Flood Hazard Study
Hagatña River

Hagatña, Guam

Final Report
30 Aug 2020

Prepared by:
U.S. Army Corps of Engineers, Honolulu District

Prepared for:
Government of Guam, Bureau of Statistics and Plan

This page is intentionally blank.

Executive Summary

The hydrology and hydraulics of the Hagatna River (formerly known as Agana River) was analyzed to create flood hazard maps of the: 10%, 4%, 2%, 1% and 0.2% annual exceedance probability (AEP) flood events, colloquially known as the 10-, 25-, 50-, 100, and 500-year respectively.

The hydrological determination was performed using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) software. Furthermore, HEC-HMS was used to perform the rainfall-runoff computations for the 10%, 4%, 2%, 1%, and 0.2% annual exceedance probability (AEP). Precipitation data was taken from the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 Precipitation-Frequency Data Server. The loss method used was the SCS Curve Number Method, which was determined by using initial conditions from soil information provided by the Guam Soil Atlas.

Since there were no usable river or rain gages in the study area, the nearest watershed with usable data was calibrated to historic rain events and used to determine adjustment ratios for the Hagatna River subbasin. The resulting calibrated data from the Hagatna HEC-HMS model was then used to represent the unsteady flow conditions for each of the five flood frequency profiles.

The hydraulic model was developed using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software. It utilizes both two-dimensional (2D) unsteady flow analysis as well as one-dimensional (1D) steady flow analysis to model the whole watershed. The HEC-RAS model was then used to create flood hazard maps for the 10%, 4%, 2%, 1% and 0.2% Annual Exceedance Probability (AEP) flood events. In conclusion, this flood study further validates the results of the 2007 FEMA produced FIRM, by providing better estimates of frequency discharge values as well as water surface profiles. This ultimately means that there are no major changes to flood conditions between the FIRM maps produced by this study and the 2007 FEMA produced FIRM, despite numerous bridge improvements that "likely improved conveyance along the Hagatna River".

Table of Contents

List of Figures

List of Tables

List of Acronyms & Abbreviations

- 1D - one dimensional
- 2D - two dimensional
- AEP – Annual Exceedance Probability
- BSP – Bureau of Statistics and Plans
- DEM – Digital Elevation Model
- ENSO – El Niño Southern Oscillation
- FEMA – Federal Emergency Management Agency
- FIRM – Flood Insurance Rate Map
- FIS – Flood Insurance Study
- FPMS – Flood Plain Management Services
- GDM – General Design Memorandum
- GIS – Geographical Information System
- GUVD04 – Guam Vertical Datum of 2004
- HEC – Hydrologic Engineering Center
- JALBTCX – Joint Airborne Lidar Bathymetry Technical Center of Expertise
- LiDAR – Light Detection and Ranging
- MSL - Mean Sea Level
- n - Manning's roughness coefficient
- NAD83 – North American Datum of 1983
- NOAA – National Oceanic and Atmospheric Administration
- NRCS - Natural Resources and Conservation Services
- NSE - Nash-Sutcliffe Efficiency
- NWS - National Weather Service
- OCM – Office for Coastal Management
- PFDS – Precipitation-Frequency Data Server
- RAS – River Analysis System
- TOC - Time of Concentration

- TR-55 - Technical Release 55
- USACE – U.S. Army Corps of Engineers
- USGS - U.S. Geological Survey
- UTM - Universal Transverse Mercator
- WGS84 – World Geodetic System of 1984
- XS - HEC-RAS cross section
- yr – year

1 Introduction

1.1 Authority

This study was completed under the authority of the Flood Plain Management Services (FPMS) Program provided by Section 206 of the 1960 Flood Control Act (Public Law 86-645). As amended, the U.S. Army Corps of Engineers (USACE) is to provide a full range of flood risk information, technical services, and planning guidance in support of active floodplain management.

1.2 Purpose and Scope

The purpose of this study is to provide updated floodplain maps of Hagatña, Guam. The Government of Guam, Bureau of Statistics and Plans (BSP) has expressed interest in using the results of this study to request a revision to the Federal Emergency Management Agency (FEMA)'s effective Flood Insurance Rate Map (FIRM) for Hagatña. Primary work products for this study include the following:

1. **Update Peak Flow Estimates**. A new flood frequency analysis will determine peak flow estimates for the 10%, 4%, 2%, 1%, and 0.2% annual exceedance probability (10-, 25-, 50-, 100-, and 500- year) flood events (5 profiles). Methods for estimating the peak flow for these events include 1) development of a rainfall-runoff model and 2) use of regional regression equations.
2. **Hydraulic Modeling**. A two dimensional (2D), unsteady flow hydraulic model will be developed using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software. The hydraulic model will include the latest bridge and topographic data available to compute the water surface profiles, flood elevations, and flood boundary for the 10%, 4%, 2%, 1%, and 0.2% AEP events (5 profiles).
3. **Report**. This report documents the changed conditions in the floodplain and technical analysis completed under this study.

1.3 Flood Problem

Nearly the entire portion of the Hagatña River basin extending from the swamp to Hagatña Bay is subject to flooding. Major development in the floodplain that are subject to damage include an extensive network of commercial and governmental buildings, modern shopping centers, improved highways, streets, and utility facilities. These improvements vary from medium-cost, low-rise structures to expensive high-rise office buildings.

Flooding is primarily attributed to the limited capacity of the Hagatña River. Because of the small capacity of the river and relatively flat topography, much of the area adjacent to the river banks is subject to flooding when the existing capacity is exceeded following heavy rain. Flooding which is a natural occurrence on the Hagatña River has become a problem because of man’s activities and development of damageable structures within the floodplain. Inadequate interior drainage within the basin also contributes to the flood problem in Hagatña. The flood problem begins near the northern end of the Hagatña Swamp along the powerline access road, a narrow, unpaved road which has altered the normal drainage pattern by cutting off the free flow of water. During high flows, flood waters exceeding the storage capacity of the swamp, flow over the powerline access road and fan out over the flat basin floor in a north-northwest direction toward the downtown area of Hagatña. The river reach through the undeveloped area between the powerline access road and East O’Brien Drive (Route 33) is estimated to have a bank-full capacity of only about 8.5 cubic meters per second (cms). Within the urbanized area along the river bank below Chalan Santo Papa Juan Pablo Dos (formerly Saylor Street) and South Marine Corps Drive (Route 1) are estimated to be approximately 100 and 75 cms, respectively.

2 Watershed Description

2.1 Location and Topography

Hagatña River is located in the capital village of the United States territory of Guam, Hagatña (formerly Agana). The elliptical-shaped Hagatña River basin (Figure 2-1) drains a total area of 26.6 square kilometers (km^2); 10.3 square miles (mi^2).

The topography of the Hagatña River basin can be divided into three sections: 1) the relatively flat, highly urbanized coastal plain; 2) the Hagatña Swamp inland of the coastal plain; and 3) the rolling hills and slopes bordering the swamp. Mount Macajna, on the western end of the basin, has the highest elevation, 214 meters (m); 702 feet (ft). The Hagatña Swamp near the lower end of the basin has approximately 2700 km^3 of storage capacity at elevation 4.2 m. The swamp helps to reduce the flood peaks downstream from East O’Brien Drive (E O’Brien Dr) by storing some of the floodwaters. The Hagatña River flows in a northerly direction through the commercial and downtown area of Hagatña, the capital village, business center, and cultural center of Guam.

Figure 2-1 shows a map of the delineated subbasins for the Hagatna River, and points out locations of key areas referenced in this study (the bay, swamp, and river).

2.2 Geology

Northern Guam is comprised of limestone karst, which lies on top of the foundation volcanic rock. Limestone karst quickly absorbs rain water, leading to high amounts of groundwater in Northern Guam. Southern Guam is comprised of volcanic rock and low-permeability soils, which slows the infiltration of rainwater into the ground. Due to this, there are more streams in Southern Guam, and no streams in Northern Guam.

The swamp and hills are underlain by limestone. Soils developed on limestone are usually shallow and highly porous. The coastal plain which was once composed of unconsolidated beach deposits, has been greatly disturbed and altered during the development of the city, and is now dominated by man-made structures such as highways and buildings.

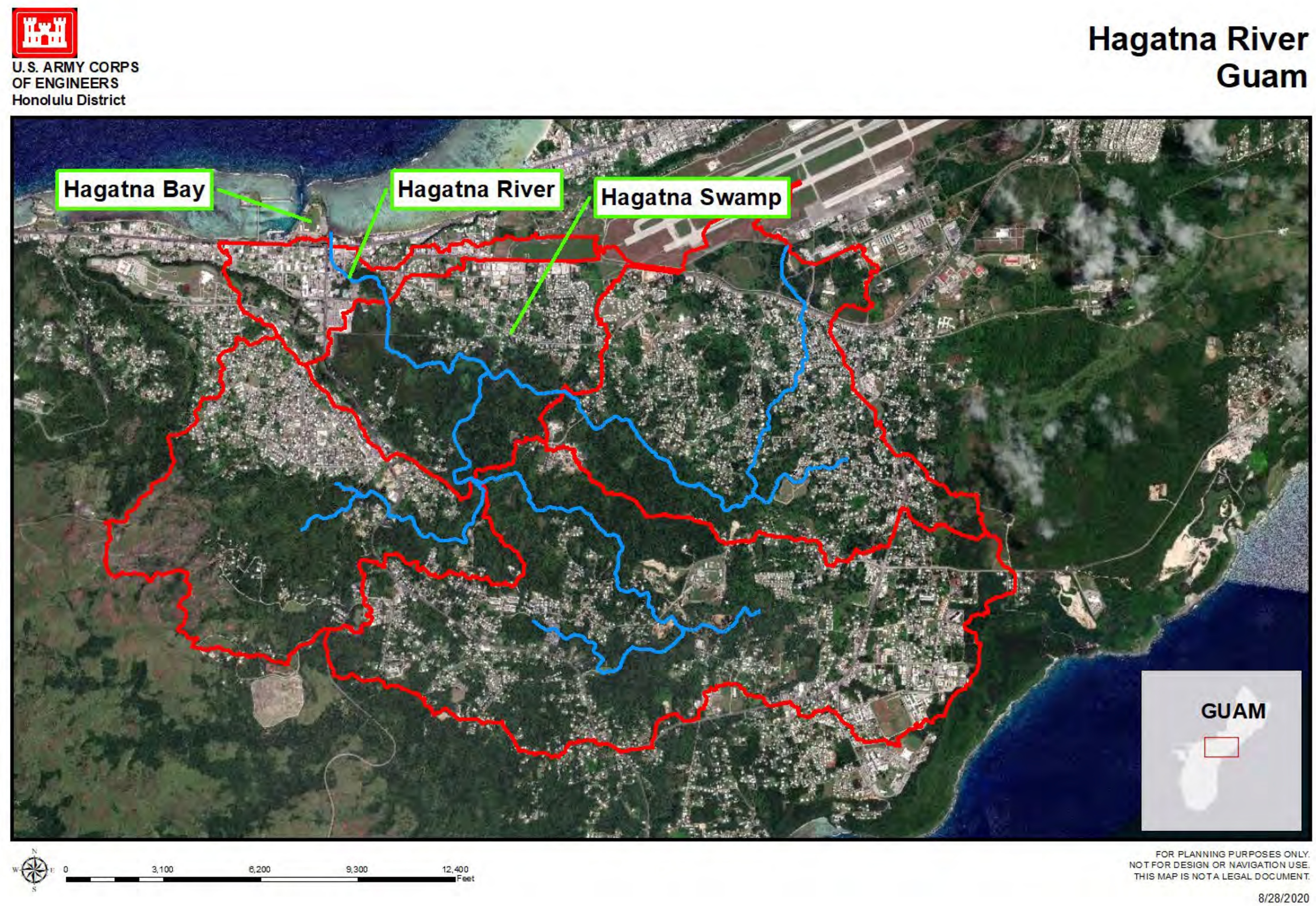


Figure 2-1: Map of Hagatna River Subbasins

2.3 Soil

Major soil categories within the study area include plastic clay, silty clay, alluvial soils and poorly graded sand. Most of Guam is covered in Agfayan and Akina series soil. Agfayan soil is very shallow and shallow soil that is well drained, with moderately slow permeability. Akina soil is very deep soil that is well drained, and also has moderately slow permeabilitiy. The marsh area upstream of the river are comprised of Troposaprists. Troposaprists are soils that are made out of highly decomposed organic materials, and are deep soils that are very poorly drained. The areas further upstream of the river are comprised of Pulantat-Kagman-Chacha soils. Pulantat-Kagman-Chacha soils are comprised of 45 percent Pulantat soils, 30 percent Kagman soils, 20 percent Chacha soils, with the remaining 5 percent containing soils of minor extent. The soil characteristics range from shallow to very deep, and somewhat poorly drained to well drained.

2.4 Vegetation

The Hagatña Swamp is dominated by tall reed, fern, and wild sugar cane. Much of the hilly land around the swamp has been altered and now supports a variety of plant communities. Various herbs and grasses are found in the undisturbed areas with larger trees on the slopes. Developed areas have been cleared of original vegetation and replanted with food and ornamental plants. A lush growth of grass covers the areas along the lower end of the Hagatña River.

2.5 Climate

Guam’s climate is considered to be tropical marine. Tropical marine climates are tropical climates that are influenced by the ocean. Tropical marine climates often have two seasons: a wet season (between July and December) and a dry season (between January and June), with very distinct differences in the amount of rainfall experienced in each season. The average amount of rain seen annually in Guam is about 100 inches (2,540 millimeters), and the average climate for the past 20 years (2000 to 2019) is 82.2 degrees Fahrenheit (ºF) or about 28 degrees Celsius (ºC) (NOAA).

Guam lies in Typhoon Alley, meaning it is common for Guam to be threatened by tropical storms and typhoons. These events typically happen during the rainy season, with the highest probability in the months of October and November. Guam averages three tropical storms and one typhoon pass within 300 kilometers of Guam each year. The strongest typhoon to pass over Guam within recent history was Super Typhoon Pongsona on December 8, 2002.

From the East West Center's "Climate Trends and Projections for Guam," information about future climate in Guam is included in Table 2-1 below:

Table 2-1: End-of-Century Projections for Select Climate Indicator Variables

Climate Indicator	Year	Projection
Mean Annual Air Temperature	2050-2074	Increase of 1.99°C over the average.
Mean Daily and Annual Precipitation	2050-2074	Moderate increase of 0.61 mm/day (222.2 mm/year) over the average
Global Mean Sea Level	2045-2065 2081-2100	An increase of 0.30 m An increase of 0.74 m
Mean Annual Extreme Events	End of 21st century	Fewer, more intense storms with changing track location (potentially moving poleward)

Source: Gingerich, Keener, & Finucane, 2015

3 Geographic Information Systems

3.1 Datum and Projection

The datum and projection for this study is as follows:

Horizontal projection: Universal Transverse Mercator (UTM) Zone 55 North (N), meters

Horizontal datum: North American Datum of 1983 (NAD83) MA11

Vertical Datum: Guam Vertical Datum of 2004 (GUVD04)

Tidal Epoch: 1983 – 2001

Geoid: 2012B

3.2 Elevation

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

Table 3-1: Elevation Data Type and Sources

Survey year	Agency	Data type	Location
2007	JALBTCX	LiDAR	Island of Guam
2012 – 2013	NOAA OCM	LiDAR	Island of Guam

Light Detection and Ranging (LiDAR) data were collected across the island of Guam by NOAA Office for Coastal Management (OCM) in 2012 and 2013 for the U.S. Geological Survey (USGS). The data is in NAD83 (MA11), vertically referenced to GUVD04, has a vertical accuracy of 8 cm, and horizontal accuracy of 0.11 m. This data was given first priority in creating the merged digital elevation model (DEM) for use in this study.

