Waiakea-Palai Flood Risk Management, Hilo, Island of Hawaii, Hawaii

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Introduction

General.

This document presents the results of the economic analysis in support of the flood risk management project for the Waiakea-Palai FRM, Hilo, Island of Hawaii, Hawaii. The primary benefit associated with a flood risk management project is the reduction in inundation damages to structures and their contents. Reducing potential flood damages to structures and contents are the only categories of benefits analyzed in the economic justification for this project. They are unquestionably the most significant National Economic Development (NED) benefits in terms of monetary impacts and the economic justification of the recommended plan. However, these are not the only NED benefits that would be realized by implementing the recommended plan.

Additional economic impacts would undoubtedly include other NED benefits, such as reductions in flood damages to utilities, roadways, automobiles, landscaping, emergency relief costs, and reducing damages to other federal projects downstream. These other categories of benefits are difficult to forecast to a reasonably degree of accuracy and create problems when added to structure and content damages which have been computed to a higher level of reliability and account for uncertainty within key variables. Further, these secondary benefits altogether would likely make up no more than an additional 20 percent of the total structural and content damages and the project already demonstrates a strong benefit-cost ratio (BCR) without them. Most importantly, inclusion of these secondary benefits would not impact the plan selection since they tend to be closely correlated with reductions in flood damages to structures and contents, and they would be roughly the same for all the structural alternatives considered; thus, they would not change the ranking order of structural solutions considered, and contribute far less to nonstructural plans.

Economic benefits for reducing structure and content damages are calculated using hydrologic and economic data. The official Corps model, HEC-RAS calculated the water surface AEP profiles associated with the different probability events. The economic analysis utilizes FY20 price levels and a 2.75 percent discount rate. Net benefits and benefit-cost ratios (BCR) are provided for two project increments: the Kupulau Ditch Levee/Floodwall with Detention and the Hilo Municipal Golf Course Detention. The analyses were performed over a 50-year period of analysis from 2023 to 2073.

Project Area Description and Location. The Waiakea-Palai Flood Risk Management Project area is located in the Hilo Metropolitan area in the County of Hawaii, commonly referred to as the Big Island. Within Hawaii County are the North and South Hilo Districts. The City of Hilo and the project study area is in the South Hilo District. The majority of the structures in the study area are residential with a much smaller number of commercial and public buildings mixed in as shown in Table 1. About 1,300 of these 1,701 structures numbers are outside the 0.2 percent AEP floodplain but within the project area floodplain; thus, they were included in the structure database used in the analysis.

Table 1
Number of Structures in the Project Area

Residential	Commercial	Public	Total
1,582	88	31	1,701

Waiakea and Palai Streams are unlined in some locations throughout the study area, not very well defined and have inadequate capacity. Poorly defined channels provide inadequate capacity to transport flood waters. Stream flow is typically intermittent and flows in direct response to rain events. These two streams are susceptible to flash flooding events. Local storm events can produce flood conditions in a matter of hours. Significant rainfall events result in overland flow of water throughout the watershed flowing towards the streams, and the natural stream channels have limited capacity to transport flood waters. Water overtops the channel and floods downstream areas. During flood events, accumulation of woody debris and vegetation can cause blockages within the channel and at bridge locations. This has historically reduced the channel capacity to convey flows and exacerbated flooding.

Historical Damages. For as long as flood records have been kept, there has not been an actual flood in these watersheds of the magnitude included in the basin model developed herein. The record keeping on historical flooding in the area has been erratic and unreliable, especially in terms of damage estimates. However, it is known that the existing lined and unlined portions of Waiakea and Palai Streams within the project area are not able to adequately contain flood water flows, as evidenced by major flood damages that occurred in the project area in November 2008, February 2000, August 1994, March 1980, and February 1979. During the November 2000 flood, residents along Awapuhi Street were stranded by floodwaters and required rescue by firefighters. Flooding at the intersection of Kanoelehua Avenue and East Puainako Street caused damage to the Prince Kuhio Plaza. In February 2008, almost 11 inches of rain fell in a 24 hour period, resulting in approximately 150 homes being damaged by floodwaters rising up to 4 feet in depth in Hilo.

At the upstream end of the project area, Waiakea Stream contains a poorly defined channel, with a channel capacity of about 800 cfs which is equivalent to about a 50 percent AEP event. When the stream overflows floodwaters travel east to enter Kupulau Ditch. At the 1 percent Annual Exceedance Probability (AEP) flood, the stream velocity ranges from 10 to 15 ft/s. The channel bed is composed entirely of lava rock and the overbanks are highly vegetated. The high velocities dislodge rock and vegetation and transport them downstream.

Kupulau Ditch (see Figure 3) was built in 1971 to divert water from the Palai basin into Waiakea Stream in order to reduce flood problems. The ditch is about 3,500 ft long, has an average depth of 7 ft, and a bed slope of 0.006 ft/ft made up of lava rock. Kupulau Ditch receives the overflow from Waiakea Stream and quickly reaches its capacity. The ditch begins to spill over its right (east) bank at the 20 percent AEP event. The overflow begins to flood the New Hope

Church, which is located adjacent to the ditch; then, crosses Kupulau Road and flows overland in an eastward direction, flooding residential structures along HaiHai Street, and Ainalako Road.

Along Kupulau Road, there are a few locations where the natural topography and roadway elevation is very low. Flood flows in response to heavy rain events can cause Kupulau Ditch to overtop resulting in the flooding of homes and Kupulau Road, causing a safety risk for drivers and residents. When Kupulau Ditch reaches capacity and overtops, the flood waters cross Kupulau Road near Kawaiolu Place and proceeds overland along Haihai Street, eventually flowing into Palai Stream causing flooding to homes and roadways. Homes in this area were flooded in the 2000 and 2008 storms.

Upstream of the Kupulau Road Bridge, the natural topography of the stream bed is higher than the invert under the bridge. As a result, a hydraulic jump is induced during high flood events, causing flood water to overtop Kupulau Road Bridge causing a life safety risk and hazard to motorists. Flood waters also cause Kupulau Road to flood in low lying areas causing a hazard to motorists and road closure.

Downstream of Kawailani Street, Palai Stream floodwaters are conveyed mainly by overland flow. Stream channels are poorly defined with low-lying areas serving as pockets of storage areas. Intense urbanization in Hilo has resulted in many residential, commercial, and industrial structures built in close proximity to the stream.

