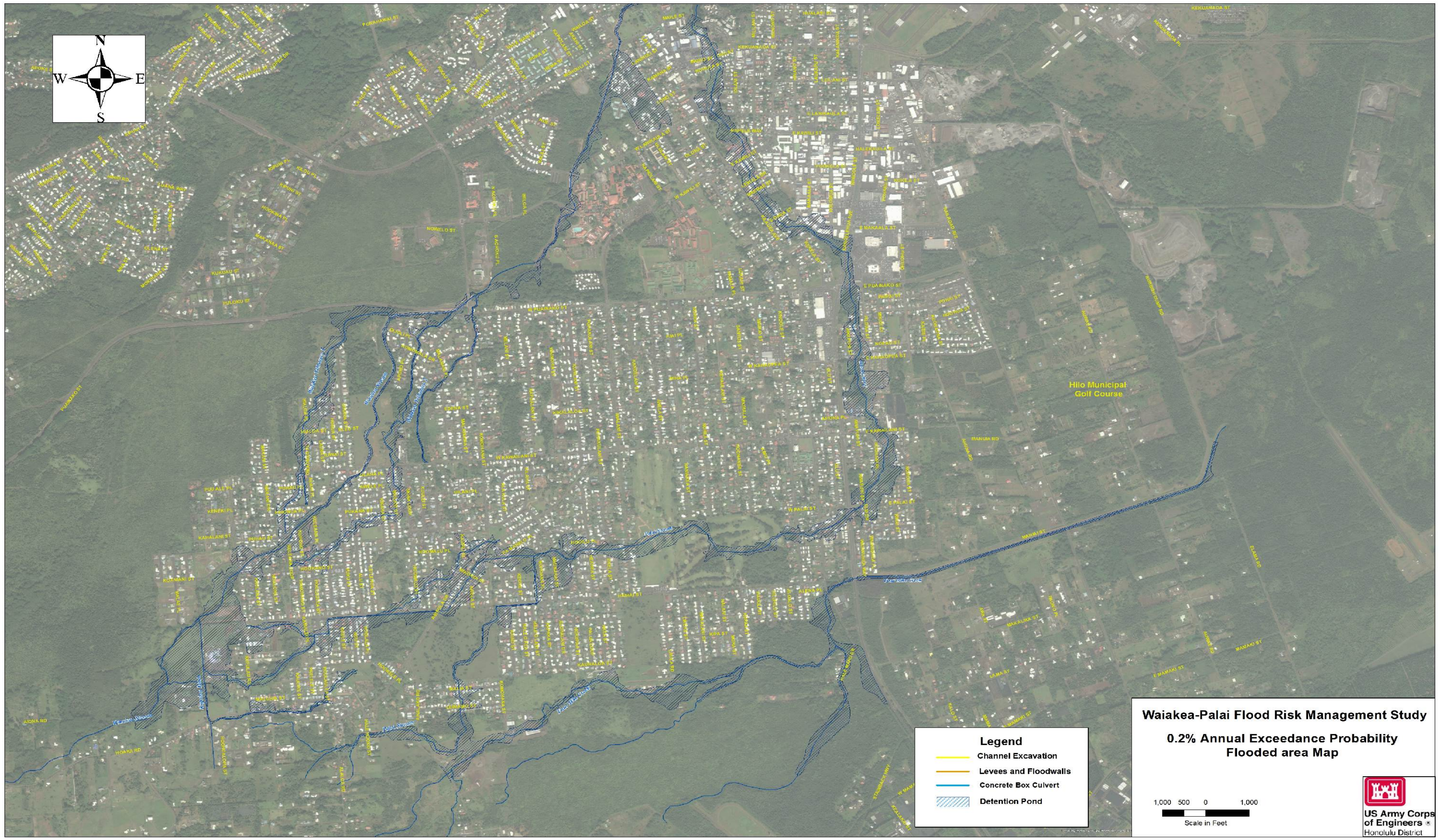


Figure 39. 0.2% AEP Without Project Flooded Area Map

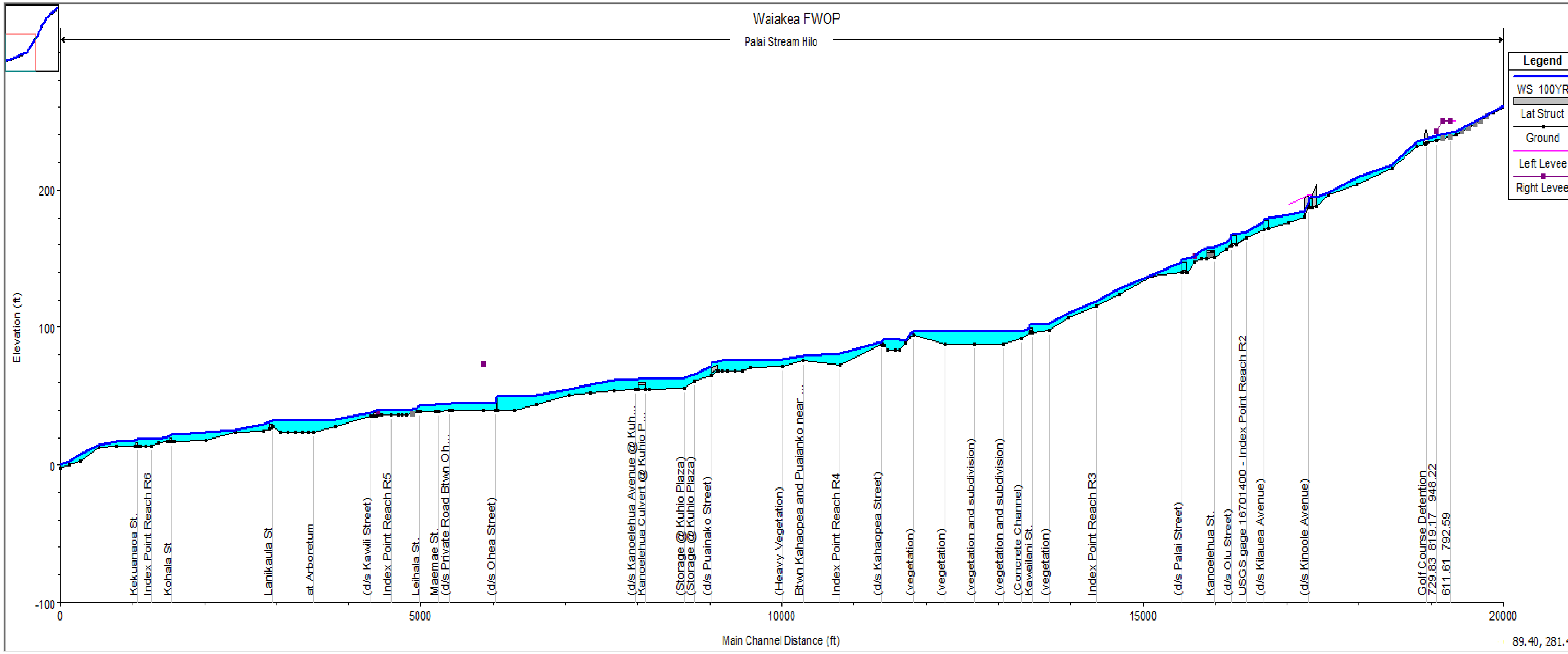


Figure 40A. Waiakea Stream Without Project Profile (Strem Distance up to 20000)

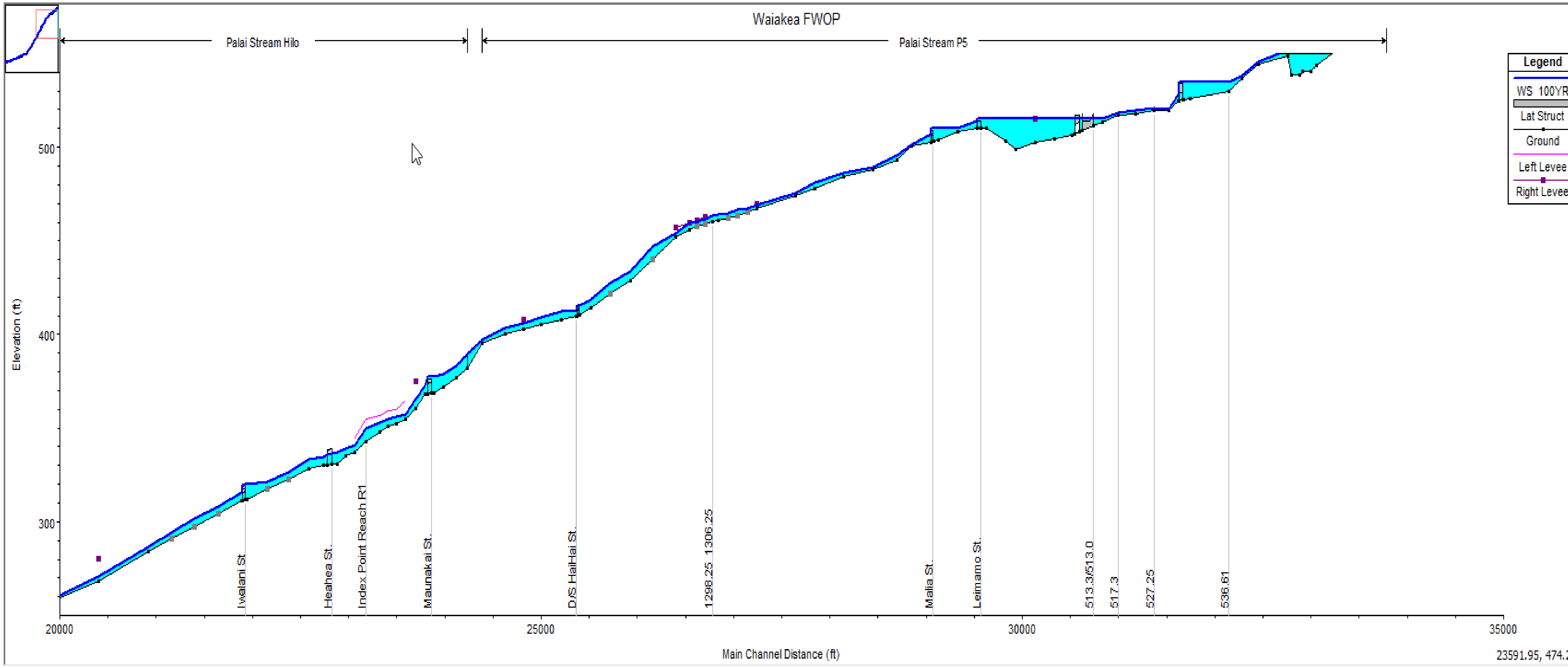


Figure 40B. Waiakea Stream Without Project Profile (Stream Distance from 20000 to 35000

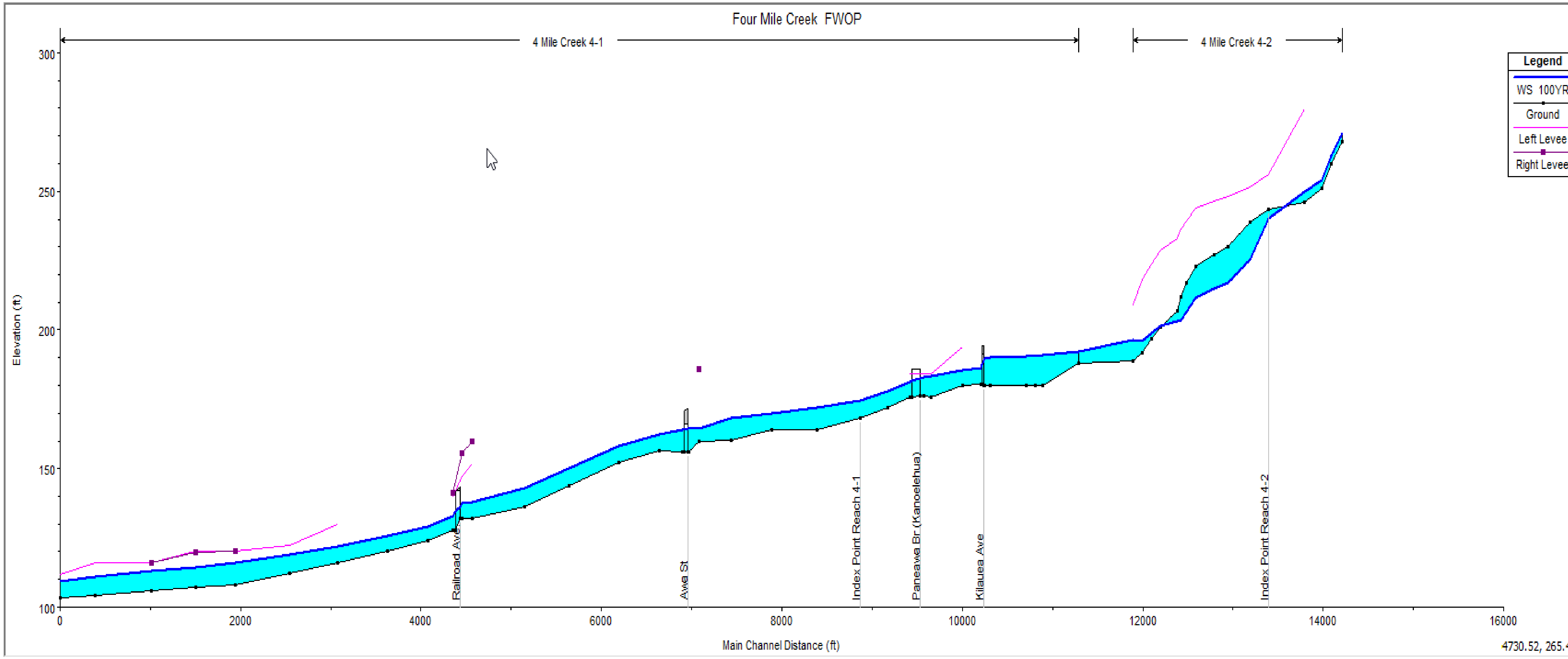


Figure 42A. Four Mile Creek Without Project Profile (Reach 1 and 2)