Additionally, LiDAR data were collected across the island of Guam by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) in 2007 for the Government of Guam Department of Public Works and the Government of Guam Office of Homeland Security. The data is based on the World Geodetic System of 1984 (WGS84), are vertically referenced to Mean Sea Level (MSL), has a vertical accuracy of

20 cm, and horizontal accuracy of 0.75 m. It was used as a secondary (supplementary) layer in creating the merged DEM for use in this study.

3.3 Imagery

High resolution imagery used for background mapping of the study area is from Digital Globe, Inc. and the Department of Defense – National Geospatial-Intelligence Agency. World Imagery, provided by ESRI, was used for larger scale background mapping, such as when it was necessary to show the entire island of Guam.

3.4 Digital Atlases of Guam

The Digital Atlas of Southern Guam and the Digital Atlas of Northern Guam, by WERI and IREI, provide public access to geospatial data that covers the entire island of Guam. The website address is: http://south.hydroguam.net/ and http://north.hydroguam.net/. Several files were downloaded and used as a resource for this study, including files on geology, climate, soil, surface water, land cover and infrastructure.

3.4.1 Land Cover and Land Use

A land cover and land use raster was developed by NOAA’s Ocean Service, Coastal Services Center in 2016 based upon high resolution (1 to 5 meter) aerial and satellite imagery. This raster was used to create the Manning’s *n* layer in the hydraulic model.

3.4.2 Soils

Geospatial data based on the Soil Survey of the Territory of Guam (1985), conducted by the USDA Soil Conservation Service (SCS, but now NRCS – Natural Resources Conservation Service), was used to identify the distribution of various types of soils in the study area

4 Development of the Rainfall-Runoff Model

The discharge-frequency relationships at key points in the study area were estimated by developing rainfall-runoff models for two watersheds using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS, version 4.5, 2020) software. In addition to the Hagatña River basin, a rainfall-runoff model was also developed for part of the Pago River basin. This was necessary for calibration purposes as the Hagatña River basin has a very short period of record of historical streamflow data. The Pago River basin was chosen due to its proximity to the study area as well as the availability of usable atmospheric and streamflow records. The calibrated values for Pago River were used to make similar adjustments to the Hagatña River model.

4.1 Basin, Subbasin and River Delineation

The basins, subbasins, and rivers were automatically delineated using HEC-HMS and manually adjusted, as needed. Each basin was divided into individual subbasins based on key locations in the watershed (e.g. the location of a stream flow gage or junction). Drainage areas and centroid locations of each subbasin are provide in Table 4-1. Figures 4-1 and 4-2 (shown below) displays the delineated subbasins in ArcGIS.

Table 4-1: Subbasin identification and information

Basin Name	Subbasin Name	Drainage area (km^2)	Centroid location	
			Latitude	Longitude
Hagatna River	Hagatna 1	6.08	13.453104	144.753376
Hagatna River	Hagatna 2	10.79	13.444742	144.786403
Hagatna River	Hagatna 3	7.45	13.459137	144.790882
Hagatna River	Hagatna 4	1.55	13.473295	144.753712
Hagatna River	Hagatna Marsh	4.16	13.467266	144.770467
Pago River	Pago 1	7.47	13.441467	144.73292
Pago River	Pago 2	7.18	13.427067	144.73452

Figure 4-3 displays how the basin model was created in HEC-HMS for the Pago River basin. There are two subbasins connected to a junction. The Pago River stream gage (USGS 16865000) is located at the junction, which references the historical streamflow data for the five calibration events. Subbasin characteristics were obtained using ArcGIS, as described in Sections 4.2 and 4.3.

Figure 4-4 displays how the basin model was created in HEC-HMS for the Hagatña River basin. Wetland routing through Hagatña Swamp will be computed using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software, based on inflow from the upper watershed and excess precipitation over the swamp. Therefore, the HEC-HMS model for this basin was developed to provide the individual inflow hydrographs for three subbasins representing the upper watershed, the excess precipitation hyetograph over Hagatña Swamp and the additional overland flow hydrograph for the lower subbasin area.