Population and Life Safety. There are approximately 5,000 residents in the project area.[1] 2014 population for Hilo Hawaii, the State's second largest city, has been estimated at 45,158. Hawaii County experienced an increase of 30.6 percent over the 2000-2014 timeframe, the largest of any of the Hawaiian Islands. Population growth has been steady within the study area, but not as extraordinary as for the County. Within Hawaii County, the South Hilo District, which includes this study area, population increased 7.5 percent between 2000 and 2013.[2]

The annual growth rate in population for Hawaii County is expected to gradually decline from about 1.8 percent (2010-2015) to 1.3 percent (2035-2040). However, by 2040 nearly 100,000 more people are expected to be calling Hawaii County home, an increase of about one-third.[3]

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[1] This population estimate uses several inputs and sources: the number of single-family residential structures, the number of single-family residential structures, the number of multi-family residential structures, and the average persons per household for Hawaii County (Hawaii Data Book, 2013). The number of multi-family structures was multiplied by 20 to estimate the number of units within each structure. The average persons per household value is the five-year average from 2009 to 2013 developed by the U.S. Census Bureau. This average of 2.83 was multiplied by the number of single-family residential structures and by the number of component units within the multi-family structures. The sum of these products approximates the total population in the study area.

[2] Source: 2014 State of Hawaii Data Book; http://dbedt.hawaii.gov/economic/databook/2014.

Life safety within the floodplain of Waiakea and Palai Streams is a major problem. There are approximately 30,000 people residing within the greater Waiakea and Palai watersheds, about 2,300 of which live within the 0.2 percent AEP floodplain, and about that many people again live between the 0.2 percent AEP floodplain and the project area floodplain. Additionally, there are thousands more people temporarily occupying or traversing the watershed on a daily basis, including tourists, school children, workers and others. In addition to some of Hilo's busiest intersections, thoroughfares and shopping areas, the project area floodplain also contains about 100 businesses, several schools, a university and other critical infrastructure.

Economic and Engineering Inputs to the HEC-FDA Model

HEC-FDA Model Description. The Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) Version 1.4 Corps-certified model was used to calculate expected annual damages and benefits over the period of analysis. The economic and engineering inputs necessary for the model to calculate damages include structure inventory, content-to-structure value ratios, vehicles, first-floor elevations, depth-damage relationships, ground elevations, and stage-probability relationships.

The uncertainty surrounding each of the economic and engineering variables was also entered into the model. Either a normal probability distribution, with a mean value and a standard deviation, or a triangular probability distribution, with a most likely, a maximum and a minimum value, was entered into the model to quantify the uncertainty associated with the key economic variables. A normal probability distribution was entered into the model to quantify the uncertainty surrounding the ground elevations. The number of years that stages were recorded at a given gage was entered for each study area reach to quantify the hydrologic uncertainty or error surrounding the discharge and stage-probability relationships.

Development of Structure Inventory. Field surveys were conducted in 2012 to develop a structure inventory consisting of residential, commercial and public structures. The commercial structure category contains 11 non-residential occupancy types. Public contains one occupancy type and residential contains five. Table 2 includes the number of buildings by structure category that comprise the HEC-FDA structure file, and shows the average depreciated replacement value for each structure type.

Most of the data on the structures in the floodplain and their characteristics were obtained from on-site, field surveys performed by USACE economists, or through the County of Hawaii Real Property Tax Office, or a combination of the two. With the goal being to determine a reasonable estimate of the depreciated replacement cost for each structure in the inventory, economists in the field relied on Marshall and Swift Valuation Service software to compute a structural value estimate independent of the assessment by the tax office. Data was also taken from both sources on square footage, condition and age of the structures throughout the floodplain.

After collecting hundreds of the sample data representative of each neighborhood and comparing the two estimates (County tax assessed vs. Marshall and Swift) for each structure, it became apparent that patterns in the data were measurable and predictable. To account for the uncertainty surrounding the structure value, a standard deviation of 19 percent was computed and incorporated into the calculation of a hybrid estimate of the depreciated replacement value for each structure. Similar techniques were used to perform an update of all the structural values to bring them up to October 2014 price levels. The structure inventory was further price indexed to FY2020 price levels from 2014 using Hawaii based RS Means index factors.

Table 2
Number of Structures and Average Depreciated Replacement Value
by Occupancy Type
FY2020 Price Levels

Structure Category	Number	Avg. Depreciated Replacement Value
Single Family Residential 1-story	1,362	$142,000
Single Family Residential 2-story	101	$241,000
Single Family Residential Split	101	$188,000
Multi-Family Residential 1-story	30	$126,000
Multi-Family Residential 2-story	10	$2,637,000
Warehouse	35	$259,000
Church	10	$187,000
Convenience Store	2	$240,000
Commercial 2 story	1	$439,000
Office	29	$2,703,000
Retail Store	2	$22,253,000
Restaurant	3	$364,000
Garage	2	$405,000
Hospital	9	$973,000
Bank	1	$648,000
Public Building 1-story	3	$99,000

Future Development. USACE planning guidance for civil works projects (Department of the Army, 2000; ER 1105-2-100) requires that the planning process incorporate a future without-project scenario. The future without-project condition attempts to describe the Waiakea-Palai Streams watershed's future makeup if there is no Federal action taken to solve the flood risk problem. This forecast becomes the basis for evaluation of project alternatives. For the Waiakea-Palai flood risk management project, the base year is 2027. Thus, the 50-year forecast period starts at 2027 and ends in 2077.

Given the great deal of uncertainty, the future condition represents a best guess of conditions in the watershed over the 50-year planning horizon. The guidance states that the planning process accounts for such future conditions such as climate variability, sea-level rise, subsidence, seismic influences, geomorphological changes, and changes from development which can place demands on the project systems during their life-cycle. The most significant of these changes over the next 50 years will likely be changes in development patterns and sea-level rise (SLR).