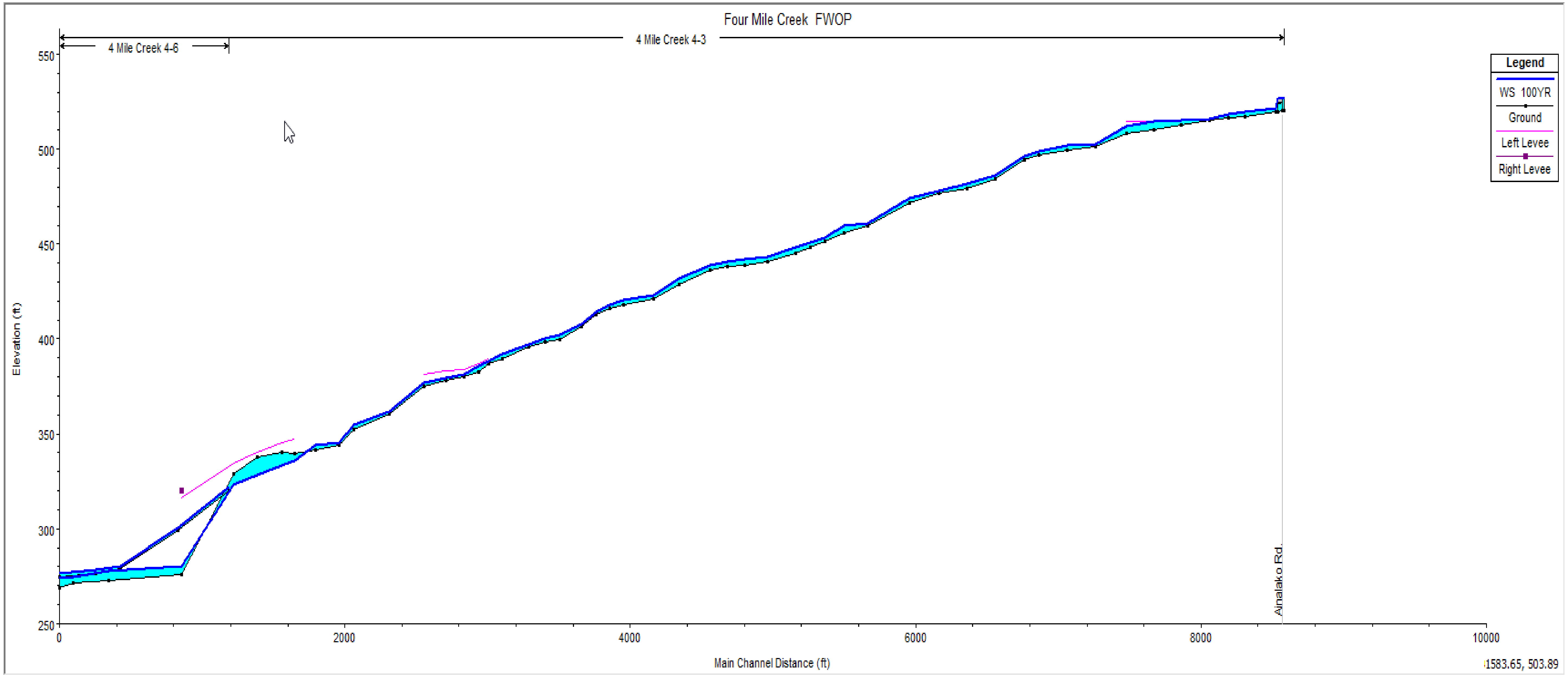


Figure 42B. Four Mile Creek Without Project Profile (Reach 3 and 6)

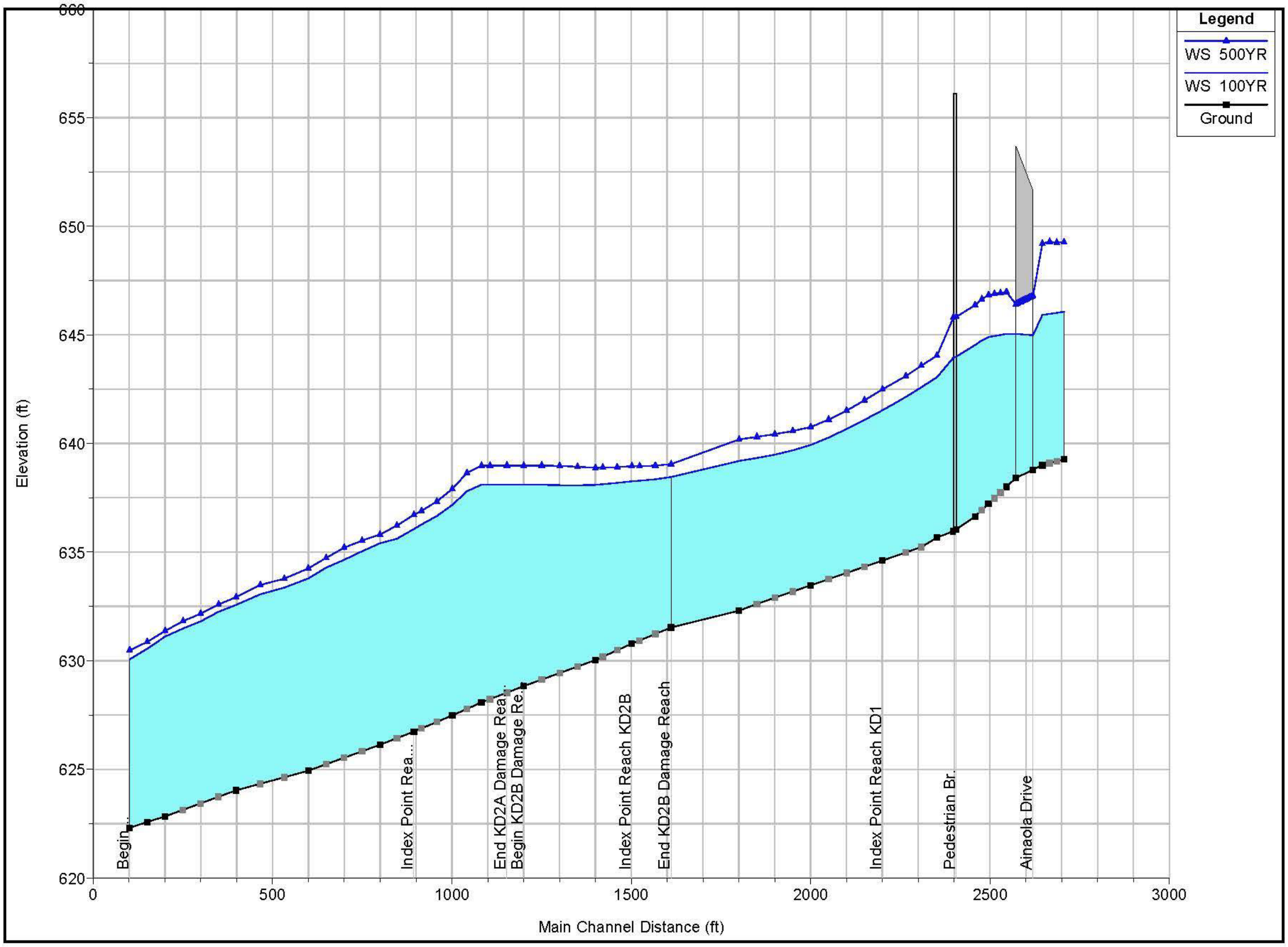


Figure 41. Kupulau Ditch Without Project Profile

5.3 Risk and Uncertainty. The determination of uncertainty in stage-discharge relationships depends on many factors. These factors include bed-forms, debris and/or suspended sediment, variation in channel shape, variations in hydraulic roughness, and channel scour or deposition. Engineer Manual 1110-2-1619, Risk-Based Analysis for Flood Damage Reduction Studies, (EM 1110-2-1619) provides guidance in determining risk and uncertainty. Stage-discharge relationships, or rating curves, were developed for the selected index stations along the streams studied.

Water surface profiles were computed for the without-project condition using the estimated values for Manning's Roughness coefficient. Sensitivity runs were made by varying the estimated "n-values" by +/- 20%. The standard deviation was estimated by using the following equation:

$$S = E_{mean} / 4$$

Using the above equation as a guide, the standard deviation was calculated. Table A7 shows an example of the computed values for stage uncertainty under without project conditions for Reach W3C. Each reach had a similar table computed for use in HEC-FDA.

Table A7. Stage-Discharge Uncertainty

	Waiakea Stream - Reach W3C					
	Index Station 21818.65					
AEP	FREQ. (%)	MIN. ELEV.	BASE ELEV.	MAX. ELEV.	FLOW	STANDARD DEVIATION
	-	618.5	618.5	618.5	0.00	0.000
	0.990	618.90	618.95	619.00	8.01	0.025
50%	0.500	625.38	625.56	625.67	1351.69	0.072
20%	0.200	625.79	625.96	626.08	1955.15	0.073
10%	0.100	626.05	626.25	626.38	2596.77	0.083
4%	0.040	626.32	626.58	626.80	3588.95	0.120
%	0.020	626.57	626.81	627.00	4438.59	0.107
1%	0.010	626.81	627.04	627.28	5669.63	0.118
0.5%	0.005	627.01	627.36	627.63	7494.06	0.155
0.2%	0.002	627.20	627.57	627.85	8474.66	0.162

6 WITH PROJECT HYDRAULIC ANALYSIS

6.1 METHODOLOGY. This section describes the methodology used in evaluating alternatives to reduce the flood potential in the Waiakea-Palai study area. A general assumption in the design process was that any alternative would provide maximum net benefits. Other design objectives included:

- avoid environmental impacts to the maximum extent possible
- minimize initial construction cost and long term maintenance
- minimize project-induced damages, both within the project area and downstream
- incorporate environmental friendly design opportunities where possible
- provide for a minimum 50 year project life

Flood damage reduction measures considered centered around two principles. These were to either reduce the volume of flow moving downstream, or to control the existing flow volume. The 2001 Reconnaissance Report identified four alternatives to reduce the flood potential. These alternatives were the construction of levees/floodwalls, channel modifications to the stream, construction of a diversion channel, and construction of a detention basin. One additional alternative was requested by the local sponsor. This alternative was to evaluate the impacts of improving the Kupulau Ditch alone without any additional work in the project area. As the study progressed additional measures were also analyzed.

6.2 STRUCTURAL MEASURES FOR WAIAKEA STREAM. This section discusses all the measures analyzed for flood risk management. For all figures illustrating the measures in this section, the north direction is toward the top of page and all figures are considered not to scale unless otherwise noted.

6.2.1 Upper Waiakea Stream Reservoirs. This measure consists of two detention basins constructed in the upper reach of Waiakea Steam above the Waiakea Homesteads to attenuate flood flows. The basins would be located upstream of the Waiakea Homesteads residential community at the edge of the Waiakea-Uka Forest Preserve. Upstream of this point the landscape rises sharply up the mountainside limiting the storage potential. The basins would be formed by creating an embankment across the landscape to form a basin with sufficient storage to reduce downstream flood damage. Figure 8 shows the location of the detention basins.

Upstream of the Waiakea Homesteads community, Waiakea Stream splits into three branches. Detention basins would be constructed on the two largest branches while the third would remain in its natural state. The detention basins would be sized to reduce the 1% chance recurrence interval peak flow down to a level so that when combined with the contribution from Kupulau Ditch, the combined flow would approach the channel capacity for Waiakea Stream downstream of Kupulau Ditch.

Preliminary analysis shows that the detention basins require the following parameters, where ac-ft is acre-feet and cfs = cubic feet per second:

Table A8. Detention Storage

	Peak Storage (ac-ft)	Peak Outflow (cfs)	Peak Stage (ft)
Reservoir1	225	1,490	1,482
Reservoir 2	250	1,800	1,452

Reservoir 1 would require construction of an embankment approximately 3,500 ft in length and ranging from 0 to 30 feet in height, while Reservoir2 would require an embankment about 3,600 feet in length and range from 0 to 40 feet in height. The side slopes of the embankment would be a minimum of 3:1 horizontal to vertical, resulting in a base footprint of about 200 to 250 feet. The outlet works would be constructed of reinforced concrete pipe (RCP).

Construction of these detention basins would occur in the Waiakea Forest Preserve, which is a pristine, environmentally sensitive area. Immediately downstream of the detention basins is the Waiakea Homesteads residential community consisting of many single family homes.

Due to their size, the detention basins would be regulated by the State of Hawaii and as such, they which would require additional analysis and design considerations in order to satisfy the state Dam Safety Regulations.

Due to the magnitude of construction for these detention basins, it is doubtful that this measure could be cost-effective. Construction of the impoundment would require large areas of pristine forest removal which would not be environmentally acceptable. The Waiakea Homesteads community would be living literally in the shadow of these basins, placing at risk a portion of the population where there is now minimal risk. It is for these reasons that this measure was not considered feasible and will not be analyzed further.

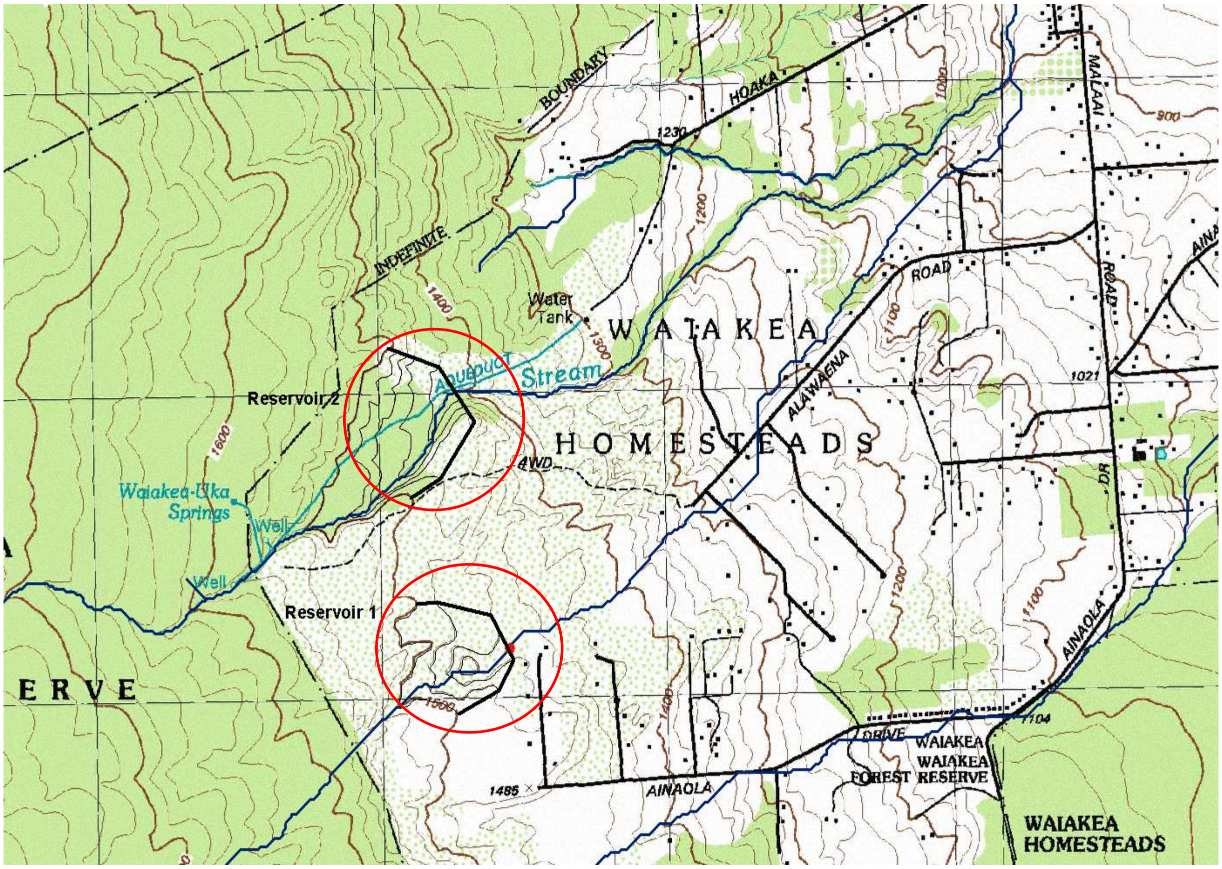


Figure 43. Upper Waiakea Basin Detention Basins Location

<u>6.2.2 Upper Waiakea Stream Levee #1</u>. This measure consists of a levee constructed along the right bank of Waiakea Stream above the confluence with Kupulau Ditch to prevent flows from leaving Waiakea and entering Kupulau Ditch. This levee would be approximately 2,000 ft in length and have an average height of about 15 ft at the 1% AEP event. While the levee prevented flow from entering Kupulau Ditch it also increased the amount of flow at the confluence of Waiakea Stream and Kupulau Ditch thereby increasing the tailwater condition for the ditch to a point where the ditch was not able to contain its own flow. Overtopping of the ditch still occurred and additional measures were required to contain the flow within the ditch. Thus, this measure was not analyzed any further. Figure 44 shows the location of the Upper Waiakea Levee #1.

