WAIAKEA-PALAI STREAMS
Hilo, Island of Hawaii, Hawaii

CONTINUING AUTHORITIES PROGRAM SECTION 205
FLOOD RISK MANAGEMENT

Appendix B-1: Hydrology

MAY 2020

US Army Corps of Engineers
Honolulu District

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APPENDIX B2 - HYDROLOGY ANALYSIS

WAIAKEA-PALAI FLOOD RISK MANAGEMENT PROJECT
HILO, HAWAII

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1.0 INTRODUCTION

1.1 Purpose and Scope. The purpose and scope of this appendix is to document the a hydrologic engineering analysis used to determine discharge-frequency relationships at key points for Waiakea and Palai Streams, and Four Mile Creek. Hydrologic analysis was originally done separately for Waiakea Stream and for Palai Stream and Four Mile Creek prior to the combination of these continuing authorities program studies under the current continuing authorities program study. As such, the hydrologic analysis for Waiakea Stream was originally completed in 2006 and that for Palai Stream and Four Mile Creek in 2004.

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 Project Location. 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. 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 (Figure 1). Palai Stream and Four Mile Creek originate down slope of the broad saddle formed between the Mauna Kea (elevation 13,796 feet) and Mauna Loa volcanic masses and flows thru the City of Hilo. The other volcanic masses on the island are the Kohala Mountains, Hualalai Mountains, and Kilauea Crater. Mauna Loa and Kilauea Crater located in the southern half of the island are the only remaining active volcanoes on the island. See Figure 1, Location Map.

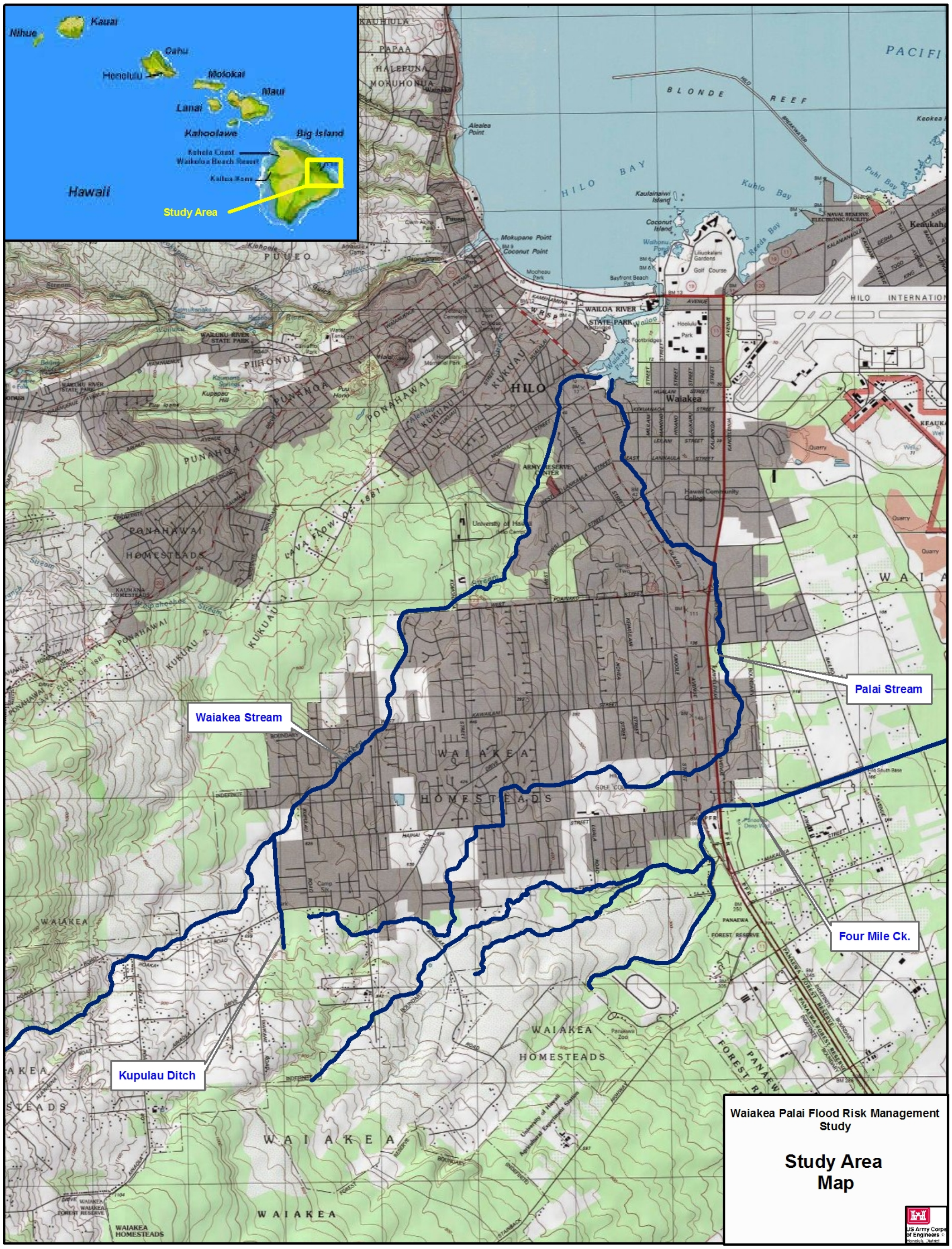


Figure 1. Study Area/Location Map

1.4 Study Area Description.

1.4.1 Basin Description, Topography, Vegetation, and Land Use. Waiakea Stream, Palai Stream, and Four Mile Creek are three of the five tributaries within the principal Wailoa River system, which drains a total of about 160 square miles. The other tributaries are Kawili, and Alenaio Streams.

The Waiakea Stream drainage basin is linear in shape, approximately 25 miles in length and not more than 2 miles wide with an area of about 35.6 square miles, measured upstream from USGS gage station 16701300 (Figure 2a). The thin soil layer over the volcanic subsurface erodes quickly with fast moving water. Hence, the drainage path keeps changing as new paths expose with erosion. In particular, the drainage pattern in the upper watershed keeps evolving with time and stream alignments are not well defined as a result. The drainage area begins at about elevation 8,600 feet and ends at 80 feet above mean sea level for an approximate channel slope of about 0.06 ft/ft. Due to the undefined flow patterns, previous studies have used the term “effective drainage area” to differentiate the portions where the stream channels are more clearly defined from the upper basin and limit their runoff analysis to the drainage area below the 2,500 foot elevation (Wilson, Okamoto and Associates, 1967; Department of the Army, 1982). The “effective drainage areas” that were computed for Waiakea Stream ranged from 11.8 to 14.8 square miles depending on the stream location starting measuring point. Above the 1,500 foot elevation, the basin is covered with ohia, tree fern, and uluhe fern vegetation of the Waiakea Forest Reserve. Below the 1,500 foot elevation, the basin is largely developed for agricultural uses with farming and pastoral land and some residential areas. Vegetation in this region is mixed ohia, tree fern, and guava forest and shrubs with tall dense Wainaku and California grasses. The highly urbanized residential area begins at about the 600 foot elevation and continues down slope into Hilo Town. Waiakea Stream is intermittent and dry during most of the year.

The Palai Stream basin has a drainage area of 7.66 square miles, extends about 4 miles from the mouth at Waiakea Pond through the town of Hilo and another 7 miles through the Waiakea Forest Reserve with elevations ranging from sea level to 2,100 feet. Below the 1,500-foot elevation (Figures 2a and 2b), the basin is largely developed or planned for commercial, residential, and agricultural development. The Palai Stream is intermittent and dry during most of the year. Stream patterns throughout many reaches above the 500-foot elevation are indefinite and not discernable.

The Four Mile Creek basin (2b) has a drainage area of 7.21 square miles, and drains to an old quarry south of the airport and east of Railroad Avenue. This basin extends through the Waiakea Forest Reserve with elevations ranging from sea level to 2,100 feet. Below the 1,500-foot elevation, the basin is largely developed or planned for commercial, residential, and agricultural development. The Four Mile Creek is intermittent and dry during most of the year. Stream patterns throughout many reaches above the 500-foot elevation are indefinite and not discernable.

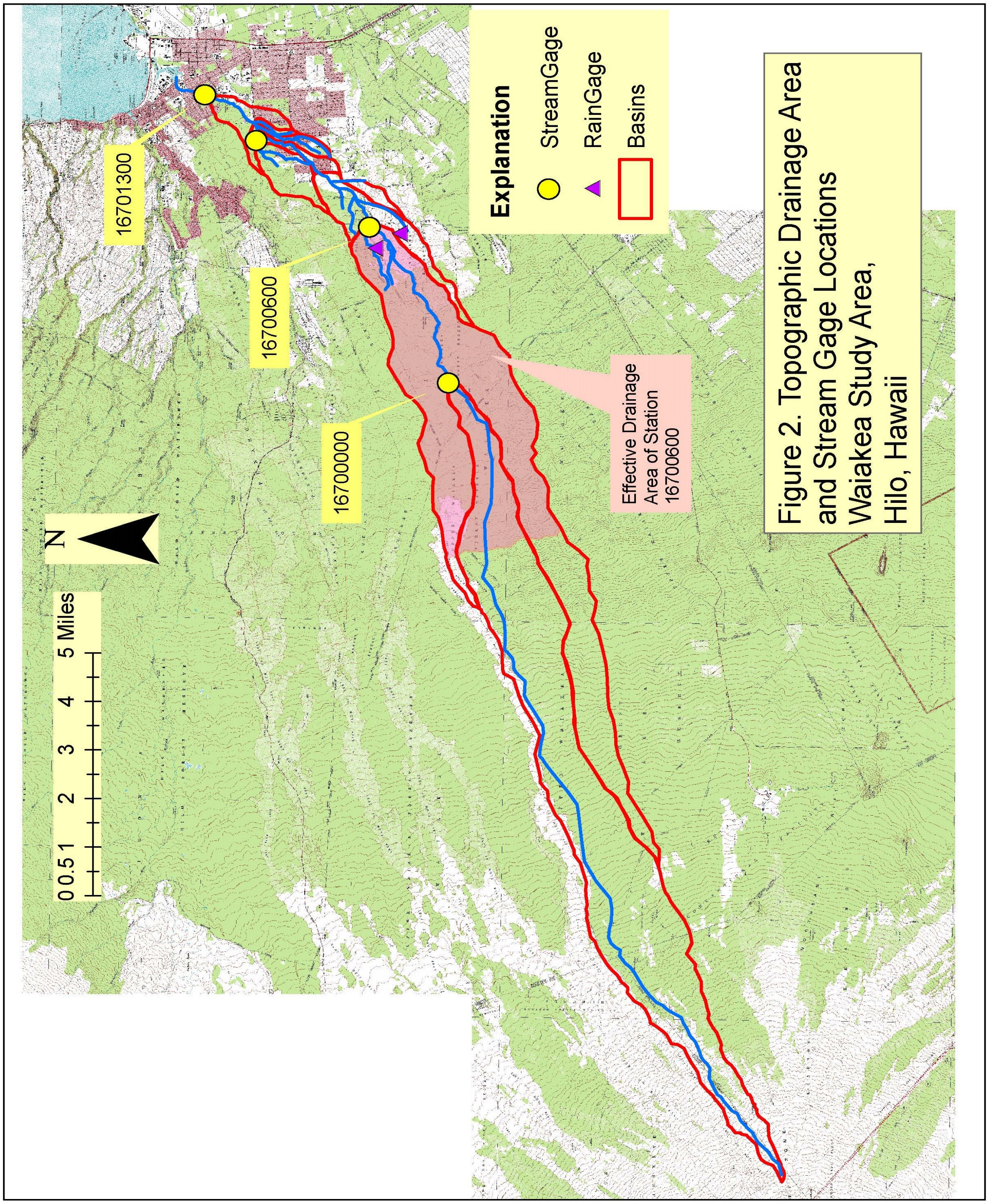


Figure 2. Waiakea Stream Drainage Basin

Figure 2a. Waiakea Basin Stream Gage Location Map

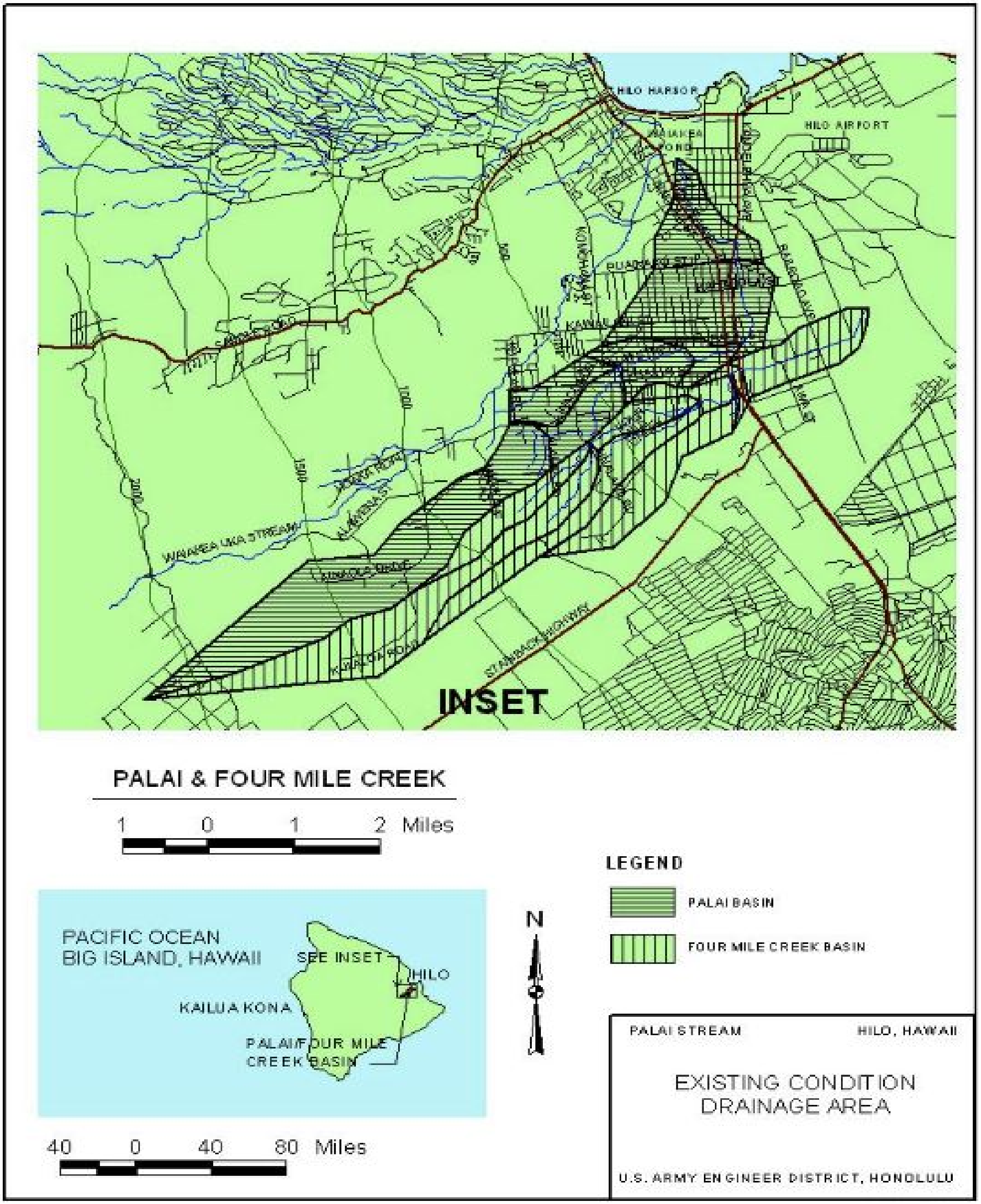


Figure 2b. Drainage Area map for Palai Stream and Four Mile Creek, Hilo, Hawaii

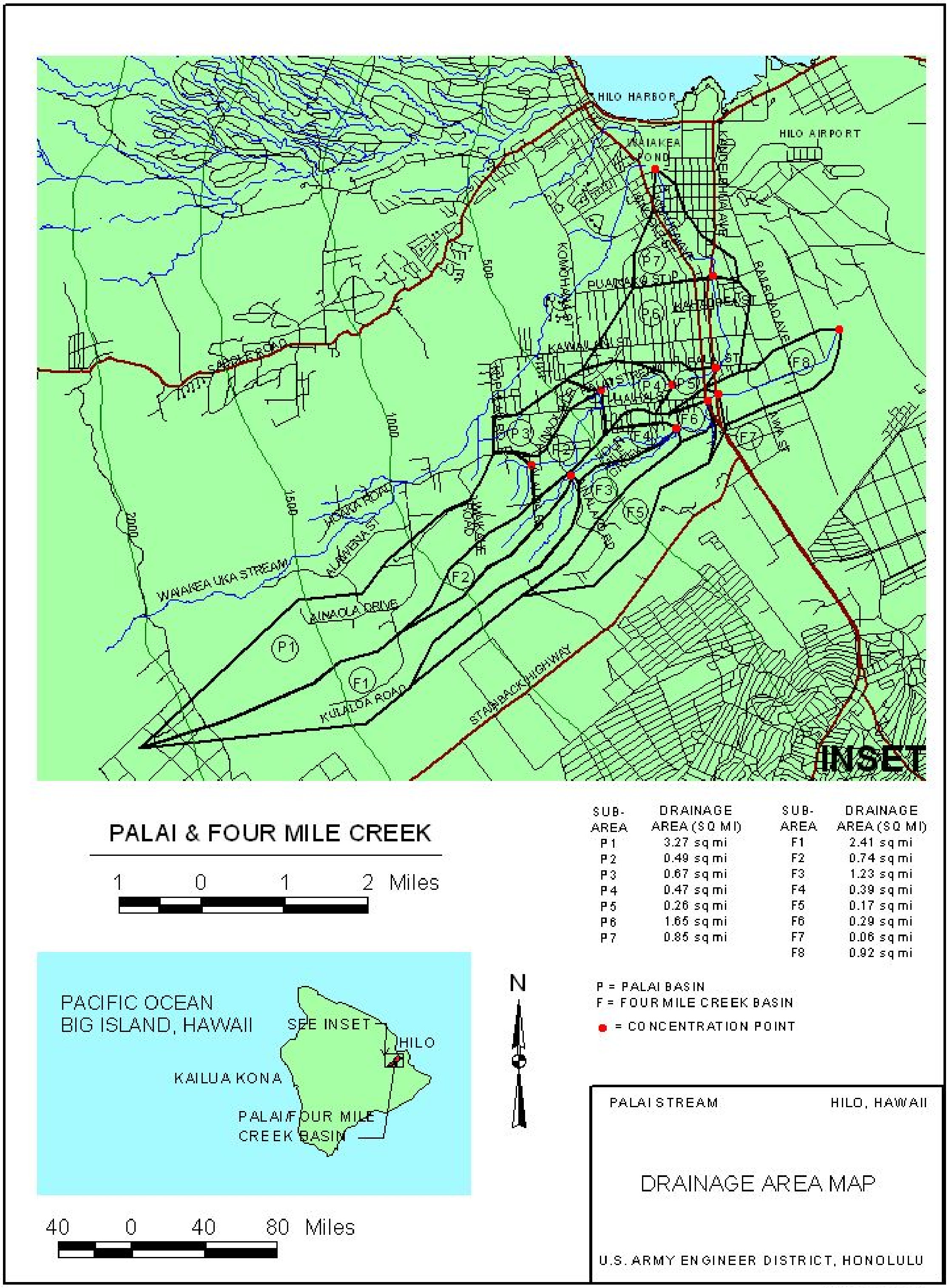


FIGURE 4

Figure 2c. Sub-Basin Areas for Palai Stream and Four Mile Creek, Hilo, Hawaii

1.4.2 Geology and Soils. The Waiakea Stream, Palai Stream, and Four Mile Creek basins lie on top of basaltic aa and pahoehoe lava flows of the Kau Volcanic Series extruded from Mauna Loa (Macdonald and others, 1983). The last historic eruption occurred in 1942 and these aa lava flows exist in the upper basin area with pockets of Pahala Ash covering Kahuku Basalts southwest of Hilo. All of the geologic materials are highly permeable, with aa lava flows having the highest permeability and almost no runoff, pahoehoe flows are less permeable except through cracks, and Pahala Ash is the least permeable (Macdonald and others, 1983; Sato and others, 1973). North of the study area, the Wailuku River forms the approximate boundary between the Mauna Kea and Mauna Loa volcanoes. According to Macdonald and others (1983, p.372) the flow of Wailuku Stream is kept flowing by runoff from the tributaries of the ash covered Mauna Kea slopes despite losing water into the Mauna Loa lavas. The larger number of well defined stream channels with greater runoff potential north of Wailuku River can probably be attributed to the geology of Mauna Kea compared to the more permeable material of Mauna Loa.