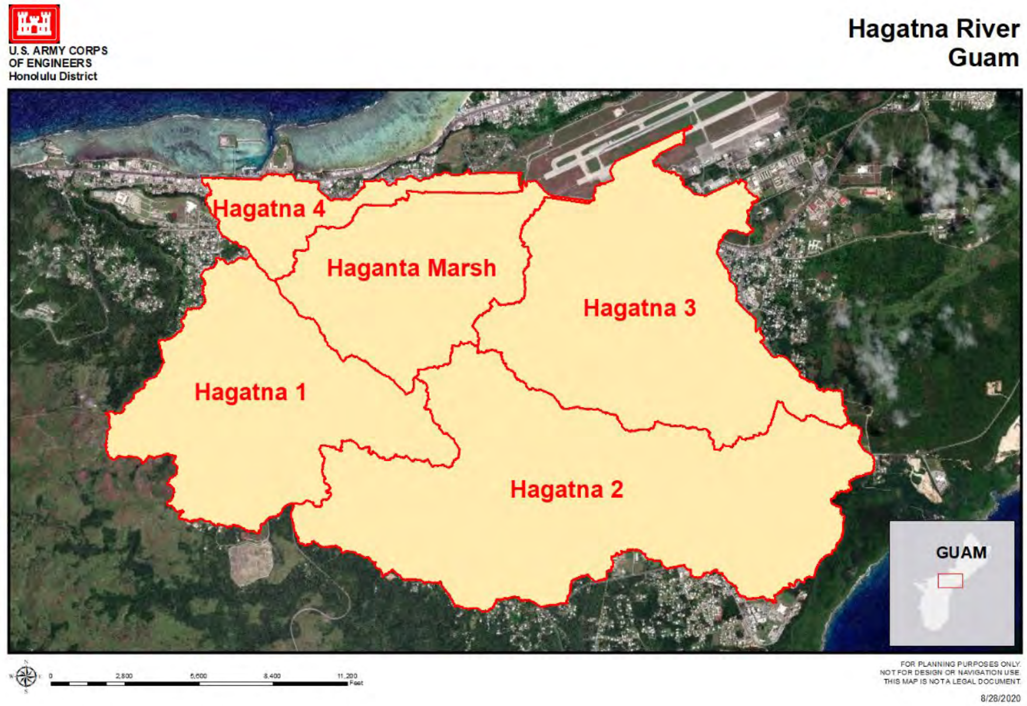


Figure 4-1: Map of Hagatna River Subbasins

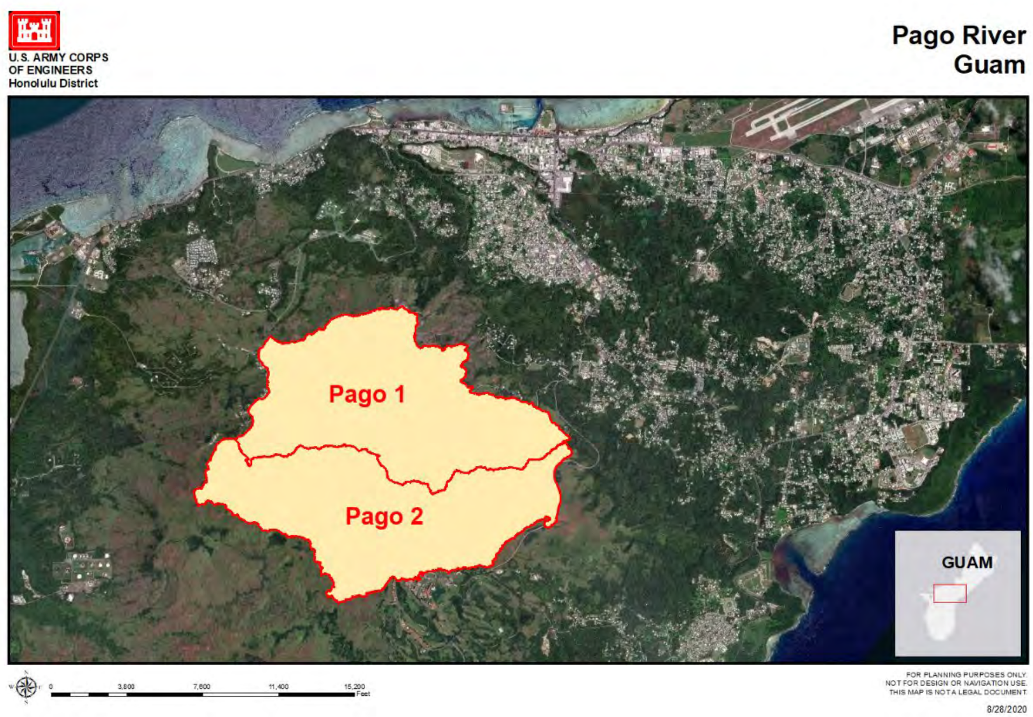


Figure 4-2: Map of Pago River Subbasins

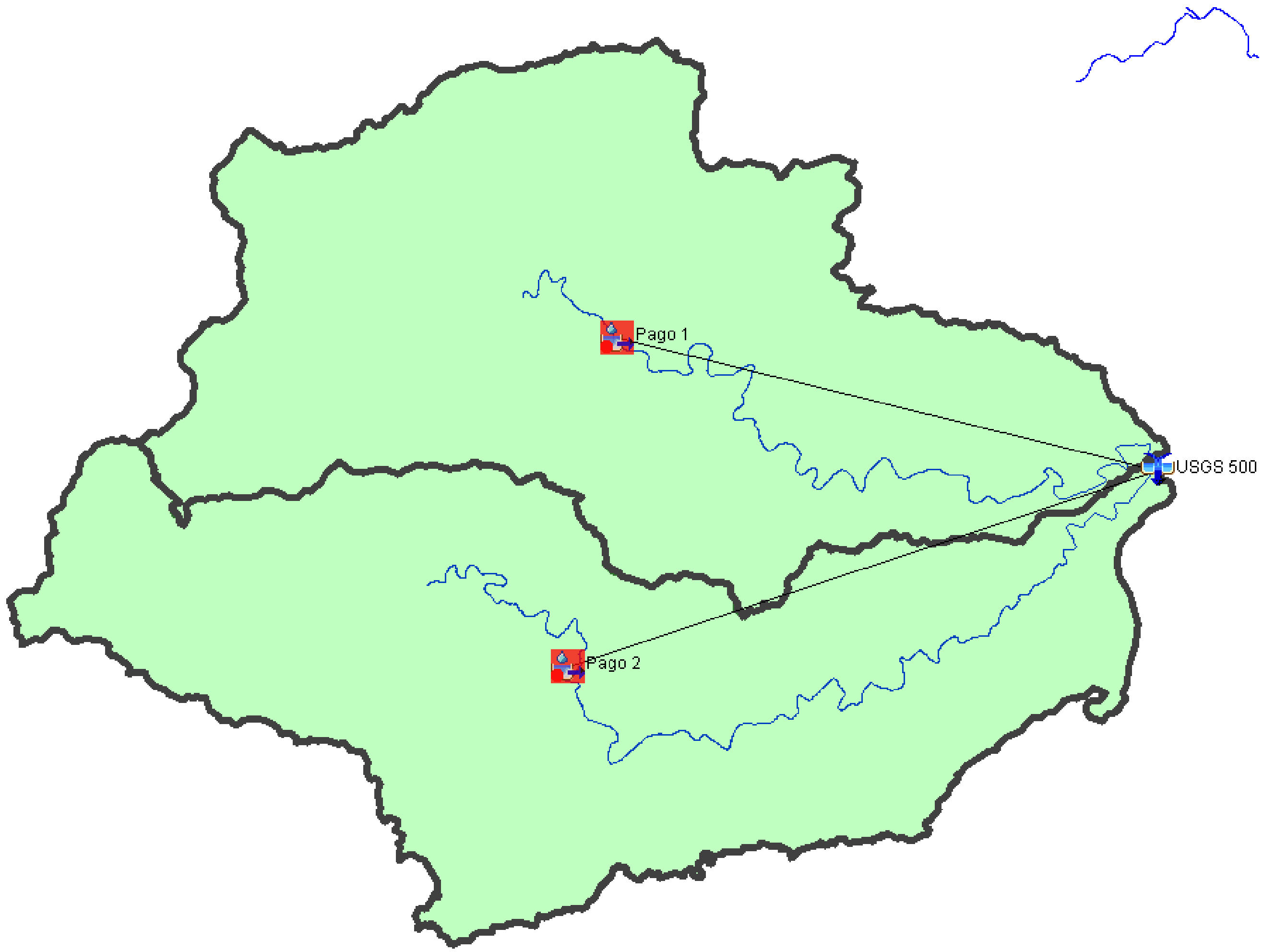


Figure 4-3: HEC-HMS Model for Pago River Watershed

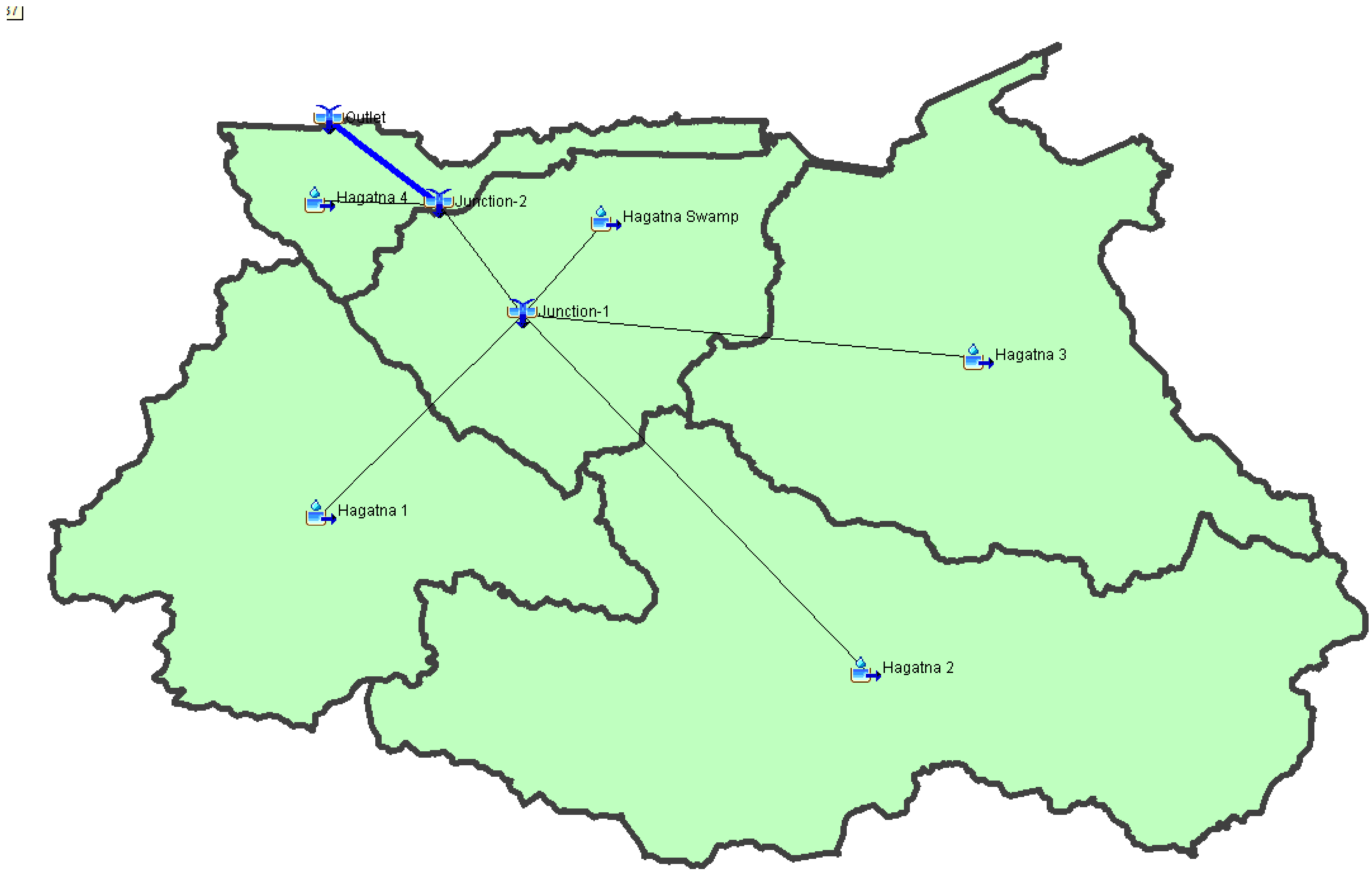


Figure 4-4: HEC-HMS Model for Hagatña River Watershed

4.2 Initial Estimation for Loss Parameters

The SCS Curve Number method was applied to the model to account for precipitation loss due to infiltration. This approach uses three parameters: initial abstraction, curve number, and directly connected impervious areas as a percentage of the total subbasin area. The initial abstraction defines the amount of precipitation that must fall before surface flow occurs. This value was left at its default value of 0.2 times the potential retention, which is calculated from the curve number. The curve number parameter is a composite curve number that represents all of the different soil group and land use combinations in the subbasin, disregarding impervious areas which are counted separately. Directly connected impervious areas (DCIA) represent all impervious areas that are directly connected to the main channel. No loss calculations are carried out on these areas – all precipitation becomes excess precipitation and is subject to direct runoff.

The composite curve number for the subbasin, CN, was determined by using the general land cover and land use raster (Section 3.4.1) and soil properties shapefile (Section 3.4.2). Individual curve numbers were assigned to specific areas based on their land cover classification and hydrologic soil group, as presented in Table 4-2 (NRCS, 1986).

Since the SCS Curve Number method already accounts for impervious areas in estimating the composite curve number, it is not necessary to account for percentages of directly connected impervious areas (DCIA) a second time. Due to this, the DCIA will be set to 0% for all subbasins across both models. This is shown in Table 4-3 below.

Table 4-2: Representative curve numbers for various land cover types

NLCU ID	Land cover description	CN ID	CN description	Hydrologic soil group			
				A	B	C	D
24	Impervious Surface	2	Urban: commercial	89	92	94	95
21	Developed, Open Space	5	Open space, fair condition	49	69	79	84
82	Cultivated Crops	6	Fallow: crop residue cover	76	85	90	93
11	Bare Land	20	Fallow: bare soil	77	86	91	94
81	Pasture / Hay	7	Pasture, grassland, or range	49	69	79	84
71	Grassland / Herbaceous						
52	Scrub / Shrub						
41	Deciduous Forest	10	Woods	30	48	65	73
42	Evergreen Forest						
90	Palustrine Forested Wetland	13	Water / wetland	0	0	0	0
95	Palustrine Scrub/Shrub Wetland						
90	Palustrine Emergent Wetland						
	Palustrine Aquatic Bed						
90	Estuarine Forested Wetland						
95	Estuarine Scrub/Shrub Wetland						
	Estuarine Emergent Wetland						
31	Unconsolidated Shore						
21	Open Water						

Table 4-3: Estimated Composite Curve Number for Each Subbasin

Subbasin	CN
Hagatna 1	76.6
Hagatna 2	77.6
Hagatna 3	80.0
Hagatna 4	84.2
Hagatna Marsh	63.6
Pago 1	73.7
Pago 2	74.2

4.3 Initial Estimation for Transform Parameters

The excess precipitation in each subbasin was transformed into surface runoff by applying the SCS Unit Hydrograph method in the hydrologic model. This method was selected because it requires only a single parameter (lag time, t_L) that could easily be determined based on the GIS data available for the study area. Other transform methods, such as Clark's Unit Hydrograph, would be difficult to apply as it relies upon distinguishing between sheet, shallow, and channel flow using elevation data that does not define channels clearly in the middle and upper watershed. t_L represents the time between the center of the mass of rainfall excess (about in the middle of the rainfall event) to the peak discharge (when there is the greatest amount of flow in the channel) and was estimated using the SCS lag equation, given as:

$$t_L = \frac{L^{0.8}(S+1)^{0.7}}{1900(Y)^{0.5}}$$

Where: t_L = lag time in hours (hrs)

L = length of the longest drainage path in feet (ft)

S = potential maximum retention in inches, (1000/CN)-10

CN = the average curve number for the subbasin

Y = the average subbasin slope in percent (%)

The average (composite) curve number for the subbasin, CN, was determined previously and presented in . The average subbasin slope was determined by creating a slope raster from the USGS LiDAR raster (Section 3.2) and then applying the "Zonal Statistics" tool to calculate the average slope for each subbasin. The computed lag times are presented in Table 4-4. HMS also provides the option of adjusting the peak rating factor (PRF) for unusual terrains and land covers, but this was left at its default value of 484.

Table 4-4: Lag time estimates for each subbasin

Subbasin ID	L (ft)	CN	S (in)	Y (%)	t_L (hrs)
Hagatna 1	5195	76.6	3.05	12.0	0.892
Hagatna 2	12402	77.6	2.89	8.20	2.30
Hagatna 3	9354	80.0	2.50	7.57	1.72
Hagatna 4	8039	84.2	1.88	5.23	1.58
Hagatna Marsh	7832	63.6	5.72	8.30	2.22
Pago 1	6495	73.7	3.57	17.5	0.983
Pago 2	6598	74.2	3.48	17.8	0.976

4.4 Reach Routing and Loss Parameterization

Muskingkum-Cunge routing was selected for the reach routing method because it is based on physical parameters such as channel shape, routing reach length, and surface roughness (Manning's *n* value). The routing parameters for modeled reaches are presented in Table 4-5.

Table 4-5: Muskingum-Cunge Routing Parameters for HEC-HMS Reaches

Reach Name	Length (ft)	Slope (ft/ft)	Manning's n	Sub-reaches	Index Flow (cfs)	Shape	Bottom Width (ft)	Side Slope (xH:1V)
Hagatña River	3,650	0.1	0.15	2	1000	Trap.	22	2.3

4.5 Model Calibration

The rainfall-runoff model for the Hagatña River watershed was calibrated by relying upon the calibration of a nearby watershed (Pago River) and applying similar adjustments. Five storm events were selected for calibration.

4.5.1 USGS Gages

While the streamflow gage within the Hagatña watershed had only a few peak flow events from a very limited period of record, *USGS 16865000 Pago River near Ordot, Guam* provides annual peak streamflow data for 51 years (Figure 4-4) and continuous flow observation data for about 22 years (Figure 4-4). Figure 4-5 shows each streamflow and atmospheric gage mapped out to display the proximity of each gage to their respective subbasin.

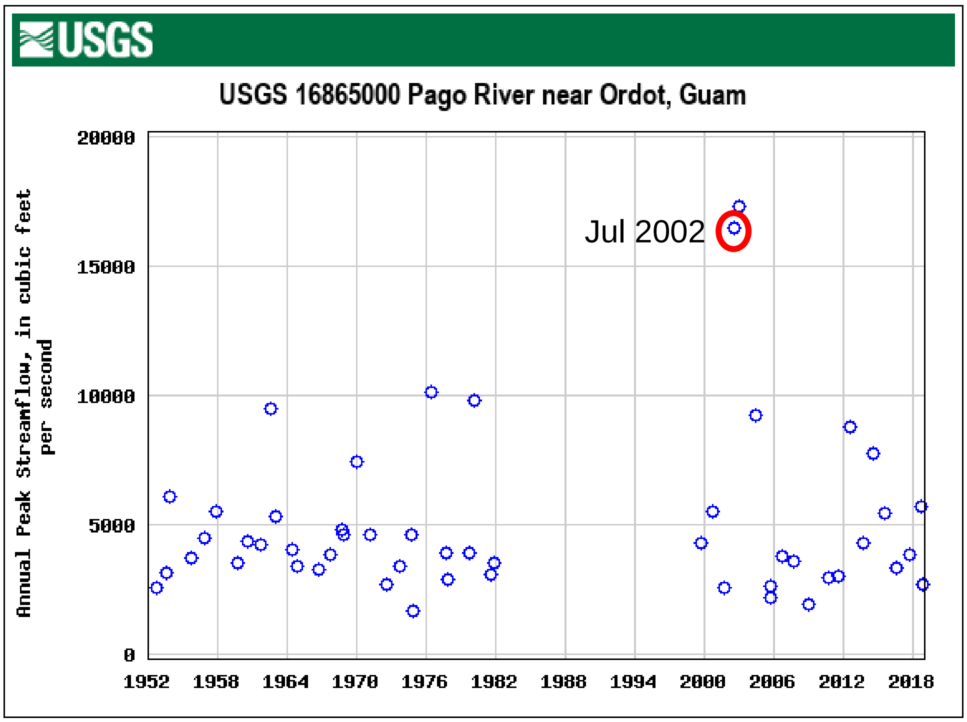


Figure 4-5: Annual Peak Streamflow, USGS 16865000

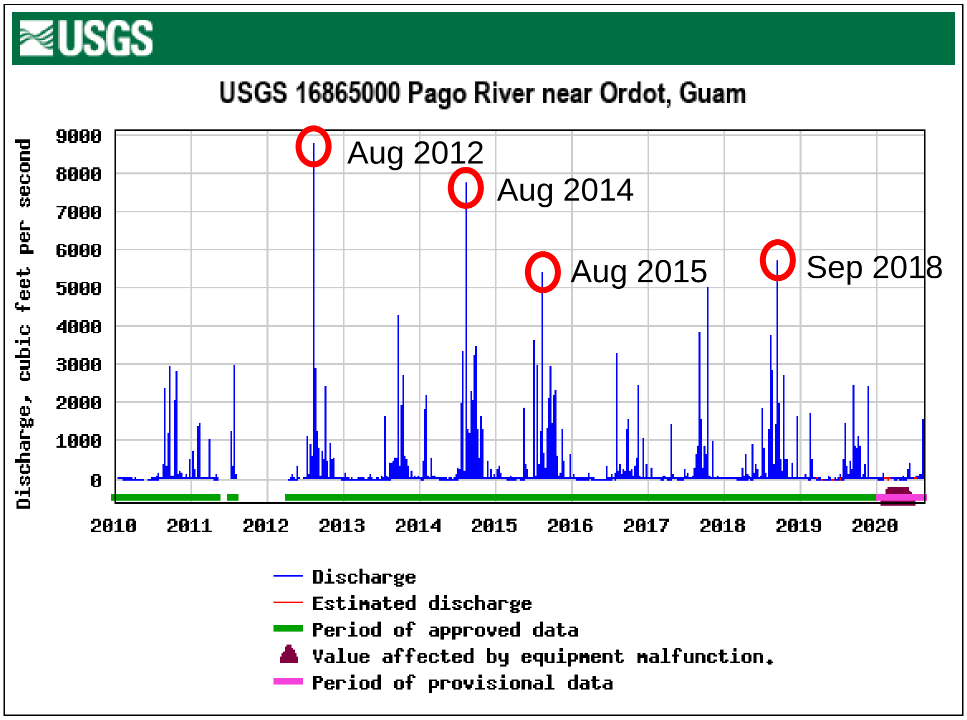


Figure 4-6: Peak Streamflow Observations from 2010 – 2020, USGS 16865000

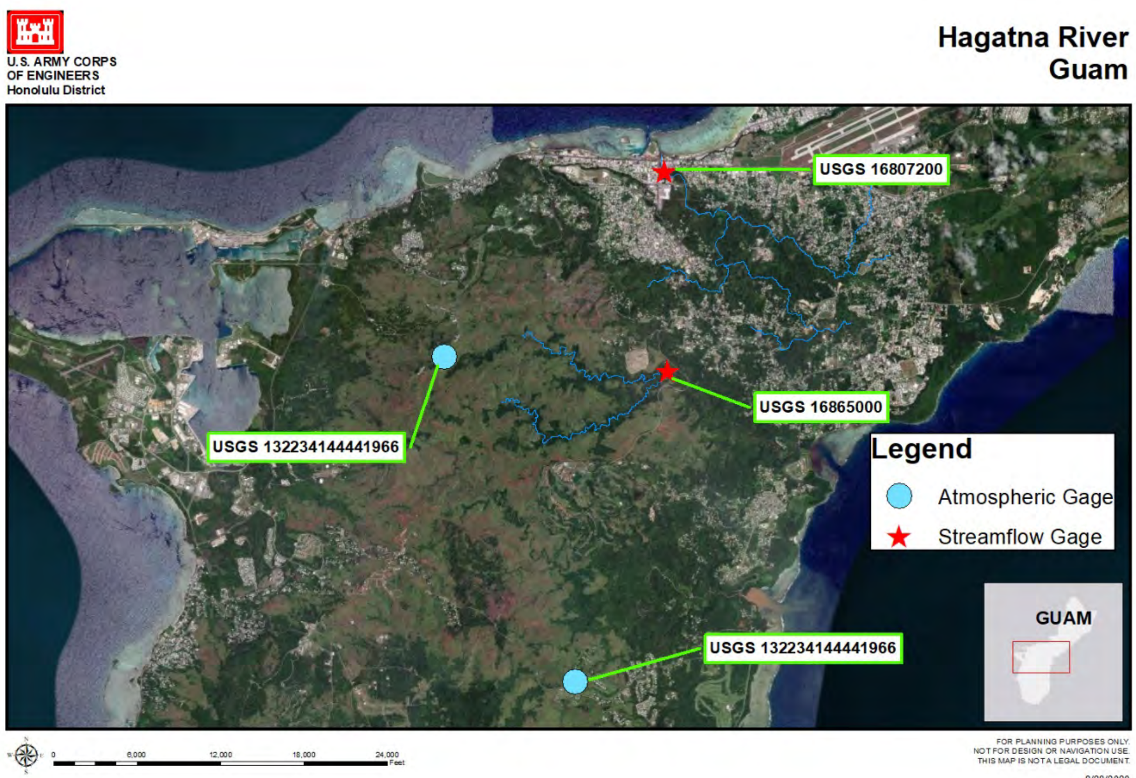


Figure 4-7: Location Map of Atmospheric and Streamflow Gages

Two precipitation gages were used for calibration: *USGS 132617144423366 Mount Chachao Rain Gage near Piti Guam* (USGS -3366) and *USGS 132234144441966 Windward Hills Rain Gage near Talofofo, Guam* (USGS -1966). The Mount Chachao rain gage was the primary site used for calibration of the model due to its proximity to the study area and overlapping data with the Pago River stream gage. However, continuous precipitation data was not available at this site for a critical storm event (July 2002 – Typhoon Chata'an). To include this event in the model calibration, continuous precipitation data from the Winward Hills rain gage was used and scaled to the known total rainfall at the Mount Chachao rain gage as presented in USGS Fact Sheet 061-03, *Flooding Associated with Typhoon Chata'an, July 5, 2002, Guam*.