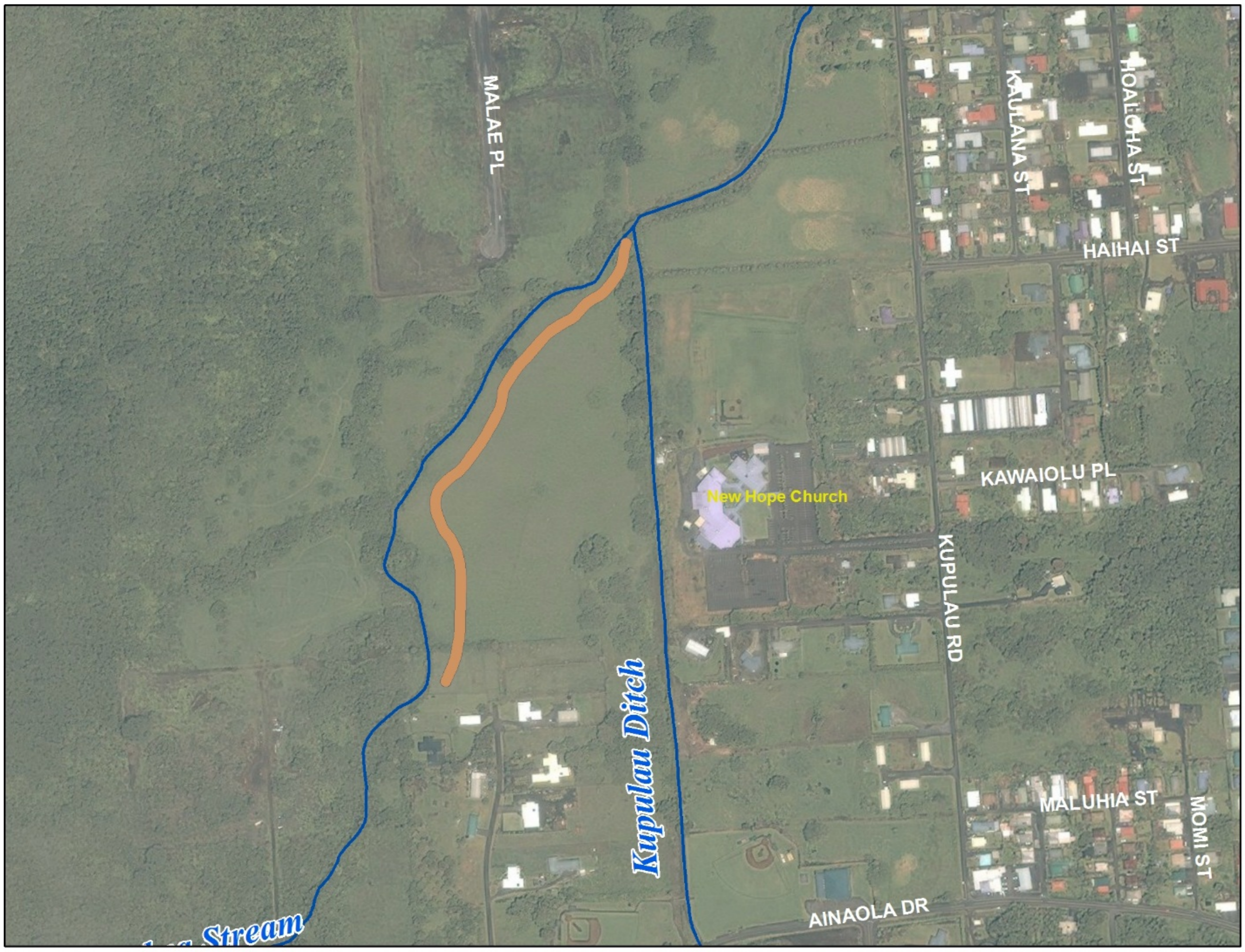


Figure 44. Location of Upper Waiakea Levee #1

<u>6.2.3 Upper Waiakea Stream Levee #2</u>. This measure consists of constructing a levee on land between Waiakea Stream and Kupulau Ditch, upstream of its confluence. This levee forms a detention area to hold excess flow in times of extreme rain events. The levee begins at Waiakea Stream and travels east to the left bank of Kupulau Ditch where it turns south and generally follows the 636 foot elevation contour. It ties into a small hill and then continues in a southwesterly direction and ties into high ground along the right bank of Waiakea Stream. This levee has a total length of about 1,810 ft and a maximum height of 6.8 ft. Figure 45 shows the location of the Upper Waiakea Stream Levee #2.

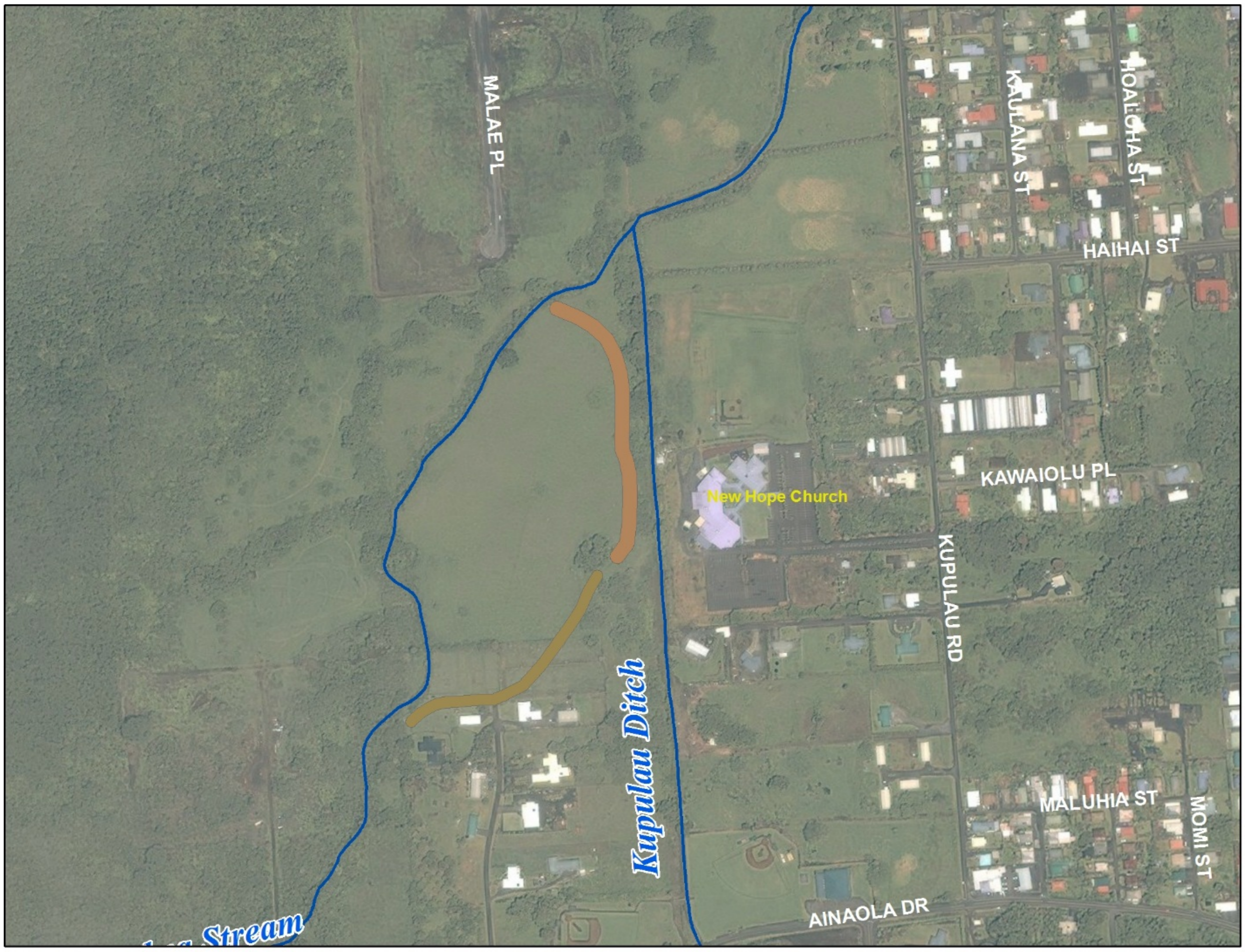


Figure 45. Location of upper Waiakea Levee #2

6.2.4 Kupulau Ditch Channel Enlargement. This measure consists of enlarging the Kupulau Ditch channel from its mouth upstream to the pedestrian bridge for a distance of about 2,400 ft. This channel excavation would be designed to contain its own flow plus the overflow from Waiakea Stream. The existing Kupulau Ditch contains a channel having a 12 foot bottom width with 2:1 side slopes. Various channel configurations ranging from a 15 foot bottom width to a 30 foot bottom width were analyzed to determine their impact on the water surface elevation of the 1% AEP flood event. Excavation of the channel could only occur along the left bank as the existing ground elevations begin to become lower along the right bank as the distance from the ditch increases. In each case the excavation was not sufficient to contain the flood profile due to the excessive tailwater condition at the confluence of the ditch with Waiakea Stream. For each configuration, additional measures were required to completely contain flow to the ditch. This effort was terminated after testing the 30 foot bottom width as excavation quantities became sufficiently too large to render this measure economically infeasible. Thus, this measure was not considered any further. Figure 46 shows the location of the Kupulau Ditch Channel Enlargement.

Figure 46. Location of Kupulau Ditch Channel Enlargement

<u>6.2.5 Kupulau Ditch Detention I</u>. The main component of this measure is the construction of a detention area to store excess runoff which now enters Kupulau Ditch. The improvements include levee and floodwall construction on Kupulau Ditch, and for Waiakea Stream, the improvements include the construction of both levees and floodwalls, along with channel deepening or improvements to Waiakea stream. Additional measures on Waiakea Stream consist of the construction of a debris control structure, grade control measures, and the removal of a privately owned bridge.

Kupulau Ditch Detention I will also require the construction of the Kupulau Ditch Levee Floodwall measure to address flooding due to the backwater effect at the confluence of Kupulau Ditch and Waiakea Stream. This will result in levees/floodwalls on both sides of Kupulau Ditch. The natural topography of the site location for the detention area will require levee heights in excess of 11 ft to contain a 0.2% AEP flood. The detention area will have a positive impact in shaving off the peak flows but improvements to Waiakea Stream downstream of Kupulau Road Bridge will still be required. The construction of levees/floodwalls on both sides of Kupulau Ditch will result in a potentially a higher overall implementation cost than Detention Area II which will not require improvements to Waiakea Stream downstream of Kupulau Road Bridge.

For Kupulau Detention I, the improvements to Waiakea Stream begin with the construction of a series of levees on the land between Waiakea Stream and Kupulau Ditch, upstream of its confluence. These levees are connected to form a storage area to hold excess flow in times of extreme rain events. The first levee is to be constructed along the right overbank of Waiakea Stream, for a length of about 795 feet. The levee ranges from elevation 644.6 to 646.0 ft, and has a maximum height of about 8.6 feet at its downstream end. The second levee for the storage area connects to the Waiakea levee and travels west across the landscape to the left bank of Kupulau Ditch where it turns south and generally follows the 636 ft contour, and ties into a small hill at approximate elevation 646.2 ft. The levee begins again on the back side of the hill and travels in a southwesterly direction and ties into high ground along the right bank of Waiakea Stream at elevation 648.0 ft. The total length of this levee is approximately 1,907 ft and has a maximum height of 11.5 ft. Construction of these levees will store water up to and including the 0.2% AEP event storm.

This levee configuration will create a storage area of about 16.7 acres and a volume of about 66.3 acre-ft at the 1% AEP event. According to the State of Hawaii Revised Statute 179 D3, the dam safety threshold of storing more 50 acre-ft of water will be triggered with this alternative, requiring additional regulatory considerations to be considered for the implementation of this measure. Water will enter the storage area by overflowing the natural bank upstream of the Waiakea levee where the overflow occurs under without project conditions. Water will re-enter Waiakea Stream by means of two (2) 36 in RCP culverts. Under high flows the outlet of these culverts will be submerged, however the head inside of the storage area will still allow some flow to be released. As the water surface in the stream recedes, the flow from the culverts will increase. It is estimated that the storage area will empty within 24 hours after the rain stops.

Continuing downstream to the confluence with Kupulau Ditch, the channel here is improved. Currently, the ditch empties into Waiakea Stream at essentially a right angle. This confluence is improved by widening Waiakea Stream from the confluence downstream to station 216+19, a distance of about 600 ft. At the confluence the channel bottom is widened to a 55 foot width to span both the outflows from Kupulau Ditch and Waiakea Stream. This bottom width is reduced to 25 feet at station 220+20, and continues at this width until the end of the improvement at 216+19. At this point, Waiakea Stream begins to increase its channel slope as it travels to the Kupulau Rd Bridge.

