US Army Corps of Engineers ®
Honolulu District

PUNA DISTRICT
HAWAIʻI ISLAND
STATE OF HAWAIʻI

Puna Flood Hazard Study

Hydrologic and Hydraulic Analysis Report

Final Report

Prepared for: County of Hawaiʻi
Prepared by: U.S. Army Corps of Engineers, Honolulu District
31 January 2024

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EXECUTIVE SUMMARY

The purpose of this study is to evaluate flood risk in the Puna community from rainfall and riverine sources. This study provides community flood hazard maps, where the floodplain for the 10%, 4%, 2%, 1%, and 0.2% (1/10, 1/25, 1/50, 1/100, and 1/500) annual exceedance probability (AEP) flood events have been delineated. These maps are provided in Appendix A. This study was completed and funded through the Flood Plain Management Services (FPMS) Program, authorized by Section 206 of the Flood Control Act of 1960, as amended (33 U.S. Code § 709a).

A flow frequency analysis was performed to determine the magnitude of the 10%, 4%, 2%, 1%, and 0.2% (1/10, 1/25, 1/50, 1/100, and 1/500) annual exceedance probability (AEP) flood discharges for the Puna community. Final flow frequency estimates were determined by developing a hydrologic model for both the Puna region and Waiakea Stream nearby, performing a Bulletin 17C analysis on a Waiakea Stream gage, and calibrating the hydrologic models to the resulting flow frequency estimates. Final flow frequency estimates are presented in Section 4.4.

The results of this study make available the water surface profiles, flood elevations, and areal extent of the floodplain for the 10%, 4%, 2%, 1%, and 0.2% (1/10, 1/25, 1/50, 1/100, and 1/500) AEP flood events (5 profiles). A two-dimensional, unsteady flow hydraulic model was developed for this study using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software. Floodplain maps are provided in Appendix A. Additional information on flood-prone areas are summarized in Section 6.

The results indicate that many residential properties and roads are at risk of being flooded frequently. The flooding mostly occurs along two or three main streams which sprawl and create shallow widespread flooding due to the streams not being well-defined.

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EQUATIONS

ACRONYMS

Acronym	Description
%	percent
°F	Fahrenheit
1D	one dimensional
2D	two dimensional
AEP	annual exceedance probability
AMS	annual maximum series
C-CAP	Coastal Change Analysis Program
DEM	digital elevation model
DFIRM	Digital Flood Insurance Rate Map
DPW	Department of Public Works
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FIRM	Flood Insurance Rate Map
FPMS	Flood Plain Management Services
ft	feet
GIS	geographic information systems
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
hr	hour
in	inch
LiDAR	Light Detection and Ranging
LMSL	local mean sea level
mi	miles
MSL	mean sea level
NAD83	North America Datum of 1983
NAVD88	North American Vertical Datum of 1988
NCEI	National Centers for Environmental Information
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
Oceanit	Oceanit Laboratories, Inc.
RAS	River Analysis System
ROG	rainfall on grid
SSP	Statistical Software Package
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator

SECTION 1 - INTRODUCTION

The Puna community receives over 100 inches of rainfall per year and has a record of severe flooding. The district of Puna experiences frequent flash flooding events that cause substantial damages, most recently in August 2018 and January 2020. The National Weather Service (NWS) reported that on August 23, 2018 Hurricane Lane brought up to 35 inches of rain to some areas of the Big Island in 48 hours. The NWS also reported 24-hour totals for the areas of Kulani and Glenwood in the Puna District measured 9.71 inches and 7.89 inches respectively in January 2020.

Puna has also not been evaluated or mapped to identify flood prone areas within the district. The analysis will provide valuable information for planning and mitigation purposes. As development continues it is important to properly plan and minimize the impact of flooding and the reduce flood risk.

1.1 AUTHORITY

This study was completed and funded through the Flood Plain Management Services (FPMS) Program, authorized by Section 206 of the Flood Control Act of 1960, as amended (33 U.S. Code § 709a).

1.2 PARTNER AGENCY

The nonfederal partner for this study is the County of Hawaiʻi, represented by its Department of Public Works (DPW). A formal request for assistance was provided by David Yamamoto, Director of Public Works, on behalf of the Puna community in a letter dated 12 August 2021.

1.3 PURPOSE AND SCOPE

The purpose of this study is to evaluate flood risk in the Puna District, island of Hawaiʻi, state of Hawaiʻi. The specific objectives are:

1) Determine the peak flow estimates at key locations throughout the study area for the 10%, 4%, 2%, 1%, and 0.2% (1/10, 1/25, 1/50, 1/00, and 1/500) AEP floods;
2) Determine the areal extent of inundation, flood depths, and water surface elevations across Puna for the five-flood frequency events.

SECTION 2 - WATERSHED DESCRIPTION

This section provides a broad overview of hydrologic conditions in the study area and corresponding watersheds. It reflects the preliminary investigations and data collection phase of the study.

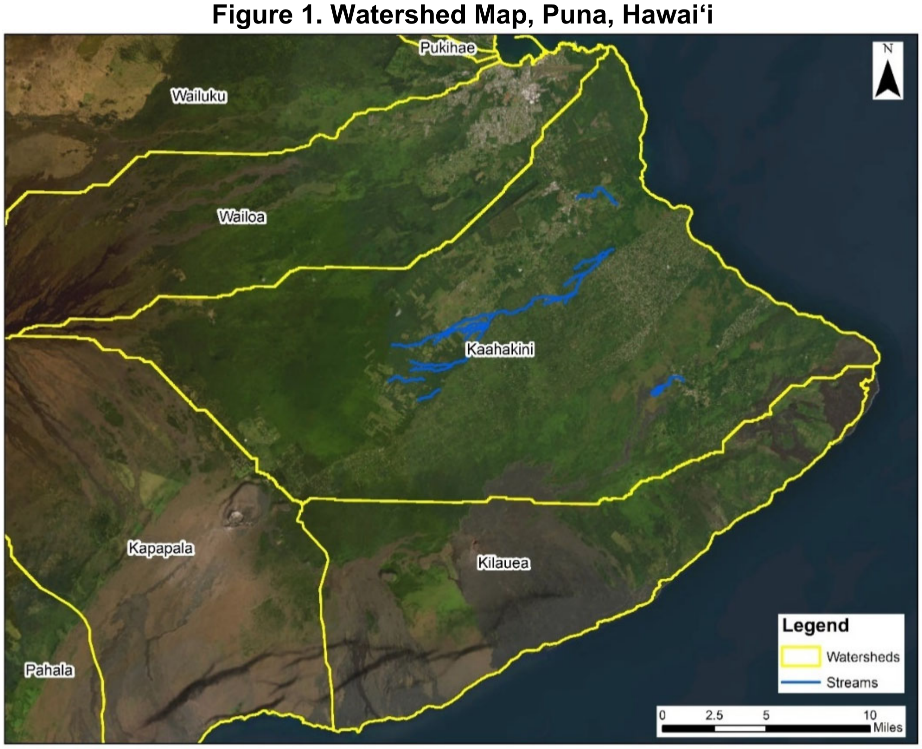
2.1 LOCATION

Puna is one of the nine districts on Hawaii and is on Hawaii's windward coast, sharing borders with South Hilo to the North and Ka'u to the West. The area is just under 320,000 acres, or 500 sq. miles and is only slightly smaller than the island of Kaua'i. The area grows several crops and is home to countless nurseries and farms.

Puna is characterized by gently sloping topography with poorly defined waterways. The Puna landscape is formed of porous volcanic rock and soils from Mauna Loa and Kīlauea volcanic eruptions. An extensive network of subterranean lava tubes runs throughout much of Puna and are accessible through collapsed openings. The altitude ranges from mean sea level along the coastal areas to 1,950 feet at Mountain View and approximately 4,950 feet at the western boundary on the slope of Mauna Loa. The entire study area is relatively flat with the average slope ranging between 2% to 6%.

The study area is located in the Kaahakini watershed as shown in Figure 1. Kaahakini watershed is approximately 242,288 acres and begins near Mauna Loa at the Pu'u Maka Ala Natural Area Reserve to the ocean. The extent of the watershed ranges from Hilo to Kahonua. The study area comprises of parts of Volcano, Mountain View, Kurtistown, Kea'au, and Pahoa subdivisions.

Figure 1. Watershed Map, Puna, Hawai'i



2.2 LAND USE

Puna contains many large underdeveloped "subdivisions." People living in Puna subdivisions are often responsible for their own water, waste, and sometimes power. 70% of households in Puna do not have access to County water in their homes and must collect rainwater for daily household needs. Many homes are "energy independent," using a combination of solar, wind, and generators to meet electrical needs. Puna is home to some lowest income communities on the Big Island, with certain neighborhoods exceeding 30% of households with incomes below the poverty level. It is one of the last places local families can find affordable housing, and also one of the fastest-growing districts on the Big Island.

A large percentage of subdivisions in Puna are private subdivisions that were created before 1966 and those subdivisions residents may lack the financial ability to properly mitigate drainage and flooding in a manner that satisfies the requirements to dedicate private roads to Hawaii County.

2.3 CLIMATE

Hawaiʻi has a subtropical climate with temperatures that are mild and fairly uniform throughout the year. The climate of the Hawaiian Islands is characterized by a two-season year; a 5-month dry season (summer) and a 7-month wet season (winter). The average monthly precipitation ranges from 2.2 inches in the wettest month (December) to 0.5 inches in the driest month (July).

Although the northeasterly trade winds produce most of the annual rainfall over the Hawaiian Islands, it is during the absence of these winds that the flood producing rainfall occurs. In particular, southerly winds bring moist warm air that creates "Kona" storms which produce the damaging floods in Hawaiʻi. These storms usually occur during the winter months.

The climate in Puna varies widely due to significant changes in elevation. Temperatures average 66 degrees Fahrenheit (°F) and the average annual precipitation is 181.69 inches.

2.4 STREAM CHARACTERISTICS

There are no perennial streams in the Puna area. Keaau Stream is the primary river in the Puna watershed (Figure 1). Typical photos of these streams are provided as Photo 1 through Photo 4.

Photo 1. Upper Keaau Stream, N. Oshiro Road

19.533673, -155.134495

Photo 2. Keaau Stream, S. Kulani Road

19.549318, -155.090502

Photo 3. Keaau Stream, Pohaku Drive

19.571795, -155.028113

Photo 4. Keaau Stream, Keaau-Pahoa Road

19.587385, -155.012708

SECTION 3 - DATA COLLECTION

This section describes the literature review on previous and related works, sources for geographic information systems (GIS) data, and field investigations done in support of the study.

3.1 PREVIOUS REPORTS AND RELATED WORK

A list of previous work related to this study is provided below:

3.1.1 2013 Hydrologic and Hydraulic Report by Oceanit

The County of Hawai‘i, Department of Public Works (DPW) previously contracted Oceanit Laboratories, Inc. (Oceanit) to perform the “Puna Flood Study” and generate Digital Flood Insurance Rate Maps (DFIRMs) for the Puna District, County of Hawai‘i. As part of this study, Oceanit also published a *Hydrologic and Hydraulic Report*.

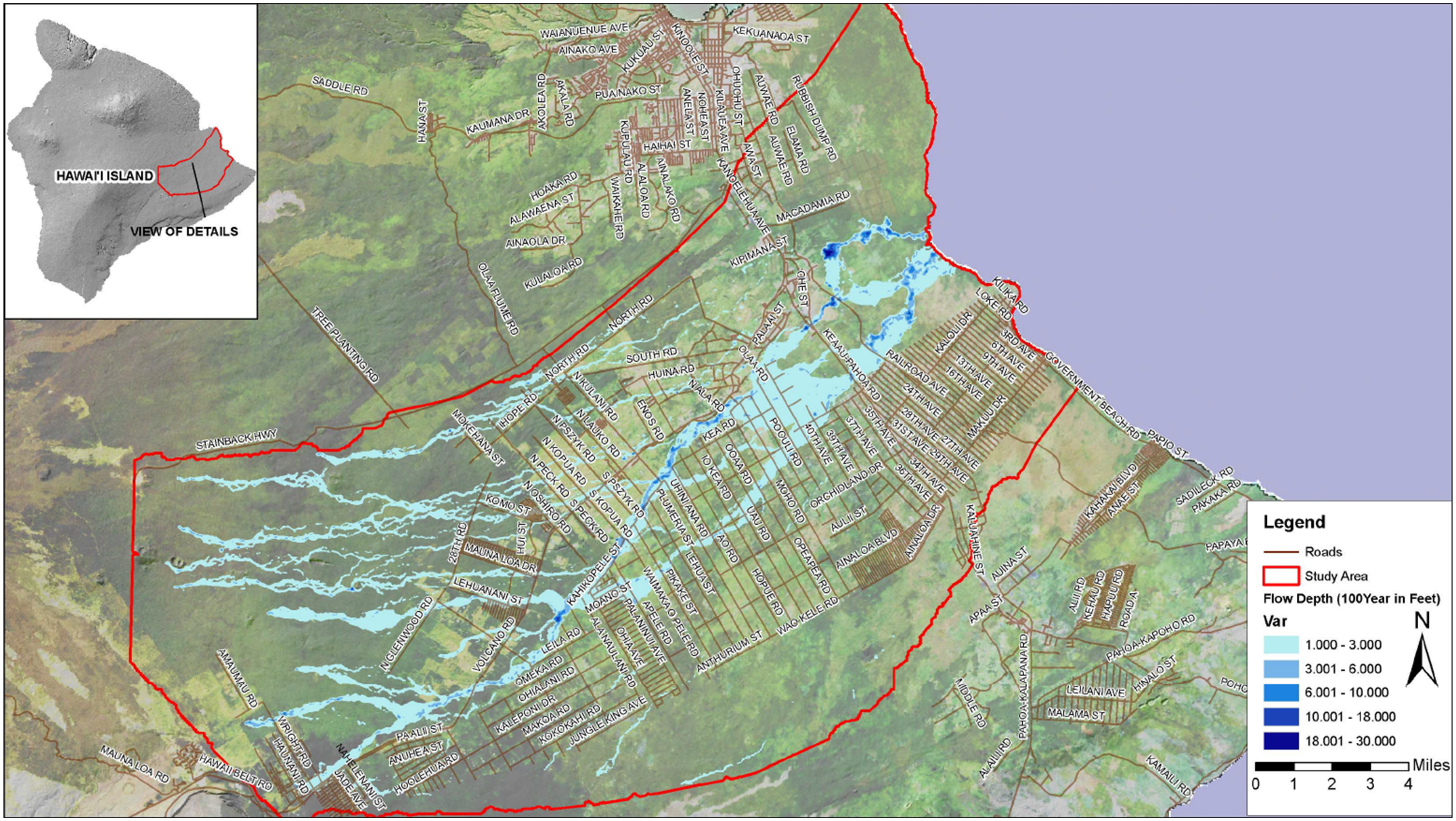
A hydrologic analysis was conducted to estimate the peak flow for the 10%, 2%, 1%, and 0.2% annual exceedance probability (AEP) flood events at various locations across the Puna region. A one-dimensional rainfall-runoff model was developed using the Hydrologic Engineering Center’s (HEC’s) Hydrologic Modeling System (HMS) software (version 3.5), using the *Green and Ampt* loss method and *Snyder Unit Hydrograph* transform method. An average conductivity (~infiltration rate) of 2.11 inches per hour (in/hr) was estimated for the entire region. This model was not calibrated to any historical storm or flood event.

A second hydrologic model was developed using FLO-2D software to help build confidence in the simulation results but was also not calibrated to a historical storm or flood event. The final peak flow estimates presented in the 2013 *Hydrologic and Hydraulic Report* are replicated in Table 1 and are considered to be high by the local sponsor. The final floodplain maps produced by Oceanit were developed by applying the flow discharges computed in HEC-HMS to a FLO-2D flood routing model.