Aa lava flows are a mass of rough, sharp fragments. Aa lava tends to drain very well through all the cracks and greatly reduces runoff. Pahoehoe lava flows have smooth, curvy surfaces. Pahoehoe does not drain well unless the infiltration reaches the cracks, and runoff tends to be moderate. Based on Soil Survey of the Island Of Hawaii (Sato and others, 1973), the bedrock of Pahoehoe lava underlays most of the Four Mile Creek basin. The bedrock combination of Aa and Pahoehoe lava is found below the 500-foot elevation of the Palai basin. The portion of Palai basin at higher elevations than 500 feet is made up of mostly Aa lava bedrock.

Soils in the study area consist of Ohia silty clay loam. Olaa extremely stony silty clay loam, and Keaukaha extremely rocky muck in the lower basin, below 1000 foot elevation area and Ohia silty clay loam, Hilea silty clay loam, and Keei extremely rocky muck in the upper basin areas (Sato and others, 1973). Permeability is considered rapid and runoff medium to slow for these soil types. Most of the soils, 8-72 inches in depth, in the study area have rapid permeability even at full depth if underlain by aa lava. Permeability rates for the soil types within the basin range from 6.3 to 20 in/hr (Sato and others, 1973) and can be variable due to a decrease in permeability at shallow depths in areas underlain by pahoehoe lavas and Pahala Ash. Areas underlain with pahoehoe lava and ash can generate shallow subsurface flow during heavy rainfall (Fontaine and Hill, 2002).

1.5 Climate and Hydrology. The climate near Hilo, Hawaii is generally warm and humid. The semi-tropical climate consists of a two-cycle season: dry, which is between May and October, and wet, which is between October and April. The ranges of rainfall and temperature values reflect the variety of physiographic characteristics of the island. Seasonal variations in rainfall are much smaller in the wetter Hilo area where rainfall comes from both winter storms and year round trade wind showers.

Average annual temperatures near the study area at Hilo Airport range from 66 to 81 ^{o}F with an average of 74 ^{o}F (Western Regional Climate Center, general climate survey website; http://www.wrcc.dri.edu/summary/ito.hi.html). Average monthly rainfall near the study area ranges from 6.5 inches in June to 14.7 inches in November with an average annual value of 126 inches (Data from 1949-2012, Rainfall Atlas of Hawaii website, http://rainfall.geography.hawaii.edu; Giambelluca and others, 2013). The highest recorded monthly rainfall was 50.8 inches in December 1954; the lowest was 0.14 inches in January 1998. Rainfall also varies with elevation due to the orographic effect of the high broad volcanic mountains. Average annual rainfall varies from 130 inches near the coast in Hilo and increases to about 200 inches between the 1,000 to 3,000 foot elevations only to decline to 60 inches at the 8,000 foot elevation (Giambelluca and others, 1986). Rainfall frequency intensity values also diminish above the 3,000 foot elevation (U.S. Department of Commerce, 1962). The mean annual rainfall in the Palai Stream basin ranges from 150 inches at Hilo to 220 inches at the higher elevations. The average annual precipitation is estimated at 160 inches for the Palai Stream and Four Mile Creek Basin. Table 1 provides a statistical summary of monthly temperature and Table 2 provides a statistical summary of monthly rainfall taken from readings between the years 1949 to 2012 near Hilo Airport also known as General Lymann Field.

Table 1. Hilo Airport Monthly Statistical Temperature Summary (1949-2005)

Month	**Average Temperature (ºF)**	**Maximum Temperature (ºF)**	**Minimum Temperature (ºF)**
January	71.5	79.5	63.5
February	71.3	79.2	63.4
March	71.8	79.2	64.3
April	72.5	79.6	65.4
May	73.7	81.0	66.5
June	75.0	82.5	67.6
July	75.8	82.9	68.7
August	76.3	83.5	69.1
September	76.1	83.7	68.6
October	75.5	83.0	68.0
November	73.9	45.9	66.7
December	72.1	81.0	64.7
Annual	73.8	81.2	66.4

Table 2. Hilo Airport Monthly Statistical Rainfall Summary (1949-2012)

Month	Average Rainfall (in)	Maximum Rainfall (in)	Minimum Rainfall (in)
January	9.59	38.35	0.14
February	11.38	45.55	0.52
March	13.12	49.93	0.88
April	12.30	43.24	2.93
May	8.64	25.01	1.46
June	6.53	22.70	1.38
July	9.60	28.59	3.53
August	9.72	26.92	2.66
September	8.10	21.82	1.59
October	9.63	26.10	2.40
November	14.70	45.90	1.01
December	12.40	50.82	0.28
Annual	125.71	195.92	63.22

1.5.1 <u>Runoff Characteristics</u>. Waiakea Stream, Palai Stream and Four Mile Creek and their tributaries are intermittent, flowing only in direct response to heavy rainfall. During storms much of the runoff may quickly seep into the ground depending on the subsurface permeability and exist as subsurface flow or possibly enter into lava tubes and reappear as spring flow in the downstream area. The exact number and locations of lava tubes in the Waiakea area has not been determined (Wilson Okamoto and Associates, 1967). One tube that has been mapped is the Kaumana Cave which is about 1 mile north of the Waiakea study area (Halliday, 2003). The movement of subsurface flow is unknown and may or may not affect peak flows, in some cases downstream spring flows have developed 2-3 days after the heaviest rainfall (U.S. Army Corps of Engineers, 1990).

The U.S. Geological Survey (USGS) has operated both continuous record and crest-stage gages along Waiakea Stream since 1931 in the upper basin and 1957 in the lower basin. A crest-stage gage collects only peak water level stage and flow for the purpose of flood-frequency analysis. Station 16701300, a crest-stage gage, is the only gage on Waiakea Stream currently in operation. Previous and current gaging efforts are listed in Table 3. Recorded flood flow hydrographs from Waiakea Stream are characterized by sharp rises of relatively short duration followed by sharp recessions; most runoff hydrographs have durations of 4 to 6 hours (Wilson Okamoto and Associates, 1967). Peak discharges typically occur within 2 hours after the end of the heavy rainfall and the flash flood characteristics of Waiakea Stream result in inadequate flood warning for the lower floodplain downtown Hilo area. In 2004, the USGS operated two continuous record gages on Waiakea Stream (Table 3). Peak flow records from two peaks, one on January 25 and the other on April 12, 2004 indicate that flood peak attenuation exists between these two sites which are about 4.2 miles apart. An approximate calculation shows an average linear reduction of 0.02 cubic feet per second per linear foot distance. However, the actual flow loss reduction may be greater than this value because of inflow from tributary drainage areas that need to be factored in. As part of the data collected after the November 2000 flood, the USGS also computed a peak discharge on Waiakea Stream upstream of Hoaka Road near the Gage station 16700600 site (Fontaine and Hill, 2002). This discharge was 6,420 cubic feet per second. The peak flow determined at Gage station 16701300 for this storm was 5,760 cubic feet per second. The flood peak attenuation from this storm was an approximate reduction of 0.03 cubic feet per second per linear foot, slightly higher for this higher peak flow event.

The USGS operates a crest-stage gage on Palai Stream at Highway 11, Kanoelehua Avenue, (USGS Gage station number 16701400). This gage records only peak water level stage and flow. This type of data is used for flood-frequency analysis. During storms much of the runoff enter into lava tubes and reappear as springs in the downstream area. In most cases these springs develop 2-3 days after the heaviest rainfall and do not have a significant impact on peak flows. Flood flows in Palai Stream are characterized by sharp rises of relatively short duration from intense rainfall over the watershed, followed by sharp recessions. Peak discharges typically occur within 2 hours after the end of the heavy rainfall. The flash flood characteristics of Palai Stream result in inadequate flood warning for the lower floodplain downtown Hilo area.

Table 3. U.S. Geological Survey Streamflow Data collected on Waiakea and Palai Streams, Hilo, Hawaii

Gage Location, Elevation, or Period of Record	Stream Gage station Number				
	16700000	**16700600**	**16701200**	**16701300**	**16701400**
Gage Location, lat.	19°38’30”	19°39’40”	19°41’42”	19°42’38”	19°40’56”
Gage Location, long.	155°10’28”	155°07’20”	155°05’51”	155°05’02”	155°04’04”
Gage Elevation	1,934 ft	860 ft	369 ft	80 ft	160 ft
Drainage Area (mi^2)	17.4	31.92	33.6	35.8	5.06
Period of Continuous Record	Oct 1930 to Sep 1991	Oct 2003 to Sep 2005	June 1957 to June 1967	Oct 2003 to Sep 2005	N/A
Period of Peak Flow Record Only	-----	-----	-----	1967 to 2003, 2006-present	1965-present with gaps
Number of Annual Peak Flows available for analysis	61	2	10	20	23

1.5.2 Climate Change Impact

The current inland hydrology civil works regulation requires that Waiakea incorporate design change to sustain climate induced vulnerabilities. USACE Climate Assessment Tool can be used to develop qualitative analysis of the climate impact analysis on Waiakea project areas. This program tool is unavailable at this time to perform a typical assessment of climate vulnerabilities in the region.

However, climate influenced water resources impact is well documented in the Hawaiian climate literature. Rainfall trended downward, so is the base flow of streams in Hawaiian Islands (Center for climate adaptation policy - 2012). Heavy rainfall and drought events become more common (Honolulu County 2018) Temperature is rising and sea level is expected to rise as much as 3.2 ft, El Nino would be dominant precipitation pattern (EPA 2016). The climate related information pointed to common direction that Hawaiian climate is changing and change in temperature, wind speed, wind pattern, sea level increase and ecosystem changes collectively influencing floods, droughts and depletes drinking water resources. Even without such climate induced issues, increased population and land degradation will exacerbate current conditions with increased runoff, particularly impacting communities which live near water courses in lower land areas.

Temperature influenced sea level rise will have no significant impact on Waiakea project area as most of the flooding occurs in sloping terrain away from ocean. However, changes in precipitation intensity and frequency may pose significant impact. The preliminary review of climate influence on water resources indicates that it is important to conduct sensitivity analysis of the Waiakea-Palai watershed and project measures to understand the resiliency and vulnerabilities posed by potential climatic and hydrologic changes. Since hydrology and hydraulic analyses will be revisited during next phase of design development, the climate induced impact analysis can be conducted at that same time.

1.6 Flood Problems. In general, flood problems in the Waiakea, Palai, and Four Mile study areas are attributed to poorly defined channels. In areas where the channel is more defined, the channel capacity is inadequate to convey excess runoff. The streams can be classified as perched or partially perched, having variable stream slopes ranging from 2 to 6 percent and severe bends. The accumulation of debris and vegetation in and near the channels, especially vegetation growth in the channels during the dry season, along with poor drainage facilities to convey storm runoff from streets and open areas contribute to the problem. High intensity rainfalls of short duration along with steep terrain, cause rapid flood flows. Deposits of sediment and other debris aggravate flood damages to agricultural land, residential and commercial properties, and public roads. These deposits cause changes in the flow directions making other areas prone to flooding. Inadequate drainage facilities to convey storm water runoff from streets and open lots cause repetitive problems in the south Hilo area.

1.6.1 Storms and Floods of Record**.** Historical accounts, although not well documented, indicate that the study area is flood prone. The following is a brief description of major storms and their accompanying floods.

2 March 1939. Torrential rainfall from this storm brought 19.2 inches of rain over 24 hours recorded at the Hilo Post Office and 18.8 inches in 24 hours at Waiakea Mill. Portions of the lower Waiakea area in Hilo were flooded up to 5 feet deep with 1 to 2 feet of water flowing along many streets (U.S. Army Engineer District, 1962). For Palai Stream, the peak flow was about 920 cubic feet per second and 1,180 cubic feet per second for Four Mile Creek. These discharges were estimated at sites located at Highway 11. Both sites were mostly undeveloped at this time.

9-10 March 1953. Thunderstorm showers produced 10 to 13 inches of rain in 24 hours in the Hilo Area. Rainfall totals of 3.91 inches on the 9th and 13.62 inches on the 10th were recorded at the Waiakea Gage (U.S. Army Engineer District, 1962).

25 July 1966. This storm brought 17 inches of rain over 24 hours according to Wilson Okamoto and Associates (1967). A peak discharge of 1080 cubic feet per second was recorded at USGS station 16701200, a gage which was located upstream of Komohana Street from 1957-66. A peak discharge of 1,000 cubic feet per second was recorded on Palai Stream. Residential damages were reported along Haihai and Kawailani Streets on Waiakea Stream and residential damages occurred along Four Mile Creek, but no discharge information is available.

20 February 1979. From this storm, 16.87 inches of rainfall was recorded at Hilo airport according to the NWS (National Weather Service). A maximum 22.3 inches of rainfall was recorded at the same rain gage over a 24-hour period according to the U.S. Army Corps of Engineers (1990). Damages totaled $6 million in the urban Hilo area along Waiakea Stream and $300,000 in the Palai Stream/Four Mile Creek area. The urban Hilo area was also evacuated during this storm. Station 16701300 on Waiakea Stream recorded a peak flow of 2,590 cubic feet per second, while the Palai stream gage recorded a peak flow of 1,260 cubic feet per second.

17 March 1980 - March 1980: Approximately 25 inches of rain was recorded in a 72-hour period with damages estimated at $3.8 million. The Palai stream gage recorded a peak flow of 1,070 cubic feet per second.

August 1994: Approximately 4 inches of rain was recorded with damages estimated at $1 million. A USGS stream gauge on Waiakea stream recorded a peak flow of 3670 cfs, estimated at a 10-15 year discharge recurrence interval. The Palai stream gage recorded a peak flow of 575 cubic feet per second.

November 2000: Approximately 29 inches of rain was recorded in a 24-hour period and rainfall intensities of 2.57-3.24 inches per hour were recorded over a four-hour period. A U.S. Geological Survey (USGS) stream gauge on Waiakea Stream recorded a peak flow of 5760 cfs, estimated at a 70-year discharge recurrence interval. In the Waiakea Stream area, bridge crossings at Kawailani Street and

Kupulau Road were washed away. Entire neighborhoods were isolated and cut off from the rest of Hilo for several days. The Palai stream gage recorded a peak flow of 1,580 cubic feet per second.

29 January 2002. This storm recorded 12.20 inches of rainfall at Hilo airport on that day according to the NWS. The USGS has no data for this storm event.

August 2018: Approximately 43 inches of rain was recorded in a 4-day period resulting from Hurricane Lane. The storm caused widespread damage to the properties (CBCNews, Aug 26, 2018)

February 2008: Approximately 16 inches of rain was recorded in a 24-hour period. Approximately 150 homes were damaged by floodwaters rising up to 4 feet deep in Hilo.

1.6.2 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) (Figure 3) the U.S. Army Corps of Engineers 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 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 (Figure 3d). 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 diverted runoff from the Palai Stream drainage basin to Waiakea Stream upstream of the Kupulau Road 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.

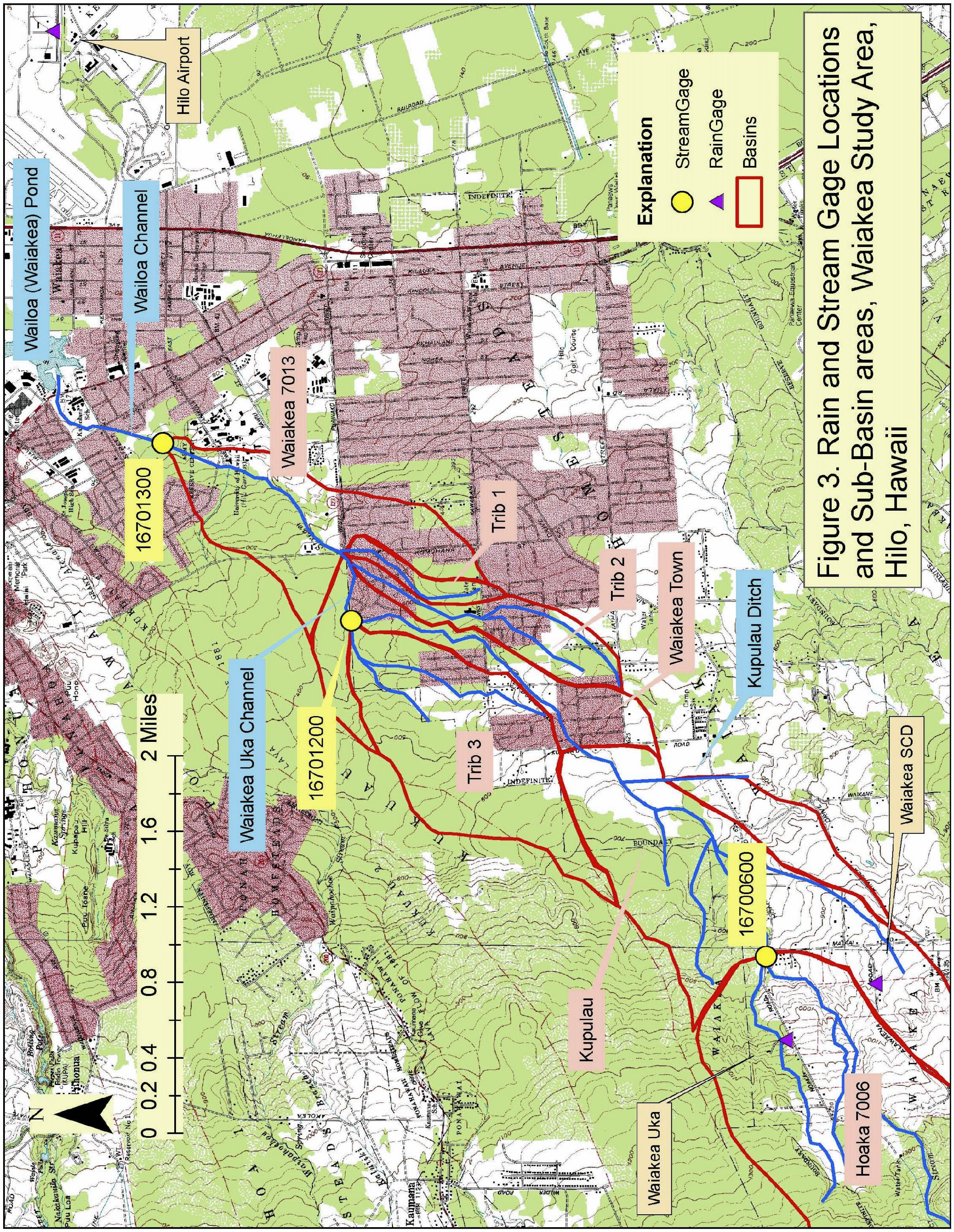


Figure 2d –Channel Modification Locations

1.6.3 Previous Flood Studies. A number of previous studies have looked at the flood problems in the upper Waiakea and Palai Stream areas and provide various suggested improvements. The Wilson, Okamoto, and Associates (1967) study titled *Hilo Drainage and Flood Control*, used streamflow data from storms in 1957, 1965, and 1966 from the USGS gage station 16701200 on Waiakea Stream to create synthetic hydrographs used to create design hydrographs for a number of streams and tributaries in the Hilo area. For Waiakea Stream at Kupulau Road a design hydrograph was created using the Soil Conservation Service (SCS) curve number method. This hydrograph used a 24 hour storm of 17 inches, a curve number of 37, and a time to peak of 1.03 hours to create a peak discharge of 3,210 cubic feet per second. From rainfall frequency analysis in this report, a 17 inch 24 hour rainfall event has a recurrence interval of about 50 years. The suggested improvements for the study area was to construct a trapezoidal channel with 30 feet bottom width and 2 to 1 side slopes in Waiakea Stream from Kawailani to Puainako Streets and 3 foot wide drainage ditch along Komohana Street which would discharge into Waiakea Stream at the Komohana Street Bridge.

A flood control reconnaissance study for Palai Stream in 1979 (Department of the Army, 1979) documented the construction by local interest of the Four Mile Creek channel downstream of Kanoelehua Highway in 1976 and the desire to provide flood mitigation for Palai Stream by diversion into Four Mile Creek. The 1981 study (Department of the Army, 1981) follows up on the reconnaissance study looking at structural and non-structural alternatives with computations of benefits and costs and determining a lack of economic justification for federal interest with a benefit cost ratio less than one.