Given the degree of uncertainty, projections were not made of the future residential and non-residential development to take place in the study area under without-project conditions. Most of the developable land within the Hilo floodplain under current zoning ordinances is already fully developed. With the nearly built-out status of the present watershed, new development will be almost entirely restricted to replacing old structures with new ones. It is highly unlikely that these redevelopment efforts will include any high-rise, residential towers in the foreseeable future. Similarly, commercial development is expected to follow suit. Exactly which buildings will be replaced and by what is impossible to say. Therefore, this study assumes that no significant changes will occur to the structure inventories or other assets on which damage categories are based, and that future conditions will be the same as present conditions for the purposes of calculating damages or costs. However, given the continued anticipated increase in Hawaii County population, it is very likely that the number of people potentially placed in harm's way from a flood in the Waiakea-Palai watershed, whether they are residents, workers, shoppers, tourists and motorists traveling through the floodplain, will increase over the 50-year planning horizon.

Another forecast requirements is to account for future hydrologic changes in the project evaluations, and sea level rise (SLR) can be a significant contributing factor in causing flood damages to increase over time. As sea-level rises over the coming decades, tidal and backwater impacts during periods of rainfall induced flooding will cause water surface elevations to rise slightly in the lower reaches of the floodplain, primarily Reaches R6 (Palai Stream) and W5 (Waiakea Stream). Given all the uncertainty surrounding the impacts of SLR, and the relatively small role in the total damage picture these two reaches play, the economic model does not attempt to capture any resulting increase in flood damages over time due to an upward shift in the stage-frequency relationship. This phenomenon is not expected to have any bearing on selecting one plan over another and would only impact a few of the many reaches.

First-Floor Elevations of Structures. The datum used in the analysis is the same datum used to determine the water surface profiles, and the source of ground elevations for this study is the same for H&H as economics. All GIS data was projected to a common projection, Hawaii State Plane, which uses the NAD1983 datum.

Basic elevation data for this study was obtained by the Honolulu District in 2005. Aerial topography and digitized mapping methods were used to derive contours at a 4 foot interval and spot elevations at a 0.1 foot accuracy. Supplemental contour data and spot elevations were obtained by the project sponsor, Hawaii County, and areas where gaps still existed were closed by using USGS 10 meter digital elevation models (DEM).

Using current aerial imagery and GIS software, structures were positioned and compared with building footprints obtained as part of the Honolulu District photogrammetry contract. Centroids of the building footprints were calculated inside the GIS software and the ground elevation at the centroid point was extracted from the elevation grid. Additional foundation heights to determine an estimate of first floor elevation were added to the structure database using a variety of methods, including actual building elevation certificates and field verification of elevations. County data was used to further refine the structure elevations by examining the data to estimate the information to determine whether the structures were build slab-on-grade or built up on piers. Finally, Google Earth was used to obtain images of structures in question to determine estimates of pier height to further refine first floor elevations.

A First Floor Elevation (FFE) Uncertainty formula was applied to calculate an uncertainty of 0.5 feet for all structures in the inventory. The formula, $\sqrt{(0.4^2 + 0.02^2)}$, was based on using equal weights for each of the types of ground surface elevation and structural survey data. For example, each of the three ways a structure was surveyed (elevation certificate, field survey, and Google Street View) all carry different levels of uncertainty. The standard deviation used in the FFE formula for each survey type was taken from the HEC-FDA User's manual, version 1.2.4. It was assumed Google Street view represented the accuracy of a hand level, elevation certificates represented an automatic level, and field surveys represented a conventional level. Equal weight was assigned between each survey type due to the uncertain amount of structures surveyed using each method.

Depth-Damage Relationships. The generic depth-damage relationships for one-story structures with no basement and for two or more story structures with no basement from EGM, 01-03, dated 4 December 2000, were used for single-family residential structures and for multi-family residential structures respectively. These curves indicate the percentage of the total structure value and their contents that would be damaged at various depths of flooding. The non-residential depth-damage relationships were developed based on curves from the Jefferson-Orleans, Donaldsonville to the Gulf, and Morganza to the Gulf evaluations. New Orleans short duration fresh water curves were used due to similar occupancies (retail, warehouses, and public buildings) and similar sources of flooding (freshwater inundation in a tropical climate). More information about the data source can be found in the CSVR discussion.

Damage percentages were determined for each foot increment from -8 feet to -1 foot, then half foot increments between -1 and 2 feet, and one foot increments between 2 feet to 15 feet above the first floor elevation.

A normal distribution was used to represent the uncertainty surrounding the residential structures and their contents. Uncertainty surrounding the commercial and public buildings and their contents is not included. Figure 1 shows the residential and non-residential depth-damage relationships developed for structures used for damage calculations by the HEC-FDA computer program.