This improvement is continued on Kupulau Ditch from the confluence upstream for about 200 feet. At station 1+01.5 on Kupulau Ditch the channel bottom is widened to 35 feet, and the right bank transitions to meet the bank on Waiakea Stream . At station 1+50.4 the channel width reduces to 25 feet and this is continued to station 2+00.4, where it then transitions to the existing bottom width.

In the vicinity of Kupulau Road, channel modifications to Waiakea Stream consists of channel excavation beginning approximately 500 feet upstream of the Kupulau Rd bridge at approximate station 211+74, to remove a large rock outcropping and provide a smoother transition into the bridge opening. Channel excavation consists of widening the present stream to a 25 foot bottom width, with 2:1 side slopes. The stream is improved along its present alignment; however, its bed slope is modified. The excavation ends at the Kupulau Road Bridge.

Floodwalls along both the right and left banks of Waiakea Stream from the Kupulau Road Bridge downstream to the upstream end of the Kawailani St Bridge will be constructed to prevent flow from leaving the stream and inundating the surrounding property. These floodwalls will consist of a CRM (Concrete Rubble Masonry) design, and were held to a maximum height of 5 feet along the banks. They are located along the path of the top of bank, and where existing topography permits the floodwall will merge with the surrounding land. It is estimated that there will be a total floodwall length of about 3,350 ft on the right bank and 3,330 ft along the left bank.

Excavation of the Waiakea Stream channel bed will increase the capacity of the stream to carry the 1% AEP event while maintaining the 5 feet height limit of the floodwalls requested by the County of Hawaii for maintaining homeowner sight lines and floodwall maintenance purposes. Channel modifications begin at Waiakea Stream station 174+18 and end at station 202+17. Channel excavation consists of widening the present stream to a 25 foot bottom width with 1:1 side slopes. The stream will be improved along its present alignment and its bed slope will be modified. From station 174+18 to station 192+14, the channel slope is 0.03286 ft/ft, at station 192+14 the channel slope changes to 0.02262 ft/ft to station 196+85, where the slope again changes to 0.03256 ft/ft to station 202+17 where the channel bed meets its existing slope. The total length of this excavation is about 2,800 ft.

Additional measures along Waiakea Stream include the construction of a debris control structure located at approximate station 10+801.33, which is just upstream of the end of the channel excavation. This structure will consist of a concrete pad containing 8 in. steel pipes filled with concrete rising from the ground an average of about 4 feet. The pipes will be spaced 4 feet apart. This will trap debris before it reaches the Kupulau Rd Bridge. An access road will be constructed to provide access for maintenance. The road will be about 300 ft in length. This structure is similar to the debris structure described in previous measures. Also, three grade control measures will be installed along Waiakea Stream where changes in slope occur. These measures consist of a concrete pad placed across the bottom of the channel to prevent erosion. This pad will be 2' wide by 25' long (going across the channel) by 4' deep (7.5 CY)

Levee/floodwall construction along the right bank of Kupulau Ditch consists of an earthen levee/floodwall combination. The CRM floodwall begins on Kupulau Ditch at approximate Kupulau Ditch station 17+85 where it ties into high ground at elevation 643.0 ft. The floodwall continues downstream to station 13+00 where it transitions to an earthen levee. This transition is due to the height of the floodwall increasing to 5 feet, a maximum height desired by the local sponsor due to maintenance concerns. This elevation is approximately 640.1 ft at this transition. The levee continues downstream past the confluence with Waiakea Stream for about 860 feet and ends on Waiakea Stream at approximate station 213+70. The downstream end of the levee is open-ended as the existing topography begins at a downward slope towards Kupulau Road. The top of levee elevation here is approximately 629.1 ft.

The levee is approximately 1,824 ft long. The levee toe is setback from the right bank a minimum of 5 feet. The proposed CRM floodwall is about 358 feet long. It is constructed with an estimated 2 foot of buried depth. This detention basin idea was considered for further analysis. Figure 47 shows the location of the Kupulau Ditch Detention I measure.

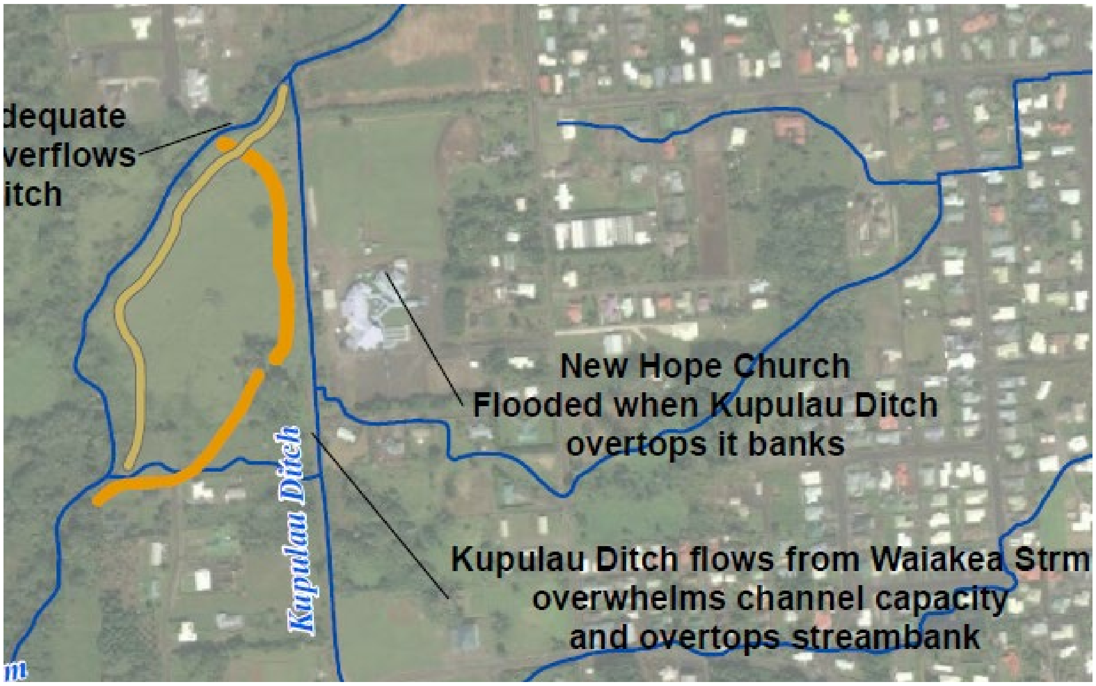


Figure 47. Location of Kupulau Ditch Detention I

<u>6.2.6 Kupulau Ditch Detention II</u>. The main component of this plan is the construction of a detention basin on property located to the north of the New Hope Church and adjacent to the right bank of Kupulau Ditch. Impounding of the runoff is accomplished by constructing a series of three levees to enclose the landscape and uses the natural topography of the area. The levees are described in the following paragraphs and a map is shown in Figure 48.

The Waiakea Stream or north levee is constructed along Waiakea Stream which separates the basin from the stream. This levee begins at approximate stream station 213+70, which is about 860 feet downstream of the confluence with Kupulau Ditch. The levee continues upstream along the right bank to approximate Kupulau Ditch station 2+00 for a length of about 970 feet. The downstream end of the levee is open-ended as the existing topography begins a downward slope towards Kupulau Rd. The top of levee elevation ranges from 624.7 to 636.4 ft with an average height of 5.7 ft.

The second levee referred to as the East Containment Levee is constructed to create the eastern boundary of the basin. This levee intersects the Waiakea Levee described above and travels in a generally southern direction for a distance of about 900 feet. The top of levee elevation ranges from 632.3 to 634.4 with an average height of 6.7 ft.

The third levee referred to as the South Containment Levee is constructed to create the southern boundary of the basin. This levee intersects the East Containment Levee and travels in a westerly direction for a distance of about 532 ft where it ends back at Kupulau Ditch. This levee has an average height of about 2.8 ft.

To protect the New Hope Church and properties to the east, a CRM floodwall is constructed along the right bank of Kupulau Ditch from the detention basin upstream for a distance of about 912 ft. The floodwall has an average height of about 5.6 ft.

Water enters the basin by overtopping the existing right bank of Kupulau Ditch between ditch stations 2+00 and 8+00 for a length of about 600 ft. To "encourage" flow into the basin, a culvert is installed at the downstream end of Kupulau ditch to limit the amount of water leaving the ditch. This culvert consists of a 12' wide x 8' high concrete box about 92 ft in length. The invert of this culvert is set at the existing channel bottom. The culvert embankment is protected by grouted rip-rap at both the downstream and upstream ends. The top of the culvert embankment is set at 3 ft above the top of the culvert to create an overflow weir for large events. This weir is protected by grouted rip-rap.

The detention basin is emptied by use of four (4) corrugated metal pipe culverts (4 ft in diameter) located at the northwest corner of the basin. The culverts will be installed through the Waiakea Levee and enters Waiakea Stream at approximate stream station 217+44, about 480 ft downstream of the confluence with Kupulau Ditch. The culvert is approximately 61 ft. long. The culvert inverts are all set at elevation 624 ft.

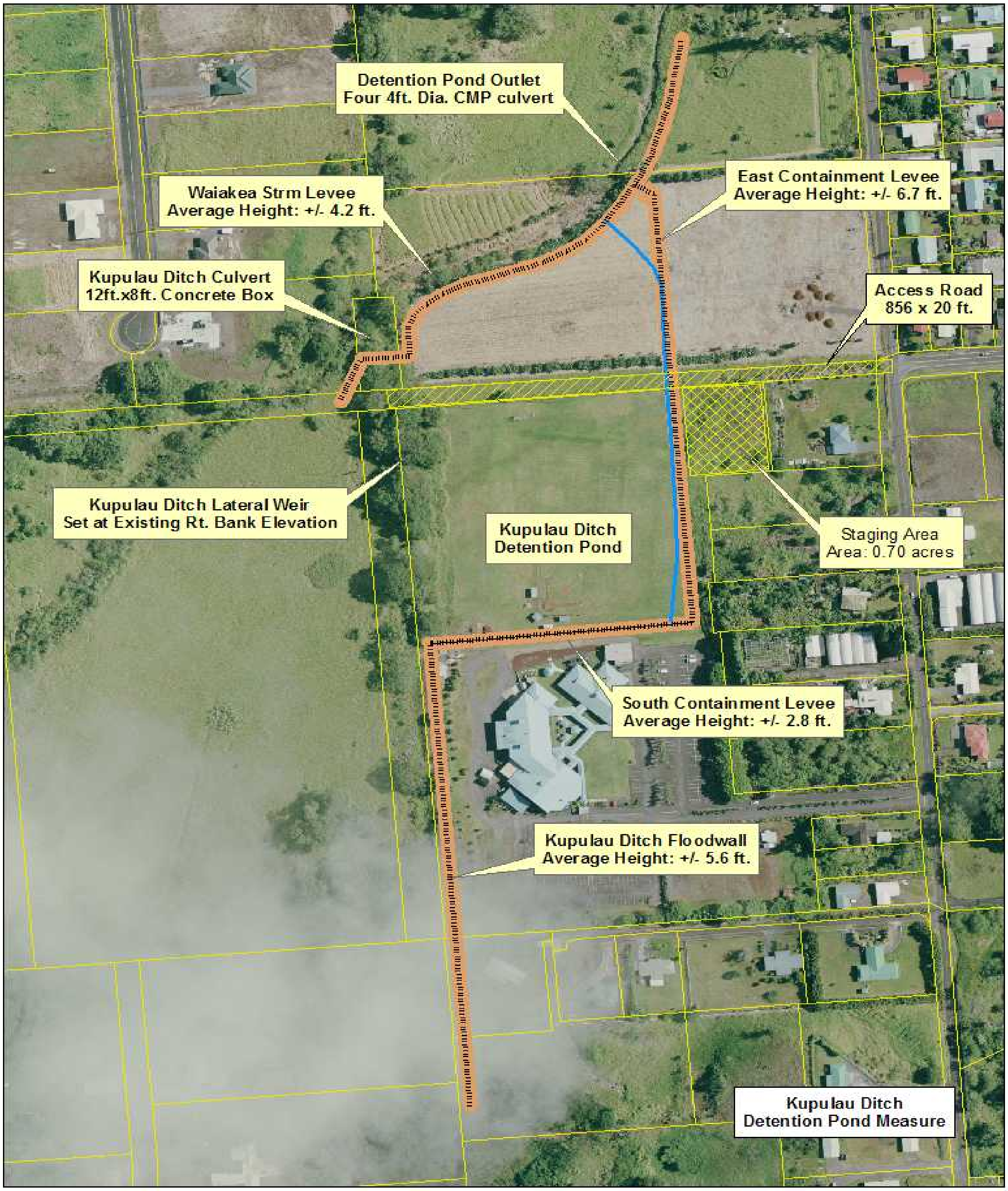


Figure 48. Kupulau Ditch Detention II

6.2.7 Kupulau Ditch Levee/Floodwall. This measure consists of a levee/floodwall constructed along the right bank of Kupulau Ditch to prevent floodwaters that are in excess of the channel capacity of the ditch from overtopping the ditch and flowing to the east causing damage to properties along HaiHai St. and eventually entering the Palai Stream basin. Due to space restrictions the upper portion of this measure is a CRM floodwall about 485 ft in length and a maximum of 5 feet in height. At this point the New Hope Church structure ends and the land opens up to a broad field. The floodwall then transitions to an earthen levee ranging from 5 to 8 feet in height with 3: 1 side slopes. This levee extends for about 1,225 ft in length along the ditch, and then continues for about 600 feet along the right bank of Waiakea Stream. The Kupulau Ditch levee/floodwall measure will prevent flow from leaving Kupulau Ditch and flooding properties to the east. However, as a result of this, there will be an increase in flow and damage to properties located on Waiakea Stream downstream of Kupulau Ditch. Therefore, this measure cannot stand alone as a flood damage reduction plan, but can be included as part of any overall alternative. Figure 49 shows the location of the Kupulau Ditch Levee/Floodwall measure.

Figure 49. Location of Kupulau Ditch Levee/Floodwall

To reduce the flood problem along Waiakea Stream, four measures were considered. They are: the Waiakea Diversion channel, channelization of the stream, construction of floodwalls, and a combination of channelization and floodwalls. These measures are described as follows. Parts of the last three Waiakea Stream measures were included in the Kupulau Detention I measure as necessary improvements to Waiakea stream to make the Kupulau Detention I measure work.