Table 4-6: USGS Gages near Pago River Watershed

Site Number	Site Name	Period of Record	Type of Data
16865000	Pago River near Ordot, Guam	1952 – 1982; 1999 – 2020	Historical Streamflow
132617144423366	Mount Chachao Rain Gage near Piti, Guam	2010 – 2020	Historical Precipitation
132234144441966	Windward Hills Rain Gage near Talofofo, Guam	2007 – 2020	Historical Precipitation

4.5.2 Storm Event Selection

Five events were selected for model calibration: 4-5 July 2002 (Typhoon Chata'an), 10 August 2012, 10 August 2014, 15 August 2015, and 10 September 2018 (Typhoon Mangkhut). These events were selected based on their significance regarding peak streamflow and the availability of both rainfall and streamflow data. Table 4-8 shows how these events rank with other events in the period of record of annual peak streamflow data for USGS 16865000.

The period of record for continuous rainfall data at Mount Chachao begins in 2010, which is why several of the calibration events selected occurred within the last 10 years. As described in the previous section, additional effort was made to represent larger events, such as Typhoon Chata'an, by relying upon other sources of data.

Table 4-7: Ranking of Calibration Events by Annual Peak Streamflow, USGS 16865000

Rank	Water Year	Date	Gage Height (meters)	Streamflow (cms)
1	2003	Dec. 08, 2002	7.27	490
2	2002	Jul. 05, 2002	7.18	467
3	1976	May 21, 1976	6.14	286
4	1980	Feb. 26, 1980	6.10	278
5	1962	Aug. 02, 1962	5.75	268
6	2004	Jun. 27, 2004	6.11	262
7	2012	Aug. 08, 2012	6.01	248
8	2014	Aug. 10, 2014	5.79	220
9	1970	Dec. 19, 1969	5.42	210
10	1954	Oct. 15, 1953	5.11	172
11	2018	Sep. 10, 2018	5.22	162
12	1958	Oct. 28, 1957	4.92	155
13	2000	Sep. 07, 2000	5.13	155
14	2015	Aug. 15, 2015	5.10	153

4.5.3 Calibrated Parameters

The optimization trials tool in HEC-HMS was used to calibrate the model to each storm event. For the optimization trial, the Simplex method was used with 100 max iterations and 0.01 tolerance. The goal setting was set to minimization of the Peak-Weighted Root Mean Square Error (RMSE). The overall goal of the calibration effort was to have a Nash-Sutcliffe Efficiency (NSE) Ratio as close to 1.00 (perfectly matched), and to match the simulated peak flow as close to the observed peak flow.

Figures 4-8 through Figure 4-12 show the observed and simulated hydrographs for each calibration event. The optimized parameters for each calibration event are presented in Table 4-8 through Table 4-12.

Figure 4-8: HMS Model Calibration of Typhoon Chata'an, 4-5 July 2002

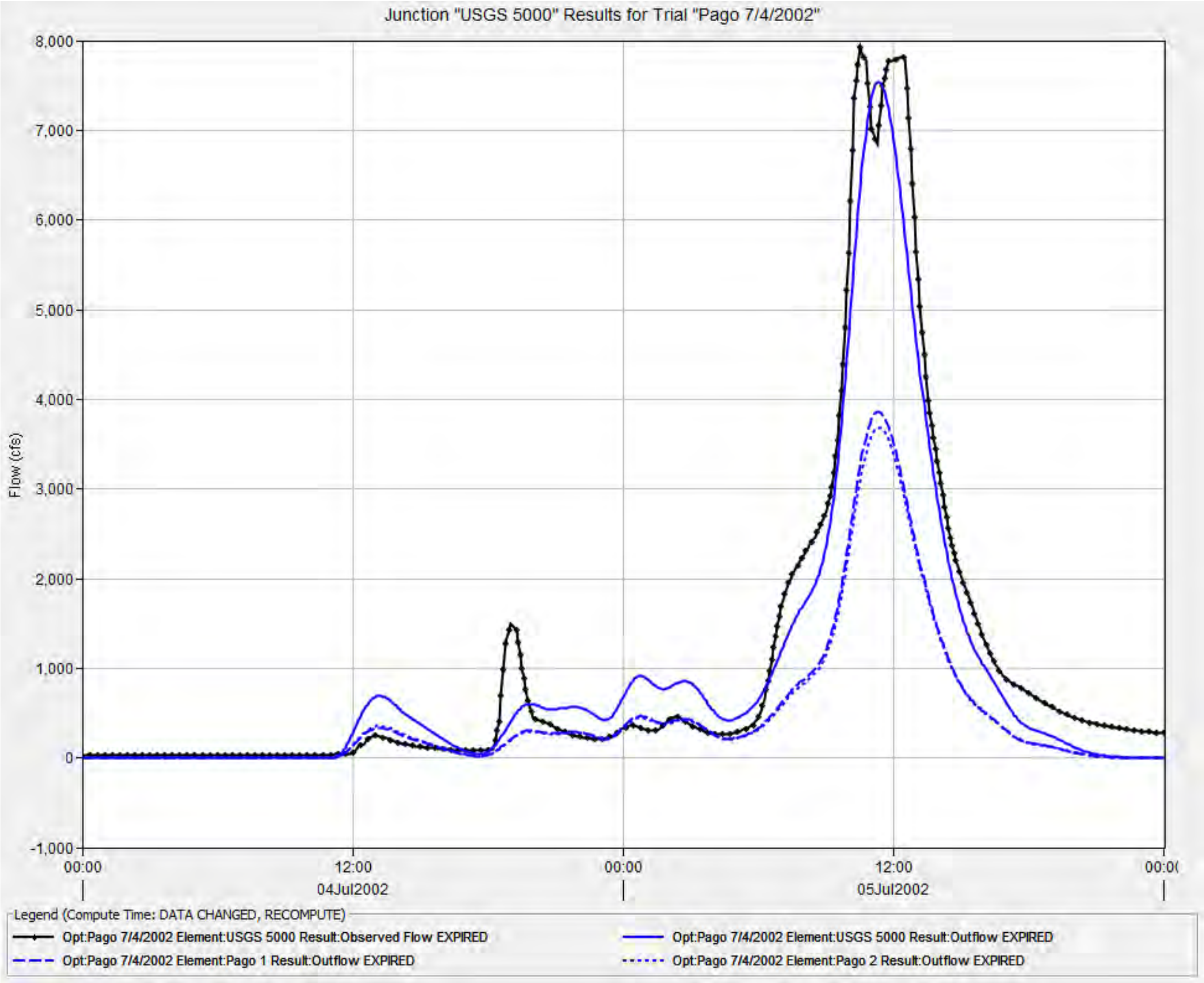


Table 4-8: Initial and Optimized Parameters for Typhoon Chata'an, 4-5 July 2002

	Curve Number		**Lag Time (min)**	
	Initial	*Optimized*	*Initial*	*Optimized*
Pago 1	73.7	97.6	59.0	96.1
Pago 2	74.2	98.2	58.5	57.2

Figure 4-9: HMS Model Calibration of the 10 August 2012 Storm

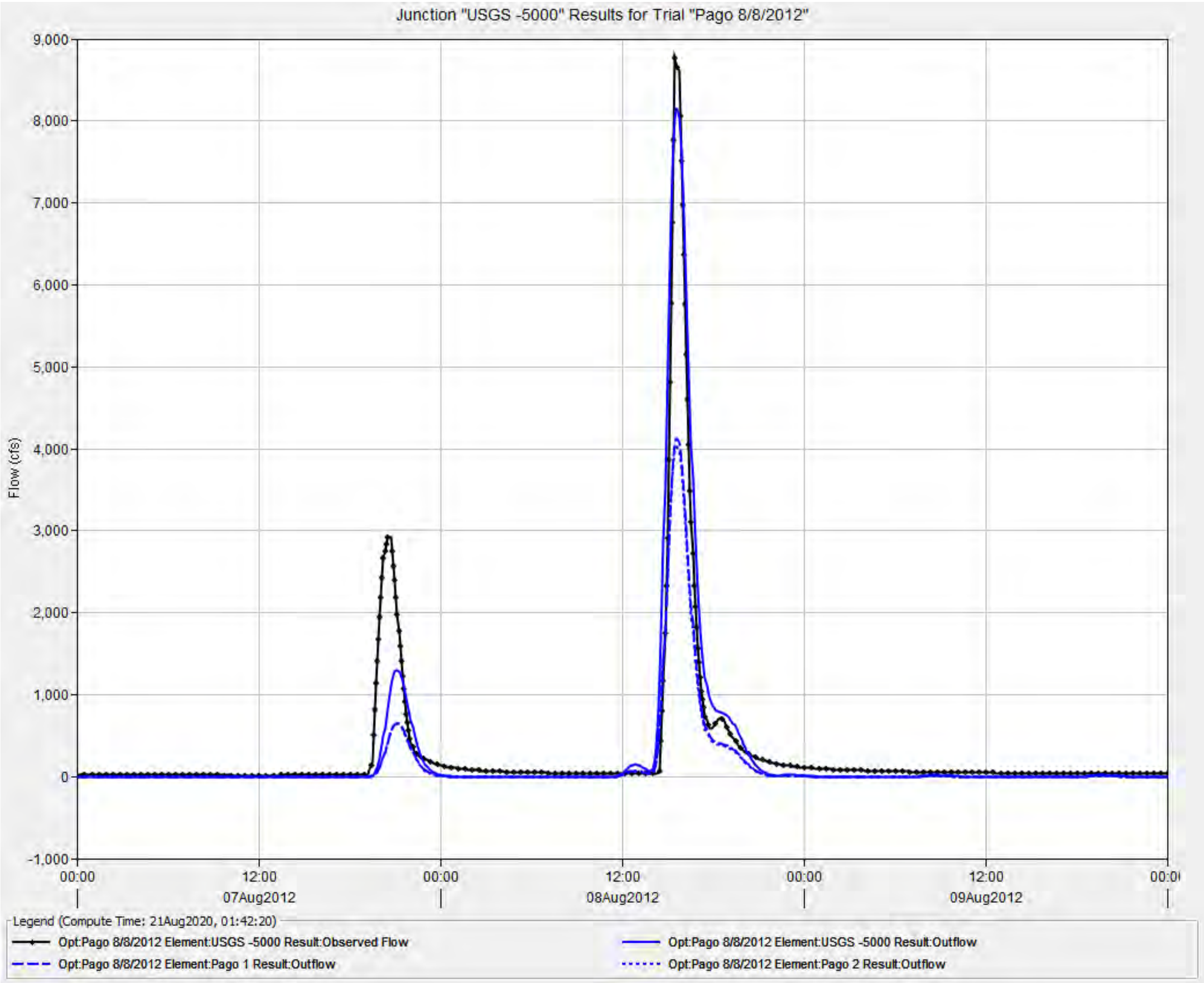


Table 4-9: Initial and Optimized Parameters for the 10 August 2012 Storm

	Curve Number		Lag Time (min)	
	Initial	*Optimized*	*Initial*	*Optimized*
Pago 1	73.7	69.0	59.0	88.7
Pago 2	74.2	69.4	58.5	88.0

Figure 4-10: HMS Model Calibration of the 10 August 2014 Storm

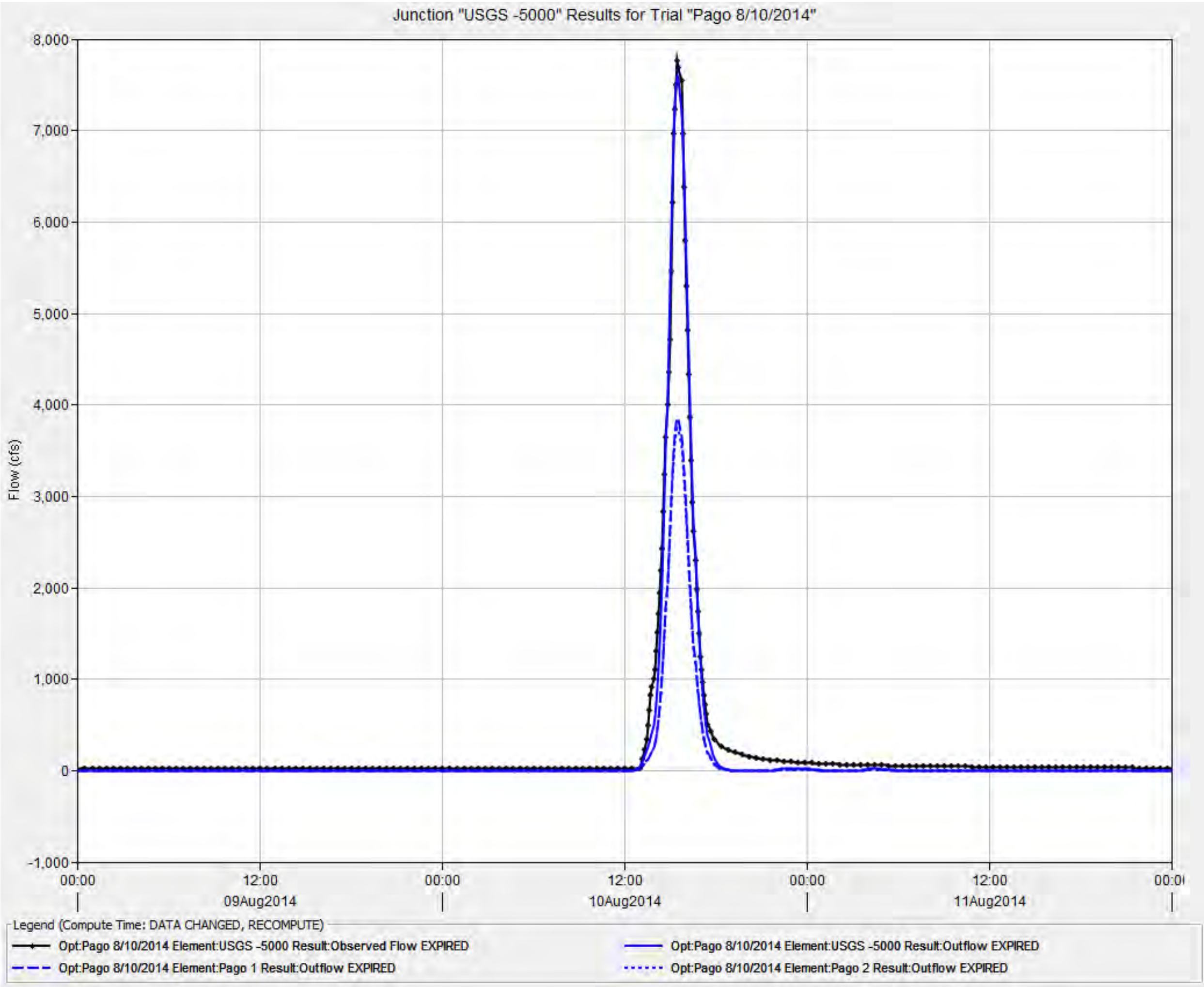


Table 4-10: Initial and Optimized Parameters for the 10 August 2014 Storm

	Curve Number		**Lag Time (min)**	
	Initial	*Optimized*	*Initial*	*Optimized*
Pago 1	73.7	68.4	59.0	77.0
Pago 2	74.2	68.9	58.5	77.0