A flood control reconnaissance study for Waiakea Stream in 1982 (Department of the Army, 1982) analyzed a trapezoidal concrete channel improvement extending from Kupulau Road to Komohana Street, about 9,800 feet long. This channel would have a bottom width of 35 feet with 2 to 1 side slopes and a channel design capacity of 6,200 cubic feet per second, about a 125-year recurrence interval. This study introduced the idea of a perched channel, where the out of bank ground elevation is lower then the stream elevation and thus creates a myriad of flooding issues once the streamflow leaves the bank. Perched channels were identified by the Kawailani Street Bridge area. This study did not recommend a further study due to a benefit cost ratio less than one.

Another flood control reconnaissance study was conducted in 1995 (Department of the Army, 1995) due to a significant storm damage in 1994. Hydrologic data form USGS gage stations 16700000 and 16701300 were used to create a regional curve which determined the 100-year discharge of Waiakea Stream at Kupulau Road to be 3,280 cubic feet per second. The proposed improvement was a detention pond design near Kupulau Road to contain either the 50- or 100-year flows. This study did not recommend a further study due to a benefit cost ratio less than one.

Also in response to the 1994 flood, the Natural Resources Conservation Service (NRCS) conducted a preliminary investigation into the Waiakea flooding problems under the PL83-566 Small Watershed Program (Natural Resources Conservation Service, 1999). This study looked at bridge replacements, levees, channel modifications, and detention basins as possible mitigation measures. This study did not recommend a further study due to a benefit cost ratio less than one.

The large flooding event of November 2000 resulted in another flood control reconnaissance study in 2001 (U.S. Army Corps of Engineers, 2001). The hydrologic analysis in this study determined a 1% Annual Exceedance Probability (AEP) design discharge of 5,724 cubic feet per second. Potential flood mitigation measures studied included channel and levee improvements, a detention pond, and extended the Kupulau Ditch to carry floodwaters around the community and return the runoff to Waiakea Stream by Komohana and Puainako Street Extension Bridges. This study did recommend further study since the benefit cost ratio was greater than one.

Dewberry and Davis (2001) computed updated hydrologic discharges and hydraulic flood elevation profiles on Waiakea Stream for the Federal Emergency Management Agency (FEMA) Flood Insurance Study as a result of the November 2000 storm. The revised 100-year discharge for Waiakea Stream is 6,230 cubic feet per second (ft^3/s), previously it was 3,750 cubic feet per second. Discharges were also updated for the three tributaries of Waiakea Stream originally mapped in 1981. These tributaries were mapped from Kawailani Street to Puainako Street. The detailed study area for the flood mapping covered the area of Waiakea Stream from Kupulau Ditch to Wailoa Pond. Flood elevation profiles were updated for certain reaches of Waiakea Stream from the previous 1995 HEC-2 model data computations. Flood Insurance Rate Maps (FIRM) for the Waiakea area are covered in panel numbers 1551660880C and 1551660890C, both last revised September 16, 1988.

URS Corporation, formerly United Research Services, (2003) conducted a study to update the Flood Insurance Rate Maps (FIRM) for Palai Stream Tributaries A, B, and C. As part of this study, flows and floodplains in the area by Kupulau Ditch and portions of Waiakea Stream near Kupulau Ditch were determined. Peak flow values were determined from USGS data on Palai Stream and existing FEMA values. The 100-year flow for Waiakea Stream that was used was 6,230 ft^3/s and 2,144 ft^3/s was used at Kupulau Ditch. The floodplain mapping was done using steady-flow split flow analysis in this area, as flow is known to leave Waiakea Stream and flow into Kupulau Ditch and then some flow leaves the Ditch as opposed to returning to Waiakea Stream to flow down Palai Stream C. The area of Palai Stream C is included as a tributary to Waiakea Stream in this study since the flow path downstream of Palai Stream C is not well defined and can be interpreted to enter Waiakea Stream as opposed to just ending at Kawailani Street.

2.0 HYDROLOGIC ANALYSIS

2.1 Hydrology. The main objective of this hydrologic analysis was to determine the "best" estimates of the 50%, 20%, 10%, 4%, 2%, 1%, 0.5%, 0.2% AEP flood events. Discharge-frequency values in this report will be referred to as the [x] percent flood which is defined as a discharge magnitude having a one chance in [100/x] of being exceeded in any given year. To determine the "best" estimate of the discharge-frequency curve three methods were applied: HEC-HMS rainfall-runoff modeling (version 3.0; U.S. Army Corps of Engineers, 2000, 2002, and 2005), Flood frequency analysis using recorded peak flow data from Waiakea and Palai Streams, and Plate 6 (County of Hawaii Storm Drainage Standards, 1970). The selection of the "best" estimate was done by comparing the various derived discharge-frequency curves graphically and by the accuracy or uncertainty of each method. The existing condition hydrologic analysis models the condition where the Waiakea and Palai Stream Basins drain into Waiakea Pond in Hilo Town, and the Four Mile Creek Basin drains into an old quarry.

2.2 Uncertainty Analysis. Department of the Army (1996) guidelines on risk-based analysis for flood damage reduction studies presents guidelines on assigning accuracies to flood frequency estimates determined by various methods in terms of equivalent years of record. Those estimates with the higher equivalent years of record are assumed to be more reliable than those with lower values. Each method used was assigned an accuracy value.

2.3 Data Availability. The USGS 1:24,000 scale topographic maps and Geographic Information System (GIS) tools were used to determine the layout and physical sub-basin characteristics for the HEC-HMS model (Figures 3 and 4). Also detailed topographic data at 4 foot contour intervals collected in 2005 for Waiakea Stream in an area between Kupulau Road and Komohana Street was also used, especially in the determination of the area and flow paths of tributaries 1, 2, and 3 of Waiakea Stream (Figure 3). Rainfall data from the NWS Waiakea-Uka, Waiakea Summary Climate Data (SCD), and Hilo Airport gages were used for calibration along with USGS stream flow data from Gage stations 167006000, 16701200, 16701300, and 16701400 (Table 3). The Waiakea-Uka gage is part of the NWS Hydronet system in Hawaii, so data is primarily used for flood forecasting and is not quality assured, start from 1995 and can only be found at website http://www.prh.noaa.gov/hnl/pages/hydrology.php (last accessed on September 12, 2006) (Kevin Kodama, Senior Staff Hydrologist, NWS, oral communication, 2004). Data from the Waiakea SCD and Hilo Airport gages are collected under other NWS programs. Data from these rain gages can be found at the National Climatic Data Center (NCDC) website http://www.ncdc.noaa.gov/oa/ncdc.html (last accessed on September 12, 2006). Data from the Waiakea Uka rain gage and the USGS stream gages are available in 15 minute intervals; the Waiakea SCD data is based on a daily read can and the Hilo Airport Data is hourly. The rainfall frequency intensity was determined from the National Oceanic and Atmospheric Administration Atlas 14 website; see Section 2.7.2 for information about this data set.

2.4 Waiakea Stream HEC-HMS Rainfall-Runoff Model. A lumped basin watershed model was constructed using the HEC-HMS software program. The HEC-HMS model has three components a basin model, a meteorological model, and a control model. The basin model divided the Waiakea Stream Watershed into a number of smaller sub-basins and used the initial and constant loss rate method and the Snyder Unit Hydrograph Method for creating peak flows. Flow routing through reaches was done by the Muskingham-Cunge method to account for peak flow attenuation. The baseflow recession method was used for the baseflow portion of the basin model. The meteorological model used both storm hydrographs for calibration and frequency based rainfall after calibration to compute synthetic flood events. The control model sets the computation parameters. A 5 minute computation interval was used for calibration and frequency storm computations. Discharge determinations were conducted at the gage station locations for Gage stations 16700600 and 16701300 and at locations in the detailed study area, most notably at the Kupulau Road and Komohana Street bridges (Figure 3).

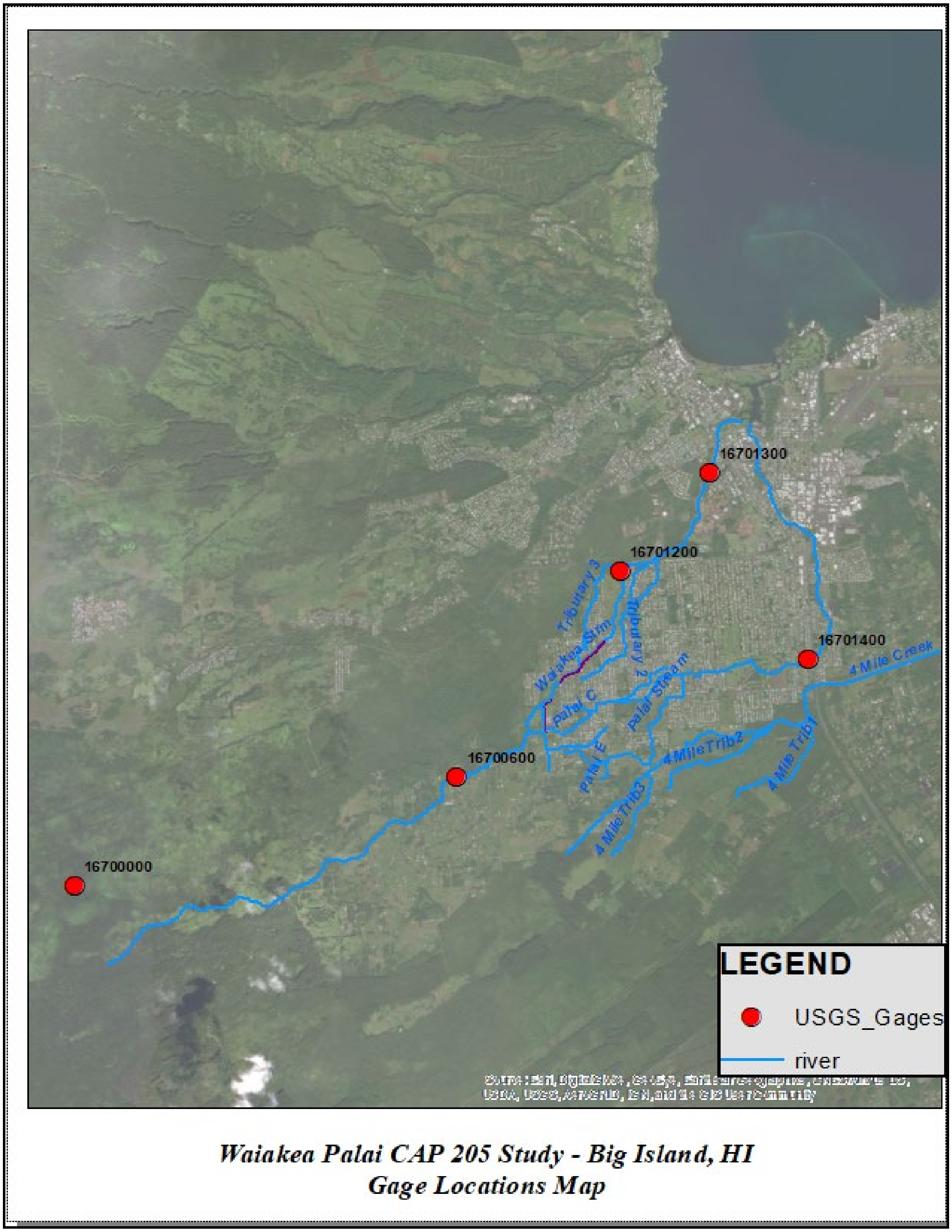


Figure 3- Gage Locations Map

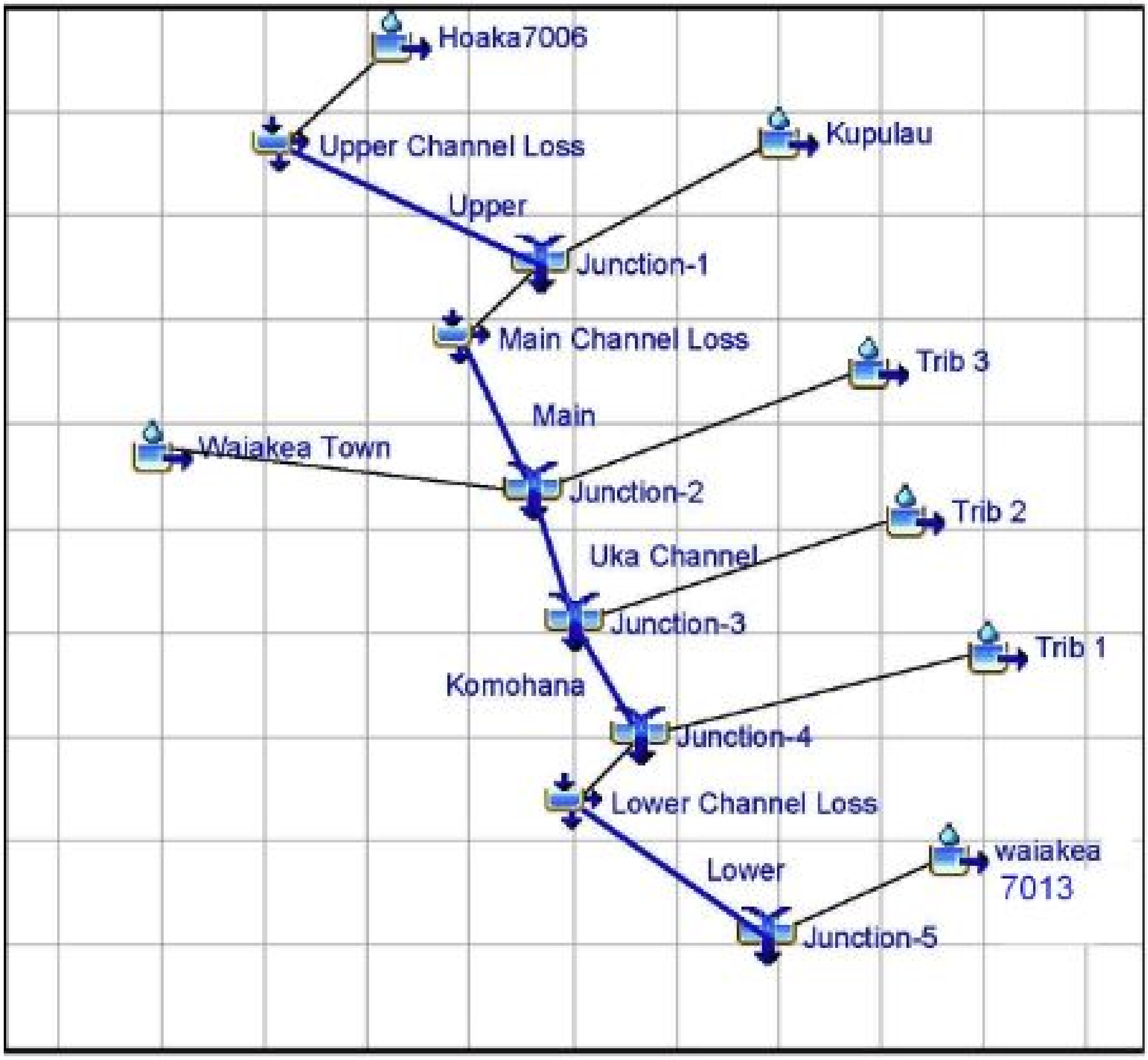


Figure . Waiakea Stream HEC-HMS Model Layout

The concept of "effective" drainage area was employed to determine the drainage areas used for the upper sub-basin area at Gage station 16700600. The topographic drainage area of Gage station 16700600 is 31.5 square miles. The use of this entire area in rainfall-runoff modeling would result in large peak flow values or the use of large soil loss coefficients to replicate observed data, therefore, only the drainage area below the 3,000 foot elevation was used to compute the sub-basin area of gage station 16700600, which is 12.2 square miles (Figure 2). Long term streamflow data from 1931-91 collected at USGS gage station 16700000 which is upstream of gage station 16700600 at elevation 1,934 feet (Figure 2) does not indicate very high rates of runoff from the upper elevations of this watershed. Topographic area of gage station 16700000 is 17.4 square miles, yet maximum recorded peak flow is only 310 ft^3/s recorded on August 26,

1970. The November 1-2, 2000 storm resulted in a higher peak stage at this site, but peak flow was not determined (Fontaine and Hill, 2002).

The HEC-HMS program allows the analyst to estimate runoff parameters automatically using the optimization manager. Observed discharge must be available for at least one element before optimization can begin. Sub-basin parameters at any element upstream of the observed flow can be estimated. The program makes an estimate of the required parameters, computes the resulting runoff, and compares the goodness of fit. The optimization manger was just one tool used in the model calibration process. The rainfall runoff models used in the Alenaio and Palai Stream studies also provided guidance (U.S. Army Corps of Engineers, 1990). The Manning's n value and channel sizes for the Muskingham-Cunge routing method were determined from a site visit in February 2006 and guidebooks such as Arcement and Schneider (1989).

The Alenaio and Palai Stream studies (U.S. Army Corps of Engineers, 1990; Section 2.6) used basin parameters calibrated from past storms on August 26, 1970 and January 23, 1979 at the USGS Wailuku River gage, station 16701800, because these records contain complete rainfall and runoff data. The Wailuku calibrated basin parameters were 0.45 as an average Snyder Peaking Coefficient, Cp, value, lag values of 1.3 to 2.4 hours, Initial soil losses ranging from 1.10 to 5.4 inches and constant soil losses of 0.47 to 0.65 inches. The Wailuku storm parameters showed higher initial and constant soil losses for larger peak flow events even in the lower permeability rocks of the Moana Kea with Pahala Ash area of the Wailuku River basin. The Palai model calibration results also resulted in higher soil losses for storms of higher magnitudes.

Between October 2003 and September 2005, two continuous streamgages have been operated by the USGS on Waiakea Stream, Station 16700600 in the upper basin above the urbanization and station 16701300 at the lower end of Waiakea Stream (Figure 3). Data from two storms, April 10-13, 2004 and November 1-2, 2000 were used for HEC-HMS model calibration. Complete rainfall and runoff data were available for the April 10-13, 2004 event while only complete rainfall was available for the November 1-2, 2000 storm. At that time, Station 16701300 was operated as a crest-stage gage so only peak flow data was collected. For that storm a peak flow calculation was also made at Waiakea Stream near Hoaka Road (Fontaine and Hill, 2002) which is near the Station 16700600 site. Rainfall data was missing at the Waiakea Uka gage for two other storms, January 25-26, 2004 and August 7-8, 2005, so these storms were not used for calibration purposes since the Waiakea Uka data is very important to proper model calibration due to its location (Table 4).

Table 4. Rainfall and Streamflow Data in and near the Waiakea Stream Study Area, Hilo, Hawaii

Gage Location, Elevation, or Storm Date	Rain Gage Daily Total Data Rain fall values in inches			Stream Gage Peak Flow Data		
	Waiakea Uka 85.2 (15 min)	**Waiakea SCD 88.2 (Daily)**	**Hilo Airport (Hourly)**	**Waiakea 16700600 (ft^3/s)**	**Waiakea 16701300 (ft^3/s)**	**Peak Flow Difference, percent of 16701300 value**
Gage Location, lat.	19°40'N	19°40'N	19°43'N	19°39'40"	19°42'38"	----
Gage Location, long.	155°08'W	155°08'W	155°03'W	155°07'20"	155°05'02"	----
Gage Elevation	1,000 ft	1,050 ft	38 ft	860 ft	80 ft	----
November 1, 2000	14.09	0.11	12.64	6,420	5,760	-11%
November 2, 2000	16.12	26.33	16.64	----	----	----
January 25, 2004	Missing	0.15	4.07	1,330	725	-83%
January 26,2004	Missing	8.82	1.24	----	----	----
April 10, 2004	2.20	0.65	1.67	----	----	----
April 11, 2004	5.67	3.62	4.65	----	----	----
April 12, 2004	6.47	9.06	7.82	1,000	701	-43%
April 13, 2004	2.07	6.28	1.25	----	----	----
August 7, 2005	Missing	3.81	2.00	990	455	-118%
August 8, 2005	Missing	3.17	0.42	----	----	----

The recorded runoff data from gage stations 16700600 and 16701300 indicate a peak flow attenuation of 11 to 118 percent between the two measuring locations (Table 2). The April 10-13, 2004 hydrographs (Figure 5) of gage stations 16700600 and 16701300 show an approximate lag of 45 minutes and a distinct flow attenuation. This flow attenuation is attributed to the highly permeable lava rocks that make up the stream channels and was modeled in HEC-HMS by removing a fixed percentage of channel flow in the three main reaches in the model (Figure 4).