Table 1. Peak Flow Estimates by Oceanit (2013)

Junctions	Description	10% AEP (1/10)		2% AEP (1/50)		1% AEP (1/100)		0.2% AEP (1/500)	
		HEC-HMS	FLO-2D	HEC-HMS	FLO-2D	HEC-HMS	FLO-2D	HEC-HMS	FLO-2D
J2	Volcano Rd & Kahaualeale Rd	9,454	9,596	23,955	22,330	35,157	33,418	46,240	46,266
J3	Near Mauaana Rd	19,063	17,648	40,749	36,532	59,984	54,024	80,339	74,770
J4	Near Apele Rd	19,538	17,410	36,533	31,291	45,384	44,008	61,031	63,610
J5	South Kūlani Rd Bridge	25,024	20,684	45,398	39,041	61,326	51,602	84,906	75,217
J7	Keaau-Pahoa Rd & Keaau Bypass Rd	15,187	14,734	30,993	31,463	40,720	40,507	63,826	59,910
J8	Volcano Rd & Huina Rd	5,859	6,017	12,212	13,046	17,055	16,191	25,270	24,023
J10	Railroad Aves. & Keaau Rd	1,361	1,248	3,916	3,684	5,539	5,640	11,894	11,935
JK1	Pulelehua Rd & Poola Rd	1,229	777	8,197	7,360	17,854	16,165	28,551	29,194
J16	Waimakao Pele Rd & Pahoehe Rd	241	171	1,035	1,080	2,672	2,608	8,712	8,581

Figure 2. 1% AEP Flood Hazard Map by Oceanit (2013)



3.2 GEOGRAPHIC INFORMATION SYSTEMS DATA

3.2.1 Datum and Projection

The datum and projection for this study is as follows:

Horizontal projection: Universal Transverse Mercator (UTM) Zone 5 North (N), US Survey Feet
Horizontal datum: North America Datum of 1983 (NAD83) (PA11)
Vertical Datum: Local Tidal Datum – Mean Sea Level (MSL)
Tidal Epoch: 1983 – 2001

3.2.2 Elevation

The following sources of elevation data were used in this study:

Table 2: Elevation Data Type and Sources

Survey year	Agency	Data type	Areal Extent
2018 – 2020	NOAA & USGS	LiDAR	Island of Hawaiʻi
Varies	USGS	Varies	State of Hawaiʻi

Light Detection and Ranging (LiDAR) data for the island of Hawaiʻi was collected by Woolpert, Inc. for the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS). The collection period for the LiDAR data was from January 2018 through January 2020. The data is in North American Datum 1983 (NAD83) PA11, UTM Zone 5, meters and vertically referenced to NAVD88, meters. This dataset has a horizontal accuracy of 40 centimeters (cm) or better and a vertical accuracy of 10 cm or better. New LiDAR data was also recently collected in the region by USGS but was not yet available for use in this study.

Supplementary elevation data was found on The National Map [https://apps.nationalmap.gov/downloader/] in the form of an elevation raster with a resolution of 1/3 Arc Second (~10 meters). USGS provides elevation data under its 3D Elevation Program (3DEP), composed of the best available raster elevation data. 3DEP data are updated continually as new data become available.

3.2.3 Imagery

High-Resolution Orthoimagery from 2021 through 2023 was provided by the U.S. Department of Agriculture, as made available on the Digital Coast online database (NOAA OCM, 2023).

3.2.4 Soil Data

A water permeability shapefile provided by the Hawaii Soil Data Atlas was used to determine initial loss parameters for the hydrologic model.

3.2.5 Land Cover

A circa 2011 high resolution (1 to 5 meter) land cover raster for the study area was developed by NOAA and downloaded from the Multi-Resolution Land Characteristics Consortium (MRLC)'s National Land Cover Database (NLCD). This raster was used to understand the different types of land usage in the study area and compute the directly connected impervious areas for the rainfall-runoff model. This raster was also used to define the Manning's roughness coefficient in the hydraulic model.

A detailed land cover map was created by Photo Science, Inc. for NOAA's OCM using 2010 imagery. High resolution imagery was analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover. This land cover raster was downloaded from NOAA's Digital Coast website [https://chs.coast.noaa.gov/htdata/raster1/landcover/bulkdownload/hires/as/].

3.3 PRECIPITATION DATA

All climate stations relevant to this study are presented in Table 3 and described in the following sections.

3.3.1 NOAA Climate Stations

There are several NOAA climate stations in the study area, as presented in Table 3. Station information and observational data for these stations are available on the National Centers for Environmental Information (NCEI) website [https://www.ncei.noaa.gov/maps/hourly/].

3.3.2 USGS Atmospheric Sites

There is one USGS atmospheric site within or near the study area, as presented in Table 3. It offers historical rainfall data from April 2010 to present (January 2024), including rainfall data from Hurricane Lane (August 2018) within the vicinity of Waiakea Stream (just north of the Puna region).

3.3.3 Precipitation Frequency Data

Point precipitation frequency estimates were provided by NOAA's National Weather Service, as published online in their Precipitation Frequency Data Server (PFDS) [https://hdsc.nws.noaa.gov/pfds/]. The annual maximum time series was used (NOAA, 2023).

Table 3. Climate Stations that Provide Instantaneous Precipitation Data for the Study Area

Agency	Site Number / Station ID	Site Name	Location	Datum of gage	Period of Record
NOAA	91287099999	CAPE KUMUKAHI HAWAII	19.5167°, -154.8167°	49.21 feet above LMSL	1994-07-10 to 2001-05-06
NOAA	91289099999	HALEMAUMAU CRATER HAWAII	19.4°, -154.8167°	3648 feet above LMSL	1973-01-04 to 2002-01-07
NOAA	998199999	HILO	19.7167°, -155.283°	0 feet above LMSL	2008-07-21 to present
NOAA	99999921515	HILO 5 S	19.645°, -155.05°	622.0 feet above LMSL	2005-09-27 to present
NOAA	91285321504	HILO GENERAL LYMAN ARPT	19.719°, -155.0827°	36.09 feet above LMSL	1943-04-15 to 1945-12-28
NOAA	91285021504	HILO INTERNATIONAL AIRPORT	19.7191°, -155.053°	29.00 feet above LMSL	1973-01-01 to 2024-01-29
NOAA	99999921504	HILO INTERNATIONAL AP	19.719°, -155.049°	36.09 feet above LMSL	1949-10-01 to 1972-12-31
NOAA	99999921503	HILO NAS	19.717°, -155.053°	34.04 feet above LMSL	1945-07-01 to 1946-01-01
NOAA	91291099999	MAUNA LOA STRIP ROAD HAWAII	19.4667°, -155.05°	5,397 feet above LMSL	2001-09-02 to 2001-09-02
NOAA	COOP:511303	HAWAII VOL. NATIONAL PARK HQ	19.4297°, -155.2562°	3,971 feet above LMSL	1976-10-31 to 2013-12-31
NOAA	COOP: 511487	HILO COUNTRY CLUB 86, HI US	19.6833°, -155.1667°	1,600 feet above LMSL	1973-04-30 to 1982-03-15

NOAA	COOP: 513510	KAUMANA 88.1, HI US	19.6801°, -155.1432°	1,180 feet above LMSL	1982-03-31 to 2013-12-31
NOAA	COOP: 515102	KURTISTOWN 91.14, HI US	19.5918°, -155.0644°	735.9 feet above LMSL	1999-07-31 to 2013-12-31
NOAA	COOP: 515460	LAVA TREE PARK 66.1, HI US	19.4833°, -154.9°	N/A	1976-11-02 to 1978-09-30
NOAA	COOP: 516552	MOUNTAIN VIEW 91, HI US	19.5487°, -155.1101°	1,530 feet above LMSL	1978-07-01 to 1985-08-31
NOAA	COOP: 516560	MOUNTAIN VIEW NUMBER 2, HI US	19.5333°, -155.1°	1,580 feet above LMSL	1985-08-31 to 1989-12-31
NOAA	COOP: 516546	MOUNTAIN VIEW NUMBER 3 91., HI US	19.5333°, -155.1333°	1,915 feet above LMSL	1990-09-30 to 1998-11-03
NOAA	COOP: 517465	PAHOA SCHOOL SITE 64, HI US	19.4904°, -154.9432°	683.1 feet above LMSL	1979-01-09 to 2013-12-31
NOAA	COOP: 518550	PUU OO 82, HI US	19.7333°, -155.3833°	6,345 feet above LMSL	1970-06-30 to 1974-01-01
USGS	194117155174801	83.0 Quarry Rain Gage at Saddle Rd, HI	19.6859° -155.2942°	--	2010-04-22 to 2024-01-30

3.4 STREAM DATA

All climate stations relevant to this study are presented in Table 3 and described in the following sections.

3.4.1 USGS Surface-Water Sites

While there are no USGS stream gages in the Puna region, there are several along the streams just north of the study area. These include gages sited along Wailuku River, Alenaio Stream, and Waiakea Stream (Wailuku River). These gages are listed in Table 3. However, Wailuku River is a very large river with very different characteristics from what is typical in the Puna region. For this reason, data from Wailuku River was not used in the study. Alenaio Stream and Waiakea Stream were a more reasonable comparison, however, instantaneous flow data from these sites were very limited. Data on these gages was downloaded from the USGS's National Water Information System [https://maps.waterdata.usgs.gov/mapper/index.html].

Table 4. Stream Gages that Provide Instantaneous Flow Data within or near the Study Area

Agency	Site Number / Station ID	Site Name	Location	Datum of gage	Period of Record
USGS	16700600	Waiakea Stream at Hoaka Road, HI	19°39'29.1" - 155°07'10.0"	860 feet above LMSL	Instantaneous: 2003-10-01 to 2005-09-30 Peak Streamflow: 2004-01-25 to 2011-07-10
USGS	16701300	Waiakea Stream at Hilo, HI	19°42'26.1", -155°04'54.2"	80 feet above LMSL	Instantaneous: 2003-10-05 to 2023-03-02[1] Peak Streamflow: 1969-02-14 to 2021-10-12
USGS	16701600	Alenaio Stream at Hilo, HI	19°42'59.5", -155°05'16.8"	80 feet above LMSL	Instantaneous: 2005-10-01 to 2006-04-18 Peak Streamflow: 1997-07-30 to 2022-05-03
USGS	16713000	Wailuku River at Hilo, HI	19°43’31.95", -155°05’30.01"	80 feet above LMSL	Instantaneous: 1993-10-01 to 1994-08-28 Peak Streamflow: 1977-08-12 to 2000-11-02
USGS	16704000	Wailuku River at Piihonua, HI	19°42’43.7", -155°09’02.7"	1,090 feet above LMSL	Instantaneous: 1990-10-01 to 2024-01-31 Peak Streamflow: 1929-02-15 to 2021-10-12

[1]: although dated to 2023, there is very limited coverage beyond 2005

3.5 SITE VISIT

Site visits by USACE for the hydrologic and hydraulic analysis of the Puna region occurred on 6-7 July 2023. During this site visit, the team also made several field observations in support of the current study effort and improved their understanding of current site conditions. USACE team members collected additional site data (photos field measurements) on bridge and culvert crossings to refine the hydraulic model.

SECTION 4 - FLOOD FREQUENCY ANALYSIS

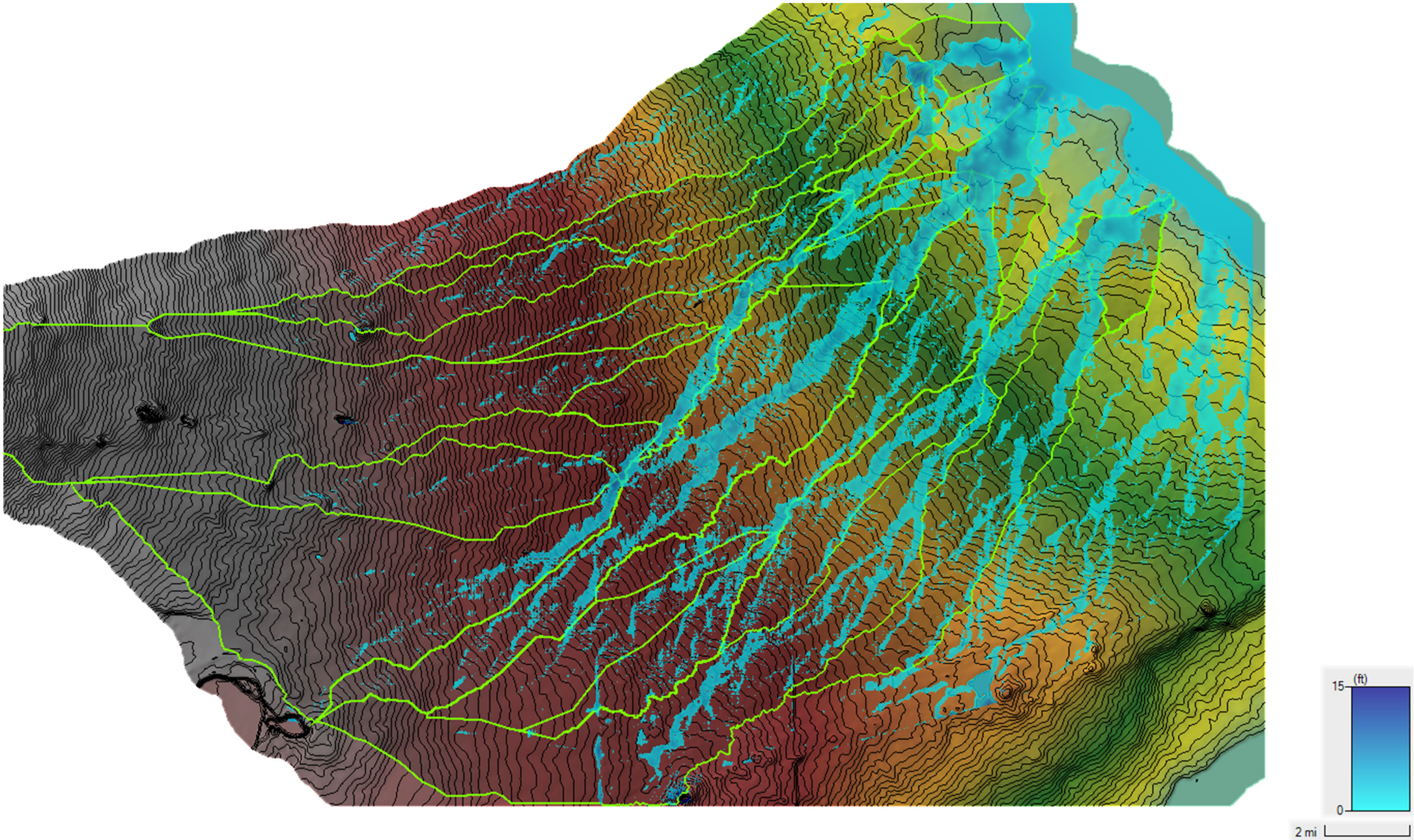
A flood frequency analysis was performed to determine the magnitude of the 10%, 4%, 2%, 1%, and 0.2% (1/10, 1/25, 1/50, 1/100, and 1/500) AEP flood discharges (also known as peak flow estimates) for the Puna region on the island of Hawaiʻi. The general methodology for establishing these peak flow estimates is as follows:

1) perform a rainfall-on-grid simulation of the study area in the hydraulic model to understand the natural flow paths that would occur during a typical storm event and divide the study area into smaller drainage areas (*subbasins*).
2) develop a hydrologic model using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) software for the study area (Puna) and Waiakea Stream.
3) complete a Bulletin 17C stream gage analysis on USGS 16701300, *Waiakea Stream* to estimate flow frequency values.
4) apply precipitation frequency data to the Waiakea Stream hydrologic model, then calibrate the hydrologic model to replicate the Bulletin 17C flow frequency estimates.
5) apply similar calibration adjustments to the Puna hydrologic model.
6) apply precipitation frequency data to the Puna hydrologic model and simulate the five flow frequency events. This will result in peak flow estimates for each event at key locations in the study area.

4.1 RAINFALL-ON-GRID SIMULATION

In this study, the entire drainage area was converted to a single two-dimensional (2D) flow area and rainfall was applied directly on the grid for the software to automatically compute flow paths. This was very helpful in delineating smaller drainage areas (*subbasins*) in the study area that would have been very difficult to determine either in HMS or manually with only contours as a reference. A visual example of the resulting flow paths from this rain-on-grid (ROG) simulation is provided in Figure 3.