Figure 4-11: HMS Model Calibration of the 15 August 2015 Storm

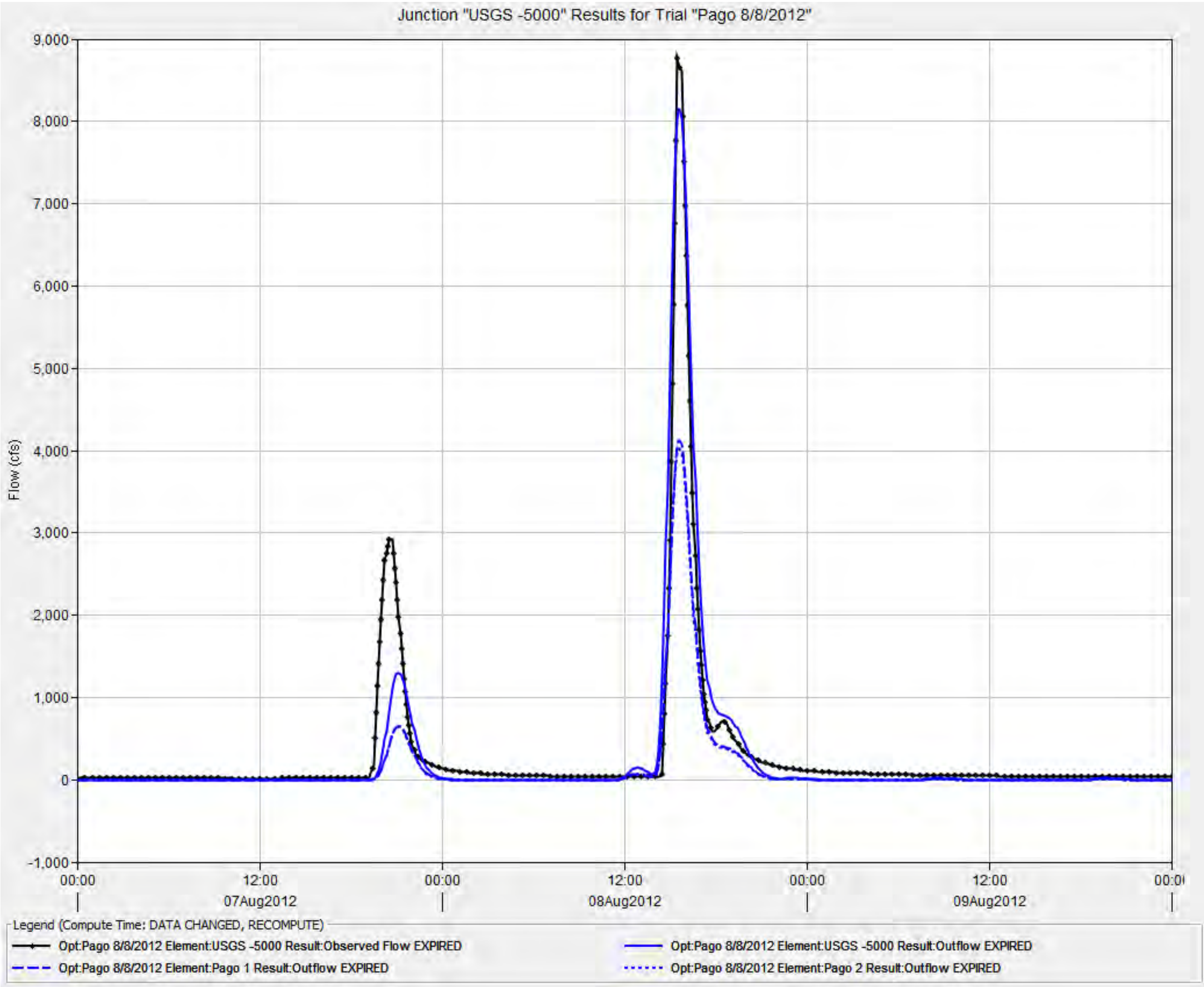


Table 4-11: Initial and Optimized Parameters for the 10 August 2014 Storm

	Curve Number		**Lag Time (min)**	
	Initial	*Optimized*	*Initial*	*Optimized*
Pago 1	73.7	93.3	59.0	71.0
Pago 2	74.2	93.9	58.5	72.0

Figure 4-12: HMS Model Calibration of the 10 September 2018 Storm

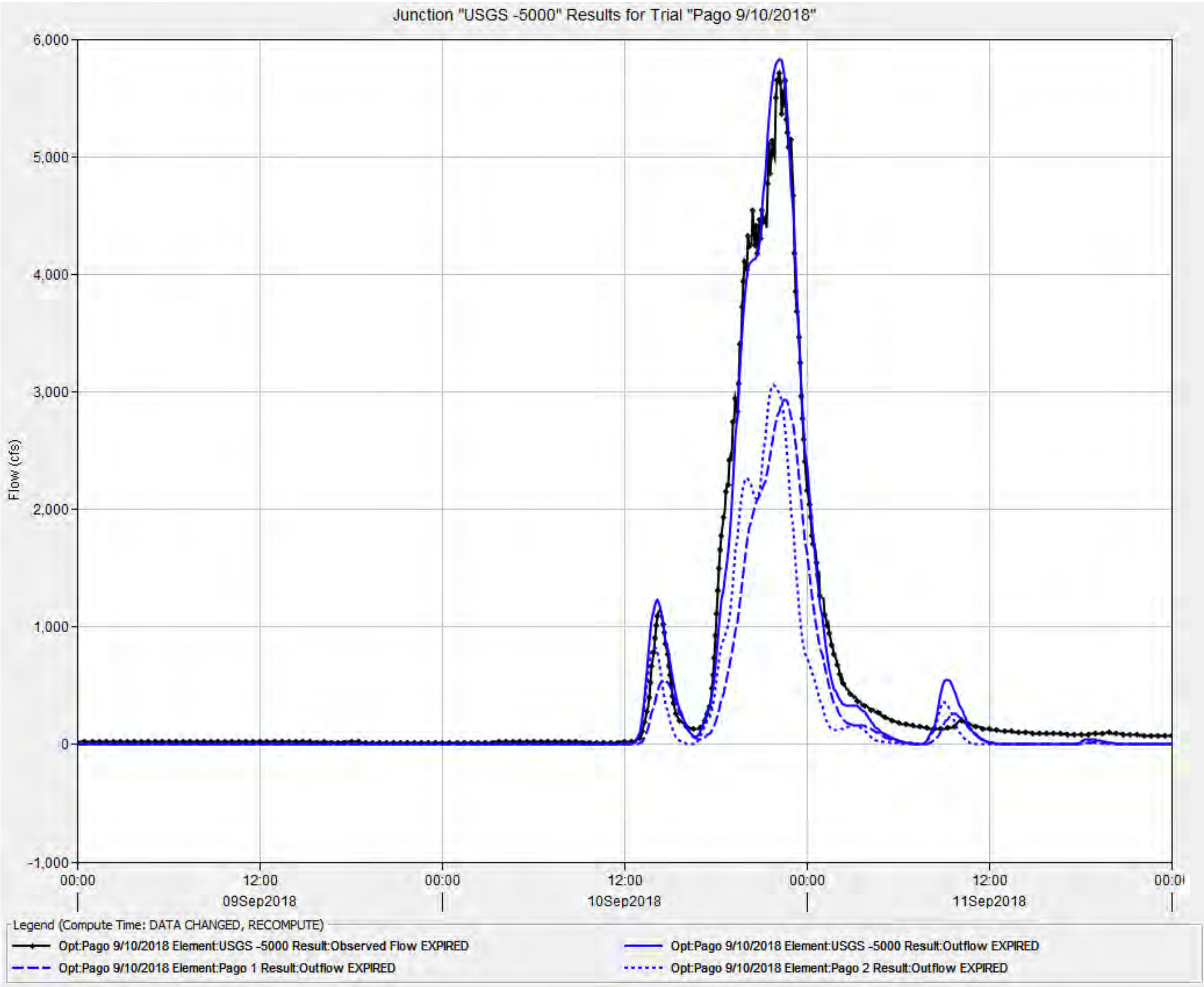


Table 4-12: Initial and Optimized Parameters for the 10 August 2014 Storm

	Curve Number		Lag Time (min)	
	Initial	*Optimized*	*Initial*	*Optimized*
Pago 1	73.7	97.6	59.0	96.1
Pago 2	74.2	98.2	58.5	57.2

As shown in and the previous figures, the model was able to effectively simulate a hydrograph that is similar the observed data.

Table 4-13: Simulated Peak Discharges versus Observed Data at USGS 16865000

Storm Event	Observed (m^3/s)	Simulated (m^3/s)	Percentage Difference (%)	Nash-Sutcliffe Efficiency
Jul 2002	7920	7538.5	4.94	0.948
Aug 2012	8760	8158.5	7.11	0.895
Aug 2014	7760	7597.9	2.11	0.991
Aug 2015	5410	4071.4	28.2	0.912
Sep 2018	5710	5822.9	1.96	0.985

The average parameter values between the five calibration events and corresponding percent increase were calculated and are presented in Table 4-15. These values were used to create the final calibrated model for Pago River. A similar adjustment was made to calibrate the Hagatña River HMS model based on the average percent increase from the initial curve number and lag time parameter values.

Table 4-14: Average Optimized Parameter Values and Percent Increase

Subbasin Name	Curve Number		Percent Increase (%)	Lag Time (min)		Percent Increase (%)
	Initial	*Optimized*		*Initial*	*Optimized*	
Pago 1	73.7	85.2	15.6	59.0	92.7	57.1
Pago 2	74.2	85.8	15.6	58.5	84.8	45.0
		Average:	15.6		**Average:**	41.1

The adjusted parameters calculated to create the calibrated HMS model for the Hagatña River watershed are presented in Table 4-15.

Table 4-15: Adjusted Parameters for the Hagatña River HEC-HMS Model

Subbasin Name	**Curve Number, CN**		**Percent Increase (%)**	**Lag Time, t_L (min)**		**Percent Increase (%)**
	Initial	*Calibrated*		*Initial*	*Calibrated*	
Hagatna 1	76.6	88.5	15.6	53.5	80.9	51.1
Hagatna 2	77.6	89.7	15.6	137.8	208	51.1
Hagatna 3	80.0	92.5	15.6	103.4	156	51.1
Hagatna 4	84.2	97.3	15.6	94.6	143	51.1
Hagatna Marsh	63.6	73.5	15.6	132.9	201	51.1

4.6 Model Validation

The calibrated model was tested for validity against two additional storm events: the 16 August 2018 storm and Typhoon Pongsona (8 December 2002). Continuous precipitation and streamflow data was available for the 16 August 2018 storm event. This event is a smaller storm with a peak flow of 107 cms. When applying rainfall data from this event into the calibrated model, the model is able to create a hydrograph that is very similar to the observed data (Figure 4-13).

Although continuous streamflow data was not available at the Pago River stream gage for Typhoon Pongsona, which occurred on 8 December 2002, the calibrated model was still tested for validity against the known peak flow of 490 cms – the largest peak flow in the entire record. The calibrated model was not able to adequately reach the recorded peak flow from this event, as shown below in Figure 4-14. While there was a sincere attempt to calibrate the model to larger storm events, lack of continuous precipitation and streamflow data within the watershed for these significant events limits the ability of the model to simulate large storm events. Therefore, while the model has demonstrated its ability to generally replicate the hydrograph shape that typically occurs, a greater emphasis should be placed on other methods for determining the flood frequency (e.g. a Bulletin 17B stream gage analysis).

Figure 4-13: HMS Model Simulation of the 16 August 2018 Storm

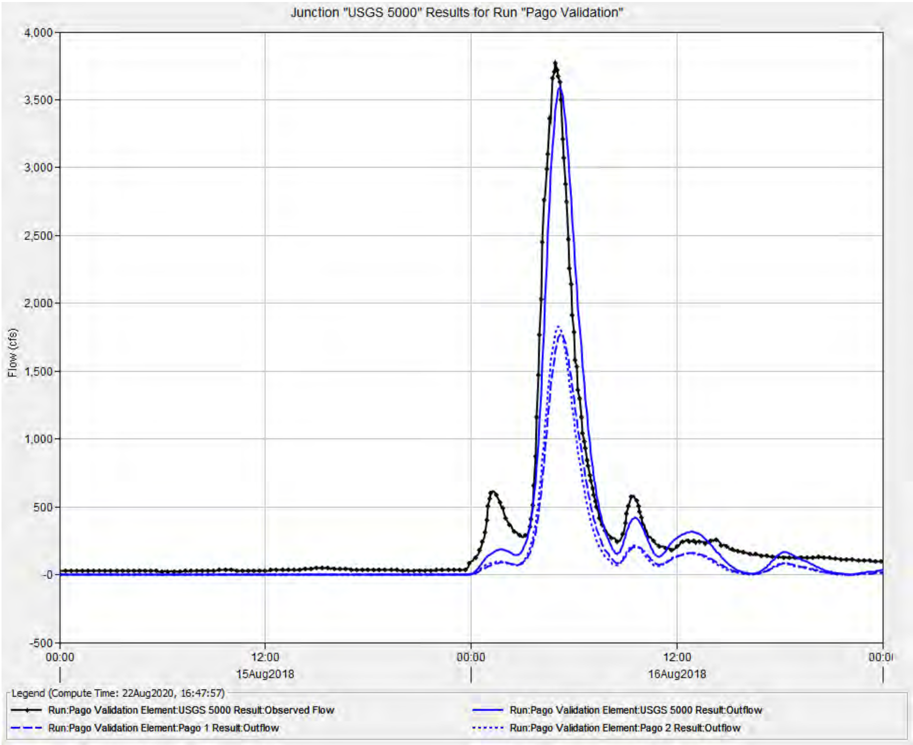


Figure 4-14: HMS Model Simulation of the 8 December 2002 Storm

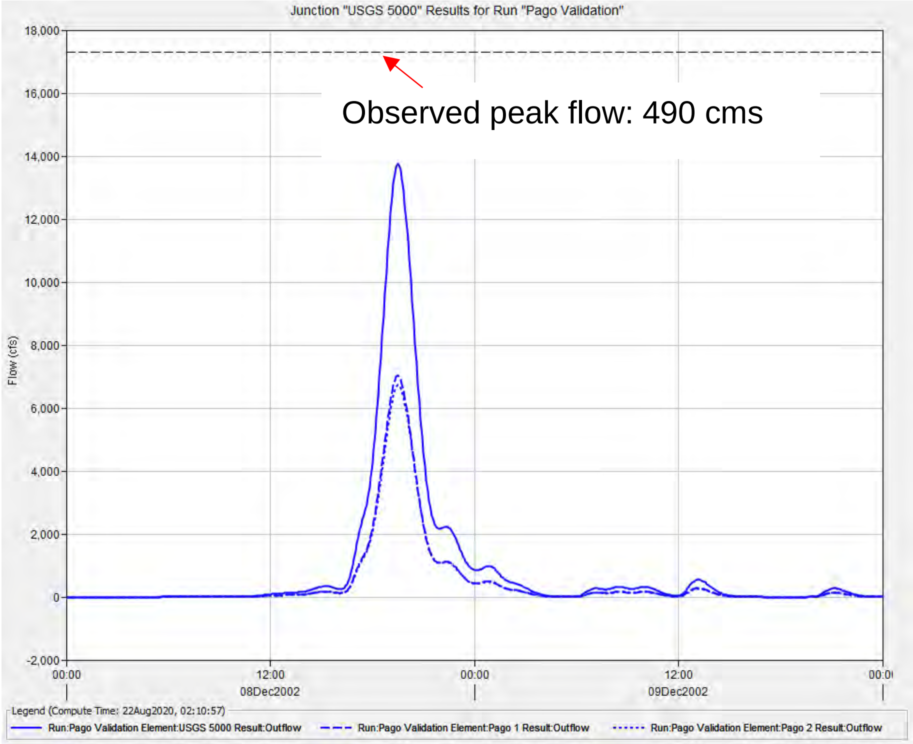


Table 4-16: Peak Flow Estimates for Each Subbasin

Subbasin Name	Drainage Area (km^2)	Peak flow (m^3/s)[1]							
		1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500
Hagatna 1	6.08	63.0	78.9	90.9	107	120	133	146	164
Hagatna 2	10.79	57.6	74.6	87.6	105	119	133	147	167
Hagatna 3	7.45	47.9	61.3	71.6	85.4	96.2	107	119	134
Hagatna 4	1.55	11.5	14.3	16.4	19.4	21.7	24.0	26.5	29.9
Hagatna Marsh	4.16	15.1	21.9	27.2	34.5	40.1	45.8	51.8	60.0
Pago 1	7.46	88.5	111	127	150	168	186	204	229
Pago 2	7.17	85.0	108	122	145	161	178	195	219
USGS 16865000	14.63	173	218	250	295	329	363	399	448