The April 10-13, 2004 storm was used in the initial model calibration with the Snyder's Cp and lag, soil loss, and baseflow recession values determined at the HEC-HMS Hoaka7006 sub-basin from the gage station 16700600 data. These values were then applied to the remaining sub-basins and further adjusted to represent the flow hydrograph at the Station 16701300 location, Junction 5 in the model. Graphical results in Figures 6 and 7 show that while the peak values at Hoaka7006 have a lag compared to the observed, the fit is better downstream at Junction 5. The initial and constant soil loss method is not fully capable of capturing all the multiple peaks observed during the April 10-13, 2004 event. Other methods such as Green-Ampt and exponential were used (U.S. Army Corps of Engineers, 2005) but did not significantly improve the fit. This was not considered a major problem with the calibration as the goal was to model events of higher magnitude. Calibrated basin parameters and rain gage weights are shown in Table 3. For the rainfall inputs, the Waiakea Uka gage represented the upper basin and the Hilo Airport gage the lower basin areas. For the sub-basins in the middle, a 50/50 split was used. The daily read data from Waiakea SCD was used only slightly to adjust the Waiakea Uka values (Table 5).

The April 10-13, 2004 calibrated model was then calibrated to the November 1-2, 2000 storm data. To replicate the observed peak flows, the constant soil losses had to be increased. This was also done in the Palai model (Section 2.6). One possible reason for having higher constant soil losses for higher magnitude events could be that the larger rainfall events cover a greater surface area of permeable soil and rocks which allow a greater capture of the rainfall and overland flow before it enters the stream channels. Other basin parameters remained the same between the two storms except that the lower channel losses were decreased to better replicate the peak at Station 16701300, Junction 5 in the model (Figure 8; Table 3). This calibrated model was then used for synthetic flow frequency analysis. Tables 6 and 7 summarize the initial and constant loss rates determined for the Waiakea Stream watershed, while Tables 8 and 9 summarize the Snyder Unit Hydrograph and Muskingum-Cunge routing parameters respectively.

Table 5. HEC-HMS Model Basin and Reach Calibrated Storm Parameters for Waiakea Stream, Hilo, Hawaii

Basin or Reach Characteristics		Soil Loss Data for Calibration Storms				Snyder's Unit Hydrograph Parameters	
Sub-Basin	Drainage Area (mi^2)	Percent Impervious	Initial Loss (inches)	April 2004 Storm Constant Loss (inches)	November 2000 Storm Constant Loss (inches)	Lag (hour)	Peaking Coefficient Cp
Hoaka 7006	12.2 [a]	0 %	4.1	0.26	2.4	0.25	0.21
Kupulau	1.63 [b]	0 %	4.2	0.27	2.2	0.3	0.21
Waiakea Town	0.47	5 %	4.4	0.29	2.2	0.3	0.21
Tributary 3	0.93	3 %	4.4	0.29	2.2	0.5	0.21
Tributary 2	0.28	5 %	4.4	0.29	2.2	0.3	0.21
Tributary 1	0.09	5 %	4.4	0.29	2.2	0.3	0.21
Waiakea 7013	0.68	3 %	4.5	0.32	2.2	1.0	0.21

	Muskingham-Cunge Routing Parameters						
Reach	Length (feet)	Slope (feet/feet)	Manning's n	Shape	Width (feet)	Side Slopes	Percent Channel Flow Loss [c]
Upper	2600	0.028	0.045	Trapezoid	30	1H:1V	15
Main	8000	0.036	0.04	Trapezoid	35	1H:1V	20
Uka Channel	1700	0.015	0.04	Trapezoid	35	1H:1V	0
Komohana	500	0.03	0.03	Trapezoid	35	1H:1V	0
Lower	6000	0.04	0.045	Trapezoid	35	1H:1V	30/15 [d]

	Baseflow Recession Parameters			Rain Gage Weight for Calibration Storms		
Sub-Basin	Initial Discharge	Recession Constant	Ratio to Peak	Waiakea Uka 85.2	Waiakea SCD 88.2	Hilo Airport
Hoaka 7006	10	0.30	0.35	0.80	0.20	----
Kupulau	1	0.30	0.35	0.80	0.20	----
Waiakea Town	0.01	0.20	0.25	0.50	----	0.50
Tributary 3	0.01	0.20	0.25	0.50	----	0.50
Tributary 2	0.01	0.20	0.25	0.50	----	0.50
Tributary 1	0.01	0.20	0.25	0.50	----	0.50
Waiakea 7013	0.01	0.20	0.35	----	----	1.0

[a] Effective drainage area for runoff computations, topographic drainage area is 31.5 mi^2.
[b] A drainage area of 1.87 mi^2 was used for calibrating the November 2000 storm and for the frequency storm calculations of the 2%, 1%, 0.5%, and 0.2% storms. This additional area represents potential in-flow from the Kupulau Ditch from area outside the topographic drainage area for this sub-basin. The 1.63 mi^2 drainage area was used in the April 2004 storm calibration and in the frequency storm computations for the 50%, 20%, 10%, and 4% storms.
[c] Diversions of channel flows to represent losses due to the high permeability of the volcanic rocks in the stream channels.
[d] The lower channel loss of 15% was used for the November 2000 storm calibration and for the frequency storm calculations of the 2%, 1%, 0.5%, and 0.2% storms. The higher 30% loss was used in the April 2004 storm calibration and in the frequency storm computations for the 50%, 20%, 10%, and 4% storms.

Table 6. HEC-HMS Frequency Storm Initial Loss Rates for Waiakea Stream Sub-Basins

Basin Characteristics			Initial Loss Rate (in.)							
Sub-basin	**Drainage Area (sq mi)**	**Imperv-iousness (%)**	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.2%**	**0.5%**
Hoaka 7006	12.2[a]	0 %	4.6	4.6	4.6	4.6	4.1	4.4	4.1	4.1
Kupulau Ditch	1.63[b]	0 %	4.6	4.6	4.6	4.6	4.2	4.4	4.2	4.2
Waiakea Town	0.47	5 %	4.6	4.6	4.6	4.6	4.4	4.4	4.4	4.4
Tributary 3	0.93	3 %	4.6	4.6	4.6	4.6	4.4	4.4	4.4	4.4
Tributary 2	0.28	5 %	4.6	4.6	4.6	4.6	4.4	4.4	4.4	4.4
Tributary 1	0.09	5 %	4.6	4.6	4.6	4.6	4.4	4.4	4.4	4.4
Waiakea 7013	0.68	3 %	4.6	4.6	4.6	4.6	4.5	4.4	4.5	4.5

[a] Effective drainage area for runoff computations, topographic drainage area is 31.5 mi^2.
[b] A drainage area of 1.87 mi^2 was used for calibrating the November 2000 storm and for the frequency storm calculations of the 2%, 1%, 0.5%, and 0.2% storms. This additional area represents potential in-flow from the Kupulau Ditch from area outside the topographic drainage area for this sub-basin. The 1.63 mi^2 drainage area was used in the April 2004 storm calibration and in the frequency storm computations for the 50%, 20%, 10%, and 4% storms.

Table 7. HEC-HMS Frequency Storm Constant Loss Rates for Waiakea Stream Sub-Basins

Basin Characteristics			Constant Loss Rate (in/hr)							
Sub-basin	**Drainage Area (sq mi)**	**Imperv-iousness (%)**	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.2%**	**0.5%**
Hoaka 7006	12.2[a]	0 %	2.4	2.4	2.4	2.4	2.4	2.3	2.4	2.4
Kupulau Ditch	1.63[b]	0 %	2.4	2.4	2.4	2.4	2.2	2.3	2.2	2.2
Waiakea Town	0.47	5 %	2.4	2.4	2.4	2.4	2.2	2.3	2.2	2.2
Tributary 3	0.93	3 %	2.4	2.4	2.4	2.4	2.2	2.3	2.2	2.2
Tributary 2	0.28	5 %	2.4	2.4	2.4	2.4	2.2	2.3	2.2	2.2
Tributary 1	0.09	5 %	2.4	2.4	2.4	2.4	2.2	2.3	2.2	2.2
Waiakea 7013	0.68	3 %	2.4	2.4	2.4	2.4	2.2	2.4	2.2	2.2

[a] Effective drainage area for runoff computations, topographic drainage area is 31.5 mi^2.
[b] A drainage area of 1.87 mi^2 was used for calibrating the November 2000 storm and for the frequency storm calculations of the 2%, 1%, 0.5%, and 0.2% storms. This additional area represents potential in-flow from the Kupulau Ditch from area outside the topographic drainage area for this sub-basin. The 1.63 mi^2 drainage area was used in the April 2004 storm calibration and in the frequency storm computations for the 50%, 20%, 10%, and 4% storms.

Table 8. HEC-HMS Frequency Storm Snyder Unit Hydrograph Parameters for Waiakea Stream Sub-Basins

Basin Characteristics		**Snyder's Unit Hydrograph Parameters**	
Sub-Basin	**Drainage Area (mi^2)**	**Lag (hour)**	**Peaking Coefficient Cp**
Hoaka 7006	12.2 [a]	0.25	0.21
Kupulau	1.63 [b]	0.3	0.21
Waiakea Town	0.47	0.3	0.21
Tributary 3	0.93	0.5	0.21
Tributary 2	0.28	0.3	0.21
Tributary 1	0.09	0.3	0.21
Waiakea 7013	0.68	1.0	0.21

Table 9. HEC-HMS Frequency Storm Muskingum-Cunge Routing Parameters for Waiakea Stream Reaches

	Muskingham-Cunge Routing Parameters						**Percent Channel Flow Loss [c]**
Reach	**Length (feet)**	**Slope (feet/feet)**	**Manning's n**	**Shape**	**Width (feet)**	**Side Slopes**	
Upper	2600	0.028	0.045	Trapezoid	30	1H:1V	15
Main	8000	0.036	0.04	Trapezoid	35	1H:1V	20
Uka Channel	1700	0.015	0.04	Trapezoid	35	1H:1V	0
Komohana	500	0.03	0.03	Trapezoid	35	1H:1V	0
Lower	6000	0.04	0.045	Trapezoid	35	1H:1V	30/15 [d]

[c] Diversions of channel flows to represent losses due to the high permeability of the volcanic rocks in the stream channels.

[d] The lower channel loss of 15% was used for the November 2000 storm calibration and for the frequency storm calculations of the 2%, 1%, 0.5%, and 0.2% storms. The higher 30% loss was used in the April 2004 storm calibration and in the frequency storm computations for the 50%, 20%, 10%, and 4% storms

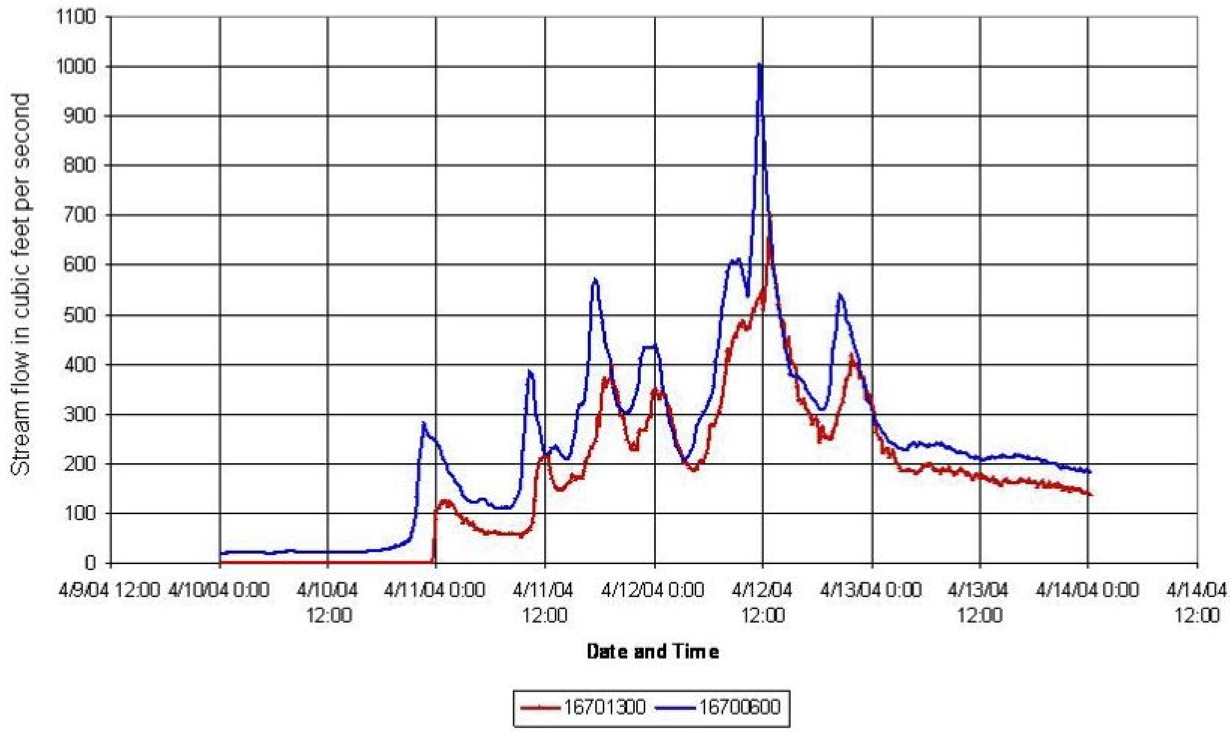


Figure 5. – Stream Flow Hydrographs, April 10-13, 2004, at USGS Stations 16700600 and 16701300 on Waiakea Stream

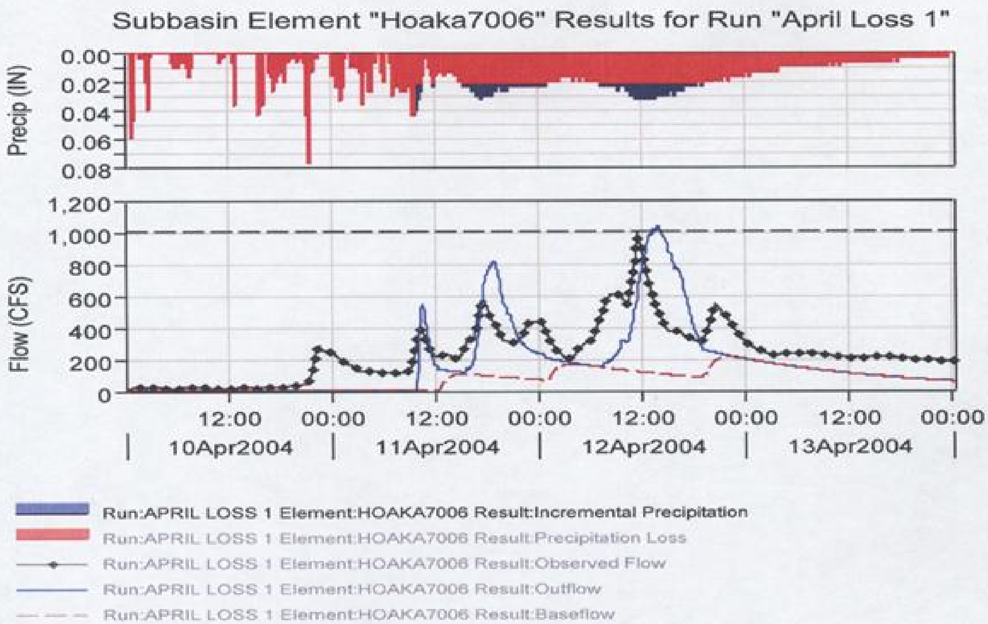


Figure 6. HEC-HMS Model Results versus Observed Data at USGS Station 16700600, Waiakea Stream near Hoaka Road, upstream end of Waiakea Stream Study Area, Hilo, Hawaii

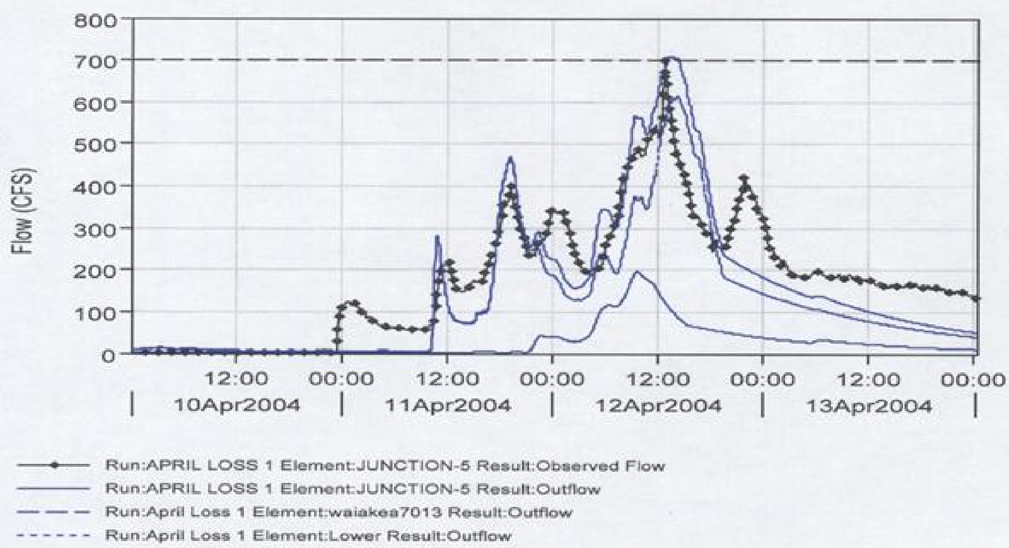


Figure 7. HEC-HMS Model Results versus Observed Data at USGS Station 16701300, Waiakea Stream near Hilo, downstream end of Waiakea Stream Study Area, Hilo, Hawaii

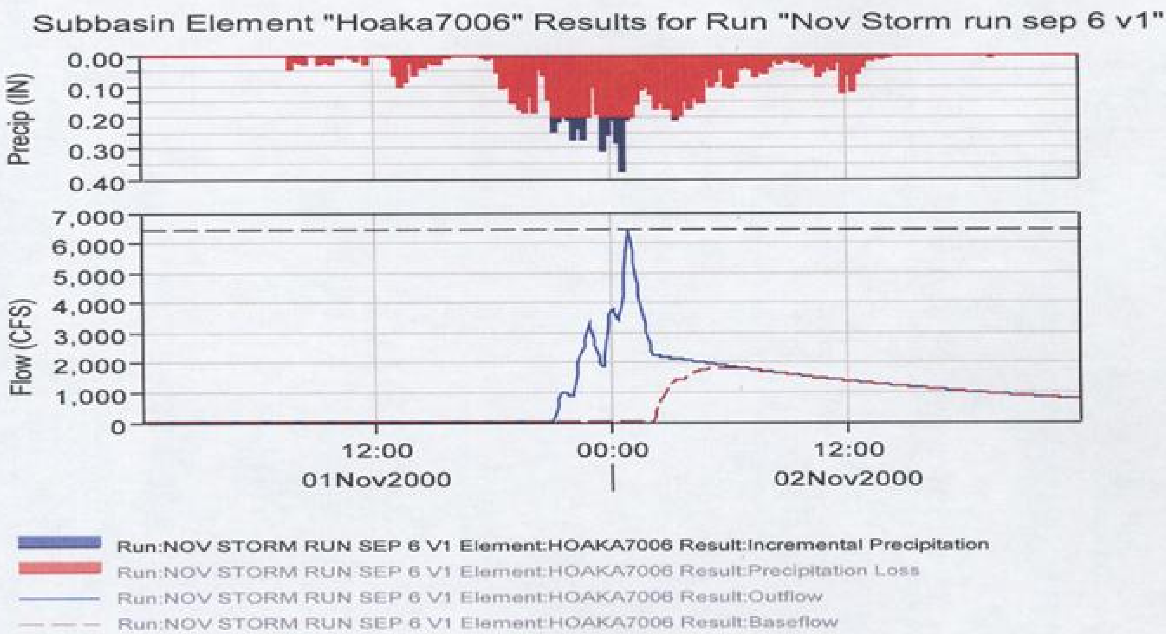


Figure 8. HEC-HMS Model Results at USGS Station 16700600, Waiakea Stream near Hoaka Road, upstream end of Waiakea Stream Study Area, Hilo, Hawaii for November 1-2, 2000 Storm Event

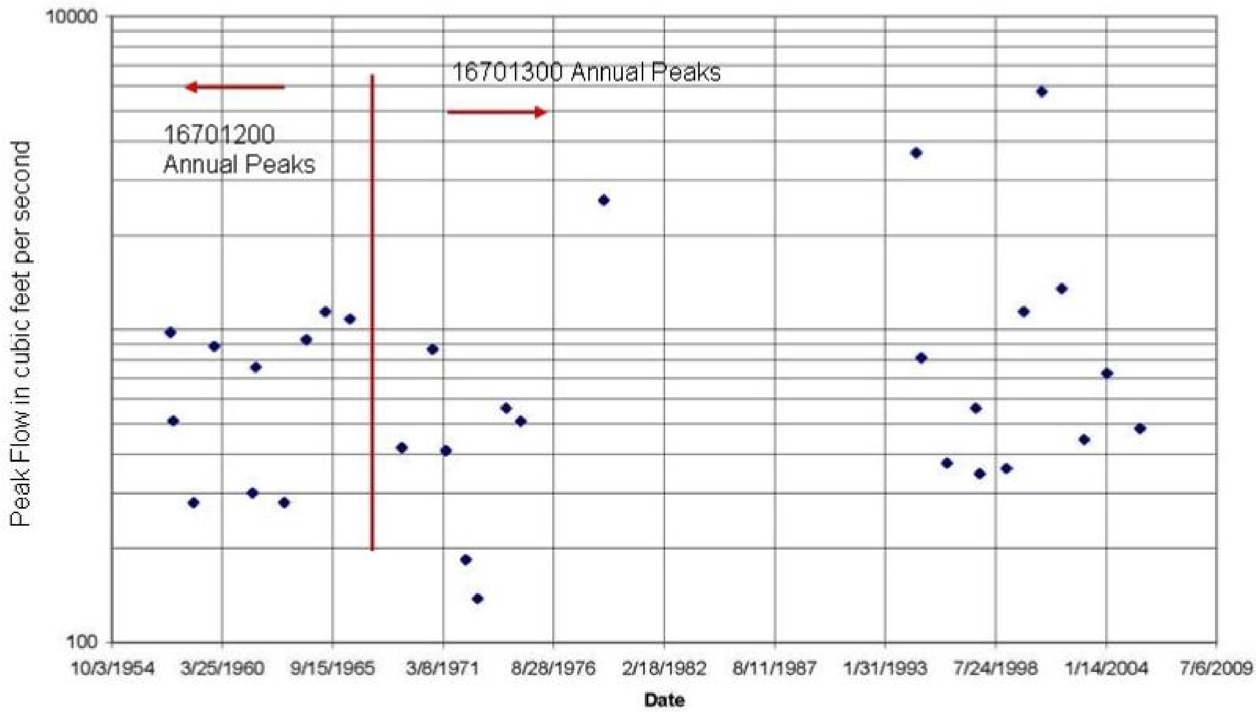


Figure 9. Annual Peak Flow Data at USGS Gage Stations 16701200 and 16701300, Waiakea Stream

2.5 Palai Stream and Four Mile Creek HEC-HMS Rainfall-Runoff Model. Similar to Waiakea Stream, a lumped basin watershed model was constructed using the HEC-HMS software program. Calibration of this model involves reconstituting basin parameters from past storms at Wailuku River because these records contain the closest continuous stream gage information to Palai Stream with complete rainfall and runoff data. These basin parameters are used in running a separate model with hypothetical storm rainfall to match the USGS gage station 16701400 statistics as described in Section 1.5.1, Runoff Characteristics. Further discussion on the USGS gage 16701400 gage statistics can be found in Section 2.7, Frequency Analysis. These basin parameters will then be compared to the historical peak, November 2000 storm within Palai Basin and Four Mile Creek for model continuity.