Figure 3. Rain-on-Grid Simulation of Puna



4.2 STREAM GAGE ANALYSIS

Annual peak flow data from the stream gage near the study area (USGS 16701300, *Waiakea Stream at Hilo, HI*) was analyzed individually using methodology from Bulletin 17C (USGS, 2019) as applied by the Hydrologic Engineering Center's Statistical Software Package (HEC-SSP) program (version 2.2, HEC, 2019). A Bulletin 17C analysis offers the opportunity to use intervals or thresholds to represent the magnitudes of flood peaks that might be known with less precision, such as historical flood data. Other thresholds were added to indicate other floods that may have occurred during data gaps in the record.

The weighted skew option was initially used, which weighs the computed station skew with the generalized regional skew. However, there was a difference greater than 0.5 and it was decided to rely only on the station skew due to the reasonable period of record (37 events) and varied conditions of the types of streams represented in the region. Table 5 contains the number and names of the stream-gaging stations upon which a Bulletin 17C analysis was performed.

Table 5. Relevant stream gages

Site Number	Site Name	Drainage are (mi^2)	No. years of usable record	Period of record used in this analysis
16701300	Waiakea Stream at Hilo, HI	36.33	37	1969 – 2021

The annual maximum series (AMS) is comprised of annual maximum flows without regard for the type of flood that caused each individual annual maximum.

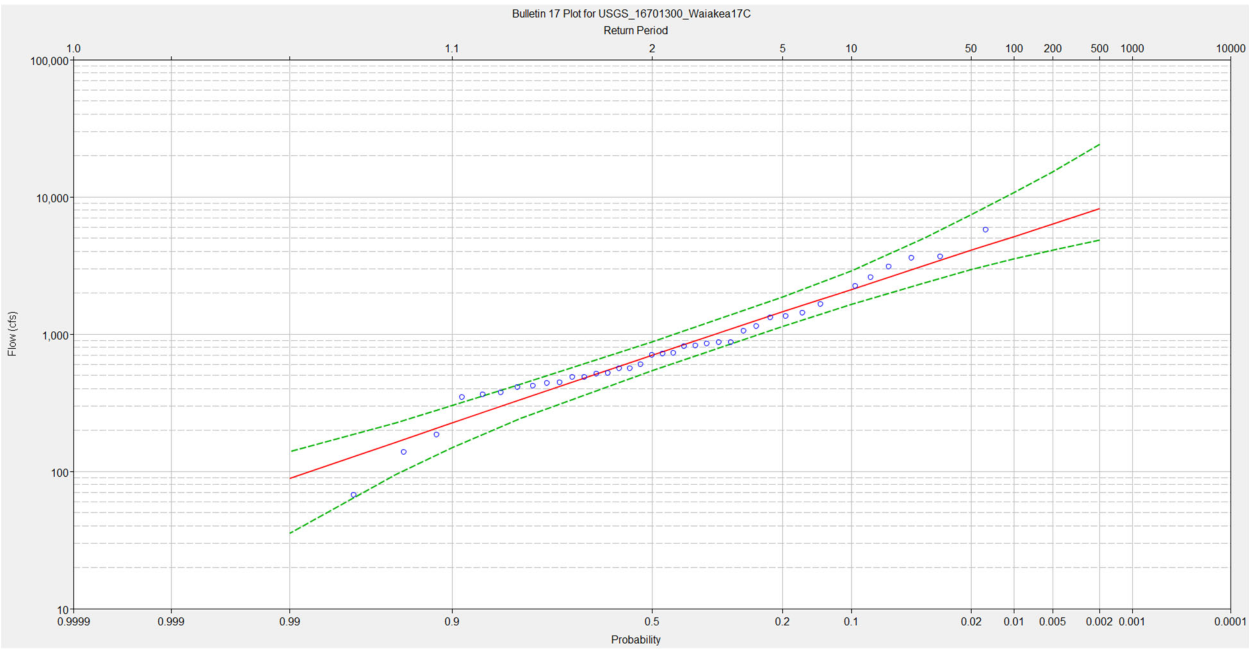
Table 6 and Figure 4 contain the results from completing this analysis on the AMS.

Table 6. Flow frequency estimates computed using Bulletin 17C methodology on the annual maximum series at USGS 16701300, Waiakea Stream at Hilo, HI

Annual Exceedance Probability (AEP)	Computed Curve Flow in ft^3/s	Variance Log	Confidence Limits	
			0.05	0.095
0.002	8,190	0.03824	24,108	4,868
0.005	6,353	0.02617	15,302	4,103
0.01	5,147	0.01890	10,719	3,523
0.02	4,087	0.01317	7,394	2,945
0.04	3,159	0.00893	5,006	2,372
0.10	2,115	0.00544	2,894	1,642

0.20	1,449	0.00421	1,859	1,136
0.50	698	0.00398	882	542
Mean: 2.841 Standard Dev: 0.379 Station Skew: -0.041		Historic Events: 0 Low Outliers and Zero Flows: 0 Missing Flows: 17		Systematic Events: 37 Historic Period: 54

Figure 4. Flow Frequency Curve based on the Annual Maximum Series



4.3 DEVELOPMENT OF THE HYDROLOGIC MODEL

Two hydrologic models were developed for this study: one representing the main study area (Puna) and one nearby watershed (Waiakea Stream) for calibration purposes. There are three main components of an HEC-HMS model: basin model, meteorologic model, and control specifications. The basin model, shown in Figure 5, contains the physical description of the watershed. Hydrologic elements (subbasins, reaches, sources, sinks, and junctions) are connected to one another to define the physical representation of the real-world watershed. The hydrologic elements such as infiltration rates and time of concentrations are needed for the program to compute the rainfall-runoff response in the watershed. The meteorologic model calculates the precipitation input needed by subbasin elements in the basin model. The control specification defines the time-period and time-step required for simulations.

Figure 5. HEC-HMS Basin Model Layout for Puna

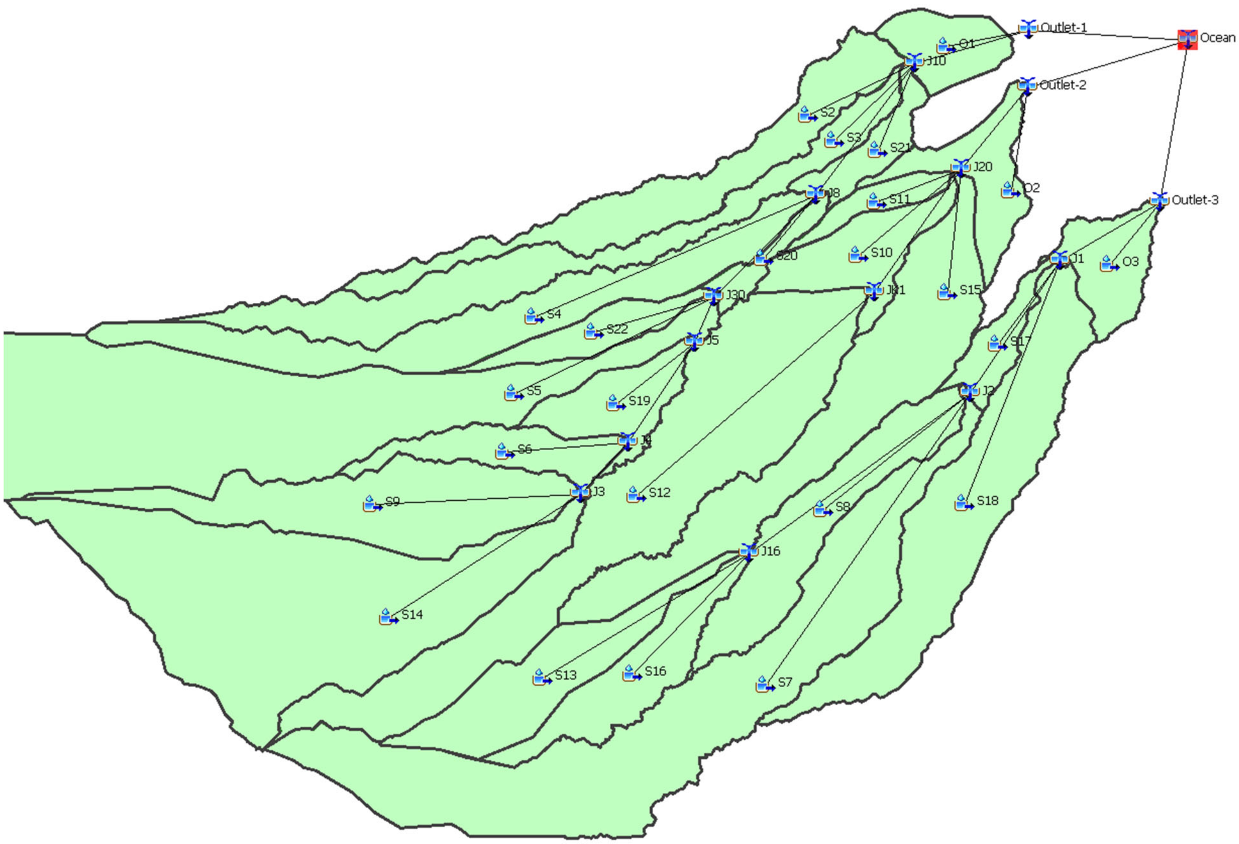
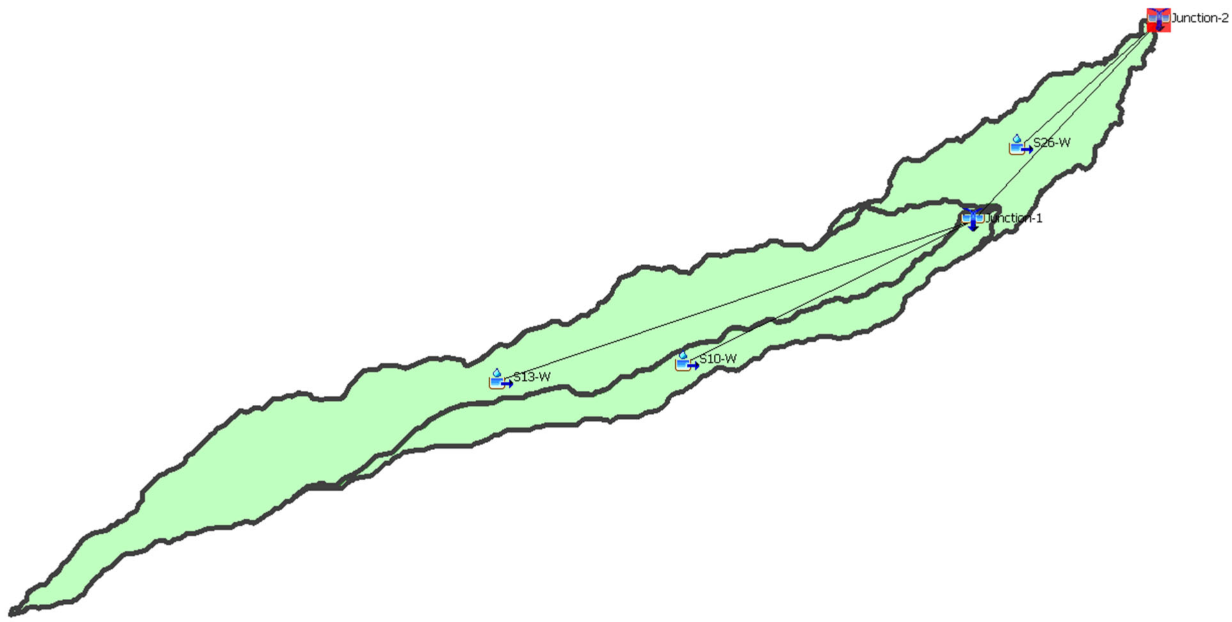


Figure 6. HEC-HMS Basin Model Layout for Waiakea Stream



4.3.1 Initial Basin Parameters

HEC-HMS contains many methods for simulating the rainfall-runoff response in a watershed. Modeling methods were chosen based on data availability and appropriateness for the project area. The *Initial and Constant* loss method was selected to perform the infiltration calculations in each subbasin. The Clark unit hydrograph method was selected as the transform method to perform the surface runoff calculations for each subbasin.

Table 7 contains the modeling methods chosen and a list of the required parameters. A routing method was not selected as there was low confidence in the ability to accurately represent the urban area (lower watershed) with a representative cross-section, especially when channels in the study area have a history of overtopping their banks frequently. Instead, the hydrologic model was used to estimate flows contributed by individual drainage areas. This data was entered into the hydraulic model, which then routed the flows across a two-dimensional mesh using site-specific characteristics for elevation, roughness, etc. (a more accurate way of routing flow in the lower watershed for this study area).

Table 7: HEC-HMS Modeling Methods and Required Parameters

Modeling Method	Parameter	Description
Initial and Constant Loss Method	Initial Loss (in)	The volume of water that is required to fill the soil layer at the start of the simulation.
	Constant Rate (in/hr)	The rate at which precipitation will be infiltrated into the soil layer after the initial loss volume has been satisfied.
	Impervious (%)	Impervious area directly connected to the channel network (no losses are computed)
Clark Unit Hydrograph Transform Method	Time of Concentration	Travel time from the most hydrological remote point in the sub-basin to the watershed outlet
	Storage Coefficient (hr)	Accounts for storage in the watershed

4.3.1.1 *Initial Loss Parameters*

The *Initial and Constant* loss method uses a hypothetical single soil layer to account for changes in moisture content. Parameters that are required to utilize this method within HEC-HMS include the *Initial Loss (in)* and *Constant Rate (in/hr)*. The *Directly Connected Impervious Area (%)* is an optional parameter.

The initial loss, the amount of precipitation lost to the soil at the beginning of the rainfall event, depends on the saturation of the soil and varies for each event. 0.1 inches of precipitation was assumed to be the initial loss due to absorption of the soil.

The constant loss rates were determined using soil data from the Hawaiʻi Soil Data Atlas, an interactive and online tool for providing basic information about each soil type (University of Hawai'i, 2014). Each soil type had previously been classified by their saturated hydraulic conductivity (Ksat) as either slow (< 3 micrometers per second; μm/s), moderate (3 to 10 μm/s), fast (10 to 100 μm/s), or very fast (> 100 μm/s). Only fast and moderate soil types were found in the study area. A geospatial shapefile provided by the Hawaiʻi Soil Data Atlas was used to compute a weighted average Ksat for each subbasin, and then converted to the appropriate units – inches per hour (in/hr). Results are provided in Table 8.

Table 8. Initial constant loss rates

Basin Model	Subbasin	Saturated hydraulic conductivity, Ksat (μm/s)	Constant loss rate (in/hr)
Waiakea	S10-W	9.80	1.39
Waiakea	S13-W	111	7.52
Waiakea	S26-W	23.8	3.38
Puna	O1	37.0	5.25
Puna	O2	69.9	9.91
Puna	O3	33.0	4.68
Puna	S10	28.8	4.08
Puna	S11	27.1	3.84
Puna	S12	59.9	8.49
Puna	S13	82.4	11.7
Puna	S14	59.4	8.41
Puna	S15	69.1	9.80
Puna	S16	82.4	11.67
Puna	S17	30.0	4.25
Puna	S18	76.9	10.90
Puna	S19	69.1	9.793
Puna	S2	39.7	5.63
Puna	S20	25.2	3.56
Puna	S21	24.9	3.53
Puna	S22	9.86	1.40
Puna	S3	37.3	5.29
Puna	S4	27.0	3.83
Puna	S5	56.6	8.02
Puna	S6	70.3	9.96
Puna	S7	68.3	9.68
Puna	S8	69.9	9.90
Puna	S9	62.7	8.90

Average constant loss rate for Waiakea: 4.1 in/hr

Average constant loss rate for Puna: 7.2 in/hr

4.3.1.2 *Initial Transform Parameters*

The excess precipitation in each subbasin was transformed into surface runoff by applying the Clark Unit Hydrograph method in the hydrologic model. This method requires two input parameters for each subbasin: the time of concentration (t_c) and the storage coefficient (R). The time of concentration, or the time it takes for runoff to travel from the most distant point in the watershed to the outlet, was calculated in accordance to the TR-55 manual's guidance. The TR-55 method breaks the surface flow in the watershed into three flow regimes (NRCS, 1986). As water travels along the longest flow path in the subbasin, it is transformed from sheet flow to shallow concentrated flow (Table 9) to open channel flow (Table 10). Sheet flow was considered to be negligible and was not included.