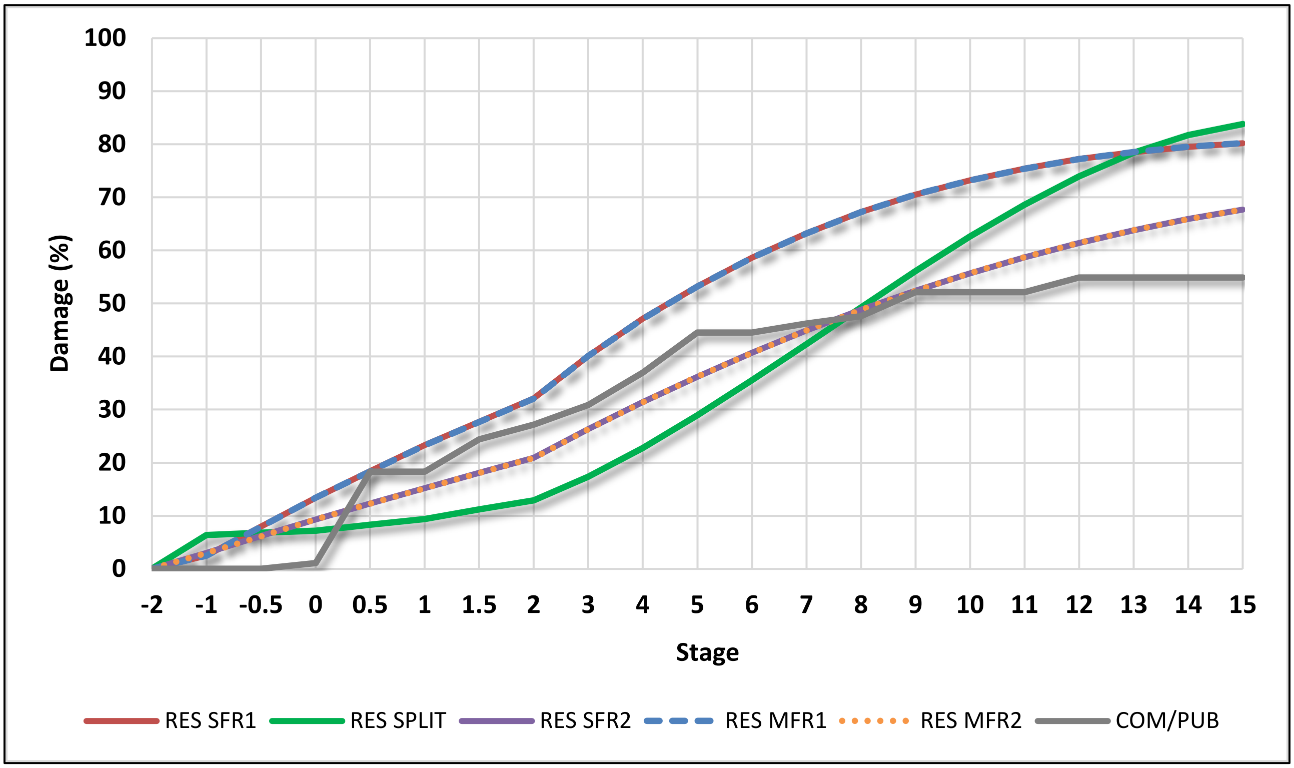

Figure 1. Waiakea-Palai Depth-Damage Relationships

Residential and Non-Residential Content-to-Structure Value Ratios. Content-to-Structure Value Ratios (CSVRs) were taken from two different sources. The single-family residential CSVR is based on the generic depth damage curves. The CSVR for the non-residential structures were developed based on the on-site interviews conducted as part of the Jefferson-Orleans, Donaldsonville to the Gulf, and Morganza to the Gulf evaluations. These interviews were conducted with the owners of a sample of structures from each of the three residential content categories and each of the eight non-residential content categories from each of the three evaluation areas. Thus, a total of 96 residential structures and 210 non-residential structures were used to determine the CSVRs for each of the residential and non-residential categories.

Since only a limited number of property owners participated in the field surveys and the participants were not randomly selected, statistical bootstrapping was performed to address the potential sampling error in estimating the mean and standard deviation of the CSVR values. Statistical bootstrapping is a method that uses re-sampling with replacement to improve the estimate of a population statistic when the sample size is insufficient for straightforward statistical inference. The bootstrapping method has the effect of increasing the sample size. Thus, bootstrapping provides a way to account for the distortions caused by the specific sample that may not be fully representative of the population.

As shown in Table 3, a CSVR was computed for each residential and non-residential structure in the sample based on the total depreciated content value developed from the surveys. The model used a normal probability density function to describe the uncertainty surrounding the CSVR for each content category. An average CSVR and standard deviation for each of the five residential structure categories and eleven commercial structure classifications was calculated as the average of the individual structure CSVRs.

Table 3
Content-to-Structure Value Ratios (CSVR)
and Standard Deviations (SD)
For Each Structure Category

Structure Category	
Residential	CSVR
Single Family Residential 1-story	100
Single Family Residential 2-story	100
Single Family Residential Split	100
Multi-Family Residential 1-story	100
Multi-Family Residential 2-story	100
Non-Residential	CSVR, SD
Warehouse	207, 325
Church	76, 52
Convenience Store	134, 78
Commercial 2 story	119, 105
Office	54, 54
Retail Store	119, 105
Restaurant	170, 293
Garage	55, 80
Hospital	54, 54
Bank	54, 54
Public Building 1-story	55, 80

Note: The generic depth-damage curves were
used for single-family residential categories

Discharge and Stage-Probability Relationships and Levee Features. Discharge and Stage-probability relationships were provided for the following conditions for 41 reaches (see Figure 2) within the study area:

- Without-project conditions
- Kupulau Ditch Levee/Floodwall with Detention (0.02, 0.01, 0.005 annual exceedance probability (AEP)
- Ainalako Diversion (0.01 AEP)
- Hilo Municipal Golf Course (0.01 AEP)
- The Combination Plan which includes the three previous measures at the following levels of risk reduction:
    - Kupulau Ditch Levee/Floodwall with Detention (0.02 AEP)
    - Ainalako Diversion (0.01 AEP)
    - Hilo Municipal Golf Course (0.01 AEP)

Discharge and water surface AEP profiles were based on the following eight Annual Exceedance Probability (AEP) events: 0.5 (2-year), 0.2 (5-year), 0.1 (10-year), 0.04 (25-year), 0.02 (50-year), 0.01 (100-year), 0.005 (200-year), and 0.002 (500-year).

Discharge and stage-probability relationships were developed for 2013 conditions. Top of levee elevations were incorporated for the Kupulau Ditch Levee/Floodwall with Detention measure at the 0.02 ACE (4.3 feet levee height), 0.01 ACE (5.7 feet levee height) and the 0.005 ACE (6.7 feet levee height) to calculate damages and benefits. The combination plan, however, includes only the 0.02 ACE (50-year) Kupulau Ditch Levee/Floodwall with Detention measure with the 0.01 ACE (100-year) Ainalako Diversion and Hilo Municipal Golf Course measures.

A 25-year equivalent record length was used to quantify the uncertainty surrounding the discharge-probability relationships for each study area reach. The record length was determined by the hydraulic engineer and is based on the amount of historical gage data available in the basin. Based on this equivalent record length, the HEC-FDA model calculated the confidence limits surrounding the discharge-probability functions. Uncertainty surrounding the stage-discharge relationship was calculated using a normal distribution. Unique standard deviation values by reach are based on sensitivity analysis using multiple HEC-RAS “N values”. The standard deviation for stage was developed by varying the Manning’s "n" value by +/- 20 percent and running the profiles in the HEC-FDA model. The standard deviations take into account backwater effects, variations in soil makeup, absorption rates and other sources of water loss such as volcanic geotechnical conditions.