For this model, the hydrograph parameters selected are initial constant loss for rainfall runoff loss rates, Snyder's unit hydrograph for unit hydrograph determination, and lag time used for routing hydrographs from higher elevation watersheds through lower elevation watersheds with a slightly defined channel.

Snyder's peaking coefficient was estimated from the reconstitution of the Wailuku River for two storms, 26 August 1970 and 23 January 1979, using HEC-HMS. Values for Snyder lag in hours and the unit-less peaking coefficient were taken from the Alenaio Stream study (U.S. Army Corps of Engineers, 1990). The rainfall runoff loss method used was the initial constant method because it provided a fairly simple and straight-forward approach. The Alenaio Stream study (U.S. Army Corps of Engineers, 1990) used a former version of HEC-HMS, HEC-1, which contained a different method for the rainfall runoff loss function which is unavailable in HEC-HMS. The selection of the initial constant loss values for the reconstitution of the two storms used a “best-fit” or “optimized” value for each storm in generating the outputs for peak flow and discharge volume. Baseflow was considered negligible as runoff occurs only as a direct response to high intensity rainfall. The input and output values for the reconstitution of the two storms are shown in Table 10 and Table 11 respectively.

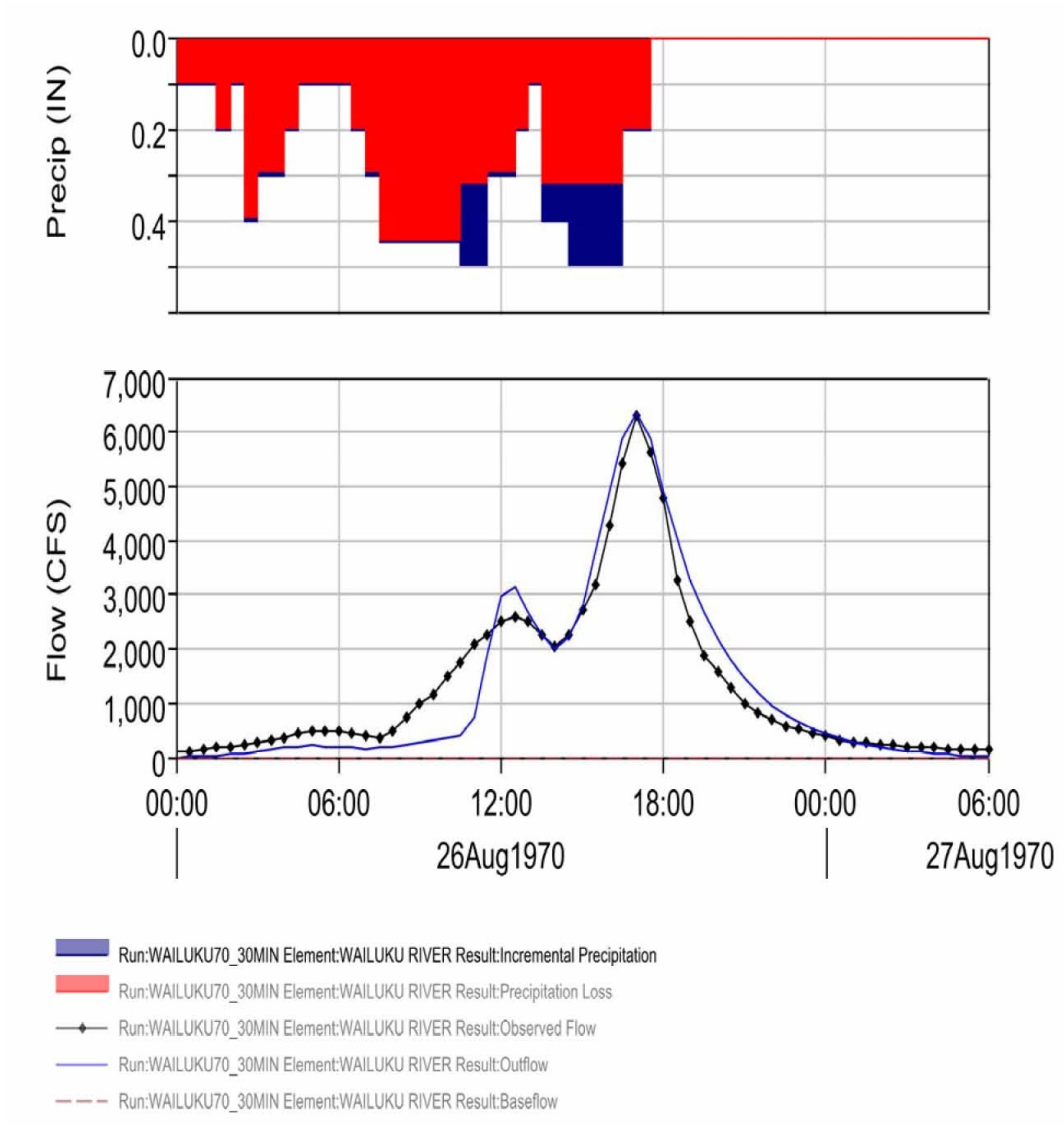
Table 10. Wailuku River Reconstitution: Input for 1970 and 1979 Storms

			Rainfall Runoff Parameters			Snyder Hydrograph Parameters from Alenaio Report March 1990	
Gage	**Date**	**Area (Sq mi)**	**Initial Loss (in)**	**Constant Loss (in)**	**% Impervious**	**Lag (hrs)**	**Cp, Peaking Coeff.**
Wailuku River near Kaumana (7018)	26Aug70	43.4	5.40 in	0.65 in	2%	1.30 hrs	0.41
	23Jan79	43.4	1.10 in	0.47 in	2%	2.40 hrs	0.49

Table 11. Wailuku River Reconstitution: Output for 1970 and 1979 Storms

		Qp, Peak Flow Output (ft^3/s; cfs)		Volume of Discharge (in)	
Gage	**Date**	**HMS Model Calc**	**Observed**	**HMS Model Calc**	**Observed**
Wailuku River near Kaumana (7018)	26Aug70	6,340	6,325	1.39 in	1.43 in
	23Jan79	5,630	5,690	1.75 in	1.75 in

Graphical output hydrographs and rainfall hyetographs for the reconstitution of these two storms are shown in Figure 10 and 11. From the reconstitution of the two storms for Wailuku River, the Snyder Peaking Coefficient, Cp, is assumed constant throughout the northeast windward territory of Hawaii which includes the Hilo District area. An average value of 0.45 for the Snyder Peaking Coefficient, Cp, will be used and applied to both Palai Stream and Four Mile Creek.

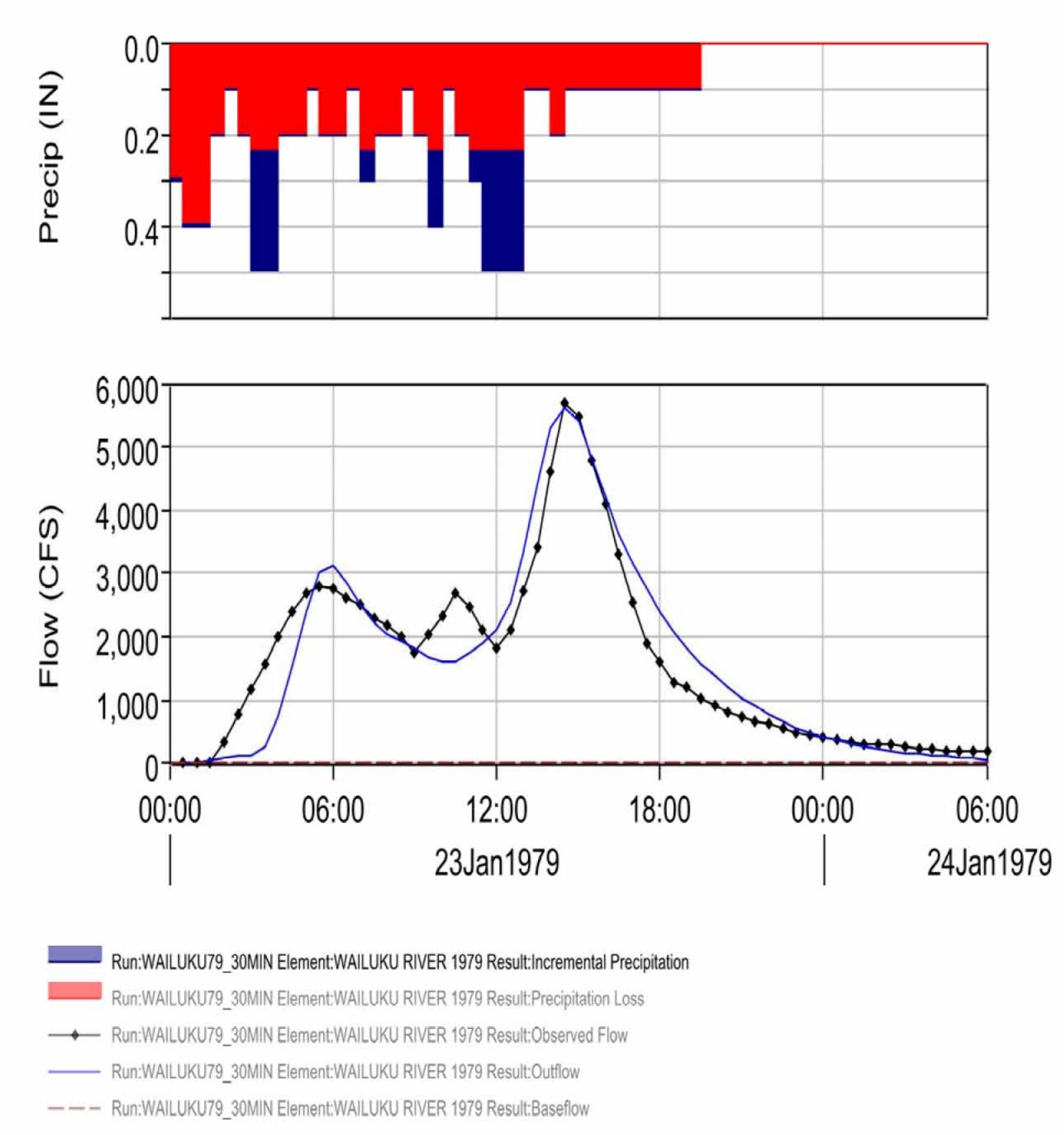


PALAI STREAM HILO, HAWAII

WAILUKU RIVER RECONSTITUITION FROM 1970 STORM

U.S. ARMY ENGINEER DISTRICT, HONOLULU

FIGURE 10. Flow Hydrograph Wailuku River from 1970 Storm



PALAI STREAM HILO, HAWAII

WAILUKU RIVER RECONSTITUITION FROM 1979 STORM

U.S. ARMY ENGINEER DISTRICT, HONOLULU

FIGURE 11. Flow Hydrograph Wailuku River from 1979 Storm

The initial constant loss rate for the HEC-HMS model is determined by a "best fit" method in achieving the peak flow rate from the USGS gage station 16701400 statistics. The frequencies used in the HEC-HMS model are from the statistical analysis of the gage station 16701400. The frequencies are the 50-, 10-, 4-, 2-, and 1- % ACP floods with peak flows of 565, 1,070, 1,360, 1,600, and 1,860 ft^3/s (from computation done in 2004), respectively. Based on information from Rick Fontaine (Hydrologist, U.S. Geological Survey, Oral Comm., 2002), and the Soil Survey (Sato and others, 1973), states that soil permeabilities in this region are between 2.0 to 6.0 in/hr aided in refining the rainfall loss amount. Rainfall losses are shown in Tables 12 to 15 with increasing constant loss rainfall from 50- to 1- % flood. The percentage impervious is measured and approximated from various maps.

Table 12. HEC-HMS Frequency Storm Initial Loss Rates for Palai Stream Sub-Basins

Basin Characteristics			Initial Loss Rate (in.)							
Sub-basin	**Drainage Area (sq mi)**	**Imperv-iousness (%)**	**50%**	**25%**	**10%**	**4%**	**2%**	**1%**	**0.2%**	**0.5%**
Upcountry P1	3.27	0 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
d/s Maunakai St P2	0.49	2 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
d/s Maunakai St P3	0.67	5 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hilo Golf Course P4	0.47	3 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Kanoelehua Ave P5	0.26	2 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Puainako St P6	1.65	10 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Waiakea Pond P7	0.85	10 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table 13. HEC-HMS Frequency Storm Constant Loss Rates for Palai Stream Sub-Basins

Basin Characteristics			Constant Loss Rate (in/hr)							
Sub-basin	**Drainage Area (sq mi)**	**Imperv-iousness (%)**	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.2%**	**0.5%**
Upcountry P1	12.2[a]	0 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
d/s Maunakai St P2	1.63[b]	0 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
d/s Maunakai St P3	0.47	5 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Hilo Golf Course P4	0.93	3 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Kanoelehua Ave P5	0.28	5 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Puainako St P6	0.09	5 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Waiakea Pond P7	0.68	3 %	3.28	2.4	4.45	4.64	4.96	5.14	5.35	5.6

Table 14. HEC-HMS Frequency Storm Initial Loss Rates for Four Mile Creek Sub-Basins

Basin Characteristics			Initial Loss Rate (in.)							
Sub-basin	**Drainage Area (sq mi)**	**Imperv-iousness (%)**	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.2%**	**0.5%**
Upcountry F1	2.41	0 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Tributary 2 F2	0.74	0 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Tributary3 F3	1.23	0 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
FourMile & Tributary 2 F4	0.39	1 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Tributary 1 F5	1.17	0 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Kilauea Ave F6	0.29	2 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Kanoelehua Ave F7	0.06	1 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Near quarry F8	0.92	1 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table 15. HEC-HMS Frequency Storm Constant Loss Rates for Four Mile Creek Sub-Basins

Basin Characteristics			Constant Loss Rate (in/hr)							
Sub-basin	**Drainage Area (sq mi)**	**Imperv-iousness (%)**	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.2%**	**0.5%**
Upcountry F1	2.41	0 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Tributary 2 F2	0.74	0 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Tributary3 F3	1.23	0 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Four Mile & Tributary 2 F4	0.39	1 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Tributary 1 F5	1.17	0 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Kilauea Ave F6	0.29	2 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6
Kanoelehua Ave F7	0.06	1 %	3.28	2.4	4.45	4.64	4.96	5.14	5.35	5.6
Near quarry F8	0.92	1 %	3.28	4.0	4.45	4.64	4.96	5.14	5.35	5.6

Using HEC-HMS, the hypothetical storms were modeled with the Snyder Peaking Coefficient value from the reconstitution of the Wailuku River storms as described. The Snyder Lag is approximated to be 60% of the time of concentration, Tc. The time of concentration is calculated from the travel time via sheet flow, shallow flow, and channel flow. Time of concentration and the time to peak, Snyder's Lag, are usually close in value to each other because storms on the Big Island tend to form hydrographs with sharp peaks with an immediate recession limb due to the steep slopes of the upper watershed areas; neither Tc nor Snyder's Lag duration are more than several hours apart. Snyder coefficients are found in Table 16 and 17.

The hydrograph routing method used is Lag time in minutes due to the lack of detailed information on the channel terrain. This Lag time is approximated by the time of travel within the channel from the start to exit points. This information can be found in Tables 16 and 17. See Figure 12 for the HEC-HMS Model setup.

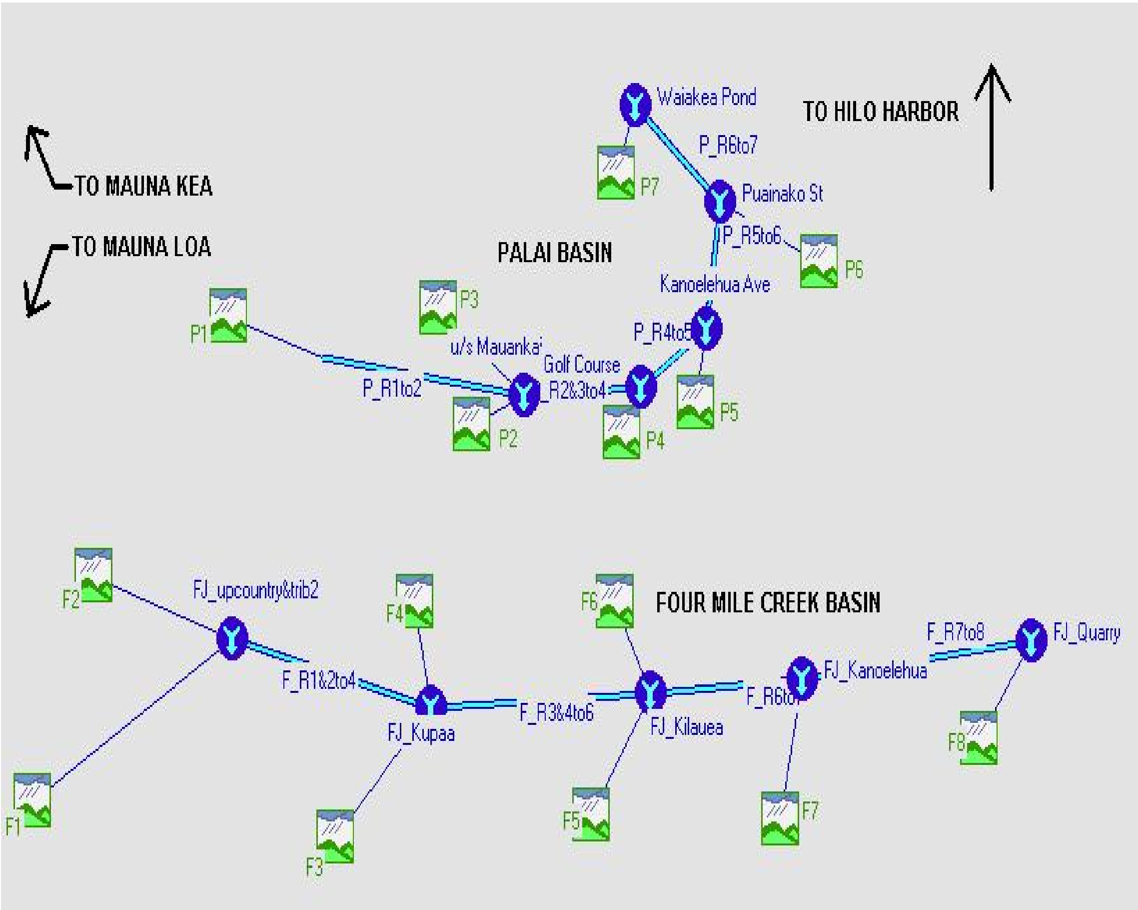
Once the Palai Basin (summation of P1 to P7) input matches output values for the USGS gage station 16701400, the same initial and constant loss rates are applied to Four Mile Creek. Baseflow is considered negligible as runoff occurs only as a direct response to high intensity rainfall. See Table 19 and 20, HEC-HMS output Model for Hypothetical Storms.