A time value is calculated for each flow regime. The time of concentration of a watershed is calculated by summing the travel time of flow through each of these flow regimes. GIS was used to determine the longest flow path, slope, and flow length of each subbasin. Representative channel cross-sections were estimated from the LiDAR data in RAS Mapper. Additional data required for the TR-55 method, such as the 2-year, 24-hour rainfall, were entered based on published data from the NOAA Atlas 14 Precipitation Frequency Data Server. The computed times of concentration are presented in Table 11.

The Clark Unit Hydrograph storage coefficient, R, accounts for storage in the watershed. The HEC-HMS User's Manual states that R, divided by the sum of R and tc, is reasonably constant over a region (between 0.23 to 0.91). Typically, a value between 0.5 and 0.7 is used as a starting point. 0.65 was assumed in this study:

Equation 1. Storage Coefficient, R

$$\frac{R}{(R + t_c)} = 0.65$$

$$\mathrm{R} = \text{Storage coefficient}$$

$$t_c = \text{time of concentration (hrs)}$$

The initial values for the storage coefficient parameter are summarized in Table 11.

Table 9: Shallow Concentrated Flow Characteristics for each Subbasin

Basin	Subbasin Name	Surface Description	Shallow Flow Length (ft)	Watercourse Slope (ft/ft)	Average Velocity (ft/s)	Tc, shallow (hrs)
Waiakea	S10-W	Unpaved	87,439	0.056	3.81	6.382
Waiakea	S13-W	Unpaved	123,427	0.061	3.98	8.606
Waiakea	S26-W	Unpaved	32,297	0.045	3.43	2.616
Puna	O1	Unpaved	16,391	0.011	1.70	2.685
Puna	O2	Unpaved	34,044	0.011	1.67	5.666
Puna	O3	Unpaved	27,999	0.013	1.87	4.154
Puna	S10	Unpaved	37,752	0.024	2.51	4.186
Puna	S11	Unpaved	29,187	0.022	2.41	3.362
Puna	S12	Unpaved	23,947	0.140	6.03	1.103
Puna	S13	Unpaved	49,125	0.034	2.96	4.616
Puna	S14	Unpaved	79,831	0.041	3.25	6.822
Puna	S15	Unpaved	82,029	0.027	2.65	8.602
Puna	S16	Unpaved	56,254	0.022	2.39	6.547
Puna	S17	Unpaved	29,175	0.019	2.24	3.621
Puna	S18	Unpaved	92,454	0.021	2.32	11.053
Puna	S19	Unpaved	27,843	0.039	3.19	2.426
Puna	S2	Unpaved	75,366	0.041	3.28	6.380
Puna	S20	Unpaved	22,699	0.030	2.78	2.272
Puna	S21	Unpaved	23,937	0.021	2.31	2.873
Puna	S22	Unpaved	37,166	0.043	3.33	3.102
Puna	S3	Unpaved	100,843	0.044	3.37	8.311
Puna	S4	Unpaved	97,352	0.047	3.51	7.714
Puna	S5	Unpaved	132,073	0.060	3.97	9.251
Puna	S6	Unpaved	35,946	0.049	3.56	2.803
Puna	S7	Unpaved	115,089	0.029	2.73	11.715
Puna	S8	Unpaved	46,029	0.033	2.92	4.381
Puna	S9	Unpaved	69,022	0.046	3.46	5.549

Table 10: Channel Flow Characteristics for each Subbasin

Basin	Subbasin Name	Cross Sectional Flow Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Channel Slope (ft/ft)	Manning's *n* Channel	Velocity (ft/s)	Flow Length (ft)	Tc, channel (hrs)
Waiakea	S26-W	300.0	40.0	7.50	0.056	0.045	30.0	18,153	0.168

Table 11. Initial times of concentration, t_c

Basin	Subbasin Name	Time of concentration, t_c (hrs)	Storage Coefficient, R
Waiakea	S10-W	6.382	8.679
Waiakea	S13-W	8.606	8.166
Waiakea	S26-W	2.784	2.283
Puna	O1	2.685	1.322
Puna	O2	5.666	4.600
Puna	O3	4.154	3.012
Puna	S10	4.186	3.355
Puna	S11	3.362	3.895
Puna	S12	1.103	0.722
Puna	S13	4.616	3.467
Puna	S14	6.822	3.867
Puna	S15	8.602	7.343
Puna	S16	6.547	6.883
Puna	S17	3.621	3.552
Puna	S18	11.053	10.557
Puna	S19	2.426	1.533
Puna	S2	6.380	6.268
Puna	S20	2.272	2.271
Puna	S21	2.873	2.273
Puna	S22	3.102	2.788
Puna	S3	8.311	10.037
Puna	S4	7.714	8.250
Puna	S5	9.251	6.818
Puna	S6	2.803	2.308
Puna	S7	11.715	9.811
Puna	S8	4.381	3.015
Puna	S9	5.549	4.449

4.3.2 Model Calibration

Rainfall and streamflow data in the study area are very limited. There were initial attempts to calibrate the Waiakea hydrologic model to a specific flood event, but because of the very limited period where instantaneous data was available, there was no single event that would have made calibration effective. Instead, the model was calibrated to replicate peak flows estimated by applying Bulletin 17C methodology on USGS 16701300.

4.3.2.1 *Calibrated Parameters*

The final, calibrated parameters are presented in Table 11.

Table 12. Final basin parameters

Basin	Subbasin Name	Constant loss rate (in/hr)	Time of concentration, t_c (hrs)	Storage Coefficient, R
Waiakea	S10-W	1	6.382	8.679
Waiakea	S13-W	10	8.606	8.166
Waiakea	S26-W	2.2	2.784	2.283
Puna	O1	3.41	2.685	1.322
Puna	O2	6.44	5.666	4.600
Puna	O3	3.04	4.154	3.012
Puna	S10	2.65	4.186	3.355
Puna	S11	2.49	3.362	3.895
Puna	S12	5.52	1.103	0.722
Puna	S13	7.59	4.616	3.467
Puna	S14	5.47	6.822	3.867
Puna	S15	6.37	8.602	7.343
Puna	S16	7.59	6.547	6.883
Puna	S17	2.76	3.621	3.552
Puna	S18	7.09	11.053	10.557
Puna	S19	6.37	2.426	1.533
Puna	S2	3.66	6.380	6.268
Puna	S20	2.32	2.272	2.271
Puna	S21	2.30	2.873	2.273
Puna	S22	0.91	3.102	2.788
Puna	S3	3.44	8.311	10.037
Puna	S4	2.49	7.714	8.250

Puna	S5	5.21	9.251	6.818
Puna	S6	6.47	2.803	2.308
Puna	S7	6.29	11.715	9.811
Puna	S8	6.43	4.381	3.015
Puna	S9	5.78	5.549	4.449

4.4 FLOW FREQUENCY ESTIMATES

The calibrated HEC-HMS model was used to perform the rainfall-runoff computations for 5 frequency events. Point precipitation data was obtained from the National Weather Service's (NWS) NOAA Atlas 14 Precipitation Frequency Data Server (PFDS). This source presents the estimated total rainfall from recurrence intervals of 1 to 1,000 years (100% to 0.1% annual exceedance probabilities) for various durations (5 minutes to 60 days) within or adjacent to the study area (NWS, 2011). The rainfall frequency dataset used in the HMS model for Puna is presented in Table 13.

Table 13. Precipitation Frequency Data

	Annual Exceedance Probability (AEP)				
	10%	4%	2%	1%	0.2%
Duration	1/10	1/25	1/50	1/100	1/500
5 Minutes	1.19	1.38	1.51	1.64	1.94
15 Minutes	1.76	2.04	2.24	2.43	2.88
1 Hour	2.22	2.56	2.81	3.05	3.62
2 Hours	3.12	3.6	3.96	4.3	5.09
3 Hours	4.1	4.74	5.2	5.65	6.7
6 Hours	6.04	7.07	7.82	8.56	10.3
12 Hours	7.31	8.59	9.54	10.5	12.6
1 Day	9.79	11.6	13	14.3	17.5

Table 14. Peak Flow Data for each Subbasin

Subbasin	Annual Exceedance Probability (AEP)				
	10%	4%	2%	1%	0.2%
	1/10	1/25	1/50	1/100	1/500
O1	1,156	1,528	1,818	2,092	2,917
O2	277	388	479	575	809
O3	808	1,051	1,233	1,436	2,128
S10	1,089	1,385	1,663	2,003	2,979
S11	394	505	614	746	1,088
S12	10,824	15,013	18,176	21,368	29,804
S13	529	743	920	1,107	1,625
S14	2,217	3,074	3,718	4,375	6,119
S15	612	858	1,061	1,270	1,785
S16	219	308	381	459	673
S17	513	655	777	927	1,382
S18	396	555	687	828	1,194
S19	746	1,046	1,292	1,546	2,173
S2	945	1,251	1,504	1,744	2,375
S20	567	740	908	1,093	1,551
S21	881	1,157	1,427	1,723	2,456
S22	2,493	3,218	3,791	4,362	5,744
S3	743	984	1,172	1,350	1,891
S4	1,329	1,704	2,082	2,546	3,750
S5	2,070	2,834	3,411	4,013	5,609
S6	507	710	878	1,053	1,484
S7	817	1,144	1,414	1,688	2,369
S8	762	1,068	1,320	1,582	2,228
S9	900	1,256	1,538	1,811	2,536

Table 15. Peak Flow Data for each Junction

Junction	Annual Exceedance Probability (AEP)				
	10%	4%	2%	1%	0.2%
	1/10	1/25	1/50	1/100	1/500
JK1	10,824	15,013	18,176	21,368	29,804
J1	2,403	3,316	4,076	4,890	7,065
J10	9,369	12,686	15,429	18,291	25,849
J16	710	997	1,236	1,487	2,183
J2	1,800	2,525	3,124	3,748	5,362
J20	11,237	15,545	18,823	22,157	30,997
J3	3,088	4,289	5,206	6,127	8,572
J30	6,338	8,688	10,556	12,461	17,455
J4	3,258	4,527	5,501	6,481	9,072
J5	3,385	4,706	5,723	6,749	9,448
J8	7,555	10,285	12,529	14,895	21,107

Table 16. Peak Flow Estimates by Oceanit (2013) compared to USACE (2023) at Junctions

Junctions	Description	10% AEP (1/10)		2% AEP (1/50)		1% AEP (1/100)		0.2% AEP (1/500)	
		Oceanit	USACE	Oceanit	USACE	Oceanit	USACE	Oceanit	USACE
J2	Volcano Rd & Kahaualeale Rd	9,454	1,800	23,955	3,124	35,157	3,748	46,240	5,362
J3	Near Mauaana Rd	19,063	3,088	40,749	5,206	59,984	6,127	80,339	8,572
J4	Near Apele Rd	19,538	3,258	36,533	5,501	45,384	6,841	61,031	9,072
J5	South Kūlani Rd Bridge	25,024	3,385	45,398	5,723	61,326	6,749	84,906	9,448
J8	Volcano Rd & Huina Rd	5,859	7,555	12,212	12,529	17,055	14,895	25,270	21,107
J10	Railroad Aves. & Keaau Rd	1,361	9,369	3,916	15,429	5,539	18,291	11,894	25,849
JK1	Pulelehua Rd & Poola Rd	1,229	10,824	8,197	18,176	17,854	21,368	28,551	29,804
J16	Waimakao Pele Rd & Pahoehe Rd	241	710	1,035	1,236	2,672	1,487	8,712	2,183

SECTION 5 - DEVELOPMENT OF THE HYDRAULIC MODEL

A two-dimensional (2D), unsteady flow hydraulic model was developed for this study using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software (version 6.4.1, HEC, 2023). This model was used to simulate flow in streams and across the floodplain within the limits of the study area. The following list provides an overview of the steps completed to create this model. Additional information is provided in the sections that follow.

1. **Establish a horizontal coordinate projection to use in the model.** The horizontal coordinate projection was set to NAD83 (PA11), State Plane Zone 1 (US Survey Feet).
2. **Develop a terrain model in RAS Mapper.** A terrain model was created in RAS Mapper based on 2018 LiDAR data and elevation data from USGS 3DEP, as described in Section 3.2.2.
3. **Build a land classification data set to establish Manning's n values (roughness coefficient) within the 2D Flow Areas.** A circa 2011 high resolution (1 to 5 meter) land cover raster was used to represent various land covers in the study area. Each cover type was assigned a unique roughness coefficient, as presented in Section 5.1.3.
4. **Add any additional mapping layers needed (i.e. aerial imagery, road networks).** High resolution imagery used for background mapping of the study area is from DigitalGlobe, the National Geospatial-Intelligence Agency and the USGS. World Imagery, provided by Esri, was used for larger scale background mapping, such as when it was necessary to show the entire island of Hawaii. Other GIS data (i.e. road networks) was provided by the County of Hawaii through the Hawaii Statewide GIS Program's Geospatial Data Portal [https://geoportal.hawaii.gov/].
5. **Outline the 2D Flow Area.** The 2D Flow Area defines the boundary for which 2D computations will occur. A 2D Flow Area was drawn to represent the study area, extending from Lehuanani Street to the shoreline. The primary 2D Flow Area represents the main river systems in the watersheds. Additional information on 2D Flow Areas is included in Section 5.1.4.

6. **Layout any break lines within the 2D flow area to force the mesh to align the computation cell faces along the break lines.** Break lines were added to represent significant barriers to flow (i.e. levees, roads, high ground). They were also added along the channel invert and banks of main river systems.
7. **Create the 2D computational mesh for each 2D flow area.** The primary 2D Flow Area “Perimeter 1” has a base cell size of 75, refined as needed along rivers, road embankments, high ground barriers, and hydraulic structures (i.e. bridges and culverts). The three 2D Flow Areas representing independent coastal drainage areas have a base cell size of 25, which was also refined, as needed.
8. **Add internal hydraulic structures or bridges inside the 2D Flow Area(s) using the SA/2D Area Hydraulic Connection feature**. An SA/2D Area Hydraulic Connection feature was created to represent each major bridge, culvert, or crossing in the study area. Additional information on how these features were modeled is described in Section 5.1.6.1.
9. **Draw any external boundary condition lines along the perimeter of the 2D Flow Areas.** Several external boundary condition lines were drawn along the upper boundary of the study area, representing flow coming from the upstream areas of Puna. Along the coast, external boundary conditions were drawn to represent the ocean stage and attenuation of flow entering it.
10. **Enter all the necessary boundary and initial condition data for the 2D Flow Areas in the Unsteady Flow data editor.** Data for the external “Flow Hydrograph” boundary conditions were computed outputs from the rainfall-runoff model described in Section 4.3, Development of the Hydrologic Model. An external “Stage Hydrograph” boundary condition was used to represent the ocean at the downstream end of the study area for all 2D Flow Areas.
11. **Run the Unsteady Flow simulation and review the results in RAS Mapper.** Results are summarized in SECTION 6 - Flood Hazard Analysis.