[1]: rounded to three significant figures

5 Flood Frequency Analysis

Methods for estimating the peak flow for the 50%, 20%, 10%, 4%, 2%, 1%, 0.4%, and 0.2% AEP (2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year) flood events (8 profiles) include the following:

1. Rainfall-runoff model
2. Stream gage analysis
3. Regional regression equations

Other peak flow estimates previously published (for reference):

1. 2015 Flood Insurance Study (FIS)

5.1 Rainfall-Runoff Model

Point precipitation frequency data was taken directly from National Weather Service's (NWS) NOAA Atlas 14 Precipitation-Frequency Data Server (PFDS). This data displays estimated total rainfall from recurrence intervals of 1 to 1000 years (100% to 0.1% AEP) for various durations (5 minutes to 60 days) for a specific location using latitude and longitude geographic coordinates. The location points used to extract PFDS data were the approximate centroid locations for each subbasin. The latitude and longitude for the centroid locations are included in Table 4-1. This rainfall data was put into the calibrated HEC-HMS model (Section 4) to compute peak flow estimates for the 8 flood frequency events at each subbasin and critical location.

5.2 Stream Gage Analysis

5.2.1 Bulletin 17B

Annual peak flow data from the Pago River stream gage (USGS 16865000) were analyzed individually using methodology from Bulletin 17B (USGS. Office of Water Data Coordination 1982) as applied by the Hydrologic Engineering Center's Statistical Software Package (HEC-SSP) program (version 2.2, HEC, 2019) which follows the Bulletin 17B guidance. The weighted skew option was used, which weights the computed station skew with the generalized regional skew. A generalized skew value of 0.22 and mean-square error of 0.169 was used per the findings of the *Guam Comprehensive Flood Mitigation Report, Phase 1 – Part 1* (USACE, 2020). Table 5-7 contains the number and name of the stream-gaging station upon which a Bulletin 17B analysis was performed. Table 5-8 presents the resulting peak flow estimates.

Table 5-1: Relevant stream gages

Station no.	Station name	Drainage area (km^2)	No. years of usable record	Period of record used in this analysis
16865000	Pago River near Ordot, Guam	14.4	51	1952-2019

Table 5-2: Peak flow estimates computed using Bulletin 17B methodology for USGS 16604500

Annual Exceedance Probability (AEP)	Computed Curve Flow in m^3/s	Confidence Limits	
		0.05	0.95
1/500	712	1029	543
1/200	567	786	446
1/100	474	635	381
1/50	392	508	322
1/25	320	401	269
1/10	238	285	206
1/5	184	213	162
1/2	118	132	105

5.2.2 Bulletin 17C

The Bulletin 17B analysis discussed in the previous section relies primarily on systematic records represented as point observations, i.e. peak discharge values recorded by a gaging station. A Bulletin 17C analysis offers the opportunity to also use intervals or thresholds to represent the magnitudes of flood peaks that might be known with less precision, such as historical flood data. Table 5-2 and Table 5-3 contain the results from completing a Bulletin 17C analysis at the two gage locations. The same generalized skew value of 0.22 and mean-square error of 0.169 were used.

Table 5-3: Peak flow estimates computed using Bulletin 17C methodology for USGS 16865000

Annual Exceedance Probability (AEP)	Computed Curve Flow in ft^3/s	Variance Log	Confidence Limits	
			0.05	0.95
1/500	712	0.01708	1,517	490
1/200	567	0.01207	1,056	412
1/100	473	0.00896	799	358
1/50	392	0.00641	601	307
1/25	320	0.00440	449	260
1/10	238	0.00253	302	201
1/5	184	0.00164	219	159
1/2	118	0.00100	133	104

5.3 Regional Regression Equations

Regression equations were developed by USACE and originally presented in the *Guam Comprehensive Flood Mitigation Report, Phase 1 – Part 1*, prepared for BSP in 2020. The final equations relate peak discharges to two basin characteristics: drainage area (DA) and the maximum 24-hour precipitation that occurs on average once in 2 years (I24H2Y) and are presented in Table 5-1.

The drainage area and centroid location of each polygon was computed automatically in GIS and previously presented in Table 4-1. The centroid location was then used with National Oceanic Atmospheric Administration (NOAA)'s Precipitation Frequency Data Server (PFDS) to determine an estimate for I24H2Y. The resulting peak discharges from using these equations are presented for six locations: four subbasins in the Hagatña River basin, two subbasins in the Pago River basin, and the combined area representative of USGS 16865000. The regional regression equations were not developed for wetland routing and therefore peak discharges contributed by the Hagatña Swamp subbasin were not computed under this methodology.

Table 5-4: Regional regression equations for peak-discharge estimates, Guam

Regression equation	Range of explanatory variables	R^2	Standard error of estimate
$Q_2 = 10^{-6.47}(DRNAREA^{0.561})(I24H2Y^{3.37})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.839	0.142
$Q_5 = 10^{-6.46}(DRNAREA^{0.575})(I24H2Y^{3.44})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.884	0.121
$Q_{10} = 10^{-6.49}(DRNAREA^{0.596})(I24H2Y^{3.52})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.879	0.127
$Q_{25} = 10^{-6.51}(DRNAREA^{0.609})(I24H2Y^{3.57})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.854	0.144
$Q_{50} = 10^{-6.55}(DRNAREA^{0.626})(I24H2Y^{3.64})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.812	0.171
$Q_{100} = 10^{-6.58}(DRNAREA^{0.637})(I24H2Y^{3.680})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.778	0.192
$Q_{250} = 10^{-6.62}(DRNAREA^{0.649})(I24H2Y^{3.72})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.744	0.213
$Q_{500} = 10^{-6.66}(DRNAREA^{0.664})(I24H2Y^{3.77})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.700	0.241

Q_X, peak discharge for X-year recurrence interval in cubic meters per second; DA, drainage area, in square kilometers; I24H2Y, maximum 24-hour precipitation that occurs on average once in 2 years, in millimeters; R^2, coefficient of determination based on the variability in the dependent variable explained by the regression; a $\leq$ *variable* $\leq$ b, the explanatory variable may be greater than or equal to a and less than or equal to b.

Table 5-5: Flood Frequency Estimates using Regional Regression Equations

Location	Drainage area (km^2)	2-year, 24-hour precipitation (cm)	Peak flow (m^3/s)[1]							
			1/2	**1/5**	**1/10**	**1/25**	**1/50**	**1/100**	**1/250**	**1/500**
Hagatna 1	6.08	17.5	33.3	49.8	75.4	94.9	125	147	172	208
Hagatna 2	10.79	16.7	39.4	59.2	90.3	114	151	179	210	256
Hagatna 3	7.45	15.9	26.9	40.1	60.4	75.8	99.4	117	137	165
Hagatna 4	1.55	16.4	12.4	18.2	26.6	32.7	41.9	48.5	55.7	65.7
Pago 1	4.16	16.5	44.2	66.5	101	128	170	201	236	287
Pago 2	7.47	18.4	46.9	70.7	108	137	181	215	252	307
USGS - 5000	7.18	18.8	67.2	102	158	202	271	323	383	471

[1]: rounded to three significant figures

5.4 Reference Flows

5.4.1 2015 Flood Insurance Study

The latest Flood Insurance Study for the Territory of Guam, dated September 2007, presents peak flow estimates for various locations along Hagatña River (Table 5-8). These estimates were based on flood frequency information documented in the 1975 interim report by USACE, *Agana River, Guam*.

Table 5-6: Peak Flow Estimates for Hagatña River, upstream of E O'Brien Dr

Annual Exceedance Probability (AEP)	Return Period (yr)	Peak Flow (m^3/s)	Peak Flow (ft^3/s)
Upstream of E O'Brien Drive (Route 33)			
10%	10	65.6	2,315
2%	50	113	3,977
1%	100	125	4,429
0.2%	500	196	6,929
DA = 21.5 km^2 (8.29 mi^2)			
Upstream of Chalan Santo Papa Juan Pablo Dos			
10%	10	64.1	2,265
2%	50	85.0	3,003
1%	100	88.9	3,140
0.2%	500	106	3,735
DA = 21.7 km^2 (8.37 mi^2)			
Upstream of S Marine Corps Drive (Route 1)			
10%	10	65.0	2,295
2%	50	75.3	2,658
1%	100	76.5	2,700
0.2%	500	81.4	2,875
DA = 22.6 km^2 (8.71 mi^2)			

5.5 Final "Adopted" Peak Flow Estimates

Peak flow estimates at USGS 16865000, as determined by applying the three different methods of flood frequency analysis, are provided in Table 5-6 and Figure 5-1 for comparative purposes. As discovered during the validity test, the rainfall-runoff model is likely to underestimate the peak streamflow for very large events. Stream gage analysis (i.e. a Bulletin 17B analysis) is likely to be the most reliable method for estimating flood frequency as it has a long period of record to rely upon. A scale factor, representing the increase from HMS flows to Bulletin 17B flows at USGS 16865000, was applied across the entire model to provide more realistic flows for various frequency events across the study area. This scale factor is presented in Table 5-6.

Table 5-3: Comparison of Various Flood Frequency Estimates at USGS 1686500

Method	Peak flow (ft^3/s)[1]							
	1/2	1/5	1/10	1/25	1/50	1/100	1/250	1/500
Rainfall-Runoff Model	6,126	7,713	8,830	10,414	11,611	12,822	14,084	15,804
Stream Gage Analysis	4,153	6,485	8,401	11,297	13,835	16,731	20,038	25,143
Regression Equations	2,374	3,610	5,591	7,138	9,570	11,423	13,534	16,633

Table 5-4: Scale Factor

1/2	1/5	1/10	1/25	1/50	1/100	1/250	1/500
0.68	0.84	0.95	1.08	1.19	1.30	1.42	1.59

Figure 5-1: Flood Frequency Curve for USGS 16865000, Pago River

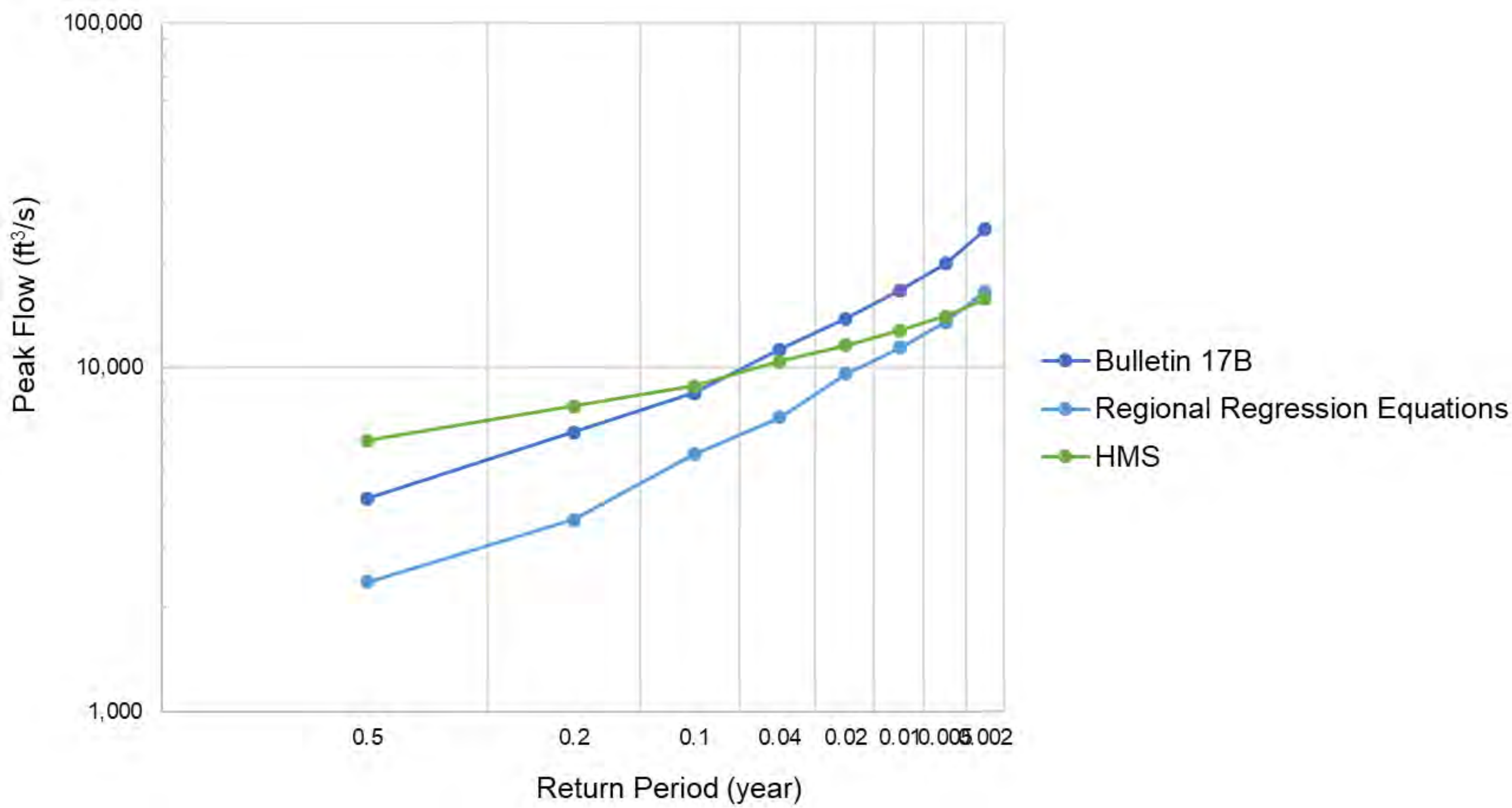


Table 5-5: Final Flood Frequency Estimates for Each Subbasin

Location	Drainage area (km^2)	Peak flow (m^3/s)[1]							
		1/2	1/5	1/10	1/25	1/50	1/100	1/250	1/500
Hagatna 1	15.74	42.7	66.3	86.5	116	143	173	208	261
Hagatna 2	27.94	39.0	62.8	83.4	114	142	173	210	266
Hagatna 3	19.30	32.5	51.5	68.1	92.6	115	140	169	214
Hagatna 4	4.00	7.8	12.0	15.6	21.0	25.8	31.3	37.7	47.5
Hagatna Swamp	10.79	10.3	18.4	25.9	37.4	47.8	59.8	73.7	95.4
Pago 1	19.32	60.0	93.2	121	163	200	242	290	365
Pago 2	18.58	57.6	90.5	116	157	192	232	278	348

[1]: rounded to three significant figures

6 Development of the Hydraulic Model

A model utilizing both two-dimensional (2D), unsteady flow analysis as well as one-dimensional (1D), steady flow analysis was created for this study using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software (version 5.0.7, HEC, 2019).