Table 16. HEC-HMS Input Model for Palai Stream Sub-Areas (Runoff Transform and Routing)

Palai Sub-Area	**Drainage Area (sq mi)**	**Snyder Lag, Tp (hrs)**	**Snyder Peaking Coefficient, Cp**	**Reach, Lag Method (min)**
P1 Upcountry Palai	3.27 sq mi	1.61 hrs	0.45	
P_R1to2				32.00 min
P2 d/s Maunakai Street	0.49 sq mi	0.32 hrs	0.45	
P3 d/s Maunakai Street	0.67 sq mi	0.17 hrs	0.45	
J_d/s Maunakai Street	**4.43 sq mi**			
P_R2&3to4				4.00 min
P4 Hilo Golf Course	0.47 sq mi	0.10 hrs	0.45	
J_Hilo Golf Course	**4.90 sq mi**			
P_R4to5				3.00 min
P5 Kanoelehua Ave	0.26 sq mi	0.10 hrs	0.45	
J_Kanoelehua Ave	**5.16 sq mi**			
P_R5to6				11.00 min
P6 Puainako Street	1.65 sq mi	0.11 hrs	0.45	
J_Puainako Street	**6.81 sq mi**			
P_R6to7				16.00 min
P7 Waiakea Pond	0.85 sq mi	0.15 hrs	0.45	
J_Waiakea Pond	**7.66 sq mi**			

Table 17. HEC-HMS Input Model for Four Mile Creek Sub-Areas (Runoff Transform and Routing)

Four Mile Creek Sub-Area	Drainage Area (sq mi)	Snyder Lag, Tp (hrs)	Snyder Peaking Coefficient, Cp	Reach, Lag Method (min)
F1 Upcountry 4Mi	2.41 sq mi	0.99 hrs	0.45	
F2 Trib2	0.74 sq mi	0.44 hrs	0.45	
F_R1&2to4				7.00 min
F3 Trib3	1.23 sq mi	1.03 hrs	0.45	
F4 4Mi&Trib2	0.39 sq mi	0.10 hrs	0.45	
FJ_Kupaa Street	**4.77 sq mi**			
F_R3&4to6				7.00 min
F5 Trib1	1.17 sq mi	0.84 hrs	0.45	
F6 Kilauea Ave	0.29 sq mi	0.10 hrs	0.45	
FJ_Kilauea Ave	**6.23 sq mi**			
F_R6to7				0.00 min
F7 Kanoelehua Ave	0.06 sq mi	0.10 hrs	0.45	
FJ_Kanoelehua Ave	**6.29 sq mi**			
F8 Near Quarry	0.92 sq mi	0.10 hrs	0.45	
F_R7to8				7.00 min
FJ_Near Quarry	**7.21 sq mi**			



EXISTING CONDITION: HEC-HMS PALAI AND FOUR MILE CREEK BASIN MODEL

PALAI STREAM HILO, HAWAII

EXISTING CONDITION:
HEC-HMS MODEL
Palai Stream and Four Mile Creek

U.S. ARMY ENGINEER DISTRICT, HONOLULU

FIGURE 12. HEC-HMS Model Schematic Palai Stream and Four Mile Creek

The November 1-2, 2000 storm resulted in a peak flow of 1,580 ft^3/s at USGS gage station 16701400 which is about a 2% AEP flood according to the gage statistics. This gage location corresponds to Palai Basin (summation of P1 to P5) junction at Kanoelehua Avenue in Figure 12. The 1,580 ft^3/s peak is the highest recorded at this location since data collection began in 1965. The previous peak of record was 1,260 ft^3/s from the 1979 storm. Figure 13 shows the observed precipitation data for the meteorological and control model received from the Waiakea Uka rain gage on November 1-2, 2000 located at latitude 19 degrees, 40 minutes north, and longitude 155 degrees, 8 minutes west. The input for the 1-2 November 2000 storm over the Palai Basin in HEC-HMS is the same as in Tables 12 to 15 except for the constant loss rate. A constant loss rate of 2.36 inches per hour was used for the November 2000 storm to produce a peak flow of 1,580 ft^3/s at the USGS gage station 16701400 location. Table 18 compares the hypothetical storms with the November 2000 storm. From Table 18, the constant loss rate of 2.36 inches per hour for the November 2000 storm shows that the rainfall frequency is less than the 50-percent hypothetical storm constant loss rate. However, when comparing peak flows at the USGS gage station 16701400, the November 2000 storm is about a 2% AEP flood. One other point of notice is the volume of 725 acre-feet for the November 2000 storm which is larger than the volume of the 1% hypothetical storm. The conclusion from this is that the November 2000 storm had a different storm pattern than the hypothetical storms. However, the model still was able to portray the hypothetical and November 2000 storm patterns by varying the constant loss rates. The output for the 1-2 November 2000 storm over Palai Basin and Four Mile Creek Basin in HEC-HMS is shown in Tables 19 and 20 respectively.

Table 18. HEC-HMS Model: Comparison of Hypothetical vs November 2000 Storm

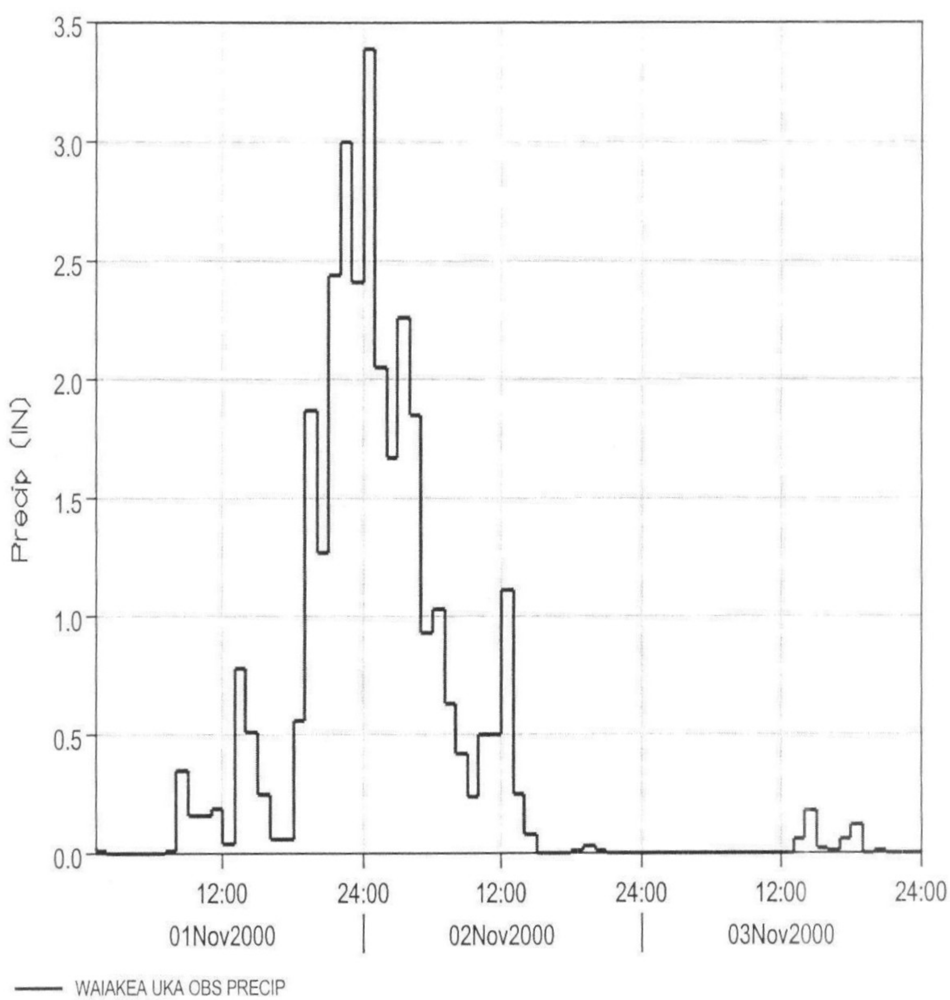
Description	Hypothetical Storm Frequency Flood					Nov 2000 Flood
	1%	2%	4%	10%	50%	
All Palai Sub-Areas Constant Loss Rate (in/hr)	5.14 in/hr	4.96 in/hr	4.64 in/hr	4.45 in/hr	3.28 in/hr	2.36 in/hr
J_Kanoelehua Ave Peak Flows (ft^3/s) DA=5.16 sq. mi.	1,860 ft^3/s	1,600 ft^3/s	1,360 ft^3/s	1,070 ft^3/s	565 ft^3/s	1,580 ft^3/s
J_Kanoelehua Ave Volume (ac-ft) DA=5.16 sq. mi.	690 ac-ft	595 ac-ft	505 ac-ft	400 ac-ft	210 ac-ft	725 ac-ft

Table 19. HEC-HMS Output Model for 1-2 November 2000 Storm at Palai Basin

Description	Drainage Area (sq mi)	Discharge Peak (ft3/s)	Volume (ac-ft)
J_ u/s Maunakai	4.43	1,290	605
J_Golf Course	4.90	1,480	685
J_Kanoelehua Ave	5.16	1,580	725
J_Puainako Street	6.81	2,450	1,180
J_Waiakea Pond	7.66	2,840	1,410

Table 20. HEC-HMS Output Model for 1-2 November 2000 Storm at Four Mile Creek

Description	Drainage Area (sq mi)	Discharge Peak (ft3/s)	Volume (ac-ft)
FJ_Upcountry&Trib2	3.15	1,240	385
FJ_Kupaa	4.77	1,860	585
FJ_Kilauea	6.23	2,420	770
FJ_Kanoelehua	6.29	2,450	780
FJ_Quarry	7.21	2,790	905



DATA USED IN METEOROLOGIC AND CONTROL MODEL

PALAI STREAM HILO, HAWAII

WAIAKEA UKA RAIN GAGE OBSERVED PRECIPITATION, 1-2 NOVEMBER 2000

U.S. ARMY ENGINEER DISTRICT, HONOLULU

FIGURE 13. November 2000 Storm Observed Precipitation Waiakea Uka Rain Gage

2.6 Frequency Analysis.

2.6.1 Recorded Data. The statistical frequency analysis was conducted following Bulletin 17B guidelines which use the Log-Pearson Type III method to compute frequency flows (Interagency Committee on Water Data, 1982). Annual flood peaks from Waiakea Stream at USGS gage stations 16701200 and 16701300 were combined to compute a single frequency curve which was assigned to the station 16701300 site for “best estimate” comparison purposes. This was done based on fact that the drainage area differences between the two stations is less than 10 percent (Thomas, 2001) and a comparison of flood peaks from these two stations over time (Figure 9) showed that the two annual series of peaks are not disparate. Frequency analysis on data from USGS gage station 16700000 was not done since such data are not representative of the flood frequency near the detailed study area. Frequency analysis on data from USGS gage station 16701400 was done for Palai Stream. There are no stream gages located on Four Mile Creek. The program HEC-SSP which follows the Bulletin 17B guidelines was used to conduct the frequency calculations. Results are shown in Tables 21 and 22.

A comparison of flood peaks on the same date between USGS gage stations 16700600 and 16701300 indicated that flood peaks were about 11 to 118 percent greater on average at USGS gage station 16700600 due to peak flow attenuation with a higher percentage loss at lower peak flows (Table 4). Therefore, an adjustment of adding 11 percent to the flood frequency values at USGS gage station 16701300 were assigned as the flood frequency values at Station USGS gage station 16700600, based on the peak flow of November 1-2, 2000. By a simple drainage area ratio adjustment, the values at USGS gage station 16700600 would be increased by about 13 percent, a similar amount. Flood frequency estimates were not transferred to other locations in the detailed study area due to the inability to properly account for tributary inflow and stream channel losses in those areas by frequency analysis.

Table 21. Peak Flow Frequency Values computed at Station 16701300 and estimated at Station 16700600 Waiakea Stream, Hilo, Hawaii

Percent Chance Exceedance	Recurrence Interval (years)	Station 16701300 Peak Flow Computation (ft^3/s)	95% Confidence Limits for Peak Flow Estimate at Station 16701300		Adjusted Peak Flow Estimate for Station 16700600 (ft^3/s)
			Lower (ft^3/s)	Upper (ft^3/s)	
50%	2	645	510	816	716
20%	5	1,400	1,070	1,850	1,550
10%	10	2,130	1,550	2,960	2,370
5%	25	3,070	2,110	4,440	3,410
2%	50	4,720	2,970	7,090	5,240
1%	100	6,370	3,740	9,760	7,070
0.5%	200	8,470	4,630	13,100	9,400
0.2%	500	12,100	6,000	19,000	13,500
Peak flow values at Station 16701300 computed by procedures in Bulletin 17B using 39 events between					

1964 and 2013 from Stations 16701200 and 16701300, mean=2.819, standard deviation=0.381, and adjusted skew=0.150. Values at Station 16700600 were estimated by increasing the Station 16701300 values by 11 percent.

Annual flood peaks from Palai Stream were recorded from a peak-stage stream gage, USGS gage station 16701400. The analysis uses 23 events between 1965 and 2013 to determine the peak frequency flows. Table 22 below summarizes the annual exceedance probability flows using an adopted skew of -0.499, a standard deviation of 0.392, and a mean of 2.645. The analysis results in Table 22 are more recent and differ from that presented in Table 18 due to additional peak flow data. It does not change the calibration results in Section 2.6.

Table 22. Peak Frequency Values computed at Station 16701400, Palai Stream, Hilo, Hawaii (computation conducted in 2014)

Percent Chance Exceedance	Recurrence Interval (years)	Station 16701400 Peak Flow Computation (ft^3/s)	95% Confidence Limits for Peak Flow Estimate at Station 16701400	
			Lower (ft^3/s)	Upper (ft^3/s)
50%	2	476	347	658
20%	5	981	688	1,470
10%	10	1,385	923	2,190
5%	25	1,820	1,150	2,980
2%	50	2,430	1,430	4,140
1%	100	2,940	1,640	9,760
0.5%	200	3,470	1,850	6,080
0.2%	500	4,210	2,110	7,450

The Flood frequency Analysis information provided in this section will be updated with new data available. The brief review of current data indicates that some gages may have been relocated and missing data exists in the interim years. A new Bulletin 17C analysis will be performed with quality assurance check of available data during design stage to make sure that the model reflects the current realities on the watershed.

2.6.2 Synthetic Event Analysis. Rainfall intensity frequency data for the study area was obtained by the use of the National Oceanic and Atmospheric Administration Atlas 14 entitled "Precipitation-Frequency Atlas of the United States" (NOAA Atlas 14). Volume 4, Version 3 of this atlas, first published in 2009 and revised in 2011 contains precipitation frequency estimates for the Hawaiian Islands. These estimates for selected durations and frequencies with 90% confidence intervals and supplementary information on temporal distribution of annual maxima, analysis of seasonality, and trends in maximum series data. The results are published through the Precipitation Frequency Data Server which can be accessed at: http://hdsc.nws.noaa.gov/hdsc/pfds.

An interactive web page for the Hawaiian Islands is available from the PFDS web page - http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_hi.html. Several options are available to obtain the precipitation information. For this study, the centroidal point of the combined

Waiakea-Palai-Four Mile watersheds was manually entered. This point, in decimal latitude and longitude is: N19.6088 and W-155.2197. The interactive web page then returns the precipitation frequency data for this point. Table 23 below shows the selected rainfall frequency intensity data used in this study.

Table 23. Rainfall Intensity Frequency Data for the Waiakea-Palai Study Area, Area Averaged between Elevations 0 to 4,000 feet, Hilo, Hawaii

	Depth (inches) for specified percent chance exceedance flood rainfall								
	100%	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Duration	**1 year**	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**
5 min	0.68	0.82	1.01	1.14	1.31	1.43	1.55	1.67	1.83
10 min	1.01	1.22	1.49	1.69	1.94	2.13	2.30	2.48	2.71
15 min	1.27	1.53	1.87	2.12	2.44	2.67	2.89	3.12	3.40
30 min	1.78	2.15	2.64	2.99	3.43	3.76	4.07	4.39	4.79
1 hour	2.34	2.83	3.47	3.93	4.51	4.94	5.35	5.77	6.30
2 hour	3.26	4.02	5.01	5.75	6.69	7.40	8.09	8.79	9.71
3 hours	3.85	4.85	6.08	7.00	8.19	9.08	9.96	10.80	12.00
6 hours	5.22	6.49	8.24	9.56	11.3	12.6	13.9	15.2	17.0
12 hours	6.92	8.70	11.1	13.0	15.5	17.4	19.4	21.4	24.1
24 hours	8.99	11.5	14.8	17.4	20.9	23.6	26.4	29.3	33.3

Rainfall frequency estimates in this table are based on frequency analysis of partial duration series. NOAA Atlas 14 Volume 4 Version 3 Precipitation-Frequency Atlas of the United States, Hawaiian Islands. NOAA, National Weather Service, Silver Spring, MD (2011). NOAA Atlas 14 provides precipitation frequency estimates for 5-minute through 60-day durations at average recurrence intervals of 1-year through 1000-year.

Flood estimates for the 50%, 20%, 10%, 4%, 2%, 1%, 0.5%, 0.2% AEP (the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year floods) flood events were determined by using the calibrated HEC-HMS models. A comparison of the recorded data from the April 10-13, 2004 and November 1-2, 2000 storm events with rainfall and peak flow frequency values (discussed in detail below) indicated that the April 10-13, 2004 event was about a 99% AEP (1-year) event in rainfall magnitude and about a 50% AEP (2-year) storm in peak flow magnitude at USGS gage station 16701300 (Tables 23 and 24). The November 1-2, 2000 event was closer to a 1% AEP (100-year) event for both the rainfall and peak flow frequencies (Tables 4 and 21). Therefore, to better represent the assumption that the resulting peak flow has the same frequency as the rainfall input, the November 1-2, 2000 calibrated basin values for Waiakea Stream were used, with one exception, for the frequency storm computations.

The exception was determined by comparing the rainfall intensity values of the November 1-2, 2000 storms to the intensity-frequency rainfall (Tables 23 to 25). Rainfall values for the 50%, 20%, 10%, and 4% AEP storms tend to have higher intensities for the 15 minute, 30 minute, 1-, 2-, 3-hour rainfall depths than were recorded for the November 1-2, 2000 storm. Therefore, the calibrated model would overestimate storms with lower recurrence intervals (50%, 20%, 10%, and 4%) due to higher rainfall inputs then actually observed. To correct this problem, the 50%, 20%, 10%, and 4% AEP peak flow computations were done using the November 1-2, 2000 model parameters with the initial and constant soil losses increased to 4.6 and 2.4 inches for all sub-basins.

The 2%, 1%, 0.5%, and 0.2% AEP peak flow computations were done with the November 1-2, 2000 basin parameters as shown in Table 5. The frequency storm method was used with a 50% storm centering and a 150 square mile storm area. This area was chosen based on the area of high intensity rainfall from the November 1-2, 2000 storm (Fontaine and Hill, 2002). Results of the HEC-HMS frequency storm computations at various flow junctions for Waiakea Stream are shown in Table 26. An accuracy value of about 25 equivalent years of record was assigned to these values.