5.1 GEOMETRY DATA

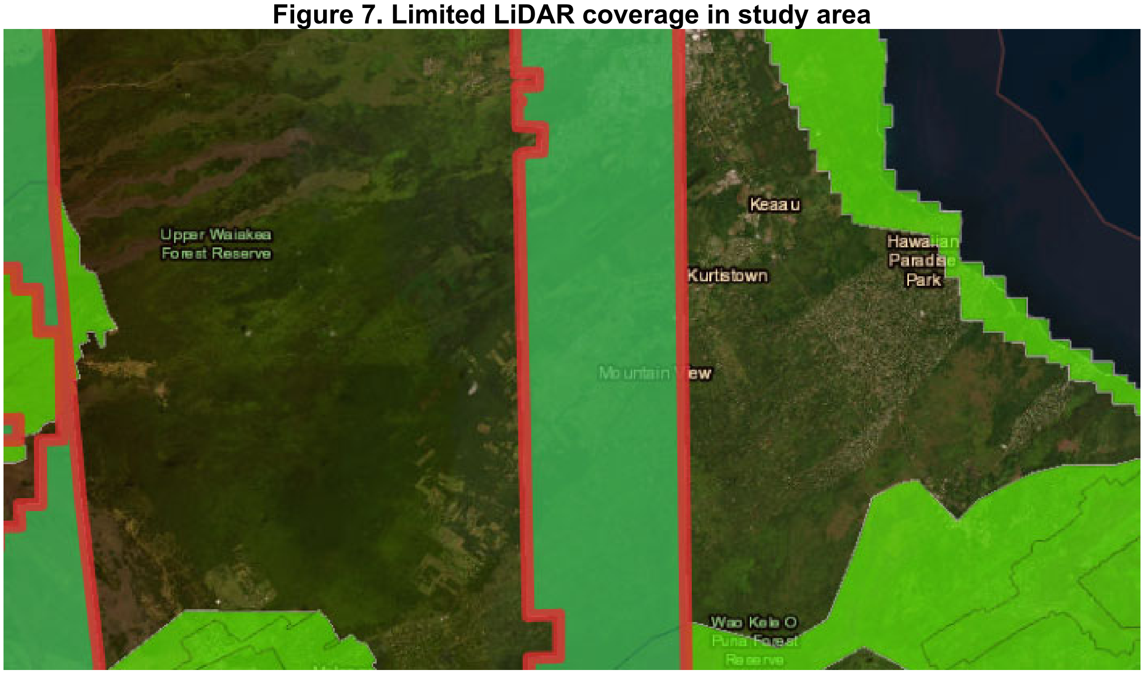
RAS Mapper, a geospatial interface in the HEC-RAS software, was used to fully develop the geometric data required for the river hydraulics model. The projection was set to State Plane Zone 1 (US Survey Feet) with reference to the NAD83 (PA11) coordinate system.

5.1.1 Elevation

Elevation data presented in Section 3.2.2, Elevation were imported and merged to create a digital terrain in RAS Mapper. Terrain modifications were applied to remove bridge obstructions, add pilot channels, and add berms, as needed to improve representation of existing site conditions.

There is limited LiDAR coverage in the study area. Only part of the study area had LiDAR data available for use in this study. Figure 7 displays the LiDAR coverage used for the study area. The elevation data gaps were filled with lower resolution (~10 meter) elevation data provided by USGS 3DEP.

Figure 7. Limited LiDAR coverage in study area



Additional LiDAR was collected within the last few years that would increase coverage in the study area within the vicinity of Kurtistown and Keaau (Figure 8). Unfortunately, this LiDAR was not yet available for use in this study. This dataset would also still not provide complete coverage to the entire Puna region and study area. However, the accuracy of the floodplain maps produced by this study could be further improved by incorporating this elevation data when does becomes available later (tentatively available to the public in Spring 2024).

Figure 8. Additional future LiDAR coverage

5.1.2 Imagery

High resolution imagery used for background mapping of the study area is from DigitalGlobe, the National Geospatial-Intelligence Agency and the USGS. World Imagery, provided by Esri, was used for larger scale background mapping, such as when it was necessary to show the entire island of Big Island.

5.1.3 Land Classification for Manning's *n*

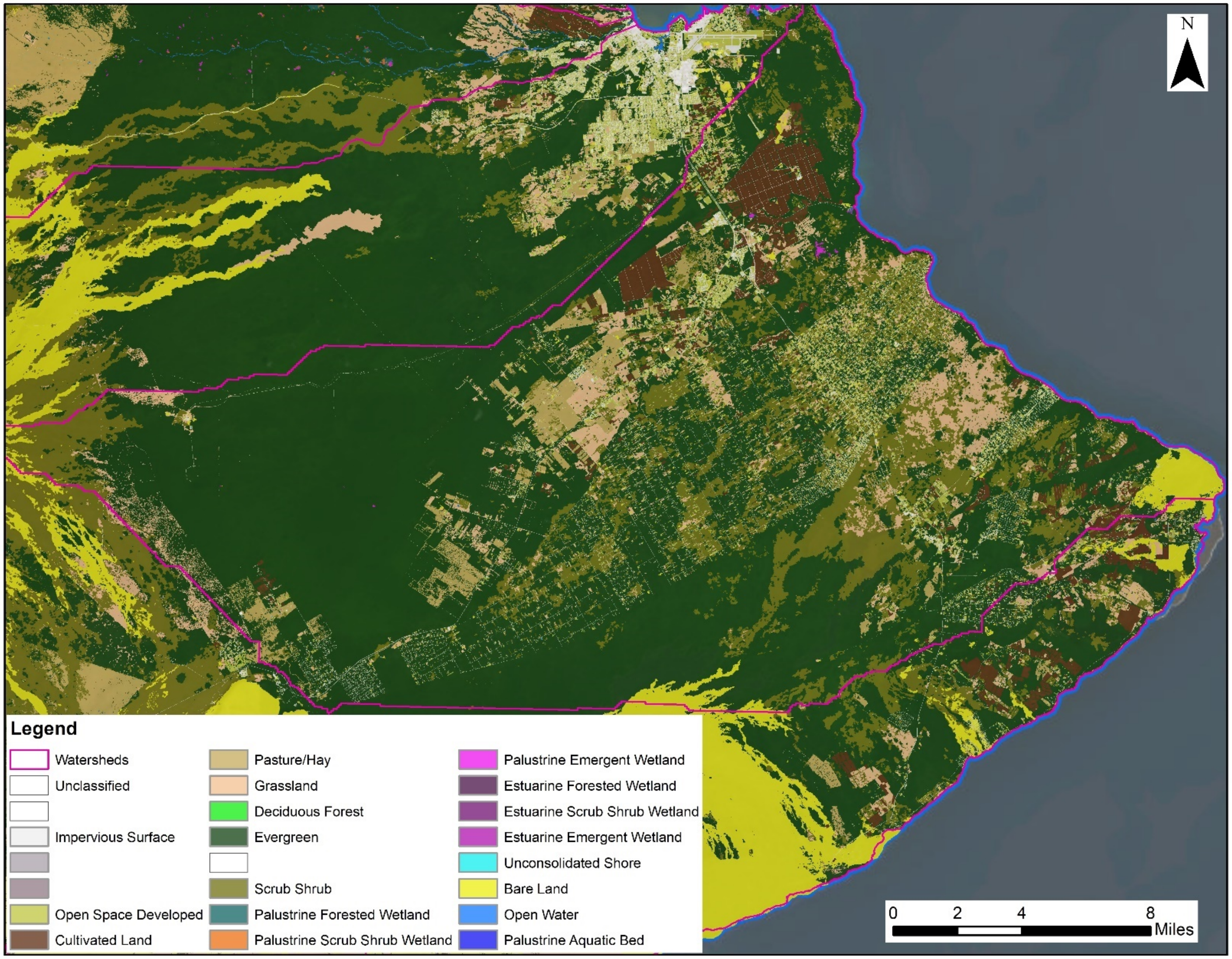
A circa 2011 high resolution (1 to 5 meter) land cover raster for the study area was developed by the National Oceanic and Atmospheric Administration (NOAA) and downloaded from the National Land Cover Database (NLCD). This raster, shown in Figure 9, was used to understand the different types of land usage in the study area and compute the directly connected impervious areas for the rainfall-runoff model. This raster was also imported into RAS Mapper to create a spatially varying Land Cover layer for the hydraulic model to reference.

Once a Land Cover layer has been created, the user can then build a table of Land Cover versus Manning's *n* values, which can then be used in defining the roughness values for 2D Flow Areas. Manning's roughness coefficient, *n*, represents the resistance to flow in channels and floodplains. Typical *n* values selected for this study are provided in Table 17, which is based on Table 2-1 in the HEC-RAS 2D User's Manual (Hydrologic Engineering Center, 2023). Additionally, the user can define Percent Impervious for each Land Cover Classification type. Percent Impervious is only needed if the user intends to use precipitation and infiltration features within HEC-RAS.

Table 17. Land Cover Data – Manning's n and Percent Impervious

NLCD Value	Land Cover Type	Manning's *n*	Percent Impervious
11	Open Water	0.035	100
21	Developed, Open Space	0.040	10
24	Developed, High Intensity	0.150	100
31	Barren Land	0.030	0
42	Evergreen Forest	0.160	0
52	Scrub/Shrub	0.100	0
71	Grassland/Herbaceous	0.035	0
81	Pasture/Hay	0.030	0
82	Cultivated Crops	0.040	0
90	Woody Wetlands	0.100	0
95	Emergent Herbaceous Wetlands	0.070	0

Figure 9. Land Cover Map



5.1.4 2D Flow Areas

A 2D Flow Area defines the boundary for which 2D computations will occur. A primary 2D Flow Area, “Perimeter 1,” was drawn to represent the main river systems in the Kaahakini watershed (Figure 10). This 2D Flow Area extends from about Lehuanani Street to the shoreline, and Ihope Road to Jungle King Avenue. The 2D Flow Area is also shown in Figure 10. The default cell spacing for these 2D Flow Areas range from 50 to 75 ft. The default Manning’s n value was 0.06.

Figure 11shows the difference between the higher resolution LiDAR and lower resolution 10-meter DEM displayed in the HEC-RAS software.

Figure 10. 2D Flow Area

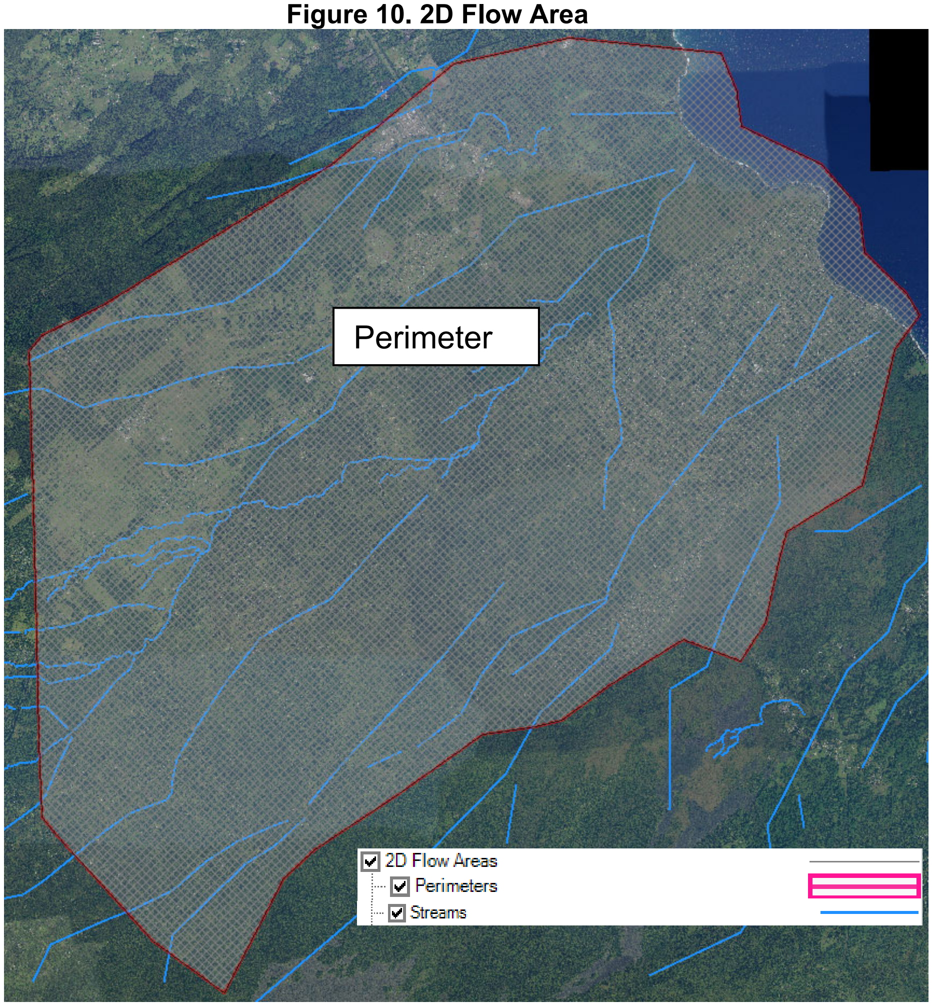
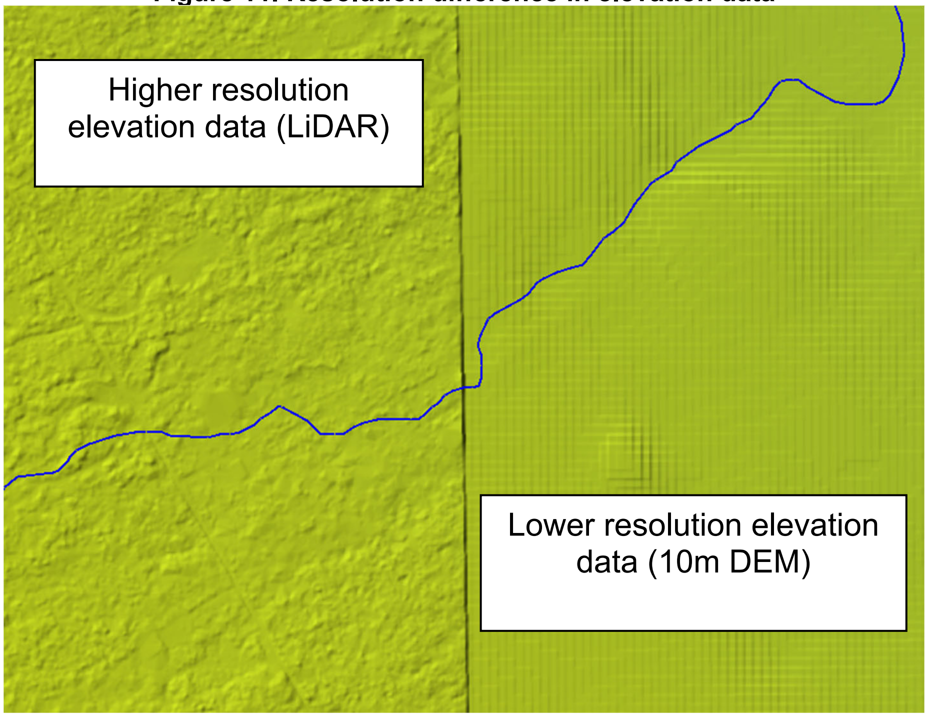


Figure 11. Resolution difference in elevation data



5.1.5 Break Lines

Break lines were sometimes used in 2D Flow Areas to align the computation cell faces along high ground and natural barriers that affect flow and direction (such as river banks). Typically, these break lines would have a Near Spacing of 25 and Far Spacing of 50.

5.1.6 SA/2D Area Connection

The SA/2D Area Connection feature was used to recognize and compute weir flow over major roads, over embankment crests and between 2D Flow Areas. For flow over a typical bridge deck, a weir coefficient of 2.6 was used. A weir coefficient of 3.0 was used for flow over elevated roadway approach embankments. A weir coefficient of 0.5 was used for flow between two 2D Flow Areas.

5.1.6.1 *Bridges and Culverts*

Thirty bridge/culvert crossings were represented in the model as an SA/2D Area Connection. The geometric features and dimensions were determined by typical photos of these crossings, as collected by field surveys, as-built plans, and national bridge inventory data (FHWA, 2023). At locations where bridge data was not available, the terrain raster was modified to remove these obstacles from the raster completely, allowing for channel flows to pass through unimpeded.

5.2 FLOW DATA

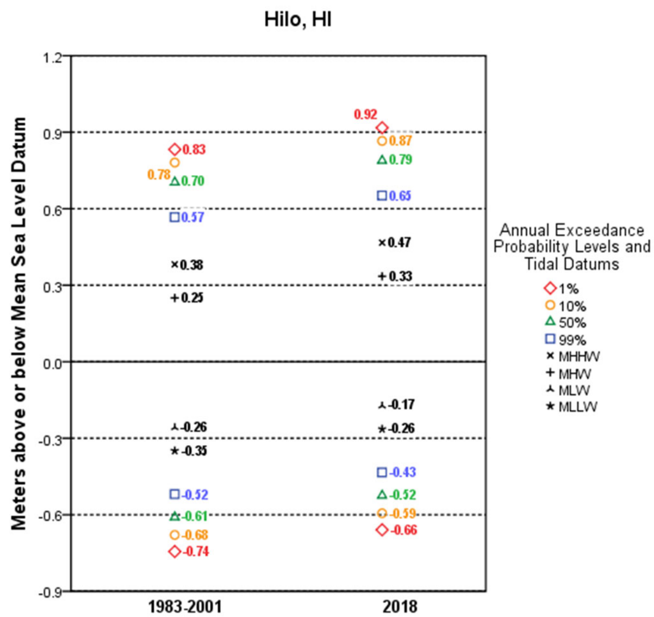
Flow frequency hydrographs computed by the calibrated HEC-HMS hydrologic model were used to represent the amount of water in the system.