Figure 2. Study Area Damage Reaches

National Economic Development (NED) Flood Damage and Benefit Calculations

HEC-FDA Model Calculations. The HEC-FDA model was utilized to evaluate flood damages using risk-based analysis. Damages were reported at the index location for each of the forty-one reaches for which engineering data was available. A range of possible values, with a maximum and a minimum value for each economic variable (first-floor elevation, structure and content values, and depth-damage relationships), was entered into the HEC-FDA model to calculate the uncertainty or error surrounding the elevation-damage, or stage-damage, relationships. The model also used the number of years that stages were recorded at a given gage to determine the hydrologic uncertainty surrounding the stage-probability relationships.

The possible occurrences of each variable were derived through the use of Monte Carlo simulation, which used randomly selected numbers to simulate the values of the selected variables from within the established ranges and distributions. For each variable, a sampling technique was used to select from within the range of possible values. With each sample, or iteration, a different value was selected. The number of iterations performed affects the simulation execution time and the quality and accuracy of the results. This process was conducted simultaneously for each economic and hydrologic variable. The resulting mean value and probability distributions formed a comprehensive picture of all possible outcomes.

Without Project Expected Annual Damages. The model used Monte Carlo simulations to sample from the stage-probability curve with uncertainty. For each of the iterations within the simulation, stages were simultaneously selected for the entire range of probability events. The sum of all damage values divided by the number of iterations run by the model yielded the expected value, or mean damage value, with confidence bands for each probability event. The probability-damage relationships are integrated by weighting the damages corresponding to each magnitude of flooding (stage) by the percentage chance of exceedance (probability). From these weighted damages, the model determined the expected annual damages (EAD) with confidence bands (uncertainty). The FY2020 price levels are used in HEC-FDA model to calculate the damages and benefits. The without-project damages by probability event are displayed by damage category in Table 4, and the number of structures receiving damage is displayed by damage category in Table 5.

Table 4
Damages by Probability Event
Without-Project Condition
($1,000s)

Annual Exceedance Probability Event (AEP)	Residential	Commercial	Public	Total
0.5 (2 yr)	1,014	-	-	1,014
0.20 (5 yr)	4,388	234	-	4,622
0.10 (10 yr)	6,659	2,529	-	9,188
0.04 (25 yr)	12,199	3,183	-	15,382
0.02 (50 yr)	15,130	3,476	-	18,606
0.01 (100 yr)	18,329	3,791	-	22,120
0.005 (200 yr)	23,264	4,821	465	28,550
0.002 (500 yr)	28,090	6,653	593	35,336

Table 5
Structures Damaged by Probability Event
Without-Project Condition

Annual Exceedance Probability Event (AEP)	Residential	Commercial	Public	Total
0.5 (2 yr)	15	0	0	15
0.20 (5 yr)	53	3	0	56
0.10 (10 yr)	90	6	0	96
0.04 (25 yr)	160	7	0	167
0.02 (50 yr)	196	7	0	203
0.01 (100 yr)	236	8	0	244
0.005 (200 yr)	282	11	21	314
0.002 (500 yr)	344	19	22	385

Project Alternatives

An array of alternatives was evaluated and compared based on several decision-making criteria that were used to evaluate the economic feasibility, environmental effectiveness and flood protection capability of each alternative. The alternatives were screened during the preliminary design of the project components. The final array of alternatives is summarized below:

No Action Plan

The No-Action Alternative is synonymous with no Federal Action. This alternative is analyzed as the future without-project conditions for comparison with the action alternatives. The No Action Alternative would result in continued flood risk along Waiakea and Palai Streams.

Kupulau Ditch Levee/Floodwall with Detention

This alternative includes 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 (located east of the confluence of Kupulau Ditch and Waiakea Stream). Impounding of the runoff would be accomplished by constructing a series of three levees and one floodwall to enclose the landscape by utilizing the natural topography of the area.

Hilo Municipal Golf Course Detention

This alternative includes construction of a detention basin in the Hilo Municipal Golf Course to attenuate flow and reduce damage to properties in the downstream reaches of Palai Stream. A 21 acre-foot detention pond would be constructed at the Hilo Municipal Golf Course to capture flood flows with an outlet structure designed to release flow to minimize flood damage to downstream property.

Ainalako Diversion

The main component of this alternative is the construction of a diversion structure to divert excess flows into Four Mile Creek. This diversion structure is located just downstream of Ainalako Road 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. This alternative was originally considered as a third component of the TSP until public meetings and discussions with local stakeholders

Identifying the NED Plan and TSP. The three action alternatives can be implemented individually or combined with each other. They are not dependent on each other and are not mutually exclusive. As such, evaluation and comparison of the final array of alternatives will include various combinations of these alternatives (e.g., Kupulau Ditch plus Golf Course Detention) to identify the optimized plan that reasonably maximizes net benefits. Table 6 shows the possible combinations that each of the alternatives could have formed.

Table 6
Net Benefits of Possible Combinations ($1,000s)
FY 2020 Price Level
FY 2020 Federal Discount Rate 2.75%

Project Alternatives - Possible Combinations	Expected Annual Benefits	Expected Annual Cost	Net Benefits	Benefit-to-Cost Ratio
Kupulau Ditch (2% AEP Plan)	$1,953	$446	$1,508	4.4
Ainalako Diversion	$358	$132	$226	2.7
Golf Course Detention	$286	$203	$83	1.4
Kupulau Ditch + Ainalako Diversion	$2,312	$578	$1,734	4.0
Kupulau Ditch + Golf Course Detention	$2,239	$649	$1,591	3.5
Ainalako Diversion + Golf Course Detention	$645	$336	$309	1.9
Kupulau Ditch + Ainalako Diversion + Golf Course Detention	$2,598	$781	$1,880	3.3

The alternative with the highest net benefits from Table 6 is the combination plan that includes Kupulau Ditch, Ainalako Diversion, and the Golf Course Detention. This table helps show the screening results of measures that became the TSP, which maximizes annualized net benefits at $1.8 million. The breakdown of costs and benefits for each of the three alternatives and the combination plan (TSP) are found in Table 7. Figure 3 shows the spatial locations of each of the three measures that make up the combination plan alternative.