Table 24. Rainfall intensity duration data from recorded rainfall data at Waiakea Uka and Hilo Airport Raingages, Hilo, Hawaii

	November 1-2, 2000 Storm		April 10-12, 2004 Storm	
Duration	**Waiakea Uka**	**Hilo Airport**	**Waiakea Uka**	**Hilo Airport**
15 min	1.13	----	0.13	----
30 min	1.98	----	0.36	----
1 hour	3.38	4.49	0.48	1.23
2 hour	5.81	7.87	0.77	2.16
3 hours	8.78	9.86	1.14	2.70
6 hours	14.8	15.69	2.15	4.89
12 hours	23.78	22.47	3.82	7.04
24 hours	29.38	27.24	7.01	10.82

On Palai Stream, the November 2000 rainfall amounts are less than the 100% (1-year) flood for the 15-min duration. The November 2000 rainfall amounts are about equal to the 100% flood for the 30-min duration, 10% flood for the 2-hour duration, and slightly greater at the 4% flood for a 3-hour duration. The November 2000 rainfall amounts are greater than the 1% flood for durations of 6-, 12-, and 24-hours.

Table 25. Depth (in) for Specified Percent Chance Exceedance Flood Rainfall Compared to Storm of November 1, 2000

Duration	Depth (in) for specified percent chance exceedance flood rainfall						
	100%	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**Nov 2000**
15 min	1.27	1.53	1.87	2.12	2.44	2.67	2.89	1.1
30 min	1.78	2.15	2.64	2.99	3.43	3.76	4.07	1.8
1 hour	2.34	2.83	3.47	3.93	4.51	4.94	5.35	3.2
2 hour	3.26	4.02	5.01	5.75	6.69	7.40	8.09	5.8
3 hours	3.85	4.85	6.08	7.00	8.19	9.08	9.96	8.8
6 hours	5.22	6.49	8.24	9.56	11.3	12.6	13.9	15
12 hours	6.92	8.70	11.1	13.0	15.5	17.4	19.4	24.3
24 hours	8.99	11.5	14.8	17.4	20.9	23.6	26.4	29.7

Synthetic storm discharges for the selected frequencies were developed using calibrated HEC-HMS basin models and the NOAA Atlas 14 rainfall estimates. The peak center of the storms was set at 50%. A 24-hour storm period was selected with a rainfall intensity of 5 minutes. The storm area for Waiakea Stream was 150 square miles, while Palai Stream and Four Mile Creek were combined for a storm area of 11.56 square miles. The control model uses a 5 minute time step on Waiakea Stream and a 15 minute time step on Palai Stream/Four Mile Creek to simulate the hypothetical rainfall for a storm duration of 24 hours. Tables 26 to 28 summarize the annual exceedance probability peak flows using the HEC-HMS model for hypothetical events for Waiakea Stream, Palai Stream, and Four Mile Creek.

Table 26. Peak Flow Discharge Frequency Values (cubic feet per second) determined by HEC-HMS Model, Waiakea Stream, Hilo, Hawaii

Flow Concentration Location	Percent Chance Exceedance							
	50	**20**	**10**	**4**	**2**	**1**	**0.5**	**0.2**
Hoaka Road, 7006	1,950	2,960	3,840	5,080	6,170	8,070	9,230	11,400
Kupulau Road, J1	1,880	2,840	3,680	4,860	6,090	7,710	9,100	11,200
Waikaea Town, J2	1,630	2,470	3,220	4,260	5,340	6,790	8,090	9,940
Uka Channel, J3	1,660	2,510	3,250	4,280	5,440	6,920	8,240	10,200
Komohana Street, J4	1,660	2,520	3,270	4,310	5,490	6,960	8,300	10,200
Station 7013, J5	1,170	1,790	2,310	3,050	4,710	4,950	7,150	8,830

Table 27. Peak Flow Discharge Frequency Values (cubic feet per second) determined by HEC-HMS Model, Palai Stream, Hilo, Hawaii

Flow Concentration Location	Percent Chance Exceedance							
	50	**20**	**10**	**4**	**2**	**1**	**0.5**	**0.2**
u/s Mauankai	421	641	797	1,040	1,160	1,310	1,450	1,630
Golf Course	548	833	1,040	1,350	1,510	1,700	1,890	2,120
Kanoelehua Ave	590	898	1,120	1,460	1,630	1,830	2,040	2,290
Puainako St	1,110	1,660	2,050	2,630	2,940	3,290	3,640	4,080
Waiakea Pond	1,350	2,000	2,470	3,160	3,520	3,940	4,370	4,890

Table 28. Peak Flow Discharge Frequency Values (cubic feet per second) determined by HEC-HMS Model, Four Mile Creek Stream, Hilo, Hawaii

Flow Concentration Location	Percent Chance Exceedance							
	50	**20**	**10**	**4**	**2**	**1**	**0.5**	**0.2**
Upcountry & Trib2	410	637	799	1,060	1,190	1,340	1,490	1,680
Kupaa	597	927	1,160	1,540	1,720	1,950	2,170	2,450
Kilauea	781	1,210	1,520	2,010	2,250	2,540	2,840	3,200
Kanoelehua Ave	790	1,230	1,540	2,030	2,280	2,570	2,870	3,230
Quarry	880	1,360	1,710	2,260	2,530	2,860	3,180	3,590

2.6.3 Regional Data. Two sets of regional regression equations to estimate peak flows based on drainage basin characteristics were created for the Island of Hawaii. One set published by the FEMA for the flood insurance study (Federal Emergency Management Agency, 2004), covered the windward or northeast side of Hawaii. Peak flows with recurrence intervals of 50% to 1% AEP (2 to 100 years) were related to two independent variables, drainage area in square miles and mean annual precipitation in hundreds of inches. These equations were first created in 1977 and have standard errors of 102 to 106 percent and coefficient of determinations of 0.79 to 0.80 (Ewart, C.J., Hydrologist, U.S. Geological Survey, written communication, 1977). The second set was published by the U.S. Army Corps of Engineers for the Alenaio Flood Control Project (U.S. Army Corps of Engineers, 1990). These equations relate the 50%, 10%, 2%, 1%, and 0.2% chance exceedance floods for 23 various streams of data along the windward northeast portion of the Island of Hawaii to drainage area in square miles. The standard errors for these equations ranged from 0.425 to 0.590 log units with coefficient of determinations of 0.50 to 0.69. Both sets of equations are considered outdated based on the revision of peak flow records for the Island of Hawaii conducted by the USGS in the 1990s which discredited some peak flow data used to create the two sets of regression equations and also by the fact that neither set of equations account for the extreme runoff event of November 2000. Therefore, neither set of equations was deemed worthwhile to use in this analysis. A newer set of regional regression equations was published by the USGS in 2010 (Oki and others, 2010). This study created new regional peak-flow regression equations for the State of Hawaii using updated peak flow data frequency analysis. The equations covering this study area, called Hawaii, Southern, had standard errors for these equations ranging from 140 to 150 percent with coefficient of determinations of 0.17 to 0.38 and used the maximum 48-hour precipitation that occurs on average once in 5 years as an independent variable. Based upon the large error in these equations and the fact that the HEC-HMS modeling was considered more accurate, no peak flow estimates were made using the latest regional regression equations for this study.

2.7 County of Hawaii Storm Drainage Standards. The County of Hawaii (1970) storm drainage standards specify the use of the Rational Method for areas of 100 acres (0.16 square miles) and less and the Plate 6 design curve for areas greater than 100 acres. The Rational Method was not applied even though Tributary One to Waiakea Stream had a drainage area of 0.09 square miles, since the interest of this computation was in the larger flow concentration areas. There were no areas in Palai Stream or Four Mile Creek that met this criteria. The Zone C Plate 6 design curve was used. This curve approximates only the 1% AEP flood and is related to drainage area (The County of Hawaii, 1970). Results are shown in Tables 29 to 31 and show that using a strict topographic drainage area results in very high values of peak flows. The use of “effective” drainage area in the Waiakea Basin, in this case, computing drainage area only below the 3,000 foot elevation, results in more reasonable estimates when compared to the other methods (Tables 21 and 26). No accuracy is provided with Plate 6 but it is assumed to be equivalent to 10 years of record (Interagency Committee on Water Data, 1982, p.21).

Table 29. Peak Flow Discharge Values determined by Plate 6 in County of Hawaii Storm Drainage Standards, Waiakea Stream, Hilo, Hawaii

Flow Concentration Location and Junction Number	Topographic Drainage Area (mi²)	Topographic Drainage Area (in 100 acres)	Plate 6 Discharge (ft³/s)	Effective Drainage Area (mi²)	Effective Drainage Area (in 100 acres)	Plate 6 Discharge (ft³/s)
Hoaka Road	31.5	202	10,500	12.2	77.8	6,500
Kupulau Road, J1	33.16	212	10,500	13.78	88.2	7,000
Waikaea Town, J2	34.56	221	10,700	15.18	97.2	7,500
Uka Channel, J3	34.84	223	10,700	15.46	98.9	7,500
Komohana Street, J4	34.93	224	10,800	15.55	99.5	7,600
Station 7013, J5	35.61	228	11,000	16.23	104	7,600

Table 30. Peak Flow Discharge Values determined by Plate 6 in County of Hawaii Storm Drainage Standards, Palai Stream, Hilo, Hawaii

Flow Concentration Location and Junction Number	Topographic Drainage Area (mi²)	Topographic Drainage Area (in 100 acres)	Plate 6 Discharge (ft³/s)
J_ u/s Maunakai	4.43	28.4	3,900
J_Golf Course	4.90	31.4	4,200
J_Kanoelehua Ave	5.16	33.0	4,400
J_Puainako Street	6.81	43.6	8,150
J_Waiakea Pond	7.66	49.0	11,000

Table 31. Peak Flow Discharge Values determined by Plate 6 in County of Hawaii Storm Drainage Standards, Four Mile Creek, Hilo, Hawaii

Flow Concentration Location and Junction Number	Topographic Drainage Area (mi²)	Topographic Drainage Area (in 100 acres)	Plate 6 Discharge (ft³/s)
FJ_Upcountry&Trib2	3.15	20.2	3,100
FJ_Kupaa	4.77	30.5	4,100
FJ_Kilauea	6.23	39.9	4,700
FJ_Kanoelehua	6.29	40.3	4,750
FJ_Quarry	7.21	46.1	5,100

2.8 Comparison of Methods and Selection of Best Estimates. The selection of the "best" estimate was done by comparing the various derived discharge-frequency curves graphically and by the accuracy or uncertainty of each method along with engineering judgment. On Waiakea Stream, comparisons of the peak flow determinations were done for the upstream end (sub-basin Hoaka7006) and the downstream end at USGS gage station 16701300, (Junction 5) in the model. Based on the comparison at the upstream end, the HEC-HMS derived values were higher for the lower recurrence intervals and lower for the higher recurrence intervals. At USGS gage station 16701300, the HEC-HMS derived values were higher for the lower recurrence intervals (50%, 20%, and 10% AEP) but fit well with the 4% and 2% AEP events, and underestimated the other methods for the higher recurrence intervals. However, with the exception of the 50% AEP recurrence interval, the HEC-HMS derived values were within the lower and upper bounds of the frequency curve. The discharge values for the lower and higher recurrence interval events were adjusted using the differences in discharge as a percent to obtain a better fit. Tables 32 and 33 show the comparison between the gage statistics and the HEC-HMS output. There is a significant interbasin flow exchange between Waiakea Stream and Palai Stream during storm events when flow exceeds the capacity of Waiakea Stream and flows into Palai Stream after overtopping the Kupulau Ditch. This interbasin transfer is not accounted for in the HEC-HMS model but has been modeled in the HEC-RAS hydraulics model for this study (see Hydraulic Appendix). For this reason, the adjusted HEC-HMS discharge values were adopted for use in this study. The final selected "best" estimates of peak flows in the Waiakea study area are shown in Table 34 and assigned an equivalent years of record (EYOR) of 25 years based on engineering judgment following guidance in Department of the Army (1996). The EYOR value is used as part of the economic analysis in the HEC-FDA program, see Economic Appendix for more details.

Table 32. Peak Flow Frequency comparison between Bulletin 17B analysis and HEC-HMS model at Station 16700600 Waiakea Stream, Hilo, Hawaii

Percent Chance Exceedence	**Recurrence Interval (years)**	**Station 16700600 Adjusted Estimate Peak Flow (ft^3/s)**	**HMS Model Result Hoaka 7006**
50%	2	720	1,950
20%	5	1,550	2,960
10%	10	2,370	3,840
4%	25	3,410	5,080
2%	50	5,240	6,170
1%	100	7,070	8,070
0.5%	200	9,400	9,230
0.2%	500	13,500	11,400

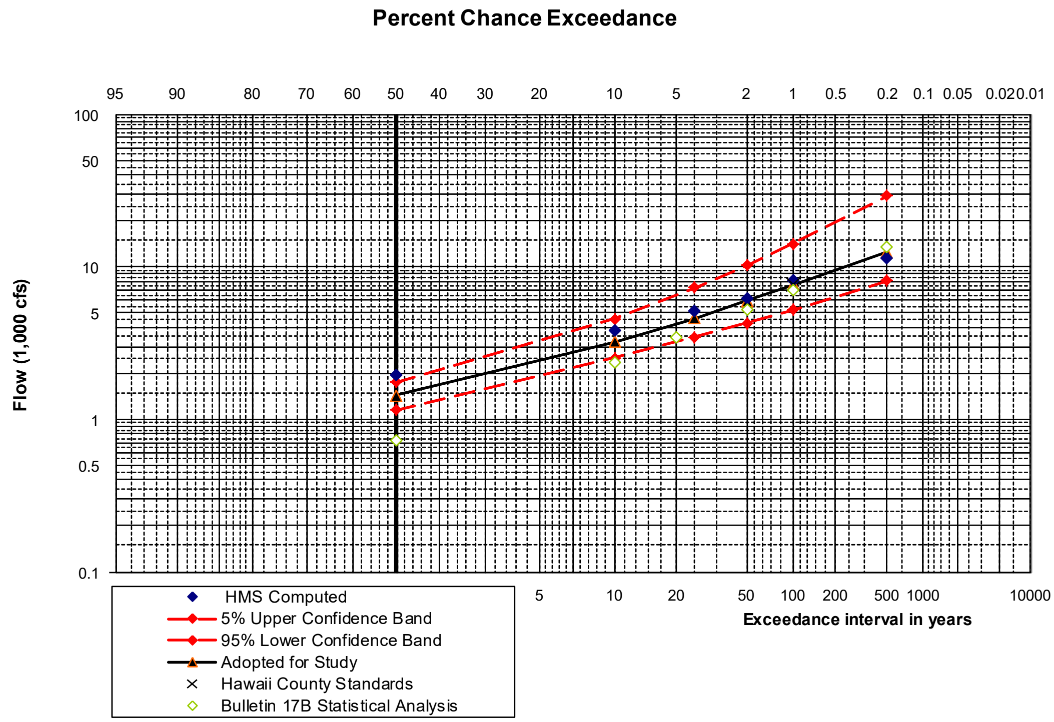
Table 33. Peak Flow Frequency comparison between Bulletin 17B analysis and HEC-HMS model at Station 16701300 Waiakea Stream, Hilo, Hawaii

Percent Chance Exceedence	Recurrence Interval (years)	Station 16701300 Peak Flow Computation (ft^3/s)	HMS Model Result Station 7013 J5
50%	2	645	1,170
20%	5	1,400	1,790
10%	10	2,130	2,310
4%	25	3,070	3,050
2%	50	4,720	4,710
1%	100	6,370	4,950
0.5%	200	8,470	7,150
0.2%	500	12,100	8,830

Table 34. Final Adjusted Peak Flow Frequency Values (cubic feet per second), Waiakea Stream, Hilo, Hawaii

Sub-Basin or Junction Number	Percent Chance Exceedance							
	50	20	10	4	2	1	0.5	0.2
Hoaka 7006	1,480	2,370	3,350	4,930	5,980	7,990	9,970	11,400
Kupulau	219	331	430	567	894	904	1,340	1,630
Kupulau Road, J1	1,430	2,270	3,680	4,710	5,965	7,630	9,830	11,230
Waiakea Town	81	117	148	190	252	290	365	440
Tributary 3	95	139	177	231	321	375	488	606
Waikaea Town, J2	1,240	1,980	2,800	4,310	5,230	6,790	8,730	9,940
Tributary 2	49	70	88	114	150	173	217	262
Uka Channel, J3	1,260	2,010	3,250	4,150	5,334	6,920	8,900	10,160
Tributary 1	16	23	29	37	48	56	70	84
Komohana Street, J4	1,660	2,020	2,840	4,180	5,375	6,960	8,970	10,240
Waiakea 7013	39	57	72	93	133	138	215	273
Station 7013, J5	761	1,430	2,110	2,840	4,430	5,600	7,940	9,540

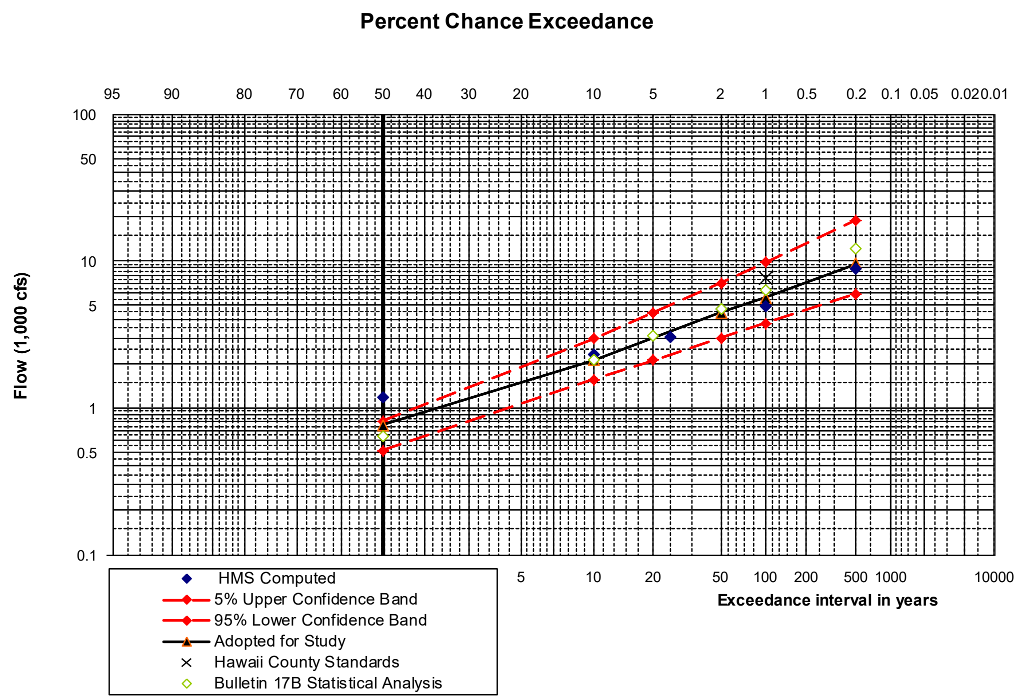
On Palai Stream, the comparison between USGS gage station 16701400 and the HEC-HMS derived values shows that the model overestimated the peak flow for the 50% AEP flood and underestimated flows for the remainder of the frequency events (Table 35). The difference in flow values may be attributed to the interbasin transfer of flow between Waiakea Stream and Palai Stream as mentioned previously. Additionally, the USGS values and the historical storm of November 2000 are based on 23 useable years of data Therefore, accuracy of these values alone is 23 years. However, with the model calibrated to the November 2000 extreme event flood, the accuracy in equivalent years of record is about 25 years which is the highest among all options as interpreted from Department of the Army (1996).