6.1 Flow Data

Peak flow rates determined in the previous section (Section 5) were used to represent the amount of water in the system for the 10%, 4%, 2%, 1%, and 0.2% AEP events (5 profiles).

6.1.1 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 Hagatña Swamp from the upper watershed at three locations. The downstream boundary condition was set to a water surface elevation of 0.30 m (0.97 ft), representing the mean higher high water (MHHW) elevation (in reference to mean sea level) of the ocean. This was determined based on the MHHW elevation at NOAA tidal station at Apra Harbor, Guam – Station ID: 1630000 (NOAA).

6.2 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 UTM Zone 55 N (Meters) with reference to the NAD83 (MA11) coordinate system. Elevation data presented in Section 3.2 were imported to create the terrain model. Several geometric layers required for the hydraulic model were digitized, some of which are described in Table 5-1.

Table 6-1: GIS layers created for 2D hydraulic models

GIS layer	Description
2D Flow Areas	2D Flow Areas are created by constructing polygon areas representing the regions to be modelled.
Boundary Condition	A Boundary Condition (BC) line was added to identify the location for a specific flow condition on the boundary of a 2D Flow Area.
Breakline	Breaklines 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).
SA/2D Area Connection	This internal connection feature can be used to represent embankment crests and major roads.

6.2.1 Manning's Roughness Coefficient, *n*

Manning's roughness coefficient, *n*, is an empirically derived coefficient that is dependent on several variables, such as vegetation, obstructions, and meandering when applied to open channels. This value was selected based on site characteristics observed in the field, aerial imagery, and land cover classifications (Section 3.4.1). Typical *n* values selected for this study are provided in Table 5-2 for 2D Flow Areas.

Table 6-2: Manning's n values

Land Cover ID	Land Cover Type	Manning's *n*
2	Impervious surface	0.015
5	Open space developed	0.04
6	Cultivated	0.04
7	Pasture / hay	0.03
8	Grassland	0.035
9	Deciduous forest	0.16
10	Evergreen forest	0.16
12	Scrub / shrub	0.1
13	Palustrine forested wetland	0.1
14	Palustrine scrub shrub wetland	0.1
15	Palustrine emergent wetland	0.07
16	Estuarine forested wetland	0.1
17	Estuarine scrub shrub wetland	0.1
18	Estuarine emergent wetland	0.07
19	Unconsolidated shore	0.035
20	Bare land	0.03
21	Open water	0.035

6.2.2 Bridges

Bridges and major culverts were represented in the model as a *Bridge/Culvert*. Bridge data (e.g. deck width, horizontal span) required for this modeling feature was based on as-built drawings, field measurements, and as provided by *BridgeReports.com*, a searchable version of the National Bridge Inventory (Baughn, 2019). Based off the 5th edition of the HEC-RAS Reference Manual (Brunner, 2016), a Bridge Weir coefficient of 1.44 was selected, representative of flow over a typical bridge deck.

There are four bridges that cross Hagatña River, shown in the photos below:

Photo 5-1: S Marine Corps Dr (Route 1) Bridge

Photo 5-2: An unnamed bridge near the Bank of Guam

Photo 5-3: Chalan Santo Papa Juan Pablo Dos

Photo 5-4: E O'Brien Dr (Route 33)

Bridge information is provided in Table 5-3 for three of the four bridges. The unnamed truss bridge near the Bank of Guam is unlikely to affect flood routing along Hagatña River due to its high clearance and was not included in the hydraulic model. The S Marine Corps Dr Bridge is a single span concrete arch structure. Data for S Marine Corps Dr and Chalan Santo Papa Juan Pablo Dos were based on as-built drawings provided by BSP. Field measurements were taken at E O'Brien Dr during a March 2019 site visit.

Table 6-3: HEC-RAS Bridge Information for Hagatna River

Name	Deck Width (m)	Deck Thickness (m)	Number of Piers	Pier Width (m)	Bedrock material
S Marine Corps Dr	31.7	0.8	0	n/a	natural
Chalan Santo Papa Juan Pablo Dos	13	1.2	0	n/a	Concrete
E O'Brien Dr	21.1	1.1	2	3-5	Natural

6.3 Results

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% AEP events (5 profiles). Shown below in Figures 5-1 to 5-5 are each of the flood hazard maps (showing both flood depth and boundaries for each of the AEP events mentioned above), as well as a flood boundary map showing all of the aforementioned AEP events (Figure 5-6).