Table 7
Screening Results Using Incremental Costs of Measures ($1,000s)
FY 2020 Federal Discount Rate 2.75%

	Kupulau Ditch Levee/ Floodwall w/ Detention	Ainalako Diversion	Re-Configured Golf Course Detention	TSP/ NED Plan
Plans & Specs	$1,492	$556	$593	$2,322
Construction Management	$711	$264	$281	$1,105
Lands	$458	$129	$501	$896
Construction Contract	$4,855	$1,800	$1,925	$7,498
Total First Cost	$7,516	$2,749	$3,300	$11,821
Interest During Construction	$275	$80	$80	$514
Total Investment	$7,791	$2,829	$3,380	$12,335
Equivalent Annual Cost	$296	$107	$128	$468
Annual O&M	$150	$25	$75	$250
Expected Annual Cost (EAC)	$446	$132	$203	$718
Expected Annual Benefits (EAB)	$1,953	$358	$286	$2,598
Incremental Net Benefits	$1,508	$226	$83	$1,880
Inc. Benefit/Cost Ratio	4.4	2.7	1.4	3.6

* The interest during construction for the TSP is spread over a longer period than that of its individual measures; therefore, these columns are not additive.

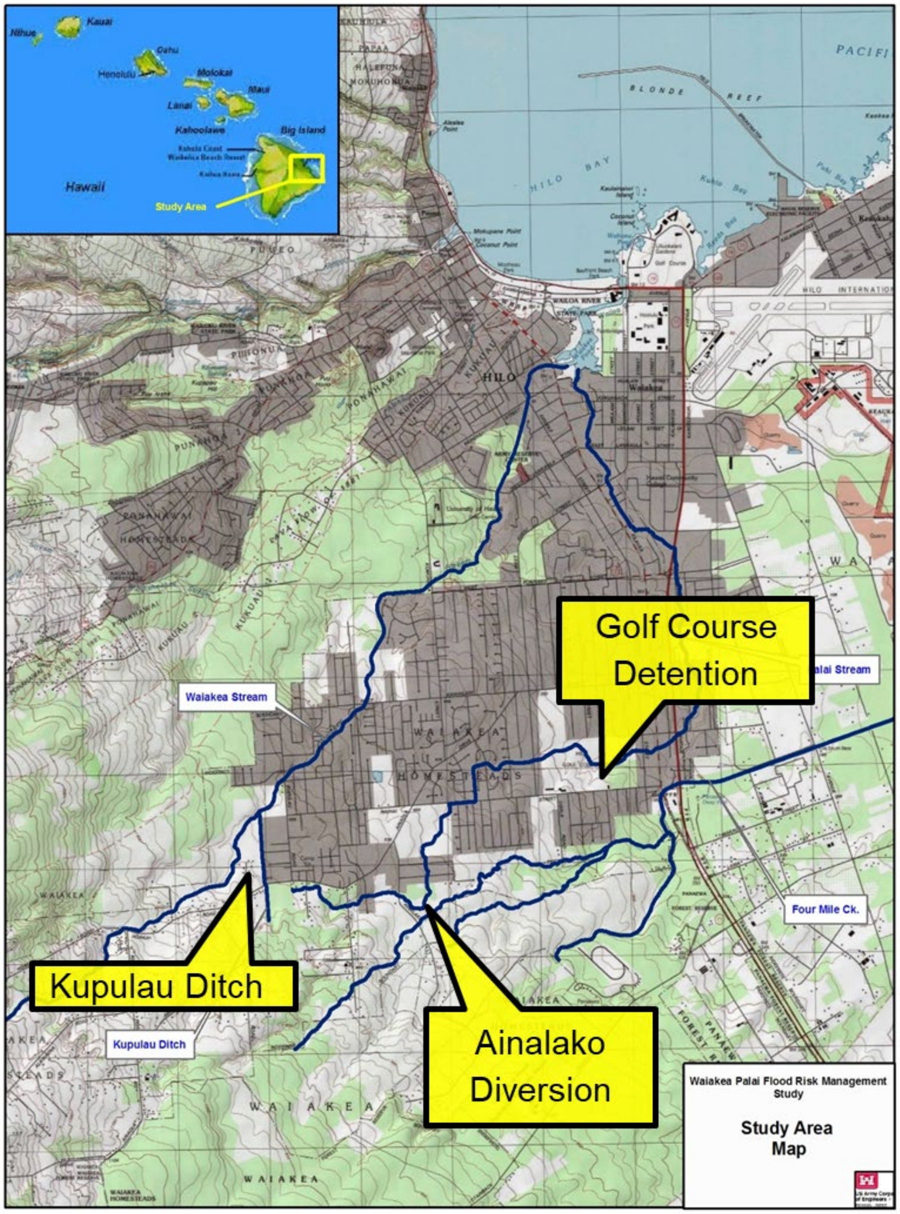

Figure 3. Location of Project Measures

Project Benefits. Table 8 shows a summary of net benefits for the final array of alternatives, that includes the combination plan that was determined to be the TSP and alternative that maximizes net benefits. The Kupulau Ditch measure is the costliest measure at $7.5 million and expected annual cost (EAC) of $446,000 but it also yields the highest benefit cost ratio (BCR) of 4.4. Incrementally, Ainalako Diversion, with an EAC of $132,000, has a BCR of 2.7, and produces net benefits of $226,000. The Golf Course Detention measure has a total cost of $3.3M, and $203,000 expected annual cost, and produces the least amount of expected annual benefits of $83,000. While all three measures could be added as pairs as shown previously in Table 6, the net benefits are maximized when combined together.

Table 8
Net Benefits ($1,000s)
FY 2020 Price Level
FY 2020 Federal Discount Rate 2.75%

Project Alternatives	Expected Annual Benefits	Expected Annual Cost	Net Benefits	Benefit-to-Cost Ratio
Kupulau Ditch L/FW w/ Detention - 2% ACE Plan	$1,953	$446	$1,508	4.4
Ainalako Diversion - 1% ACE Plan	$358	$132	$226	2.7
Reconfigured Golf Course Detention - 1% ACE Plan	$286	$203	$83	1.4
Combination Plan (TSP)	$2,598	$718	$1,880	3.6

These three measures, collectively referred to as the combination plan, reduce expected annual damages in the overall study area by approximately 50 percent. Other individual structural measures and combinations of measures were investigated, but they were found to be incrementally infeasible producing no net benefits or captured the same benefits as the three measures comprising the combination plan, only they did so less efficiently.

Project Costs. The schedule of project costs begin in the year 2021 and end in August 2023. The remaining cost estimates were provided for the authorized project in FY 2020 price levels. The initial construction cost (first costs), along with the schedule of expenditures, were used to determine the interest during construction. Interest during construction was calculated based on two years of construction for the Kupulau Ditch, one year of construction for the Ainalako Diversion and one year of construction for the Reconfigured Golf Course Detention. The combination plan assumed the three measures were separate and independent and therefore could be fully constructed in two years.