6.2.8 Waiakea Stream Diversion Channel. This measure consist of constructing a diversion channel from the junction of Kupulau Ditch and Waiakea Stream downstream to a point where it re-enters Waiakea Stream upstream of Komohana St for a distance of about 10,400 ft. It also requires construction of a new bridge crossing the channel on Puainako St. Construction of this measure would be through largely undeveloped land and would potentially cause significant environmental impacts. However, there has been recent residential development along the proposed channel alignment. It would not be feasible to change the alignment as it would add significant excavation to the construction increasing an already high cost. This measure will not be considered any further. Figure 50 shows the location of the Waiakea Diversion Channel.

Figure 50. Location of Waiakea Stream Diversion Channel

6.2.9 Waiakea Stream Channelization. This measure consists of excavating a channel along the Waiakea Stream to contain the flood flows, from upstream of Kupulau Rd to upstream of Kawalani St. The channel excavation consists of a rectangular channel having a 50 ft bottom width for a distance of about 2,155 ft long between Kupulau Road and Kawailani St. Upstream of Kupulau Rd the channel cut has a 25 ft bottom width for a distance of about 500 ft. This measure also constructs a debris trap composed of concrete filled steel pipes designed to reduce debris transport into Waiakea Stream and subsequent flood damage due to debris dams. This trap would be installed upstream of the channel improvements and would trap large woody vegetation and rocks while allowing water to flow around the structure and continue downstream. It also improves the Kupulau Rd Bridge by raising and extending the upstream bridge guard wall to elevation 604 ft in order to prevent floodwaters from overtopping the bridge. Grade control structures consisting of concrete filled trenches will be installed at changes in channel slope to control bed erosion. Figure 51 shows the location of the Waiakea Channelization measure.

Figure 51. Location of Waiakea Stream Channelization

<u>6.2.10 Waiakea Stream Floodwalls</u>. This measure consists of two CRM floodwalls constructed along both the left and right banks of the stream from Kupulau Rd downstream to approximately Kawalani St. This prevents floodwaters from causing flood damage to properties along each side of Waiakea Stream. The floodwalls are 3,530 ft each in length and range from 3 to 9 ft in height. Upstream of Kupulau Rd. the channel will be excavated to a 25 ft. bottom width for a distance of about 500 ft. This measure also constructs a debris trap composed of concrete filled steel pipes designed to reduce debris transport into Waiakea Stream and subsequent flood damage due to debris dams. This trap would be installed upstream of the channel improvement and would trap large woody material and rocks while allowing water to flow around the

structure and continue downstream. It also improves the Kupulau Rd. Bridge by raising and extending the upstream bridge guardwall to elevation 604 ft in order to prevent floodwaters from overtopping the bridge. Figure 52 shows the location of the Waiakea Stream Floodwalls measure.

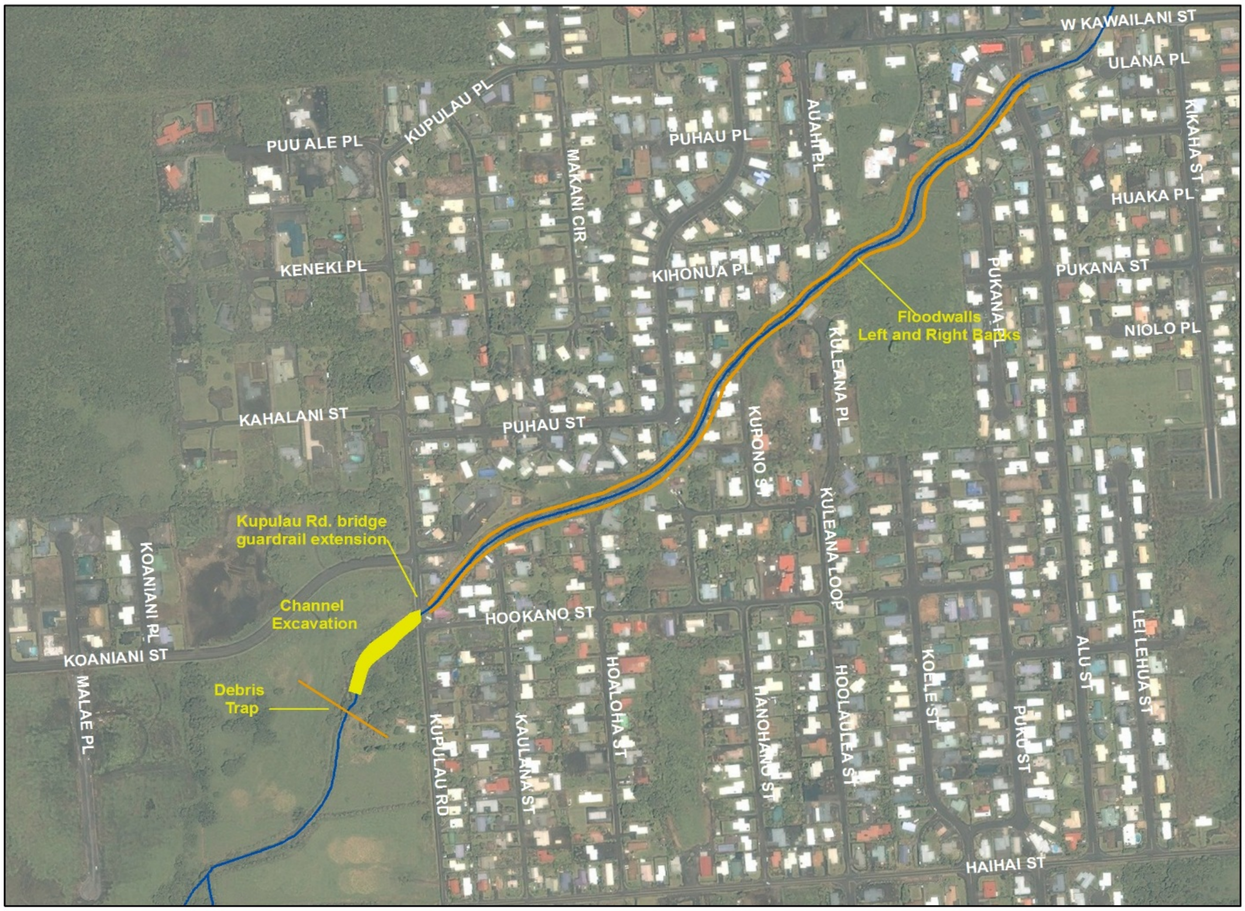


Figure 52. Location of Waiakea Stream Floodwalls

<u>6.2.11 Combination of Waiakea Steam Floodwalls and Channelization</u>. This measure consists of the construction of floodwalls and channelization of Waiakea Stream from Kupulau Rd to Kawalani St. This measure reduces the height of the floodwalls from Waiakea Stream Floodwalls measure previously discussed and reduces the excavation from the Waiakea Stream Channelization measure described above. The floodwalls are reduced to a maximum height of 5 ft, and the channel excavation consists of a 25 ft bottom width upstream of Kupulau Rd for a distance of about 500 ft. Downstream of Kupulau Rd the excavation consists of a rectangular channel having a 30 ft. bottom width for a distance of about 2,155 ft. This measure also constructs a debris trap composed of concrete filled steel pipes designed to reduce debris transport into Waiakea Stream and subsequent flood damage due to debris dams. This trap would be installed upstream of the channel improvements. It also improves the Kupulau Rd. Bridge by raising and extending the upstream bridge guard wall to elevation 604 ft in order to prevent floodwaters from overtopping the bridge. Grade control structures consisting of concrete filled trenches will be installed at changes in channel slope to control

bed erosion. Figure 53 shows the location of the Waiakea combination floodwalls and channelization measure.

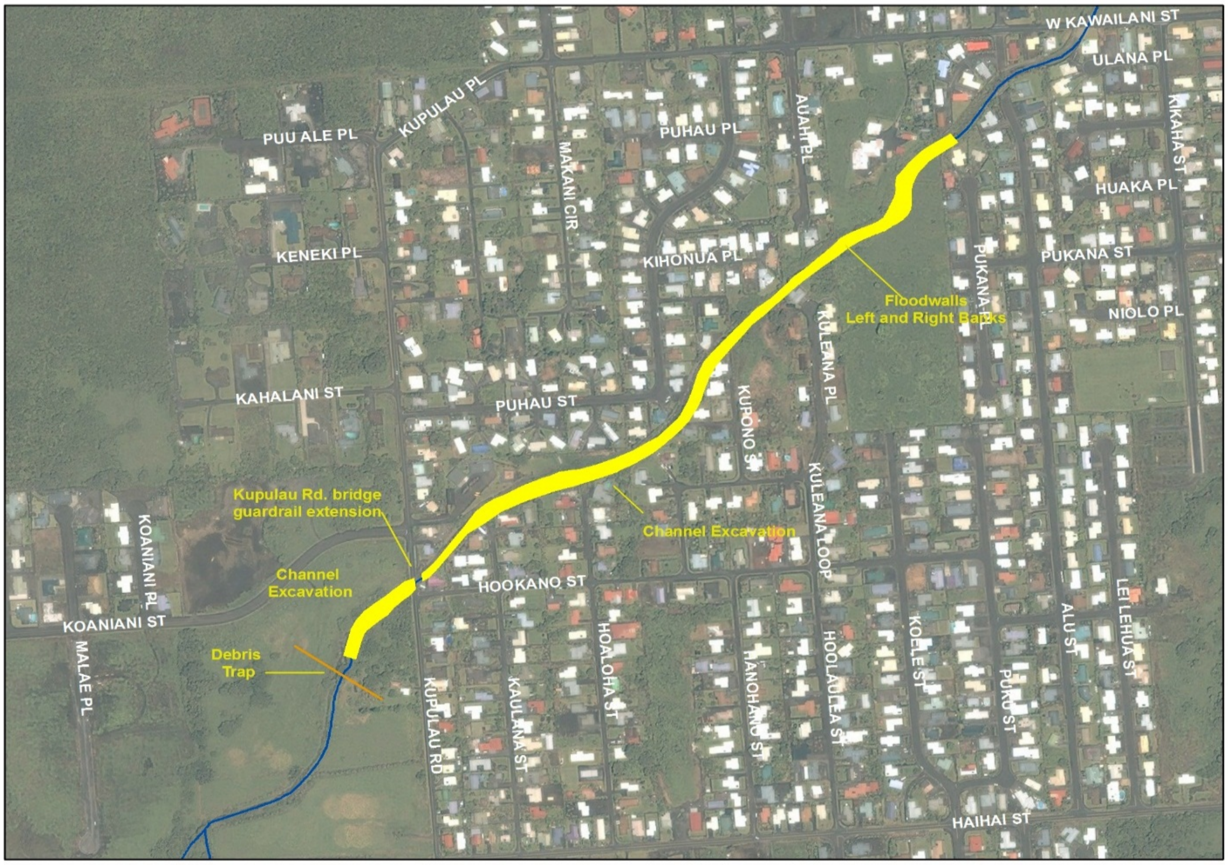


Figure 53. Location of Waiakea Stream Combination of Floodwalls and Channelization

6.3 STRUCTURAL MEASURES FOR PALAI STREAM. Intense urbanization of Palai Stream watershed downstream of the Hilo Municipal Golf Course poses significant challenges to creating flood risk management measures in the areas where the flooding occurs, because many residential, commercial, and industrial properties are located in the stream channel or in very close proximity to the stream banks. Therefore, no structural measures in this area were considered to address the flood risk.

The remaining Palai Stream flood problem results from the generation of runoff within the watershed, this was analyzed by considering the following measures: the Hilo Municipal Golf Course Diversion, Hilo Municipal Golf Course Detention Basin, HaiHai St. Detention, and Ainalako Diversion. These measures are described in the following paragraphs.

6.3.1 Hilo Municipal Golf Course Diversion. This measure consists of constructing a new diversion channel beginning in the Hilo Municipal Golf Course and traveling around the perimeter of the Palai Church property down to HaiHai St., where it enters an underground conduit before emptying into Four Mile Creek.

This measure would include a 2.5 acre-ft. detention pond in the golf course to attenuate flow, leading to approximately 1,000 ft. of open channel transitioning to about 1,840 ft. of two 10' wide by 9' tall underground box culverts running under HaiHai St. to the Panaewa Bridge at Kanoelehua St. where they will enter the existing Four Mile Creek county flood control channel. This measure will reduce flood damage to properties in the downstream areas of Hilo. Due to the high cost, this measure will not be considered further. Figure 54 shows the location of the Hilo Municipal Golf Course Diversion measure.

6.3.2 Hilo Municipal Golf Course Detention Basin. This measure consists of constructing a 21 acre-ft detention basin in the Hilo Municipal Golf Course to attenuate flow and reduce damage to properties in the downstream reaches of Palai Stream. The basin is formed by constructing an in-channel structure across Palai Stream creating a dam embankment having an expected maximum height of 20 ft from the existing channel invert, designed to hold the 1% AEP event. The total length of the embankment is about 1,374 ft. The top of the embankment is set at elevation 250.0 ft.

A 60 foot wide overflow spillway allows flow in excess of the 1% AEP event to exit the basin. The spillway elevation is set to 247.0 ft, which is about 0.4 feet above the 1% ACE water surface elevation inside the basin. The spillway is constructed of concrete and is 29 ft in length and has vertical side walls rising to the top of the embankment. The weir is protected by grouted rip-rap on both the upstream and downstream face. The outlet itself will consist of two (2) 6 foot diameter Aluminized Steel pipes.

Figure 54. Location of Hilo Municipal Golf Course Diversion

At the 1% AEP event, the detention basin has a storage volume of 16.7 Acre-ft. and at the 0.2% ACE event the storage volume is about 20.2 Acre-ft. Maximum water depth at the 1% Event is about 12.7 feet and about 13.9 feet at the 0.2% event. Since the estimated peak storage is less than 50 acre-ft, the detention basin would not be categorized as a regulated dam by the State of Hawaii. It is estimated that the basin will empty in less than 24 hours for all events.

The detention basin is located entirely within the golf course property which is owned by the county of Hawaii. The location of the impoundment incorporates the existing terrain in developing the necessary storage. There would be some modifications to the golf course configuration required for this impoundment, but it would not be extreme. Figure 55 shows the location of the Hilo Municipal Golf Course Detention Basin.

Figure 55. Location of Hilo Municipal Golf Course Detention Basin

<u>6.3.3 HaiHai St Detention</u>. This measure consists of constructing a 28 acre-ft detention basin on Palai Stream upstream of HaiHai St on a 69 acre parcel of state-owned land. It is located on the southeast corner of the intersection of HaiHai St and Ainaola Rd.