Figure 6-1: 10% AEP (10 yr) Flood Hazard Map

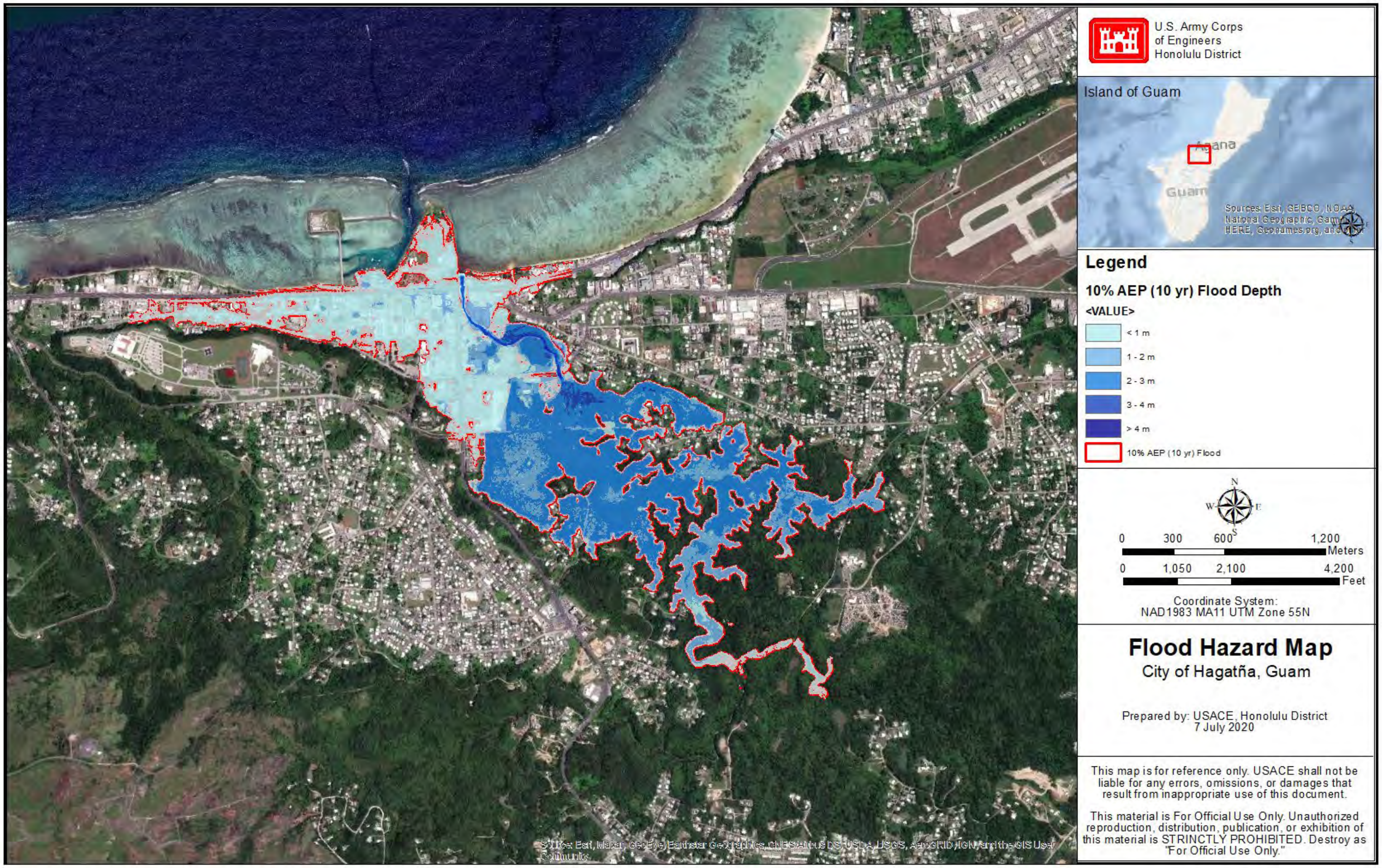


Figure 6-2: 4% AEP (25 yr) Flood Hazard Map

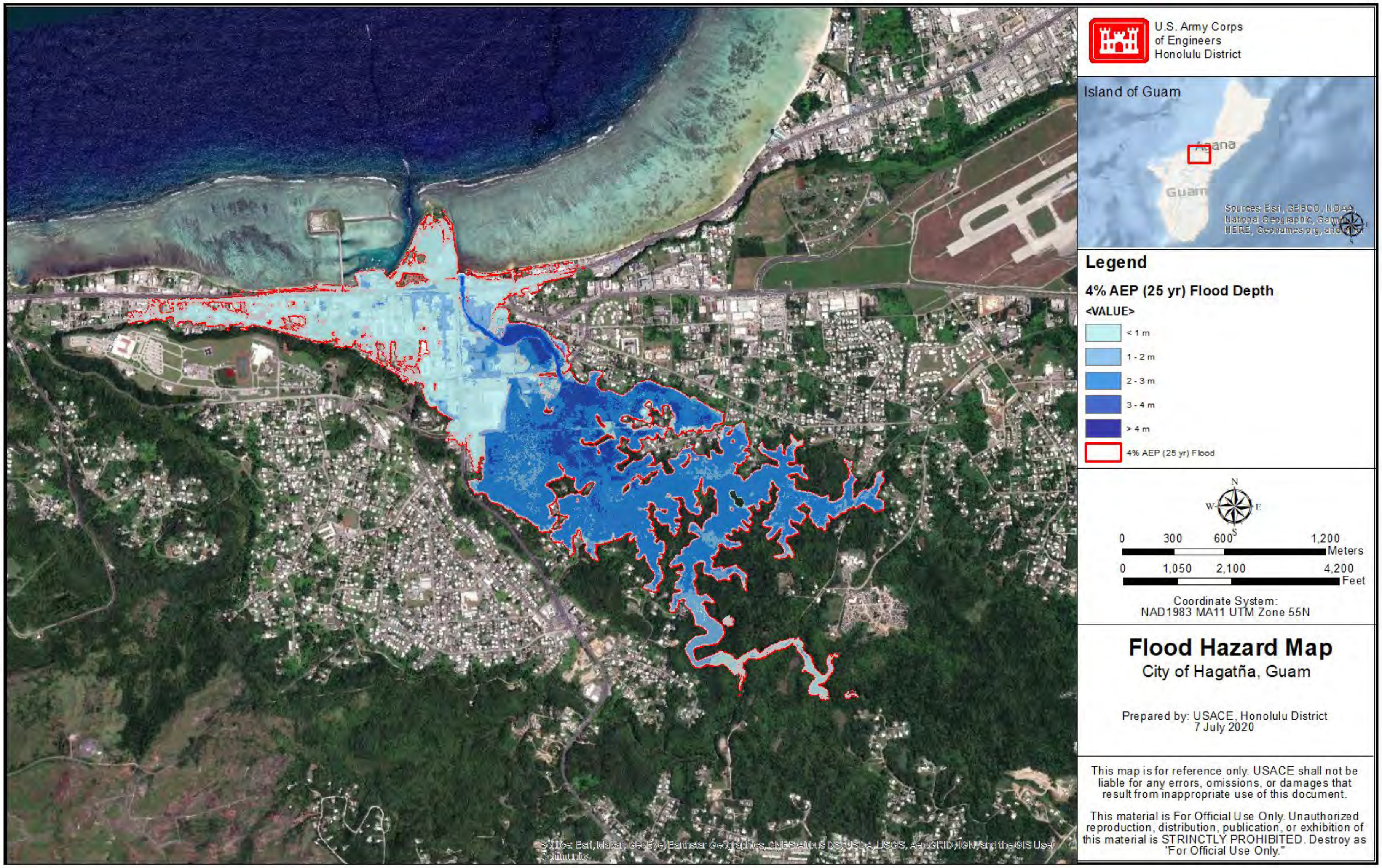


Figure 6-3: 2% AEP (50 yr) Flood Hazard Map

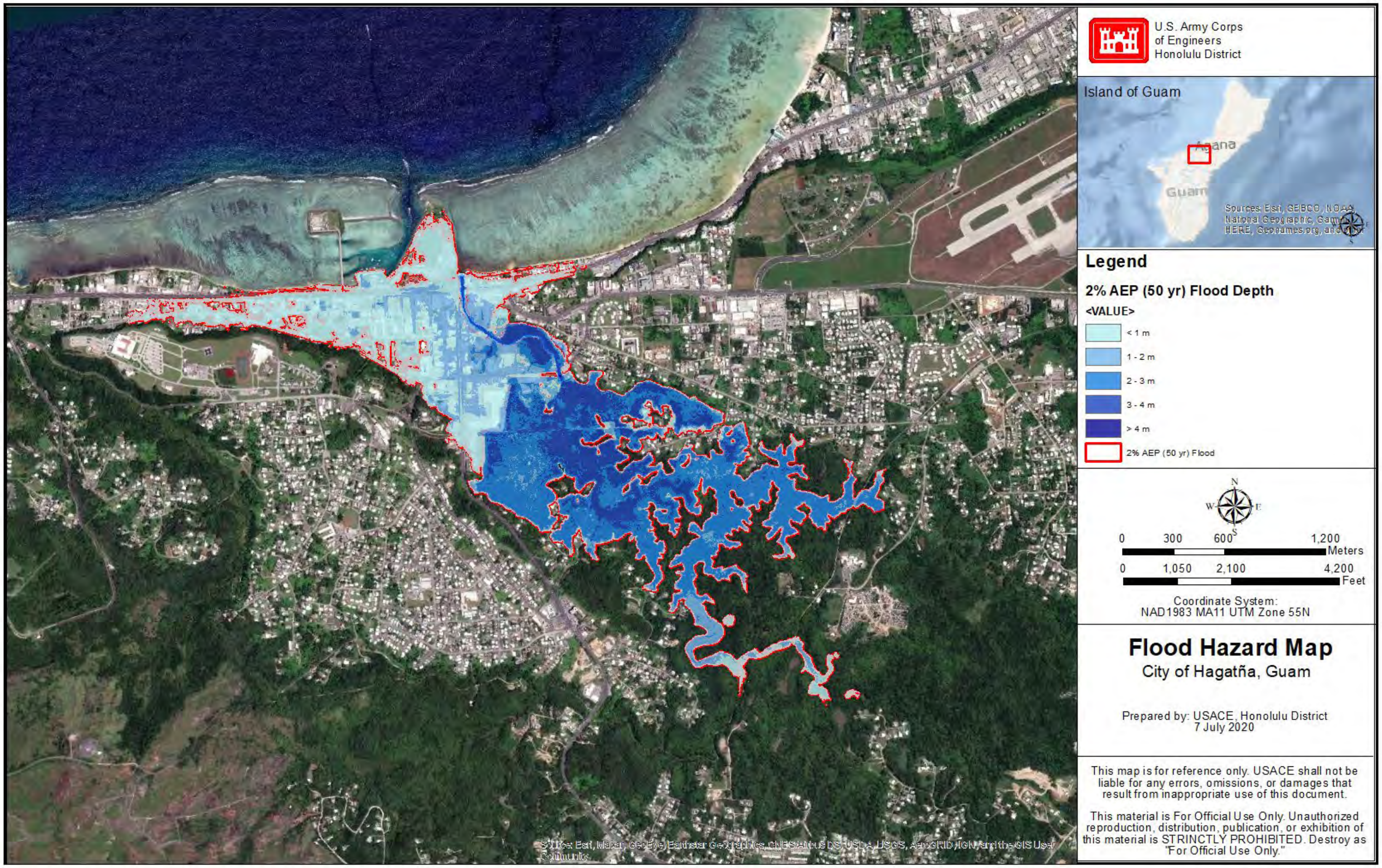


Figure 6-4: 1% AEP (100 yr) Flood Hazard Map

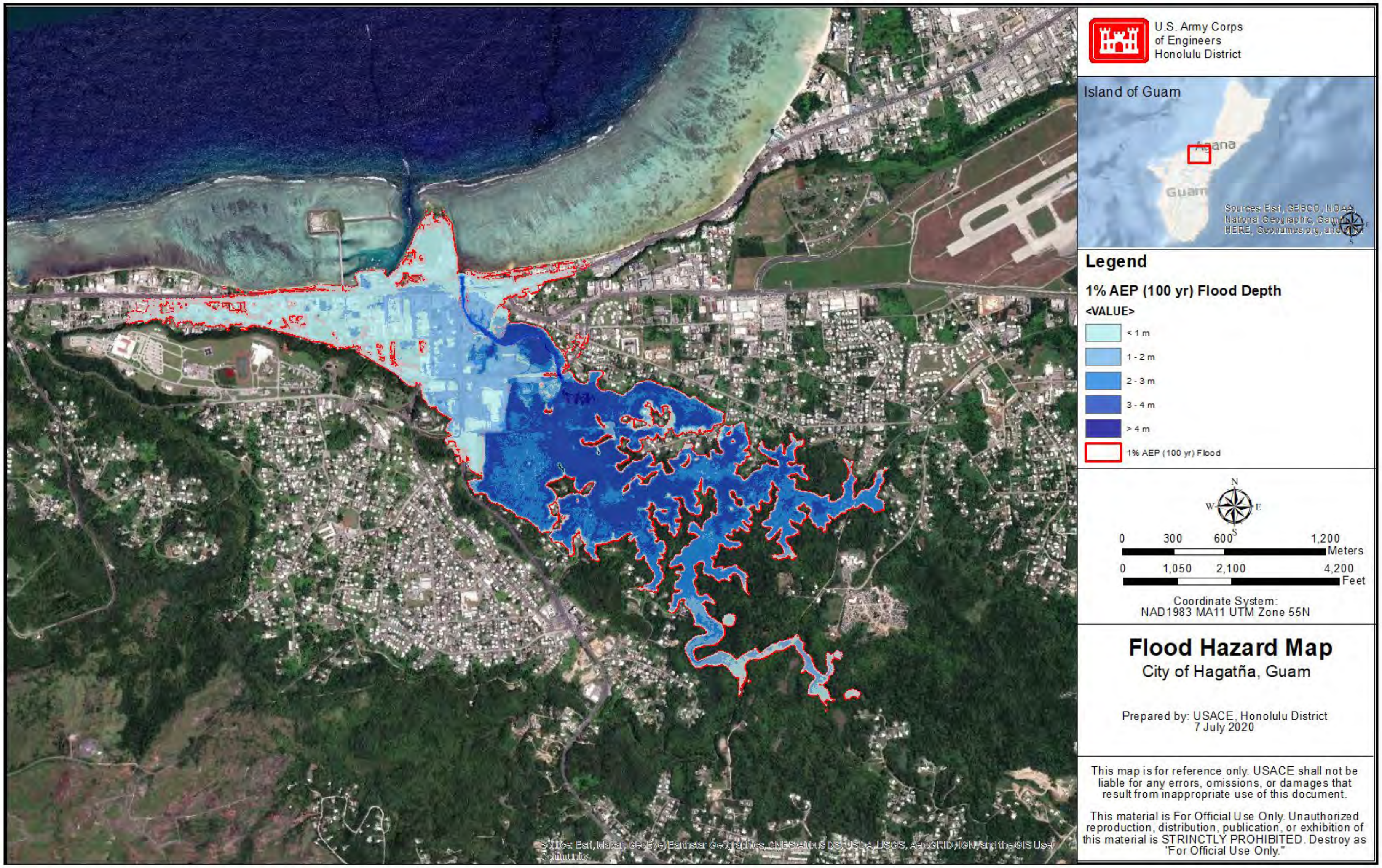


Figure 6-5: 0.2% AEP (500 yr) Flood Hazard Map

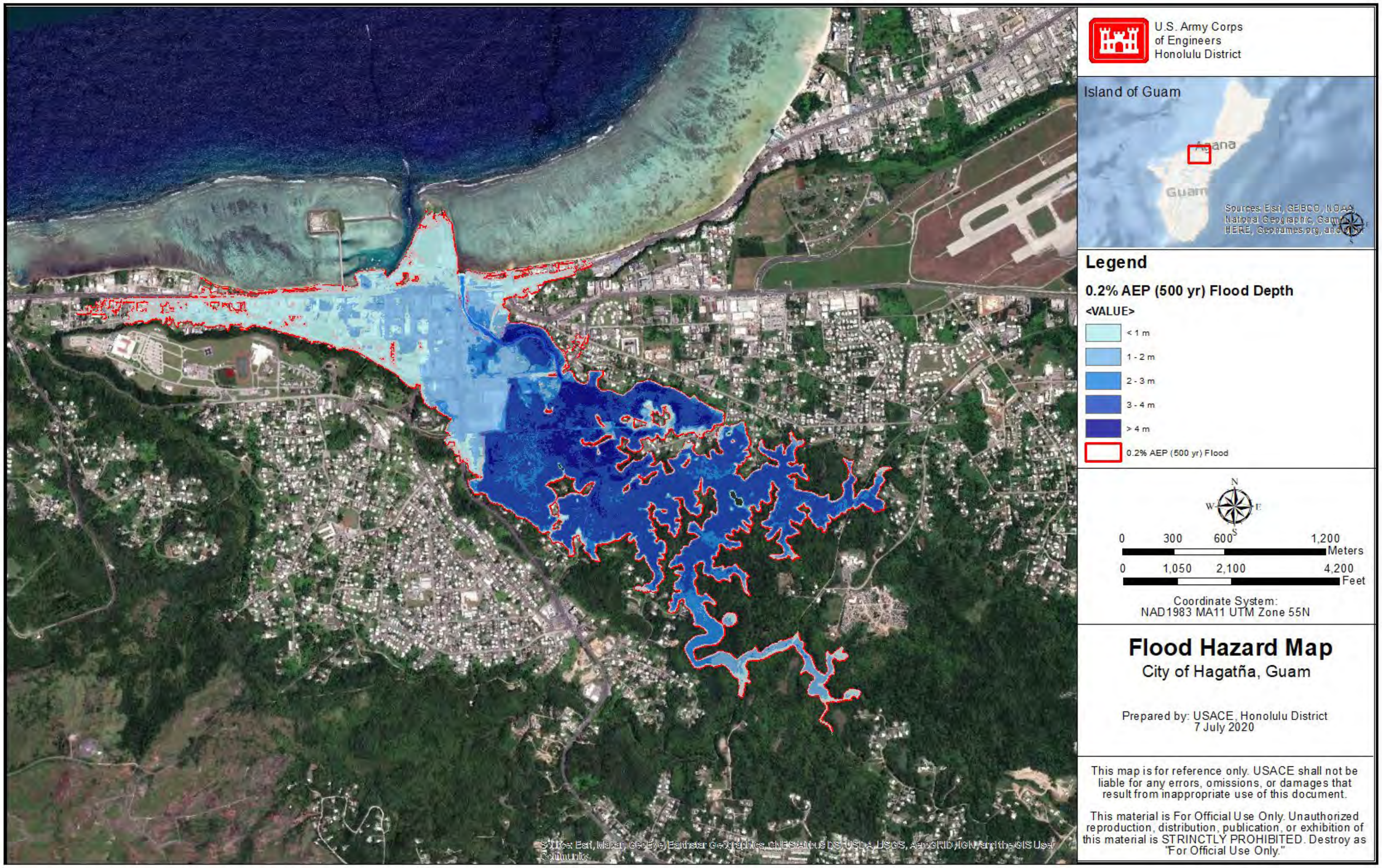
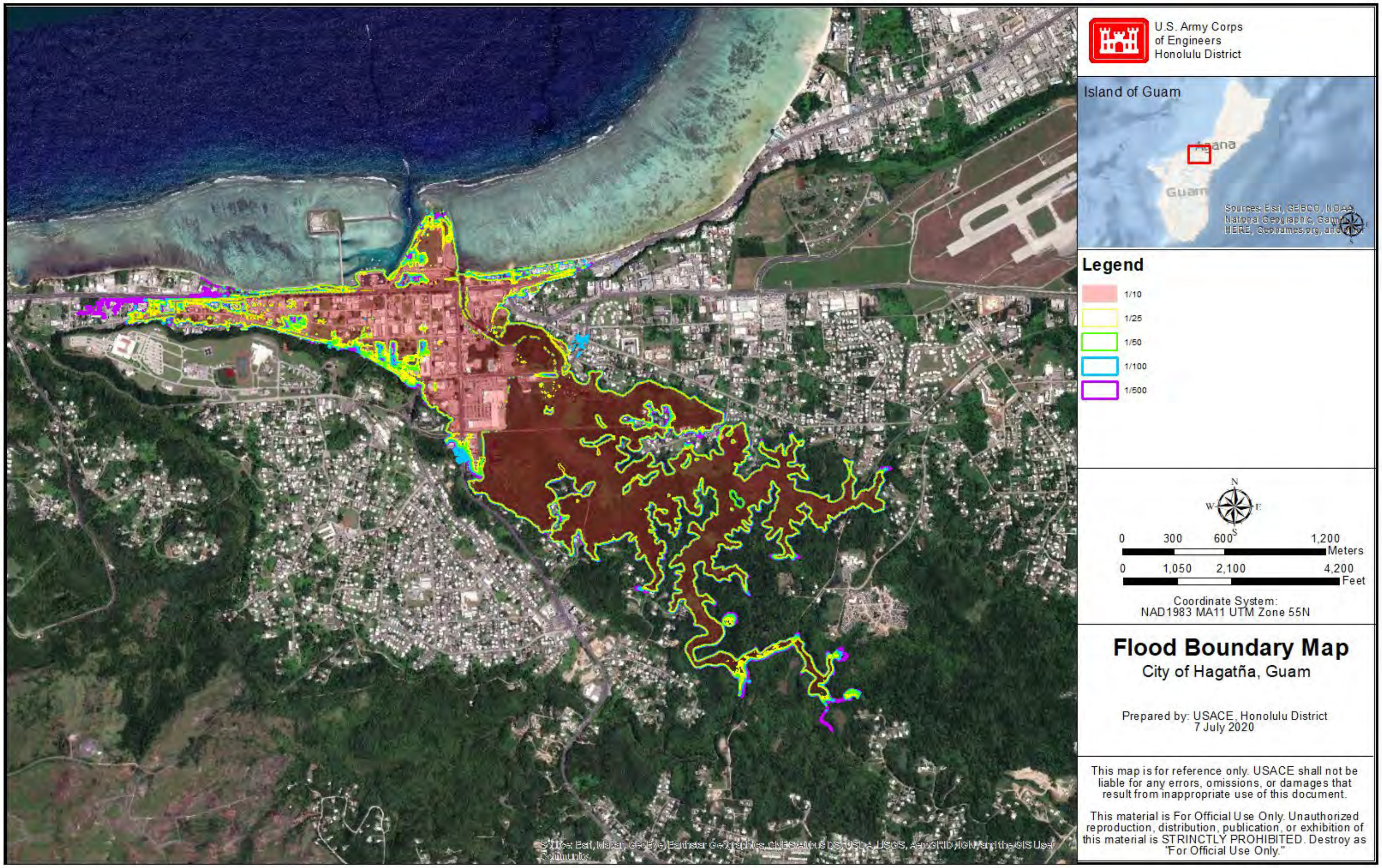


Figure 6-6: Combined Flood Boundary Map



7 Conclusion

After closer inspection of each flood hazard map, it is apparent that there is still flooding in most of the city east of the Hagatna River. This is similar to the Flood Insurance Rate Maps (FIRM) produced by FEMA in 2007 (shown in the Appendix, Section 8.1 “2007 FEMA Flood Insurance Rate Map”). Most of the flooding to the east of the river is less than one meter in depth. The same area to the east of the river on the 2007 FEMA produced FIRM was labeled as zones with less than 1 foot (0.3 meters) of flooding, which is consistent with what is shown in the new flood hazard maps. The extents of the inundation boundary are similar in both the 2007 FEMA FIRM and the newly produced flood boundaries.

In conclusion, this flood study further validates the results of the 2007 FEMA produced FIRM, by providing better estimates of frequency discharge values as well as water surface profiles. This ultimately means that there are no major changes to flood conditions between the FIRM maps produced by this study and the 2007 FEMA produced FIRM, despite numerous bridge improvements that “likely improved conveyance along the Hagatna River”.

8 References

Baughn, J. (2019). Retrieved from BridgeReports.com: http://bridgereports.com/hi/

Brunner, G. W. (2016). *Hydrologic Engineering Center- River Analysis System (HEC-RAS), Hydraulic Reference Manual, Version 5.0*. Davis, CA: US Army Corps of Engineers Hydrologic Engineering Center (HEC), 5-22.

NOAA. (2017, April 21). *NOAA Atlas 14 Point Precipitation Freqeuncy Estimates*. (National Oceanic and Atmospheric Administration. National Weather Service. Hydrometeorological Design Studies Center) Retrieved from Precipitation Frequency Data Server (PFDS): https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_hi.html

NOAA. (n.d.). *Datums for 1630000, Apra Harbor, Guam*. Retrieved from Tides & Currents: https://tidesandcurrents.noaa.gov/datums.html?id=1630000

9 Appendix

9.1 2007 FEMA Flood Insurance Rate Map