5.2.1 Boundary Conditions

Boundary conditions are necessary to establish the starting water surface at the upstream and downstream ends of the channel system. A flow hydrograph was used to represent the amount of flow entering at the upstream ends of the hydraulic model. At some locations, it was necessary to further divide the hydrograph developed for each subbasin to represent flow entering from an additional location (typically, a smaller tributary). In this instance, the hydrograph was divided based on the corresponding drainage area for each individual reach segment.

The downstream boundary condition was set to a water surface elevation of the extreme water levels, meters above the mean sea level datum. This was determined based on the MHHW elevation at NOAA tidal station at Hilo Bay, HI – Station ID: 1617760 (NOAA) as shown in Figure 12.

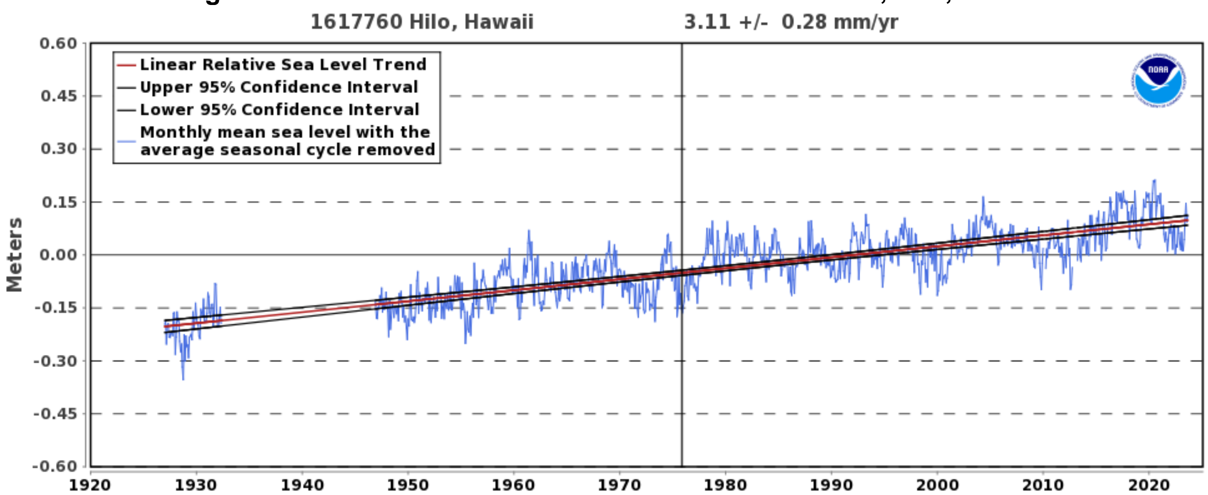
Figure 12. Annual Exceedance Probability Levels and Tidal Datums



5.3 SEA LEVEL CHANGE

In following Engineer Regulation 1100-2-8162, *Incorporating Sea Level Change in Civil Works Programs* (USACE, 2013) and ETL 1100-2-1, *Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation* (USACE, 2014), three scenarios of sea level change were projected: *low*, *intermediate*, and *high.* The gage at Hilo, HI (NOAA ID: 1617760) was used for the analysis (NOAA). This gage was established in 1946 and in its present location since 1989. It is located in the Port of Hilo, approximately 9 miles northwest of Puna. The relative sea level trend for this tidal gauge is 3.11 mm/year (0.0102 ft/yr) with a 95% confidence interval of +/- 0.28 mm/yr based on monthly mean sea level data from 1927 to 2022, which is equivalent to a change of 1.02 feet in 100 years.

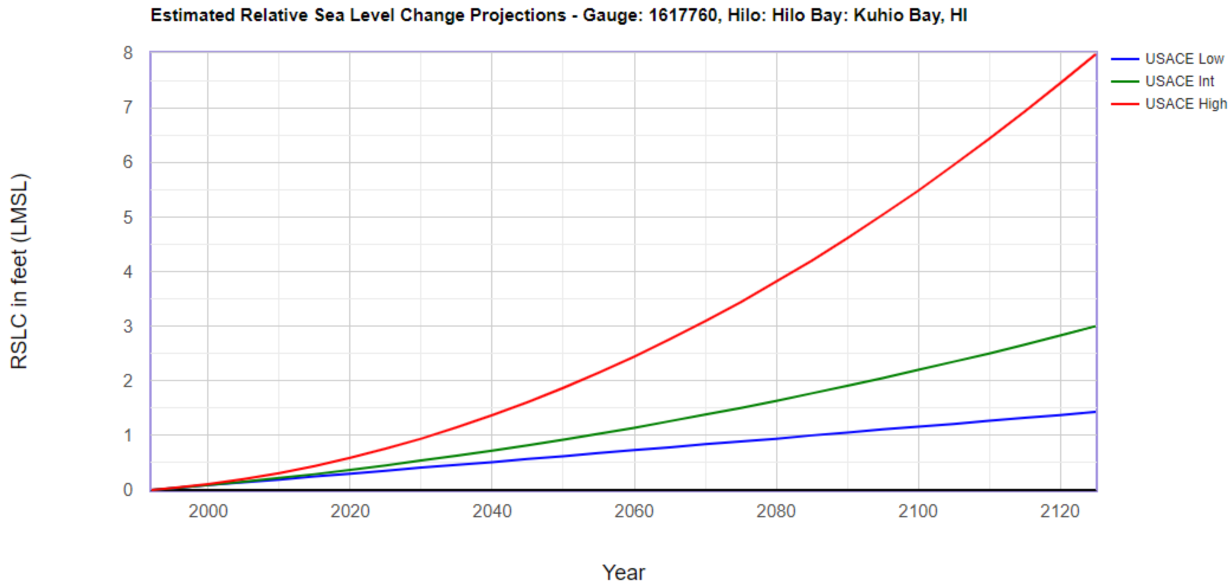
Figure 13. Relative Sea Level Trend for Station 1617760, Hilo, Hawaii



The gage site was selected in the USACE Sea Level Change Calculator (Version 2022.72). The 2006 NOAA sea level change rate of 0.01073 ft/yr was greater than the 2022 rate (0.0102 ft/yr). The more conservative rate (NOAA 2006) was entered as the SLC rate for estimating relative sea level change projections.

The result of the calculation indicates a relative sea level change of 7.26 feet over the next 100 years for the *high* condition (7.98 feet for the year 2125 minus 0.76 feet for the year 2025 equals 7.26 feet). For the *intermediate* condition, the change was 2.57 feet, and the *low* condition shows an increase of 1.08 feet. These values are relative to Local Mean Sea Level (LMSL) as the calculator states NAVD88 datum is not available at this station. The resulting sea level rise curve is shown in Figure 14.

Figure 14. Estimated Relative Sea Level Change Projections – Gauge: 1617760, Hilo, HI



The calculator also outputs a table showing the progression of sea level rise. This table was derived in 5-year increments and is shown in Table 18.

Table 18. Sea Level Rise by Year

Year	USACE		
	Low	***Intermediate***	***High***
1992	0.00	0.00	0.00
1995	0.03	0.03	0.04
2000	0.09	0.09	0.11
2005	0.14	0.15	0.20
2010	0.19	0.22	0.31
2015	0.25	0.29	0.44
2020	0.30	0.37	0.59
2025	0.35	0.45	0.76
2030	0.41	0.54	0.94
2035	0.46	0.63	1.15
2040	0.51	0.72	1.37
2045	0.57	0.82	1.61
2050	0.62	0.92	1.87
2055	0.68	1.03	2.15
2060	0.73	1.14	2.44

2065	0.78	1.26	2.76
2070	0.84	1.38	3.09
2075	0.89	1.50	3.44
2080	0.94	1.63	3.82
2085	1.00	1.77	4.20
2090	1.05	1.91	4.61
2095	1.11	2.05	5.04
2100	1.16	2.20	5.48
2105	1.21	2.35	5.95
2110	1.27	2.50	6.43
2115	1.32	2.66	6.93
2120	1.37	2.83	7.45
2125	1.43	3.00	7.98

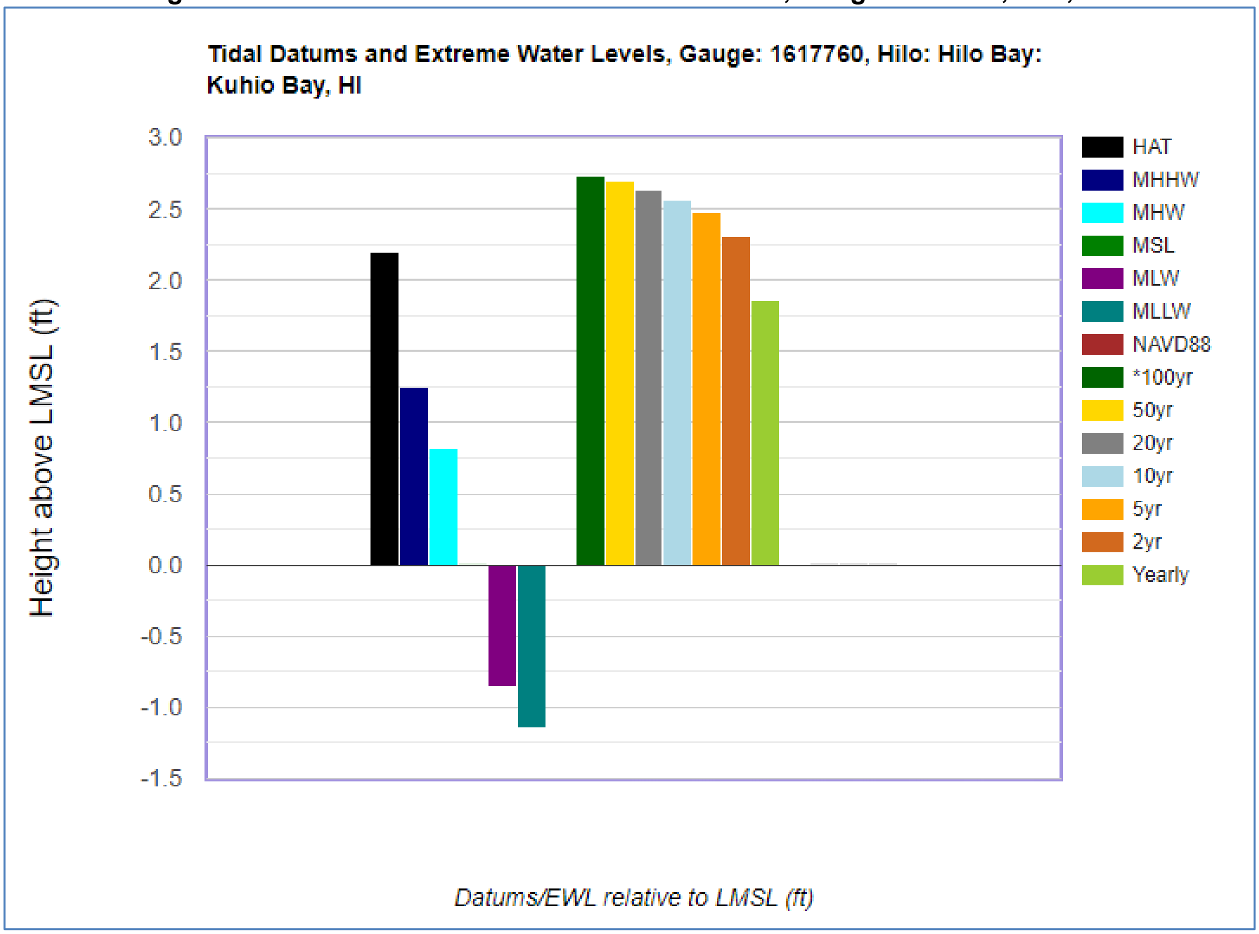
The calculator also provides extreme water levels expected across several datums. These datums and their respective values are shown in the table and figure below:

Table 19. Tidal Datums and Extreme Water Levels, Gauge: 1617760, Hilo, HI

Datum / Extreme Water Level (EWL)	Height above LMSL (ft)
HAT	2.2
MHHW	1.25
MHW	0.82
MSL	0.00
MLW	-0.85
MLLW	-1.15
NAVD88	NaN
EWL Type	NOAA GEV
1/100 AEP	2.73
1/50 AEP	2.69
1/20 AEP	2.63
1/10 AEP	2.56
1/5 AEP	2.48

1/2 AEP	2.31
Yearly	1.86
Monthly	NaN
From	1927
To	2007
Years of Record	80

Figure 15. Tidal Datums and Extreme Water Levels, Gauge: 1617760, Hilo, HI



The highest tide level occurred in January 2020 and was 1.75 ft MHHW (0.5 ft MSL). Under *high* sea level rise conditions, this max tide level would be 8.46 ft MHHW (7.39 ft MSL) in 2125. The relative change in sea level from 2025 to 2125 is 6.70 feet.

The downstream boundary in the hydraulic model was adjusted to represent the mean higher high water (MHHW) elevation under the three different sea level change conditions. Even under *high* sea level conditions (7.77 ft MSL), the impact to the extent and depths of flooding was minimal.[1]

[1] Impacts from wave action or shoreline erosion are not represented in this analysis.

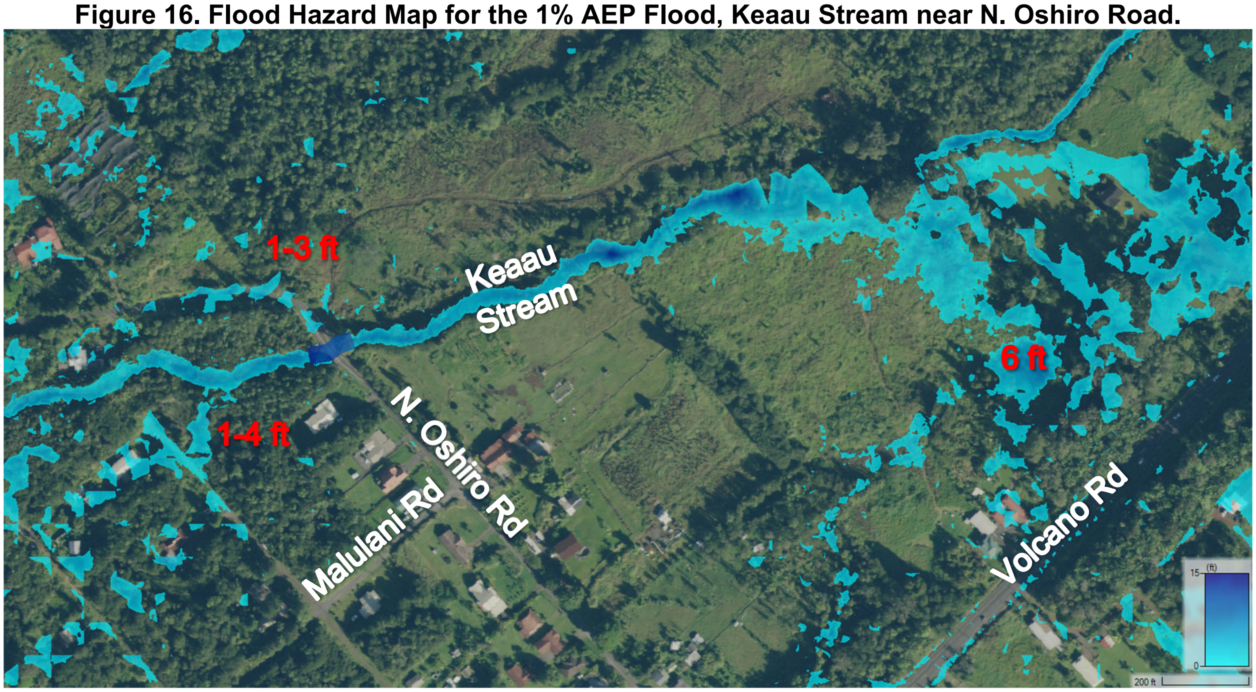
SECTION 6 - FLOOD HAZARD ANALYSIS

Flood hazard maps are included in Appendix A. General flood risk to the community is described in the following sections.