<u>HEC-HMS Conditional Probability Statistics</u>
logMean: 3.187
Skew: 0.839
log Std Dev: 0.238
HEC-HMS 90% confidence band statistics computed with equations in Appendix 5, Bulletin 17B (Interagency Committee on Water Data, 1982)

WAIAKEA-PALAI STREAM FLOOD RISK MANAGEMENT H&H STUDY, HAWAII, HAWAII
COMPARISON OF DISCHARGE FREQUENCY CURVES FOR EXISTING CONDITION USGS STATION 16700600
U.S ARMY CORPS OF ENGINEERS HAWAII ENGINEER DISTRICT

Figure 14. Waiakea Stream USGS Gage Station 16700600 Discharge Frequency Curve Comparison



HEC-HMS Conditional Probability Statistics
logMean: 2.645
Skew: -0.499
log Std Dev: 0.392
HEC-HMS 90% confidence band statistics
computed with equations in Appendix 5, Bulletin 17B
(Interagency Committee on Water Data, 1982)

WAIAKEA-PALAI STREAM FLOOD RISK MANAGEMENT
H&H STUDY, HAWAII, HAWAII

COMPARISON OF DISCHARGE
FREQUENCY CURVES FOR EXISTING CONDITION
USGS STATION 16701300

U.S ARMY CORPS OF ENGINEERS
HAWAII ENGINEER DISTRICT

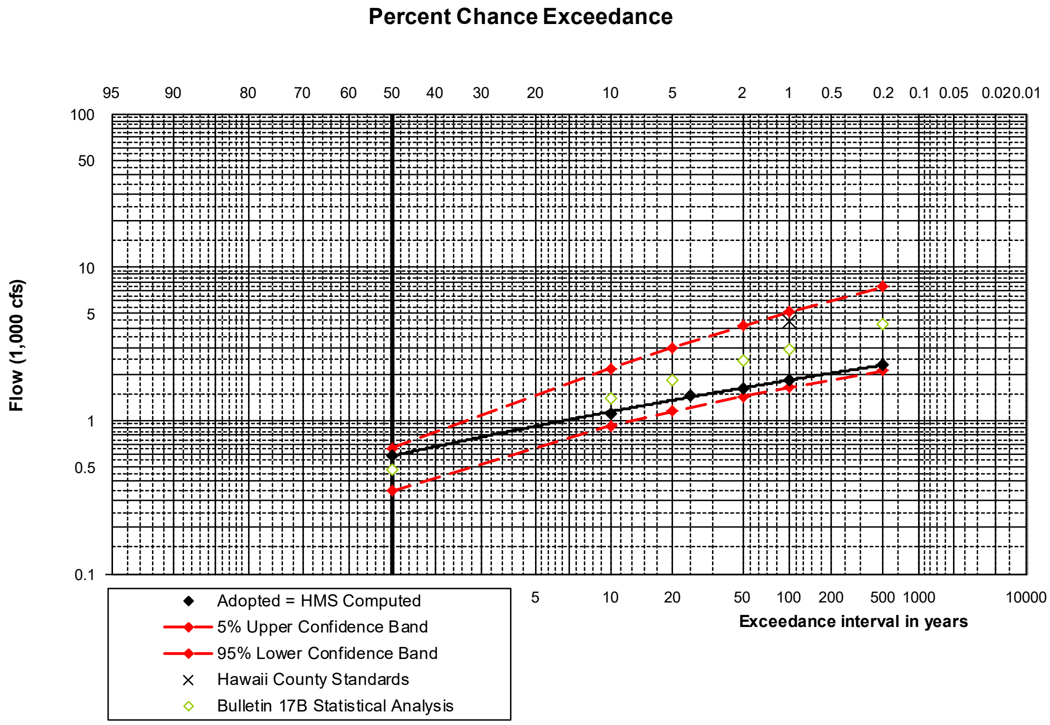
Figure 15. Waiakea Stream USGS Gage Station 16701300 Discharge Frequency Curve Comparison

Table 35. Peak Flow Frequency comparison between Bulletin 17B analysis and HEC-HMS model at Station 16701400 Palai Stream, Hilo, Hawaii

Percent Chance Exceedence	Recurrence Interval (years)	Station 16701400 Peak Flow Computation (ft^3/s)	HMS Model Result J_Kanoelehua Ave
50%	2	476	590
20%	5	981	898
10%	10	1,385	1,120
4%	25	1,820	1,460
2%	50	2,430	1,630
1%	100	2,940	1,830
0.5%	200	3,470	2,040
0.2%	500	4,210	2,290

The Hawaii County Standards (Plate 6) yields one point, a roughly 1-percent AEP flood peak, at each of the concentration points. The peak flows determined from this method tend to be on the higher end when compared with the other methods at all locations. For these reasons the HEC-HMS hypothetical model is the chosen option for the percent chance exceedance flood flows for most of the junction concentration points on Palai Stream and Four Mile Creek (except Palai junction at Puainako and Waikea Pond as will be discussed) because it is based on the study area attributes, calibrated to storm events, and although lower than the USGS stream gage 16701400 peak flow values, they are within the confidence limits of the stream gage statistics (Figure 16).

2.8.1 Linear Decreasing of Hydrologic Flows for Palai Stream and Four Mile Creek. An exception to the chosen HEC-HMS values are concentration points downstream of the USGS gage at Kanoelehua on Palai Stream, Puainako and Waikea Pond. Based on a survey of the households and businesses downstream of the USGS gage along Palai Stream, there had been little to no flooding in the past few decades. Also from this survey, the November 2000 flood did little flooding too many of the downstream areas. An explanation for this may be underground lava tubes throughout the downstream portion of Palai Stream. Based on data from an adjacent intermittent watershed, Waiakea Stream, shown in Figure 1, there is a linear decrease of flow from upstream to downstream even though there is a larger drainage area downstream. There were two USGS gages that were operational at the same time during 2003 to present on Waiakea Stream, which are about 4.2 miles apart from each other. The upstream gage station number is 16700600 and the downstream gage is 16701300 as shown in Figure 10. Based on data from these gages, there were two peaks that occurred on 25 January 2004 and 12 April 2004. Both these peaks showed that there was a linear decrease in flow between the two gages. See Tables 36 and 27 for a summary of the linear peak flow reduction. Based on the data from these tables, the average linear reduction is 0.02 cubic feet per second per linear foot (cfs/lf) in distance. However, the actual flow loss reduction is greater than 0.02 cfs/lf distance because of losses from downstream drainage areas that need to be factored in.



HEC-HMS Conditional Probability Statistics
logMean: 2.645
Skew: -0.499
log Std Dev: 0.392
HEC-HMS 90% confidence band statistics computed with equations in Appendix 5, Bulletin 17B (Interagency Committee on Water Data, 1982)

WAIAKEA-PALAI STREAM FLOOD RISK MANAGEMENT
H&H STUDY, HAWAII, HAWAII

COMPARISON OF DISCHARGE FREQUENCY CURVES FOR EXISTING CONDITION USGS STATION 16701400

U.S. ARMY CORPS OF ENGINEERS
HAWAII ENGINEER DISTRICT

Figure 16. Palai Stream USGS Gage station 16701400 Discharge Frequency Curve Comparison

For example if the upstream flow rate is 1,000 ft^3/s (cfs) then 500 feet downstream the flow rate should be 1,200 ft^3/s without any 0.02 cfs/lf distance linear reduction because an additional 200 ft^3/s has been added from the downstream drainage areas. Now using 0.02 cfs/lf distance loss for 500 feet, the upstream flow is still 1,000 ft^3/s, but a reduction in 10 ft^3/s results in a downstream flow of 990 ft^3/s. The difference between 1,200 ft^3/s without linear reduction less the linear reduction factor flow of 990 ft^3/s is 210 ft^3/s. Taking 210 ft^3/s and dividing this by 500 linear feet, then the actual loss factor from upstream to downstream including all downstream drainage areas then becomes 0.42 cfs/lf.

The 25 January 2004 event had a larger reduction than the 12 April 2004 event because the 12 April 2004 event had greater soil saturation from previous rainfall events than the 25 January 2004 event. Statistical data from 19 years of peak flow data suggests that USGS gage station 16701300 peaks for both events is about a 50-percent flood. Similar statistical data for the USGS gage station 16700600 is not computed because it has only been in existence for about 3 years. Despite the peak event being only a 50-percent flood, a linear reduction amount greater than 0.02 cfs/lf distance can be expected for larger events. Without further data, a linear decrease larger than 0.02 cfs/lf of distance cannot be used for larger events. At a minimum, a linear reduction of 0.02 cfs/lf distance along the stream will be applied to Palai Stream, downstream of USGS gage station 16701400 for all events due to a survey of households in this area which claimed little to no flooding during the November 2000 event, past historical events, and the adjacent Waiakea Stream flood reduction analysis. Similarly, a reduction in peak flows will be applied to Four Mile Creek downstream of Kupaa Street which has a similar drainage ratio area to total watershed area as Palai Stream at USGS gage station16701400; 66 percent total drainage area at Kupaa on Four Mile Creek and 67 percent total drainage area at USGS gage station 16701400 on Palai Stream, respectively. See Table 38 for Palai Stream and Four Mile Creek linear rates of flow reduction for a given frequency flood. Slight differences in the linear flow reduction between Palai Stream and Four Mile Creek can be attributed to the longer path of travel for Palai Stream and larger drainage flows for the developed downstream Palai drainage areas.

Table 36. Linear Peak Flow Reduction 25 January 2004

		25-Jan-04		
Gage	**DA (sq. mi.)**	**Peak discharge (cfs)**	**Peak discharge/DA (cfs/sq. mi)**	**Reduction (cfs/lf)**
16700600	31.9	1,330	41.67	na
16701300	35.8	725	20.25	0.027

Table 37. Linear Peak Flow Reduction 12 April 2004

		12-Apr-04		
Gage	**DA (sq. mi.)**	**Peak discharge (cfs)**	**Peak discharge/DA (cfs/sq. mi)**	**Reduction (cfs/lf)**
16700600	31.9	1,000	31.33	na
16701300	35.8	701	19.58	0.013

Table 38. Linear Flow Reduction for Palai Stream and Four Mile Creek

Percent Chance Exceedence	**Linear Reduction in Flow (cfs/lf)**	
	Palai Stream	**Four Mile Creek**
0.20%	0.18 cfs/lf	0.16 cfs/lf
0.40%	0.16 cfs/lf	0.13 cfs/lf
1%	0.14 cfs/lf	0.12 cfs/lf
2%	0.12 cfs/lf	0.11 cfs/lf
4%	0.11 cfs/lf	0.09 cfs/lf
10%	0.09 cfs/lf	0.08 cfs/lf
20%	0.08 cfs/lf	0.07 cfs/lf
50%	0.06 cfs/lf	0.05 cfs/lf

<u>2.8.2 Adopted Flows for Palai Stream and Four Mile Creek</u>. See Tables 39 and 40 for the adopted peak percentage floods for the floodplain study for the existing Palai Basin and Four Mile Creek, respectively, based on HEC-HMS modeling and linear decreasing application as described in the above paragraph. The two adopted discharge values on Palai Stream, J_Puainako Street and J_Waiakea Pond; which have linear decreasing peak flows, are based on the discussions in the paragraphs above. Note that the adopted flows are the best estimate of the flows in the Palai Stream and Four Mile Creek watersheds based on the available information. However, it should also be noted that lava tubes in the area may not be reliable sources of infiltration as the effect is estimated in the model while in actuality; the effect on peak flow reduction will be variable depending on flood event and location

Table 39. ***Final Adjusted Peak Flow Frequency Values (cubic feet per second), Palai Stream, Hilo, Hawaii***

Sub-Basin or Junction	Percent Chance Exceedence							
	50	**20**	**10**	**4**	**2**	**1**	**0.5**	**0.2**
J_Golf Course	548	833	1,040	1,350	1,510	1,700	1,890	2,120
J_Kanoelehua Avenue*	590	897	1,120	1,460	1,630	1,830	2,040	2,290
J_Puainako Street	1,110	1,660	2,050	2,630	2,940	3,290	3,640	4,080
J_Waiakea Pond	1,350	2,000	2,470	3,160	3,520	3,940	4,370	4,890
u/s HaiHai St	250	389	488	646	725	818	913	1,030
Palai C	254	384	476	617	689	774	859	965

* Represents the location of USGS gage 16701400 location

Table 40. *Final Adjusted Peak Flow Frequency Values (cubic feet per second), Four Mile Creek, Hilo, Hawaii*

Sub-Basin or Junction	Percent Chance Exceedence							
	50	20	10	4	2	1	0.5	0.2
F_U/S Tributary 2	294	457	574	760	852	962	1,070	1,210
F_U/S Tributary 1	403	626	799	1,060	1,190	1,340	1,490	1,680
FJ_Kilauea	781	1,210	1,520	2,010	2,250	2,540	2,840	3,200
FJ_Kanoelehua	790	1,230	1,540	2,030	2,280	2,570	2,870	3,230
FJ_Quarry	880	1,360	1,710	2,260	2,530	2,860	3,180	3,590
F_Tributary 1	167	260	326	431	484	546	609	686
F_Tributary 2	188	293	367	490	545	616	687	774

3.0 CONCLUSION

A hydrologic analysis was conducted to determine the “best” estimates of the 50%, 20%, 10%, 4%, 2%, 1%, 0.5%, 0.2% AEP (the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year floods) flood events for the Waiakea-Palai Stream study area as part of the Waiakea-Palai Stream Flood Damage Reduction Study. The “best” estimate of the discharge-frequency curves were determined by adjusting peak flow values computed by a HEC-HMS model with peak flows computed by frequency analysis of data from USGS gaging stations. The HEC-HMS rainfall-runoff model was calibrated using storm data from two events, April 10-13, 2004 and November 1-2, 2000. The County of Hawaii Storm Drainage Standards while useful for comparison purposes was not used in determining the “best” estimate. Regional regression peak flow equations were not considered sufficient in accuracy due to limitations of the data for South Hawaii and were not used in this analysis. The adopted flows are the best estimates of the flows in the Waiakea Stream, Palai Stream, and Four Mile Creek watersheds based on the available information and were used in the companion HEC-RAS hydraulic model. An equivalent years of record of 25 years accuracy was assigned for risk and uncertainty analysis in the companion HEC-FDA model. In this analysis future without project and future with project modeling parameters and resulting flow frequency estimates are assumed to be identical except where influenced by proposed flood damage reduction measures.

4.0 LIST OF REFERENCES

Arcement, G.J. Jr., and Schneider, V.R., 1989, *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains*: U.S. Geological Survey Water Supply Paper 2339, 38p.

County of Hawaii, 1970, *Storm Drainage Standard*, Department Public Works, County of Hawaii, October 1970, 42p.

Department of the Army, 1982, *Waiakea-Uka Stream, Hawaii, Hawaii-Reconnaissance Report on Small Flood Control Project*, Department of the Army, Pacific Ocean Division, Corps of Engineers, May 1982, 6p. 5 plates.

Department of the Army, 1995, *Waiakea Flood Control Reconnaissance Study, Island of Hawaii, Hawaii*, Department of the Army, Pacific Ocean Division, Corps of Engineers, November 1995, 6p.

Department of the Army, 1996, *Risk-based Analysis for Flood Damage Reduction Studies*, EM 1110-2-1619, Department of the Army, U.S. Army Corps of Engineers: Washington, D.C., August 1, 1996, various pagination. [available at website: http://www.usace.army.mil/publications/, last accessed on December 21, 2004]

Dewberry and Davis LLC, 2001, *Hilo, Hawaii County, Hawaii, Flood Hazard Assessment*, HMTAP EMW-2000-CO-0247 Task Order 040 prepared for the Federal Emergency Management Agency, November 2001, various pagantion.

Federal Emergency Management Agency, 2004, *Flood Insurance Study, Hawaii County, Hawaii,* Volumes 1-4, Study Number 155166V001A, revised April 2, 2004, various pagnation.

Fontaine, R.A., and Hill, B.R., 2002, *Streamflow and Erosion Response to Prolonged Intense Rainfall of November 1-2, 2000, Island of Hawaii:* U.S. Geological Survey *Water Resources Investigations Report 02-4117, 31p.*

Giambelluca, T.W., Q. Chen, A.G. Frazier, J.P. Price, Y.-L. Chen, P.-S. Chu, J.K. Eischeid, and D.M. Delparte, 2013: Online Rainfall Atlas of Hawaiʻi. *Bull. Amer. Meteor. Soc.* 94, 313-316, doi: 10.1175/BAMS-D-11-00228.1.

Giambelluca, T.W., Nullet, M.A., and Schroeder, T.A., 1986, *Rainfall Atlas of Hawaii*, Report R-76, State of Hawaii, Department of Land and Natural Resources, 267p.

Halliday, W.R., 2003, *Raw Sewage and Solid waste Dumps in Lava Tube Caves of Hawaii Island*, Journal of Cave and Karst Studies, Vol. 65, No. 1, April 2003, p. 68-75.

Haraguchi, Paul, Consulting Meteorologist, Prepared for the State of Hawaii, Department of Land and Natural Resources Land Division, Engineering Branch, March 2001, *Post Flood Report Storm of November 1-2, 2000 South Hilo, Puna and Kau Districts Island of Hawaii Circular C130*, 95p.

[U.S.] Interagency Advisory Committee on Water Data, 1982, *Guidelines for Determining Flood Flow Frequency*, Hydrology Subcommittee Bulletin 17B, 28p. app 1-14.

Macdonald, G.A., Abbott, A.T., and Peterson, F.L., 1983, *Volcanoes in the Sea: The Geology of Hawaii*, University of Hawaii Press, Honolulu, 517p.

Oki, D.S., Rosa, S.N., and Yeung, C.W., 2010, Flood-frequency estimates for streams on Kauai, Oahu, Molokai, Maui, and Hawaii, State of Hawaii: U.S. Geological Survey Scientific Investigations Report 2010-5035, 121 p.

Owenby, J.R., and Ezell, D.S., 1992, *Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1961-90, Hawaii*, Climatography of the United States No.81, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, North Carolina, 26p.

Sato, H.H, Ikeda, Warren, Paeth, Robert, Smythe, Richard, and Takehiro, Minoru, Jr., 1973*, Soil Survey of the Island of Hawaii, State of Hawaii*, U.S Department of Agriculture, Soil Conservation Service, 115p., 195 sheets, 1 plate.

Thomas, Wilbert, Jr., 2001, *Hydrologic Analysis for Waiakea Stream Tributaries, Hilo, Hawaii*. An analysis conducted for the Federal Emergency Management Agency, Region IX, June 2001, 7p.

US Army Corps of Engineers, July 1979, *Palai, Four Mile Creek Flood Control, Hilo, Hawaii Reconnaissance Report,* , U.S. Army Corps of Engineers, Honolulu District, July 1979, 10p.

US Army Corps of Engineers, 1981, *Flood Plain Management Planning Assistance Report for Palai Stream and Four Mile Creek, Hilo, Hawaii*, U.S. Army Corps of Engineers, Honolulu District, September 1981, 23p. plus plates and appendices.

U.S. Army Corps of Engineers, 1990, *Alenaio Stream Flood Control Project, Hilo, Hawaii, General Design Memorandum and Environmental Assessment Study*, U.S. Army Corps of Engineers, Honolulu District, March 1990, 23p. plus appendices and plates.

U.S. Army Corps of Engineers, 2000, *Hydrologic Modeling System HEC-HMS: Technical Reference Manual*, CPD-74B, Hydrologic Engineering Center, March 2000, 149p. [available at website: http://www.hec.usace.army.mil/software/hec-hms/hechms-document.html, last accessed December 21, 2004]

U.S. Army Corps of Engineers, 2001, *Waiakea Stream Flood Control Reconnaissance Study, Hilo, Island of Hawaii*, U.S. Army Corps of Engineers, Honolulu Engineer District, 14p.

U.S. Army Corps of Engineers, 2002, *Hydrologic Modeling System HEC-HMS: Applications Guide*, CPD-74C, Hydrologic Engineering Center, December 2002, 105p. [available at website: http://www.hec.usace.army.mil/software/hec-hms/hechms-document.html, last accessed December 21, 2004]

U.S. Army Corps of Engineers, 2005, *Hydrologic Modeling System HEC-HMS: User's Manual Version 3.0*, CPD-74A, Hydrologic Engineering Center, December 2005, 178p. [available at website: http://www.hec.usace.army.mil/software/hec-hms/hechms-document.html, last accessed August 21, 2006]

U.S. Army Corps of Engineers, in press, *Hydrology and Hydraulic Floodplain Appendix, Palai Stream and Four Mile Creek, Palai Stream Flood Damage Reduction Project*, U.S. Army Corps of Engineers, Honolulu District, draft July 2006, 63p.

U.S. Army Engineer District, 1962, *Wailoa Stream and Its Tributaries, Hilo, Hawaii, General Design Memorandum*, U.S. Army Engineer District, Honolulu, Corps of Engineers, June 1962, 25p. various plates and appendices.

U.S. Department of Commerce, 1962, *Rainfall-Frequency Atlas of the Hawaiian Islands for Areas to 200 square miles, Durations to 24 Hours, and Return Periods from 1 to 100 Years*, Technical Paper No. 43, U.S. Department of Commerce, Weather Bureau, 60p.

URS, 2003, *Flood Hazard Analysis to Update Flood Insurance Rate Maps along Palai Streams A, B and C,* Technical Support Data Notebook prepared for The County of Hawaii Department of Public Works, Contract No. 02080, County Job No. p-3549, March 7, 2003, various pagnation.

Wilson, Okamoto and Associates, Inc., 1967, *Hilo Drainage and Flood Control*, Prepared for the County of Hawaii, Hilo, Hawaii, January 1967, 82p.