The impoundment is created by constructing an in-channel barrier with an uncontrolled outlet in the shape of a flow restricting flume. The flume has a throat width of 4.5 feet and is 34 feet in length. It has an invert elevation of 461.0 ft. The upstream approach section of the flume is 40 ft wide and reduces to the throat width at a 45 degree angle. The exit section of the flume is similar. The top of the flume is set at an elevation of 474.0 ft where an overflow weir is constructed. This weir is 40 ft wide and will allow flows in excess of the 1% AEP event to pass over the structure. The top of the weir sidewalls are set at elevation 478.0 ft. This outlet configuration is preferred over a culvert outlet in that with the flume the upstream head of the structure is reduced resulting in a lower upstream water surface elevation.

On the north side of the structure and running parallel to HaiHai St will be an earthen levee embankment having a total length of about 138 ft and will have an average height of about 7.2 ft. South of the outlet structure and running parallel to the east property line a second earthen levee embankment will be constructed. This embankment will have a total length of about 782 ft and have an average height of 9.2 ft.

At the 1% AEP event, the detention basin has a storage volume of 21.4 Acre-ft. and at the 0.2% AEP event the storage volume is about 27.9 Acre-ft. Maximum water depth at the 1% ACE event is about 13 ft and about 13.9 ft at the 0.2% AEP event. The detention basin will be located entirely within state owned land. Figure 56 shows the location of the HaiHai St. Detention measure.

Figure 56. Location of HaiHai St Detention

6.3.4 Ainalako Rd Diversion. The main component of this measure is the construction of a diversion structure to divert excess flows into Four Mile Creek. This diversion structure will be located just downstream of Ainalako Rd on Palai Stream. It takes advantage of the natural topography along the right overbank of Palai Stream and the natural drainage pattern of the immediate area. The location of this area is shown on Figure 57.

Along the right overbank of Palai Stream there exists a natural depression between two small mounds, creating what can be referred to as a "saddle" effect. Under without project conditions water overtops the saddle and enters Four Mile Creek. The difference in elevation between the Palai Stream channel bottom and the saddle is about 3 feet.

To "encourage" flow to enter the diversion structure an in-channel barrier with an uncontrolled outlet consisting of two (2) 5 foot diameter pipes will be constructed. The invert of the pipe is set at elevation 507.6 ft, which results in a pipe about 72 feet long. The total length of the in-channel barrier is about 500 ft. The top of the embankment is set at elevation 518.0 ft.

The "saddle" has a minimum elevation of 514.0 ft. At that elevation, the diversion weir is 200 ft in length. Under without project conditions, the overflow is covered with scrub brush and tall grasses. Improvements to the overflow weir will increase its efficiency and allow an increase in flow over the diversion weir. These improvements will consist of clearing the weir section of grass and brush, stripping of the top layer of soil, and placing a cap of grouted rip-rap on the crest to prevent erosion.

A grassed swale will be constructed to direct the overflow from the weir into Four Mile Creek. This swale will utilize the natural topography of the land. It is estimated that this swale will be about 276 ft in length and an average width of about 182 ft.

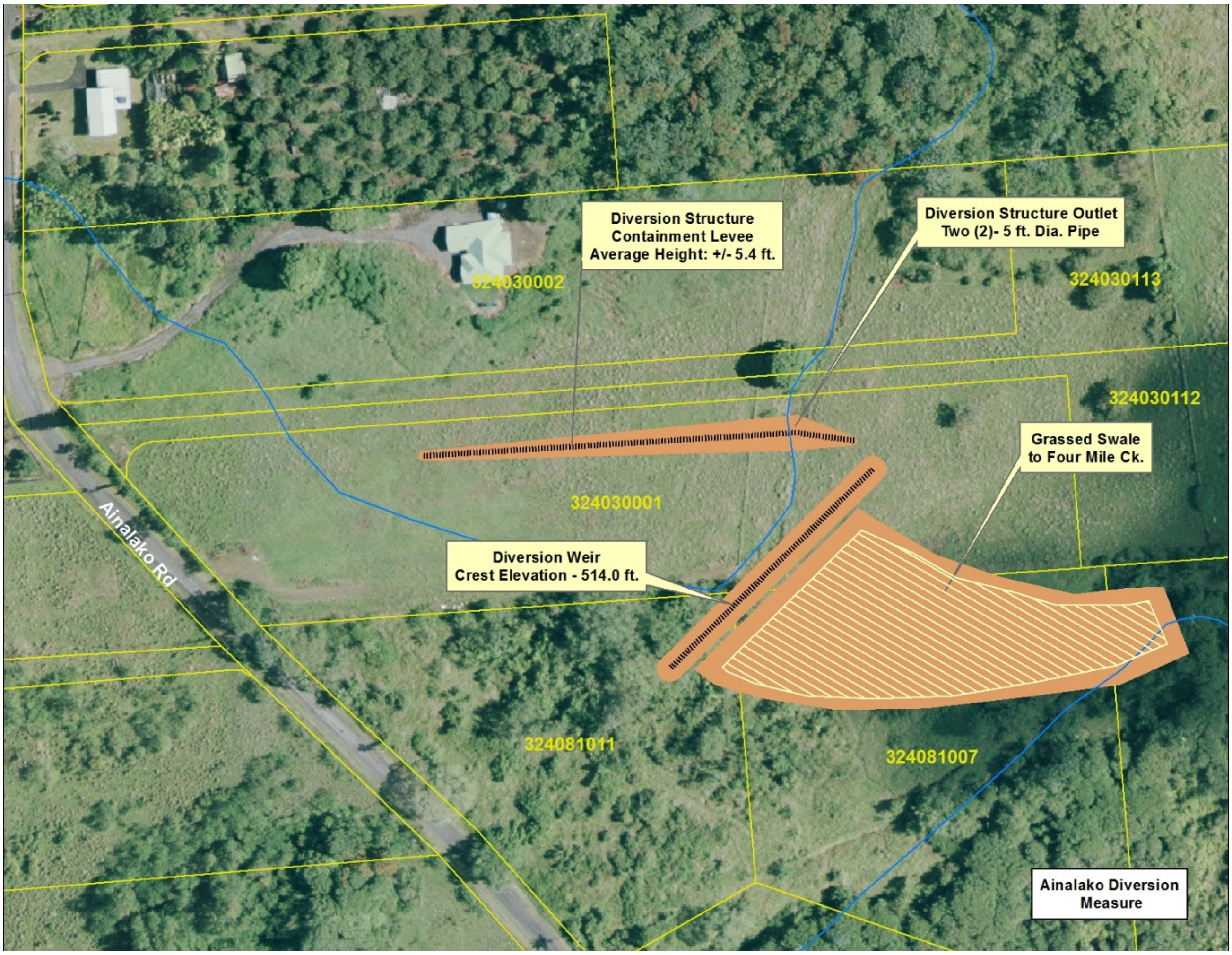


Figure 57. Location of Ainalako Rd Diversion

6.3.5 Tandem Alternative. This plan combines the Ainalako Rd Diversion measure with a reconfigured Hilo Municipal Golf Course Detention Basin measure. Peak flows on Palai Stream will be reduced when the Ainalako Rd Diversion Plan is implemented. This allows for a smaller detention basin in the Hilo Municipal Golf Course.

The smaller Hilo Municipal Golf Course Detention basin is created by constructing an in-channel barrier with an uncontrolled outlet consisting of three (3) 4 ft. diameter aluminized steel pipes. The design of this structure has a crest width of 10 ft with side slopes of 3:1 and a total length of about 823 ft. Side embankments located on the north and south side of Palai Stream prevent flow from escaping the stream. The levee embankment will require about 652 CY of material. The top of the embankment is set at elevation 244.0 ft. The in-channel embankment has a height of about 10 ft. The north side embankment has an average height of about 2.4 ft, while the south embankment has an average height of about 2.1 ft.

Grouted riprap on both the upstream and downstream face of the in-channel embankment is required to protect it from erosion. The grouted rip-rap on both the upstream and downstream slopes of the outlet will require approximately 2,682 SF of coverage, and at a thickness of 1 ft., it will require about 100 CY of material.

The outlet of basin is comprised of three (3) 4 ft diameter pipes. Analysis of this structure has a storage volume of about 7 acre-ft. at the 1% AEP event and about 12 acre-ft. at the 0.2% chance event. Maximum water height at the 1% event is about 7.3 ft and about 9.2 ft. at the 0.2% event. Figure 55 shows the alignment of the impoundment; the actual dimension as explain are smaller than shown on Figure 55. This outlet configuration approaches the existing downstream channel capacity of Palai Stream.

7. PREFERRED ALTERNATIVE FOR FLOOD RISK MANAGEMENT

A combination of measures were selected to provide a complete solution to managing the flood risk to the Waiakea-Palai study area. These alternatives are discussed in the main report under the plan formulation and alternatives analysis section. The preferred measure selected include Kupulau Ditch Detention II (Figure 45) andthe Tandem Plan including both the Ainalako Road Diversion (Figure 53) and the re-configured Hilo Municipal Golf Course Detention Basin (Figure 55).

7.1 Kupulau Ditch Detention Storage

The proposed Kupulau Ditch detention plan provides protection from excess runoff of the 1% AEP event for properties east of Kupulau Ditch and areas along Waiakea Stream downstream. The main component of this plan is the construction of a detention basin on property located to the north of the New Hope Church, adjacent to the right bank of Kupulau Ditch. Impounding of the runoff is accomplished by constructing three levees to enclose the storage landscape.

Waiakea Stream Levee (Figure 48) serves as a barrier between storage basin from the Waiakea stream. This levee begins at approximate stream station 213+70, which is about 860 feet downstream of the confluence, and continues upstream along the right bank to station 2+00 approximate for a length of about 970 feet. The downstream end of the levee is open-ended as the existing topography begins a downward slope towards Kupulau Road. The top width of the of levee is 10 ft, side slopes 3:1 and top elevation ranges from 624.7 to 636.4 with an average height of 5.7 feet. This levee requires 6078 CY of material to build.

East Containment Levee forms the eastern boundary of the basin. This levee travels in a southerly direction about 900 ft and intersects the Waiakea Levee. The top width of the levee is 10 ft, side slopes 3:1, top elevation range from 632.3 -634.4 ft with average height of 6.7 ft. This levee requires 6997 CY of material to build

South Containment Levee forms the southern boundary of the basin. This levee is located a short distance north of the New Hope Church structure. This levee segment is 532 ft long and connects Kupulau Ditch Levee and East Containment Levee. The top width of the levee is 10 ft, side slopes 3:1, top elevation is 634.5 ft with average height of 2.8 ft. This levee requires 1041 CY of material to build.

Water enters the basin by overtopping the existing right bank of Kupulau Ditch between stations 2+00 and 8+00 for a length of about 600 feet. To "encourage" flow into the basin, a culvert is installed at the downstream end of Kupulau ditch to limit the amount of water leaving the ditch. This culvert consists of a 12' wide x 8' high concrete box about 92 feet in length. The end sections of the culvert are mitered to conform with the embankment side slopes. The invert of this culvert is set at the existing channel bottom. The culvert embankment is protected by grouted rip-rap at both the downstream and upstream ends. The top of the culvert embankment is set at 3 feet above the top of the culvert to create an overflow weir for large events. This weir is protected by grouted rip-rap.

Restricting the outflow of the ditch causes a surcharge upstream of the culvert. The ditch overtops into the detention basin starting at the 50% AEP event. At the 1% AEP event the basin overtops through spillway to Waiakea stream. The calculated depth of water over the spill way is 0.3 ft and 1.2 ft for 1% and 0.2% AEP respectively. The outlet of the detention basin consists of four 4-ft diameter, 60-ft long corrugated metal pipes. The invert of the detention basin culvert is at elevation 624 ft, and is located approximately 480 ft downstream from Kupulau Ditch outlet. The top of the 50-ft long spillway is set at an elevation of 630.5 ft, which is 0.5 ft above the 1% AEP water surface. The calculated depth of water – for the 1% AEP – at the culvert is 6 ft and the velocity of flow ranges from 1.3 fps at the upstream end of the basin to 4.5 fps at the culvert outlet.

A flood wall along the right bank of the Kupulau Ditch has a top width 2.5 ft, 1:4 side slopes, is 912 ft long, and has a top elevation range between 634.5 -642.7 ft with average height of 5.6 ft. This floodwall requires 1425 CY of material to build. Once completed, the proposed flood wall will protect New Home Church and other properties to the east.

Basin Storage_- The detention basin was designed to comply with the Hawaii Dam Safety Regulations._The table A9 below illustrates the results of the hydraulic modeling of the detention basin.

Table A9 - Kupulau Detention Basin Storage Calculation

Event		Q (cfs)	Max. Depth (ft.)	Storage (Ac-ft)	Area (Ac)	Outflow (cfs)	Est. Time to Empty (hrs)
AEP (%)	Frequency						
50	2	387	1.7	2.9	4.7	39.2	0.9
20	5	996	2.5	6.5	6.6	78.5	1.5
10	10	1672	3	9.8	7.5	113.8	1.9
4	25	2803	3.8	14.7	8.3	162.1	2.3
2	50	3881	4.4	19.23	8.8	194.3	2.6
1	100	4848	4.9	23.4	9.4	216.5	2.8
0.5	200	6717	5.8	31.9	10	470.7	3
0.2	500	7468	6.2	35.3	10.1	681.8	3.1

Downstream Impacts – The analysis of the impacts of the detention basin confirms that 0.5% AEP flow stays within channel and the 0.2% AEP flow becomes bankfull with minor spillovers. Table A10 below shows the with project and without project discharge and corresponding water elevations.

Table A10. - Comparison of without project and Kupulau Detention

Waiakea Stream					
Index Station 19776.7					
Event		Without Project		Kupulau Detention	
AEP (%)	Freq	Flow	Stage	Flow	Stage
50	2	1352	564.89	972	564.21
20	5	1955	565.84	1071	564.40
10	10	2597	566.68	1240	564.70
4	25	3589	567.85	1463	565.09
2	50	4439	568.88	1507	565.16
1	100	5659	569.96	2013	565.94
0.5	200	7459	572.25	2353	566.38
0.2	500	8424	572.71	2708	566.81

Real Estate Requirements - Some real estate properties will be impacted by construction of detention basin. Table A11 below shows land ownership and areas affected.