6.1 N. OSHIRO ROAD

There is moderate risk of flooding to the residential properties near N. Oshiro Road (Figure 16), where properties are inundated 1 – 3 feet during the 1% AEP flood. It appears that along Keaau Stream water is diverted or overtopped and sheet flows toward Volcano Road reaching flood depths of approximately 6 ft.

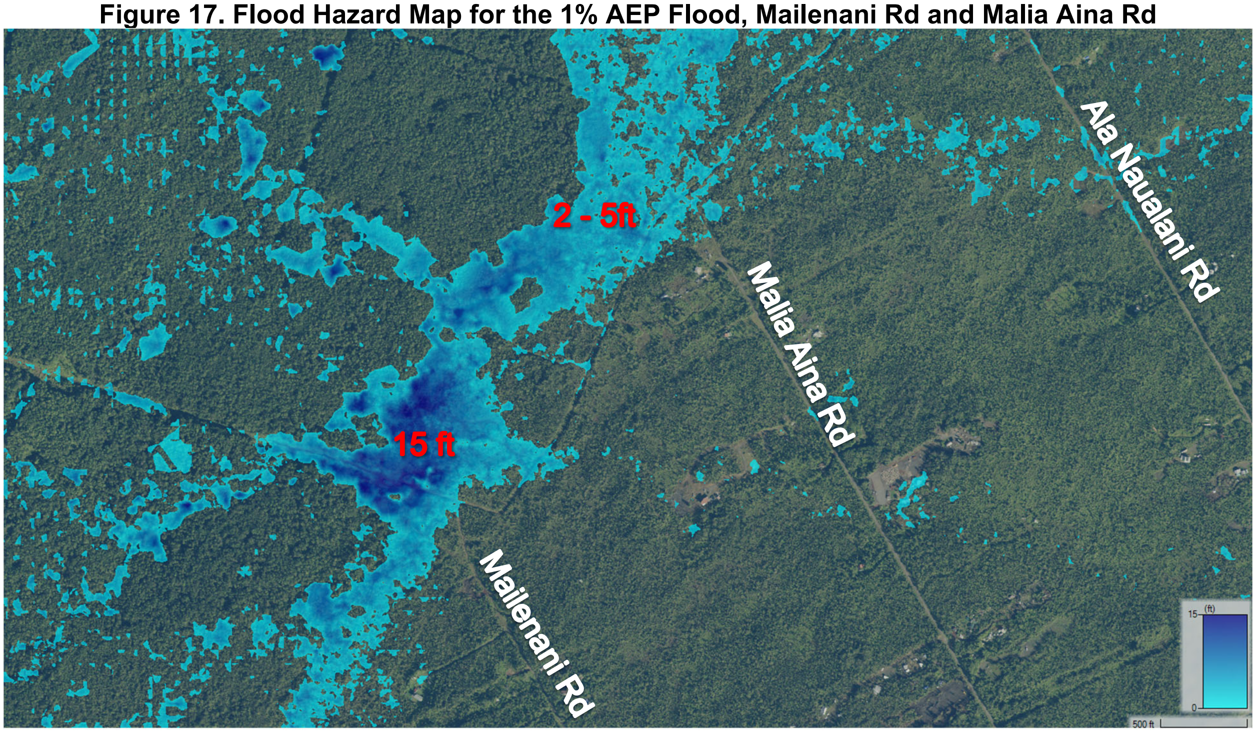
Figure 16. Flood Hazard Map for the 1% AEP Flood, Keaau Stream near N. Oshiro Road.



6.2 MAILENANI RD AND MALIA AINA RD

An undeveloped area between Mailenani Road and Malia Aina Road are at risk of flooding at depths of approximately 1 – 15 ft during the 1% AEP flood (Figure 17). The end of Mailenani Road has inundation depths of 15 ft. There is widespread flooding near Malia Aina Road and the flood depths range from approximately 2 - 5ft.

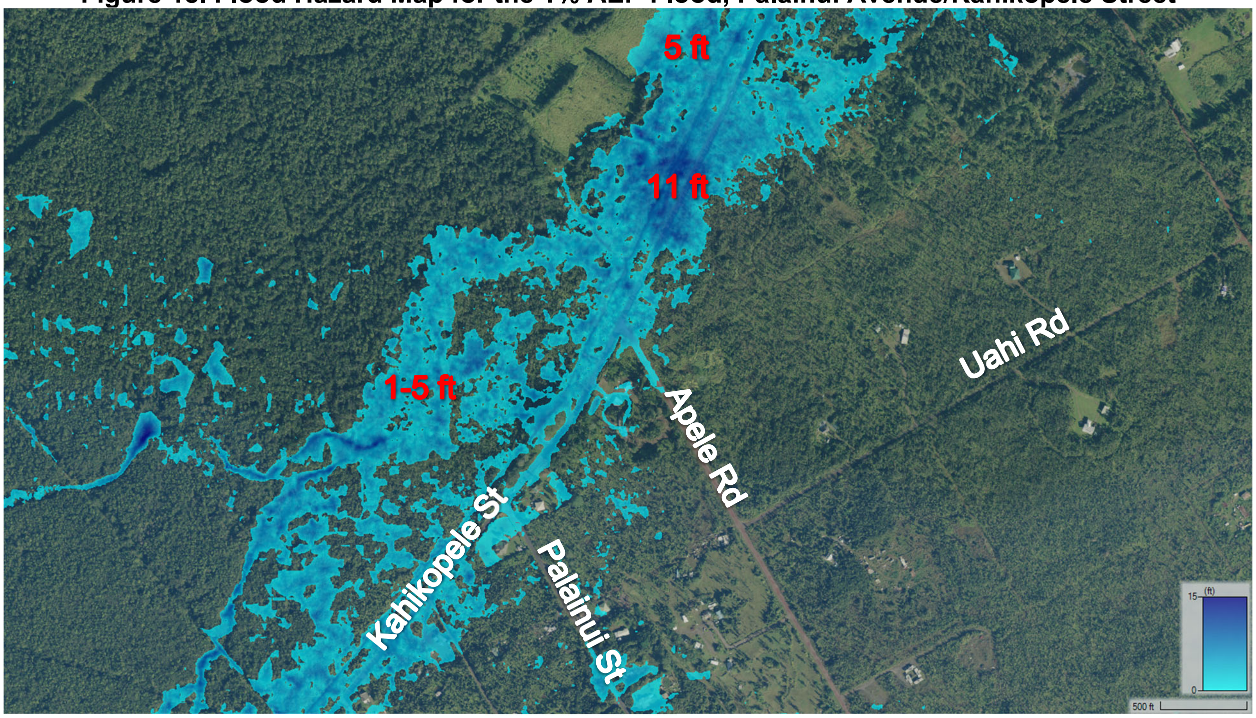
Figure 17. Flood Hazard Map for the 1% AEP Flood, Mailenani Rd and Malia Aina Rd



6.3 PALAINUI STREET/KAHIKOPELE ST

Overtopping from Keaau Stream results in additional flow entering the Kahikopele Street. Residential properties along Kahikopele St and Palainui St are likely to experience flooding of 1 – 5 ft (Figure 18) during the 1% AEP flood. Properties along Kahikopele St that are close to a stream or tributary also experience flooding of 1 – 5 ft. Flood depths along Kahikopele St reach to approximately 11 ft at the deepest location.

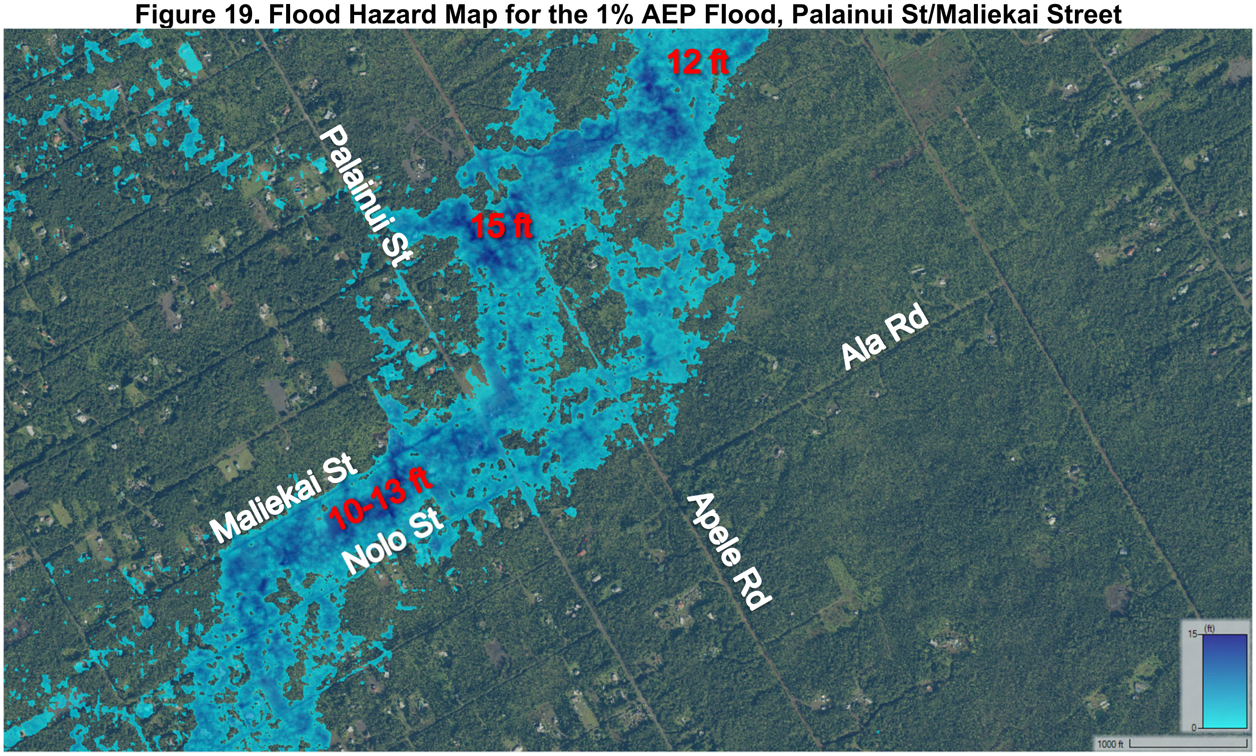
Figure 18. Flood Hazard Map for the 1% AEP Flood, Palainui Avenue/Kahikopele Street



6.4 PALAINUI ST/MALIEKAI STREET

This area was not identified as a stream layer however, in performing the hydrology and based on the terrain this location appears to be a frequent location of substantial flooding. Flooding in this area is more extensive with depths ranging from 1 – 15 ft during the 1% AEP flood. The location between Maliekai St and Nolo Street has flood depths ranging from 10 – 13 ft. Between Palainui St and Apele flood depths reach to 15 ft as shown in Figure 19.

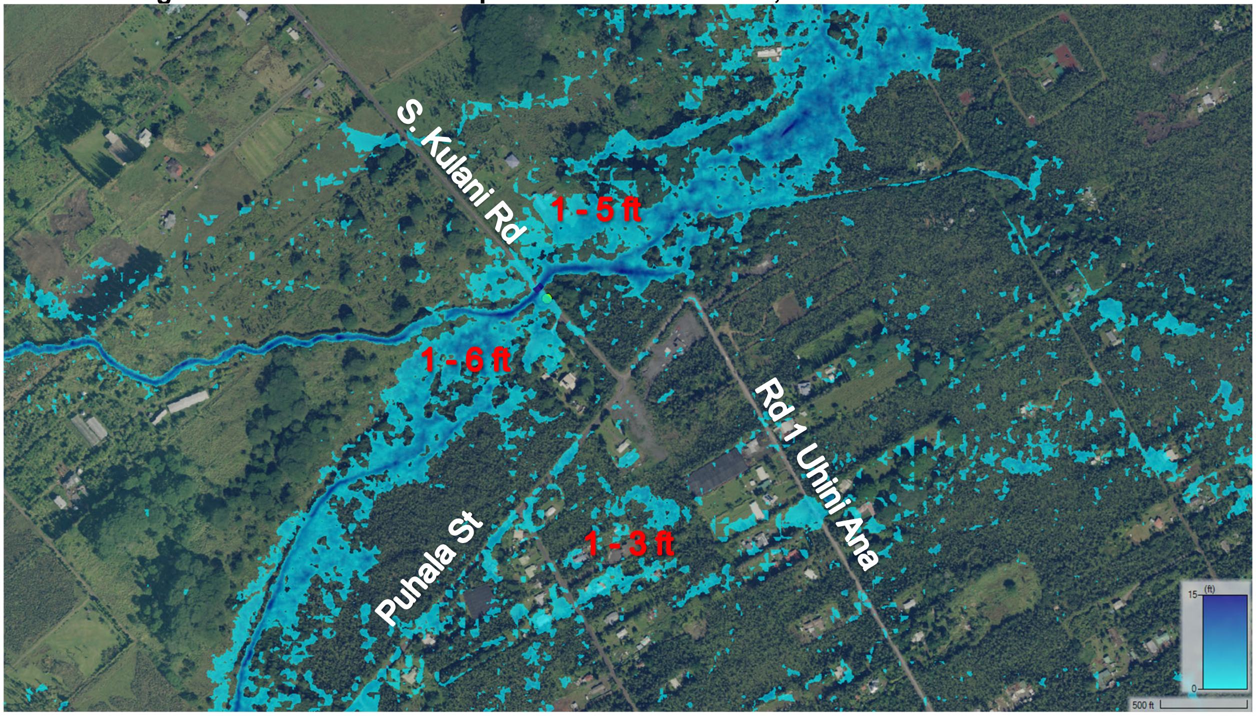
Figure 19. Flood Hazard Map for the 1% AEP Flood, Palainui St/Maliekai Street



6.5 PUHALA STREET/S. KULANI RD

Overtopping of Keaau Stream along S. Kulani Rd inundates properties in the vicinity with 1 – 6 ft of flooding during the 1% AEP flood (Figure 20). There is also widespread flooding as tributaries converge at S. Kulani Rd. Properties along Puhala St also experience shallow flooding with depths approximately 1 – 3 ft during the 1% AEP flood.