The FY 2020 Federal discount rate of 2.75 percent was used to compound the costs to the base year and then amortize the costs over the 50-year period of analysis, as previously shown in Table 7 and Table 8.

Net Benefit Analysis

Calculation of Net Benefits. The expected annual benefits attributable to the project alternative are calculated using the FY20 Federal discount rate of 2.75 percent. The base year for this conversion is the year 2021 for the Tentatively Selected Plan (TSP). The expected annual benefits were then compared to the average annual costs to develop a benefit cost ratio for the alternative. The net benefits for the alternative were calculated by subtracting the average annual costs from the expected annual benefits. The net benefits were used to determine the economic justification of the project alternative.

Table 8 summarized the expected annual damages and benefits, total annual costs, benefit cost ratio, and expected annual net benefits for each component of the TSP. Net benefits for the TSP of $1,880,000 were calculated by subtracting the average annual costs from the expected annual benefits. The benefits and costs are displayed FY 2020 price levels. At the prescribed FY 2020 discount rate of 2.75 percent, the benefit cost ratio for the TSP is 3.6.

Plan Adjustments – Recommended Plan

The TSP presented in Table 8 has been modified following agency, technical, and public review of the report as well as completion of feasibility-level design refinements including site visits. Based on subsequent coordination efforts between the Corps, the non-Federal sponsor, and local landowners in the study area, the alternative including Kupulau Ditch Levee/Floodwall with Detention and Hilo Golf Course Detention is presented as the recommended plan (Table 9). This plan does not include the Ainalako Diversion feature. Based on public input and site visits conducted by the study team, it was determined that the Ainalako Diversion would require substantial design modifications and additional real estate requirements in order to be implemented successfully to reduce flood risk, avoid transferring of flood risk to Four Mile Creek, and minimize impacts of induced flooding. Ultimately, the cost to redesign and construct the Ainalako Diversion feature would reduce overall cost effectiveness for this feature and the NED plan.

Per ER 1105-2-100, a categorical exemption to the NED plan may be pursued. In this instance, the without-project residual risk is not unreasonably high and the alternative that does not include the Ainalako Diversion still has greater net benefits than smaller-scale plans (e.g., implementation of Kupulau Ditch only). While less comprehensive than the original recommended plan, this alternative is still considered complete, acceptable, efficient, and effective, and it reduces flood risk in the study area. At the FY 2020 discount rate of 2.75 percent, the total project first cost of the Recommended Plan is $10.8 million, and the benefit cost ratio is 3.5.

Table 9
Net Benefits ($1,000s)
FY 2020 Price Level
FY 2020 Federal Discount Rate 2.75%

Project Alternatives	Expected Annual Benefits	Expected Annual Cost	Net Benefits	Benefit-to-Cost Ratio
Kupulau Ditch L/FW w/ Detention - 2% ACE Plan	$1,953	$446	$1,508	4.4
Reconfigured Golf Course Detention - 1% ACE Plan	$286	$203	$83	1.4
Revised Combination Plan (TSP)	$2,239	$649	$1,591	3.5

TSP Optimization

Net benefits for the Kupulau Ditch alternative are reasonably maximized at the 4.3-foot average height (roughly equivalent to a 2 percent AEP flood). The average height of 4.3 feet includes about +2.5 feet of height to achieve a conditional non-exceedance probability (CNP) of at least 95%. Net benefits decline about 5 percent as the height of the wall goes to an average height of 5.7 feet (roughly equivalent to a 1 percent AEP flood), and further declines with a 6.7-foot average height (roughly equivalent to a 0.5 percent AEP flood), optimizations for the 1 percent and 0.5 percent designs also included the necessary additional height to achieve a CNP of at least 95 percent.

The HEC-FDA model was also used to help inform if either of the two measures within the TSP could be designed to a reduced level of protection to ensure that the selected TSP was optimized. This analysis exclusively looked at economic damages by stage for both alternatives and did not receive tailored cost estimates to determine the maximization of net benefits, as was explained in the previous paragraph. The results of the analysis are found in Figure 4 and show vertical lines where both alternatives are limited in its damage reduction. The data for Figure 4 was pulled from the reach that the alternative reduced the most damage in and is represented as total damage, not average annual damages. Table 4 shows that damages reduce for Kupulau Ditch by 33% by moving from a 2% AEP to a 4% AEP design level of protection. Similarly for the Golf Course Detention, damages reduced fall by 18% by moving from a 1% AEP to a 2% AEP design level of protection. This analysis alone does not fully inform the lower bracketing of alternatives since net benefits cannot be calculated without originating new cost estimates for the reduced LOP alternatives.

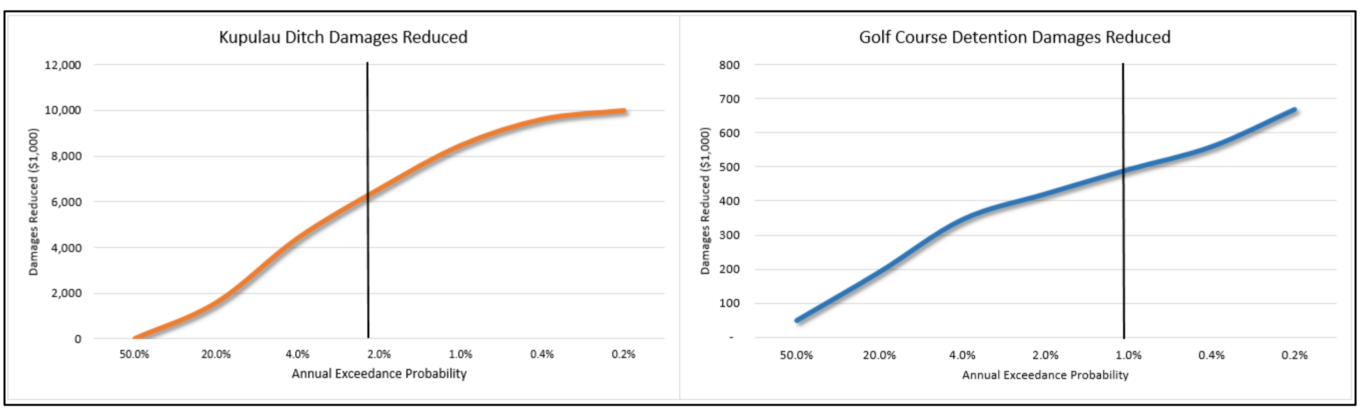

Figure 4. Stage-Damage Functions for TSP Alternatives

With its wall height set at an average of 4.3 feet, the size of the detention site has been designed to take full advantage of the existing topographic constraints and capture as much flood reduction as practical at this site while working in concert with the two other properly sized measures. To construct the levee/floodwall any higher would have little to no impact on the optimal sizes of the reconfigured golf course detention, and would not be as good of return on the investment and would cost more than would be gained in flood reduction benefits.