Table A11. - Real Estate Impacts

Kupulau Ditch Detention Real Estate Requirements		
TMK	Ownership	Area (Acres)
324036001	Church	6.6
324065036	Private	3.83
324036999	Public	0.63
324076044	Private	0.18
324065035	Private	0.44
324036001	Church	1
324035003	Private	0.22
324035032	Private	0.16

7.2 Golf Course Storage

The Golf Course detention basin provides flood risk reduction to the properties in City of Hilo for flows that exceed 1% AEP in Palai Stream. The Golf Course detention basin works in conjunction with Analako Diversion, which will provide additional flood risk reduction to the area downstream of Golf Course. The detention basin is built in within the golf course boundary, taking advantage of natural topography and drainage conditions (Figure 55).

The impoundment is created by constructing a barrier across the Palai stream and installing a 3-ft diameter aluminum culvert outlet. The top elevation of the 823ft long earth barrier structure is 244 ft. It has a top width

10 ft, side slopes at 3:4, and the average height is 10 ft. This barrier requires 652 CY of material to build. The facility includes side embankments to prevent water from escaping on sides. Both north and south embankments are extended to a natural ground elevation of 244 ft, and corresponding average heights are 2.4 and 2.1, respectively.

The golf course outlet structure, which consists of three 4-ft diameter pipes, is configured to allow flow leaving the facility equal to that of the capacity of the Palai stream downstream. The detention basin can store 7-ac-ft of water in the 1% AEP, 12 ac-ft in 0.2 AEP, and 7.3 ft and 9.2 ft of water at corresponding events.

The detention area is located entirely within the golf course property which is publicly owned. Construction of the stream crossing would not be unduly complex. The location of the impoundment incorporates the existing terrain in developing the necessary storage. There would be some modifications to the golf course configuration required for this impoundment, but they do not appear to be extreme.

7.3 Ainalako Diversion

Ainalako Diversion provides flood risk reduction to properties along Palai Stream down to City of Hilo from excess runoff of the 1% AEP event. The main feature of the proposal is the diversion structure which diverts excess flow over a weir to Four Mile Creek, thus reducing flow in the Palai stream.

Along the right overbank of Palai Stream, there exists a natural depression between two small mounds, referred to as a “saddle” effect. Under general conditions, water passes this saddle and enters the Four Mile Creek. The proposed diversion takes advantage of this natural ground and drainage patterns on right side of Palai Stream to direct floodwater to Four Mile Creek, just downstream of Ainalako Road (Figure 57). The difference in elevation between the Palai Stream channel bottom and the saddle is about 3 feet.

In order to facilitate flow through the saddle, a diversion containment levee and outlet structure are proposed. The outlet structure consists of two 5-ft diameter, 72-ft long, aluminum steel pipes with an invert at elevation 507.6 ft. The diversion containment levee begins from the right bank of the Palai Stream, runs across the stream and meets natural ground on the left side. This structural feature facilitates additional flow over the saddle. The diversion levee is 500-ft long, with a top width is10 ft, side slopes at 3:1, and a top elevation is 518.0 ft. This levee requires 465 CY of material to build.

The saddle is at elevation 541 ft, is 200 ft long, and covered with grass and brush thus reducing the natural carrying capacity of flow compared to clean conditions. Once cleared and capped with rip-rap and grout, the new diversion weir on the saddle will be 220 ft long with side slopes at 3:1. The area of clearing, stripping and riprap is 2200 sq ft. Down from the diversion weir, the channel flow follows the natural drainage path until it reached Four Mile creek about 272 ft away. The proposed actions will affect 6 real estate properties in the area.

<u>Four Mile Creek Impacts</u>

Based on current findings, there are a couple of properties adjacent to Four Mile Creek that may be affected by increased flow. Some of these properties are already in flood prone areas without project conditions. The proposed action intend to reduce flood risks. Any induced flooding as a result of the proposed measure will be addressed during design phase with updated surveys, updated modeling and consideration of structural and non-structural measures to address the induced flooding concerns.

7.4 Feature Optimization

Risk analysis was performed on the Kupulau Ditch Detention II measure to determine the optimum levee heights that would maximize the net benefits. The Ainalako R. Diversion measure is based on existing topography, and in its present form, provides an efficient optimal design not subject to scaling. The re-configured Hilo Municipal Golf Course Detention Basin measure is reduced in size from the original configuration (Figure 55). Therefore, it is felt that this measure has been optimized to its ideal design based on net benefits and site constraints. The preferred alternative with-project flood inundation map is shown in Figure 58.

The PDT (Project Development Team) feels that a 4.3-foot average floodwall/levee height is the preferred alternative for Kupulau Ditch Detention II (KD) and, along with the logically sized Ainalako Rd. Diversion and smaller Hilo Municipal Golf Course Detention, most reasonably comprises the NED (National Economic Development) Plan. Not only is this the height that maximizes net benefits, but in terms of the residual risk and resiliency perspective, the 4.3 ft average height at KD provides a performance CNP (Conditional Non-Exceedance Probability) of 96% for the 1% AEP flood. The average height of 4.3 feet for the Kupulau Ditch Levee/Floodwalls includes about +2.5 feet of height to achieve greater than 95 percent assurance so the measure will safely convey a 1% AEP event. Sensitivity modeling was performed that showed with less than +2.5 feet, the conditional non-exceedance probability dropped below 95% to about 76%, at less than 90% CNP, this was an unacceptable level of confidence.

In developing the final performance table, several iterations involving changing standard deviations of the stages in the stage-discharge relationship and adding large floods of 0.01 frequency and greater were run through the HEC-FDA model. These sensitivity runs had a minimum effect on the bottom line expected annual damages and benefits results (generally less than $10,000 annually, or less than 1%) and, in no case, indicated that the optimal levee/floodwall height would be anything other than 4.3 feet, which includes +2.5 feet of overbuild.

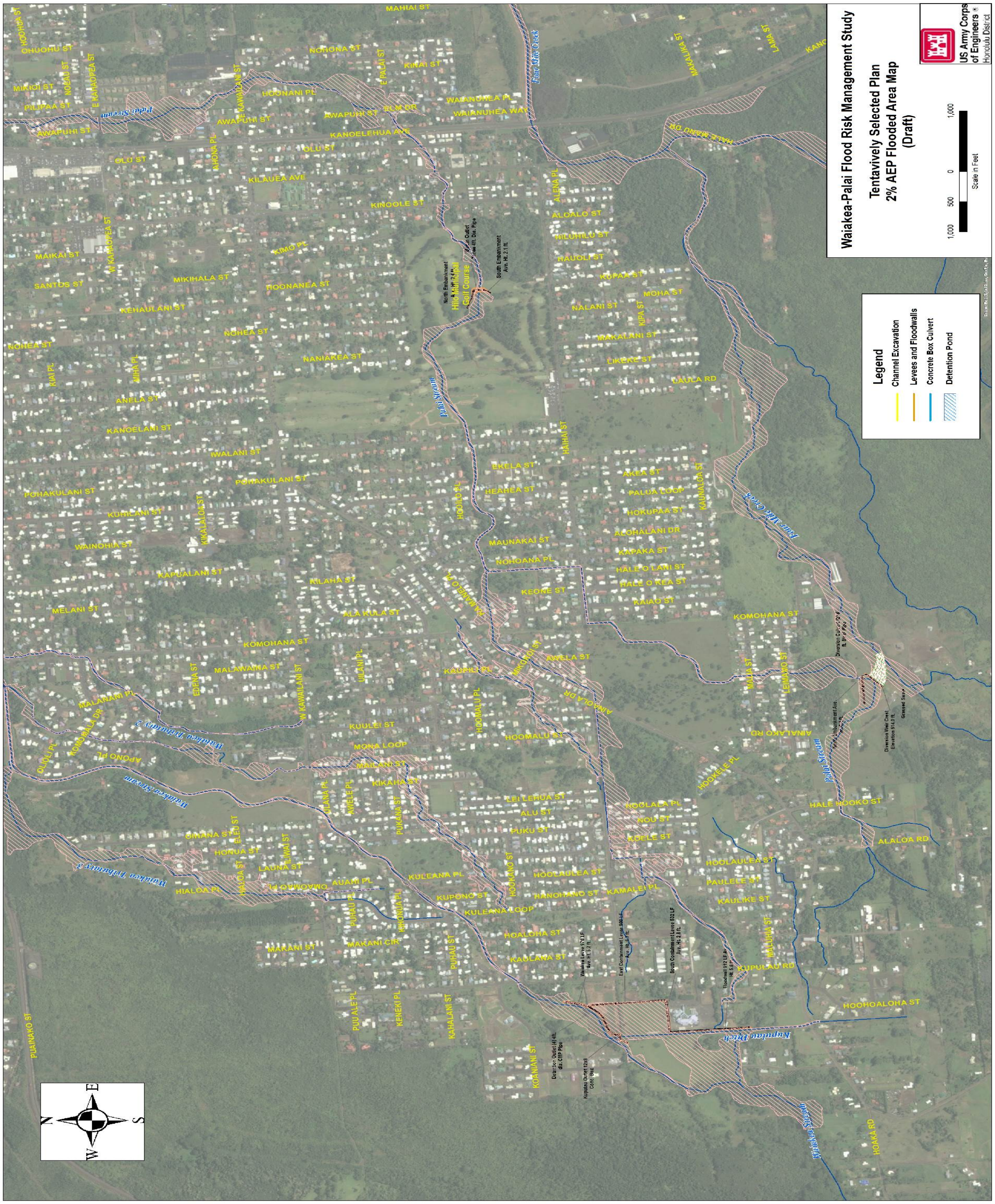


Figure 58. With Project Flooded Area Map (Draft)

7.5 WITH PROJECT WATER SURFACE PROFILES (Preferred Alternative)

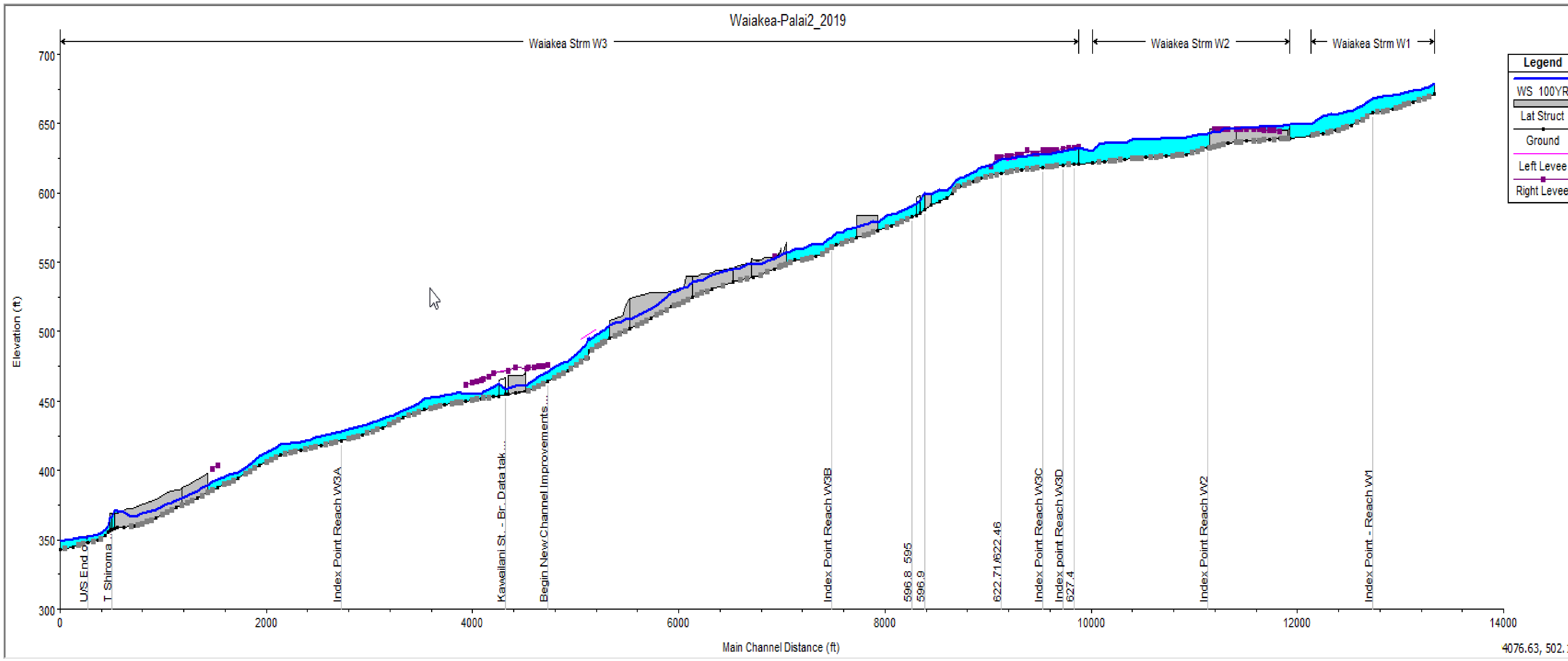


Figure 59A. With Project Waiakea Stream Water Surface Profiles (Reach W1-W3)