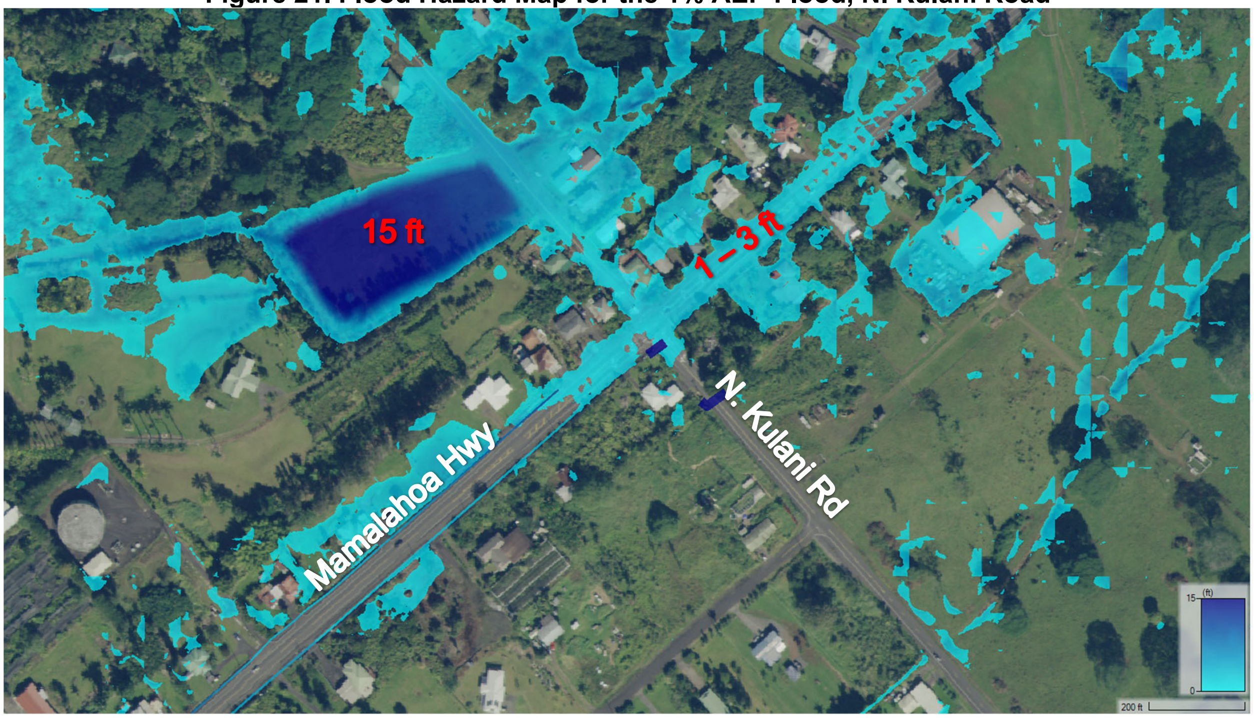
Figure 20. Flood Hazard Map for the 1% AEP Flood, Puhala Street/S. Kulani Rd



6.6 N. KULANI ROAD

There appears to be a low spot in the terrain along N. Kulani Road which collects flood waters that reach up to 15 ft during the 1% AEP flood (Figure 21). There are also drainage ditches on both sides of Mamalahoa Hwy which overtop in some locations which impact residential and commercial properties. The approximate flood depths are 1 – 3 ft during the 1% AEP flood.

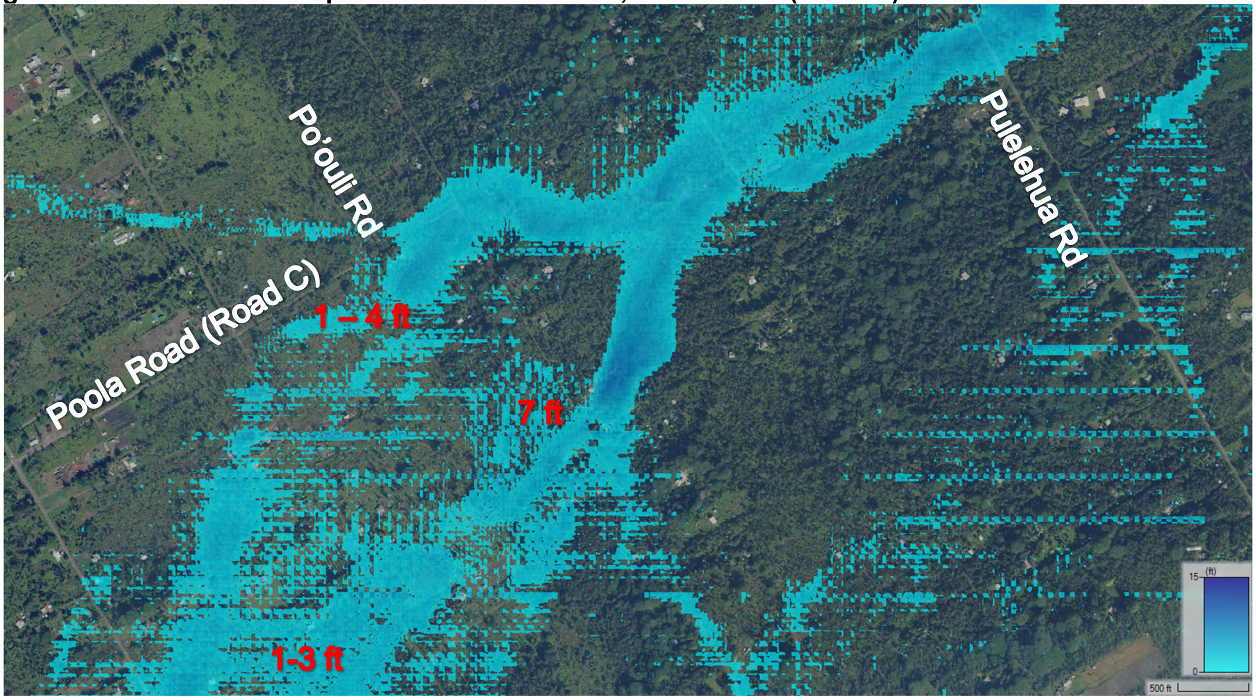
Figure 21. Flood Hazard Map for the 1% AEP Flood, N. Kulani Road



6.7 POOLA ROAD (ROAD C)/PO'OULI RD

There is widespread flooding in this location due to converging of tributaries. Residential properties along Poola Road experience shallow flooding with depths ranging 1- 4 ft during the 1% AEP flood. Properties just off Po'ouli Road experience inundation of up to 7 ft (Figure 22).

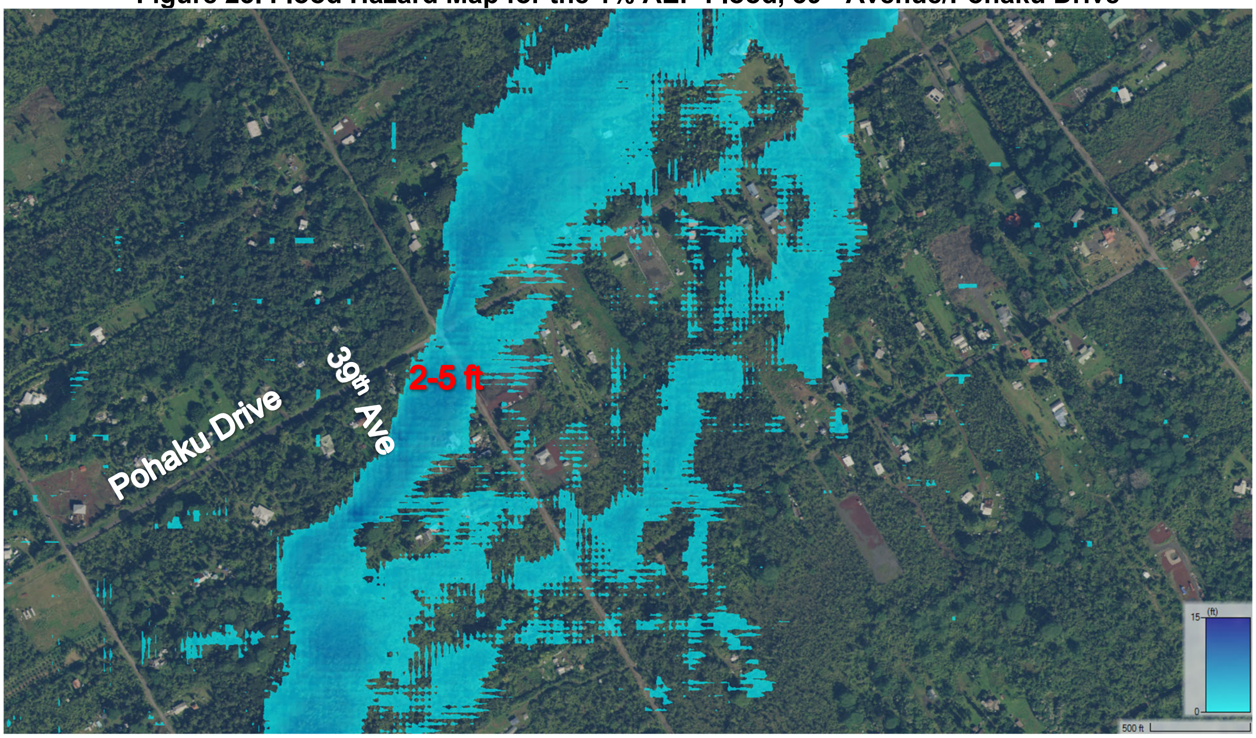
Figure 22. Flood Hazard Map for the 1% AEP Flood, Poola Road (Road C) / Po'ouli Road



6.8 39TH AVENUE/POHAKU DRIVE

The intersection of 39th Avenue and Pohaku Drive is a known location for flooding. Figure 23 shows flooding at this intersection with inundation ranging from 2- 5 ft during the 1% AEP.

Figure 23. Flood Hazard Map for the 1% AEP Flood, 39th Avenue/Pohaku Drive



6.9 OLAA ROAD/40TH AVENUE

There is widespread flooding in the vicinity of Olaa Road and 40th Avenue with flood depth ranging from 1 – 4 ft during the 1% AEP flood. Figure 24 shows the expansive shallow flooding near Pualani Street.

Figure 24. Flood Hazard Map for the 1% AEP Flood, Olaa Road/40th Avenue

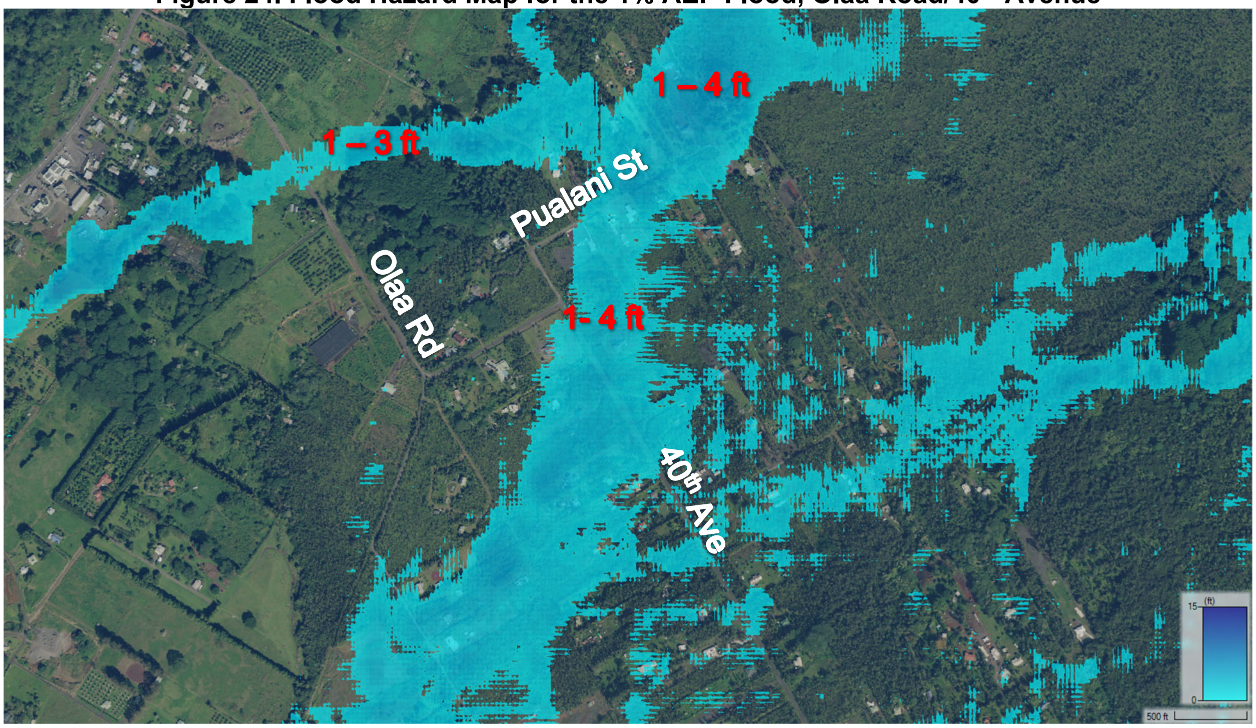
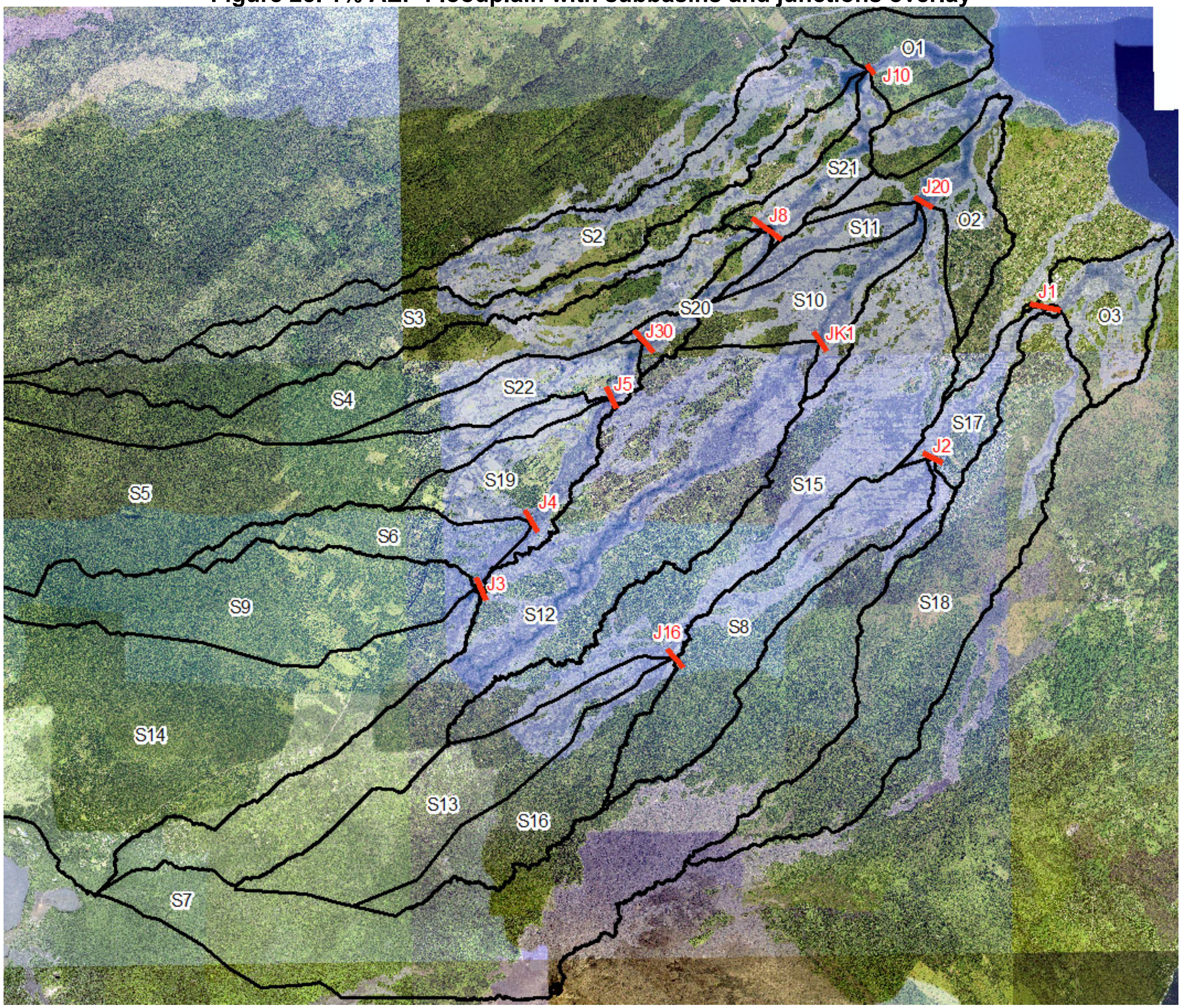


Figure 25 displays the 1% AEP floodplain with the overlay of the HEC-HMS subbasins and junctions.

Figure 25. 1% AEP Floodplain with subbasins and junctions overlay



SECTION 7 - CONCLUSION

The results of this study make available the water surface profiles, flood elevations, and areal extent of the floodplain for the 10%, 4%, 2%, 1%, and 0.2% (1/10, 1/25, 1/50, 1/100, and 1/500) AEP flood events (5 profiles). There are not many well-defined streams in the Puna study area. Keaau Stream splits into many tributaries which experience widespread flooding and overtopping. The results indicate that many residential properties and roads are at risk of being flooded frequently. The flooding mostly occurs along two or three main streams which sprawl and create shallow widespread flooding due to the streams not being well-defined.

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