Residual Risk Metrics for Flood Risk Management Reporting

Residual Risk. Residual risk is the risk remaining after implementation of a plan; that is, it is the difference in damages between the with- and without-project conditions. Depending on the current conditions and the changes created by the alternative plan, inundation at a reach usually starts to occur at different AEPs. These changes in AEPs are correlated to structure and content dollar damages. In the case of the Waiakea-Palai project, the residual risk is computed as the remaining dollar damages to commercial, public, and residential structures and contents after implementing the TSP/NED Plan.

According to Table 10, there are residual expected annual damages of approximately $2.5 million following the implementation of the TSP. The largest portion of these residual damages come from Palai Stream, but Waiakea Stream has significant residual damage as well since the Kupulau Ditch improvement is the only one of the TSP measures that reduces the risk of flooding to properties along Waiakea. Table 10 also shows that after incorporating the TSP, there will be approximately 53% of existing condition damages that remain as residual damages.

Table 10
Residual Damages ($1,000s)
FY 2020 Price Level
FY 2020 Federal Discount Rate 2.75%

Study Area Reach	Existing Condition Damages	Damage Reduced		Residual Damages
		Kupulau Ditch - 2% AEP Plan	Golf Course Detention - 1% AEP Plan	
4 Mile Creek	91	-	-	91
Ainolako	173	111	-	62
Debris	25	-	-	25
HaiHai	128	71	-	57
Kupulau	816	816	-	-
Palai	2,785	709	286	1,790
Puhau	5	5	-	-
Waiakea	715	240	-	475
Total	4,739	1,953	286	2,500

Project Effectiveness. The TSP reduces without-project damages (no Federal project) by approximately 47 percent. Table 11 shows that there is a greater than 75 percent chance that expected annual benefits for the combination plan will exceed $1.6 million. Compared with the current expected annual cost estimate of $649K for the TSP, this means there is a greater than 75 percent change that the benefit to cost ratio for the TSP exceeds 2.0.

Table 11
EAD Probability Distribution ($1,000s)
FY 2020 Price Level
FY 2020 Federal Discount Rate 2.75%

Project Alternatives	Expected Annual Benefits	Probability Damage Reduced Exceeds Indicated Values		
		75%	50%	25%
Kupulau Ditch - 2% ACE Plan	$1,953	1,236	1,917	2,699
Reconfigured Golf Course Detention - 1% ACE Plan	$286	173	269	405
Revised Combination Plan (TSP)	$2,239	1,409	2,186	3,104

Project Performance. How a project performs can be described three different ways within a risk-informed decision process that includes Mean Annual Exceedance Probability (AEP), Long-Term Exceedance Probability (LTEP), and Conditional Non-Exceedance Probability by Frequency (CNP). Table 12 and Table 13 shows similar conclusions to Table 10, that the TSP does not reduce significant flood risk for 4 Mile Creek, Ainolako, Debris, and Puhau. As it relates to Kupulau, the TSP reduces flood risk to having a 100% chance of containing the 1% AEP flood event, despite the project being designed for a 2% AEP event. The 4.3 foot average height includes an additional 2.5 feet in order to achieve a (CNP) of at least 95 percent. Therefore, with the additional height, the Kupulau Ditch contains the 1% and even the .2% AEP flood event. For Waiakea, the TSP reduces flood risk to having a 65% chance of containing the 1% AEP flood event.

Table 12
Existing Condition Project Performance By Study Area
FY 2020 Price Level
FY 2020 Federal Discount Rate 2.75%

Study Area Reach	Mean AEP	Long-Term Exceedance Probability			Conditional Non-Exceedance Probability by Frequency					
		10	30	50	0.10	0.04	0.02	0.01	0.004	0.002
4 Mile Creek	0.999	100%	100%	100%	0%	0%	0%	0%	0%	0%
Ainolako	0.579	100%	100%	100%	0%	0%	0%	0%	0%	0%
Debris	0.999	100%	100%	100%	0%	0%	0%	0%	0%	0%
HaiHai	0.999	100%	100%	100%	0%	0%	0%	0%	0%	0%
Kupulau	0.501	100%	100%	100%	0%	0%	0%	0%	0%	0%
Palai	0.948	100%	100%	100%	0%	0%	0%	0%	0%	0%
Puhau	0.013	15%	39%	56%	100%	88%	58%	42%	36%	35%

Waiakea	0.035	43%	72%	86%	81%	53%	36%	24%	19%	19%

Table 13
TSP Project Performance By Study Area
FY 2020 Price Level
FY 2020 Federal Discount Rate 2.75%

Study Area Reach	Mean AEP	Long-Term Exceedance Probability			Conditional Non-Exceedance Probability by Frequency					
		10	30	50	0.10	0.04	0.02	0.01	0.004	0.002
4 Mile Creek	0.999	100%	100%	100%	0%	0%	0%	0%	0%	0%
Ainolako	0.312	98%	100%	100%	0%	0%	0%	0%	0%	0%
Debris	0.999	100%	100%	100%	0%	0%	0%	0%	0%	0%
HaiHai	0.999	100%	100%	100%	0%	0%	0%	0%	0%	0%
Kupulau	0.000	0%	0%	0%	100%	100%	100%	100%	100%	100%
Palai	0.058	48%	82%	93%	75%	41%	27%	20%	8%	4%
Puhau	0.000	0%	0%	0%	100%	100%	100%	100%	100%	100%
Waiakea	0.004	5%	14%	21%	100%	100%	90%	65%	47%	41%