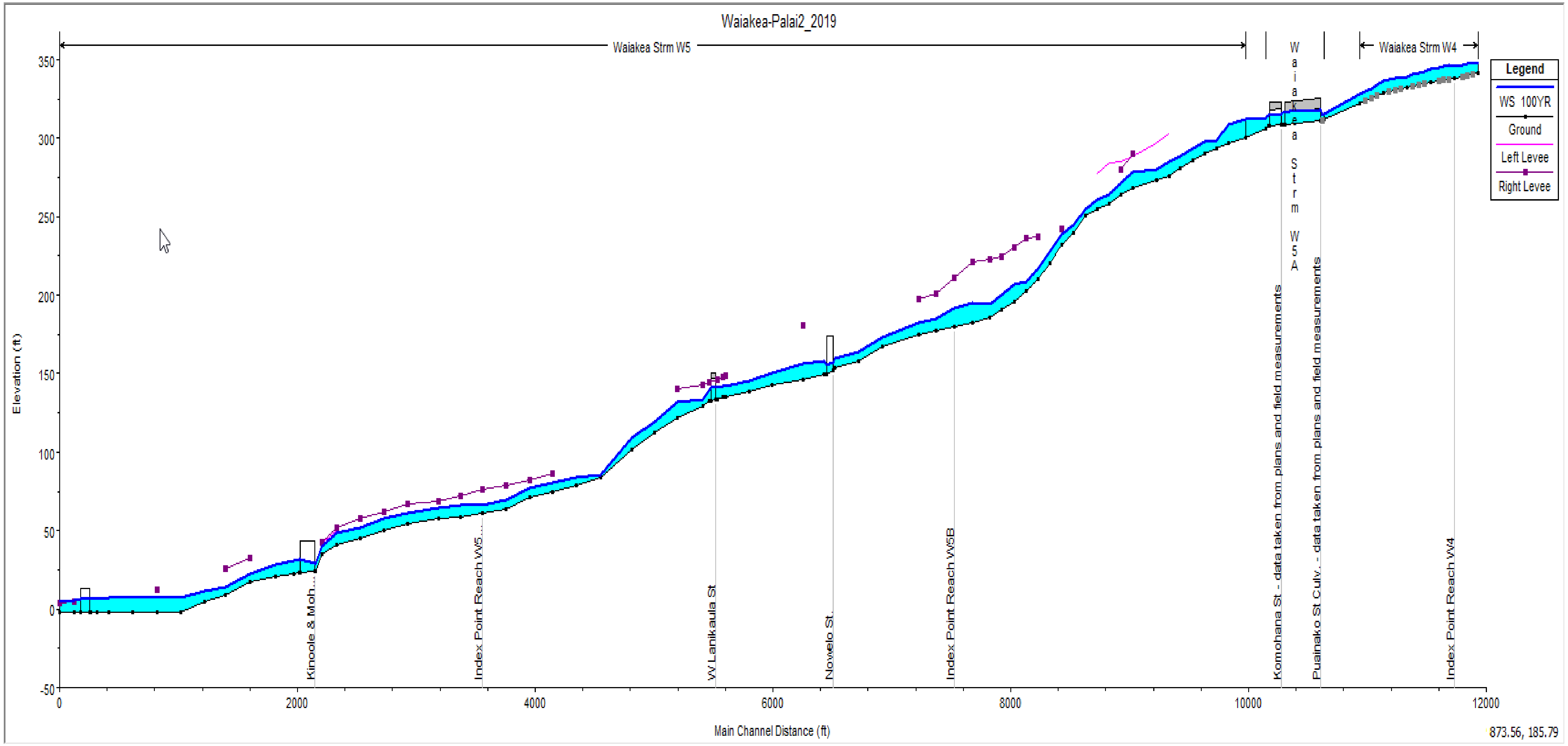


Figure 59B. With Project Waiakea Stream Water Surface Profiles (Reach W4-W5A)

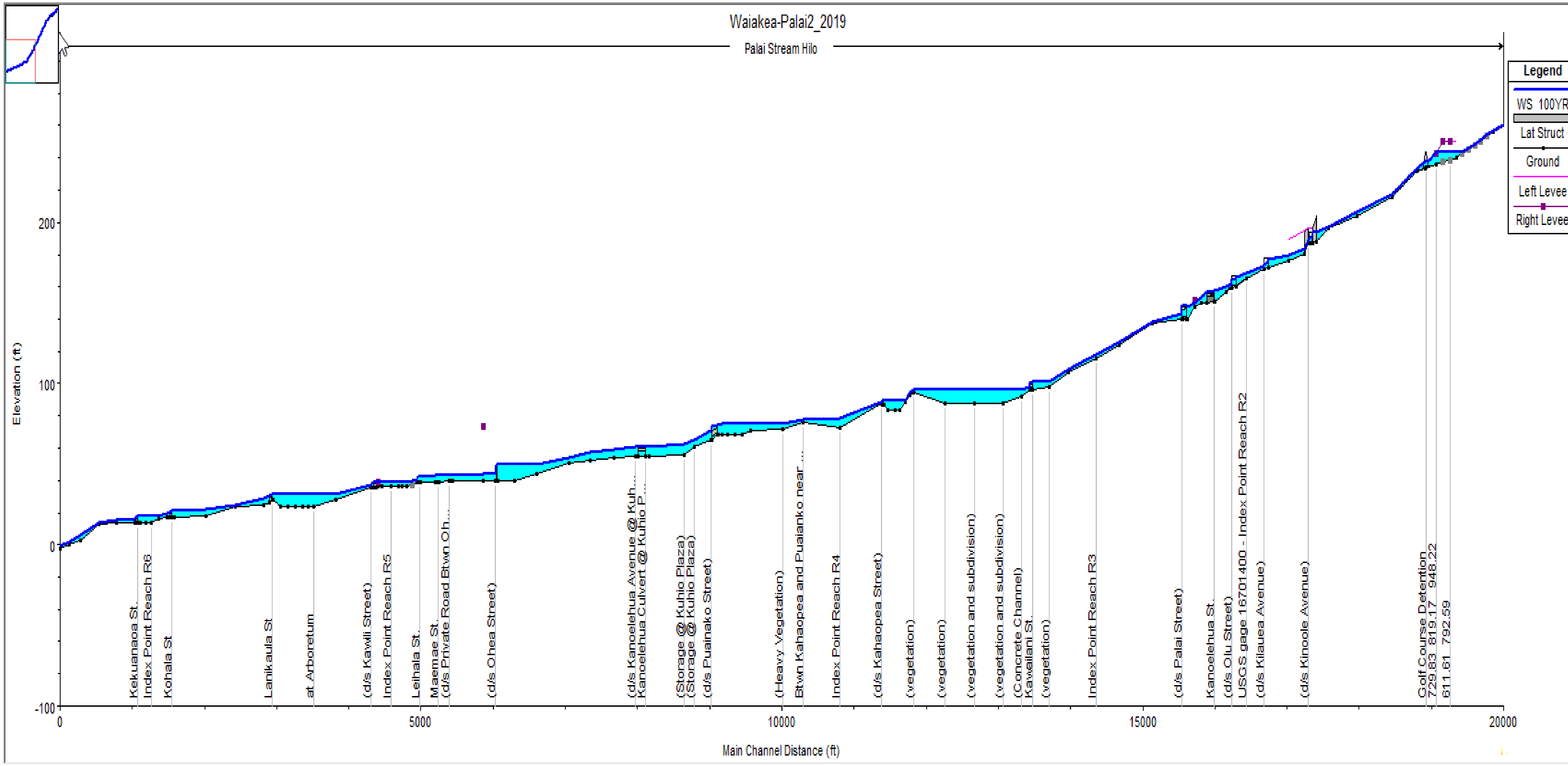


Figure 60A. With Project Palai Stream Water Surface Profiles (Reach Hilo)

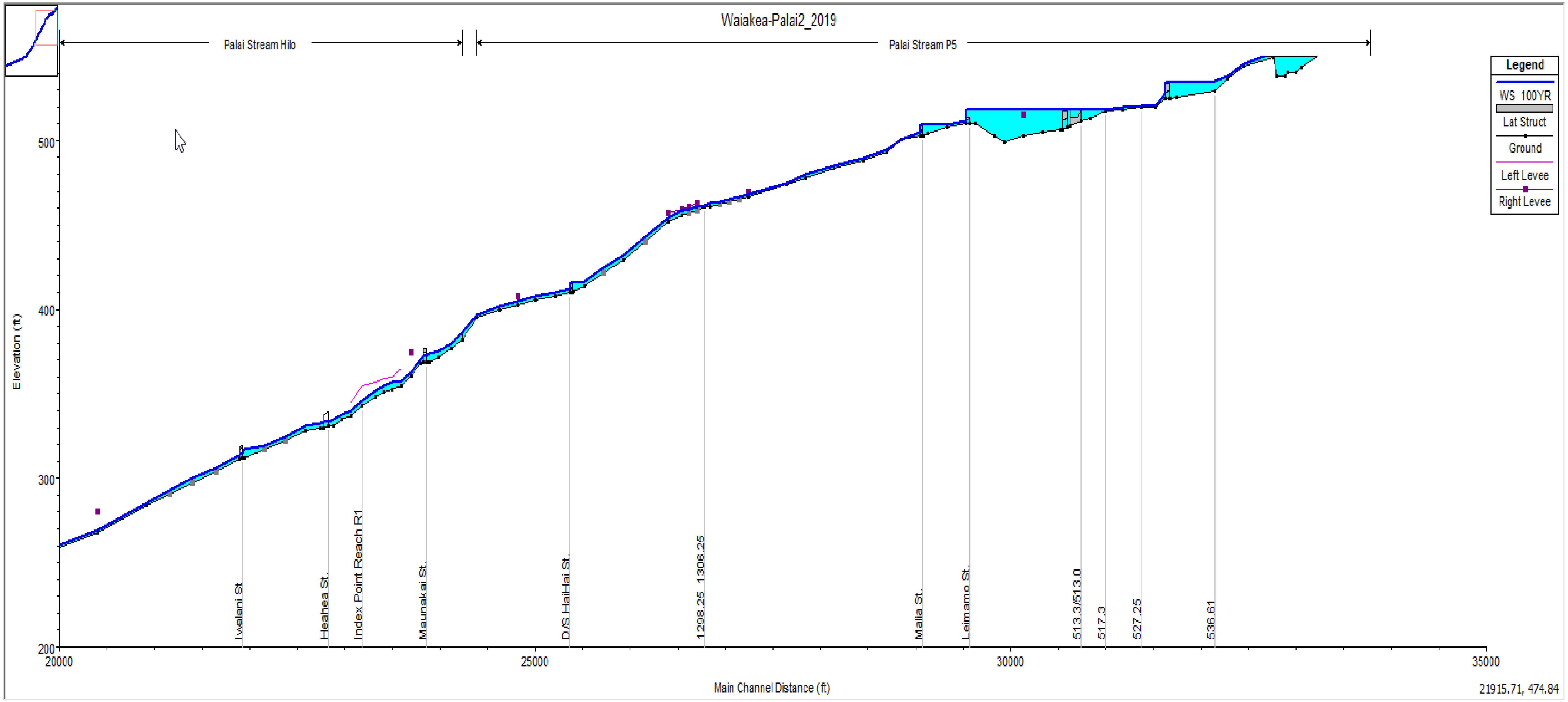


Figure 60B. With Project Palai Stream Water Surface Profiles (Reach Hilo and P5)

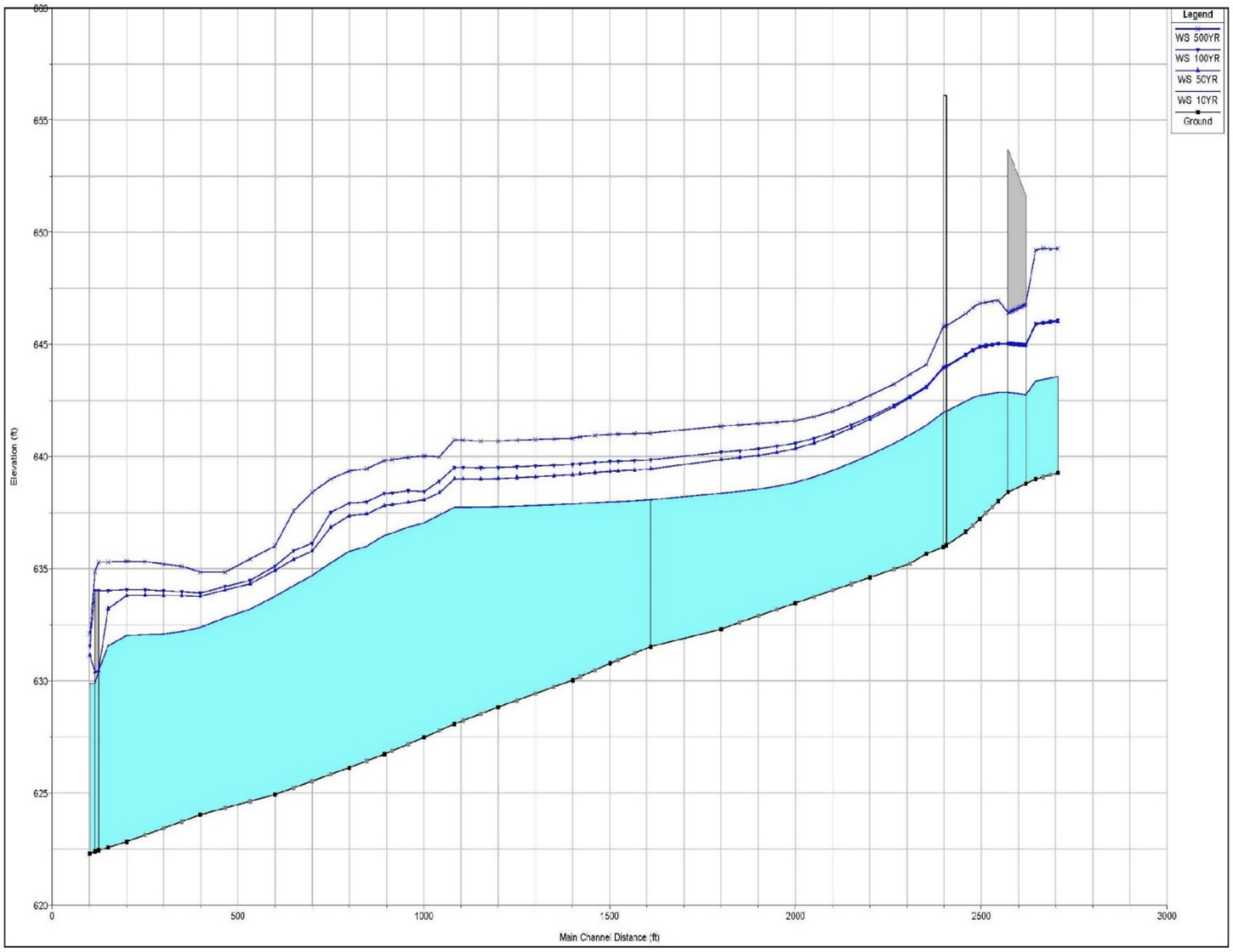


Figure 61. With Project Kupulau Ditch Water Surface Profile

8. SUMMARY

This appendix presented a discussion on creating a HEC-RAS model for Waiakea drainage basin area to simulate the flood problems in Waiakea Palai, Four Mile Streams and their tributary areas. Model results show the impact of flooding on the channel and overland areas of Waiakea and Palai Streams and their tributaries, from

Discharge estimates from eight frequency storms (50%, 20%, 10%, 4%, 2%, 1%, 0.5%, and 0.2% AEP) events were analyzed with HEC-RAS. Input discharge data for the model was obtained from the results of the Hydrologic Appendix B1 and field observations. Flood inundation boundary for 2% AEP was provided alone with 10%, 2%, 1% and 0.5% profiles. The results were compared with field observations during past flood events for reasonableness and accuracy. The model provides reasonable estimates of the flood magnitudes, depths and damages.

A number of flood risk management measures were created and analyzed with the HEC-RAS model. Then, combinations of measures (or alternatives) were analyzed to optimize outcome. The model was fine tuned to adjust the performance of the proposed measures to justify the preferred alternative in terms of technical feasibility and economic viability.

9. References

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