Guam Comprehensive Flood Study – Part 4

Flood Hazard Study
Upper Namo River

Agat-Santa Rita Area, Guam

Final Report
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Executive Summary

The Guam Comprehensive Flood Study represents a collaborative approach between the US Army Corps of Engineers (USACE) and the Government of Guam to understand flooding hazards across the island. The technical work done by USACE is meant to serve as the planning framework that the Government of Guam will use to work toward reducing flood risk for its communities.

The purpose of the study is to provide the Government of Guam with 1) an update of the regional flood frequency analysis for southern Guam; 2) site-specific hydrologic and hydraulic analysis of two to four flood prone areas within the inventory; and 3) preliminary flood mitigation design concepts for the aforementioned sites. Documentation for the study was divided into four parts:

Part 1 – Flood Frequency Estimates for Streams on Guam
Part 2 – Flood Hazard Study for Umatac River, Guam
Part 3 – Flood Hazard Study for Nelansa (Manell) River, Guam
Part 4 – Flood Hazard Study for Upper Namo River, Guam

This document presents information on Part 4, the objective of which is to 1) provide estimates of the magnitudes of the 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% Annual Exceedance Probability (AEP) peak stream discharges at Upper Namo River, 2) provide inundation maps representing existing conditions in the floodplain for the 1% and 0.2% AEP flood events, and 3) provide site-specific preliminary flood mitigation design concepts to address flooding caused by Upper Namo River.

Three different methods were used to estimate the peak flow for the 8 frequency events: 1) stream gage analysis following Bulletin 17B methodology, 2) regional regression equations as introduced in Part 1 of this study, and 3) rainfall runoff modeling. The peak flow estimates computed by the rainfall-runoff model (Table 4-14) were determined to be the most reliable dataset as it was based on site-specific basin characteristics and calibrated to historical streamflow data. These flows were used as input for the hydraulic model.

A one-dimensional, steady flow model was created using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software. Field measurements and observations made during the October 2018 site visit were incorporated into the geometry of the HEC-RAS model. The results of the hydraulic model indicate that the Namo River is able to contain the 1% AEP (100 year) flood event without inundating residential structures. However, the October 2018 site visit identified overland runoff as a potential source of erosive flows across Namo Falls Park Street / Sgt E Cruz Street. Modeling results support this theory as the inundation limits created by the main river do not extend to the identified problem area. The inundation map generated by the HEC-RAS model for the 1% AEP (100-yr) event is provided in Appendix A.

Flood mitigation alternatives specific to this site include: 1) a debris structure along Namo River Falls Park Street / Sgt E Cruz Street and 2) road and bank protection near Namo Falls Park Street / Sgt E Cruz Street. The source of erosive flows along this road are two small, unnamed tributaries that enter Namo River by either crossing underneath the road through a small culvert or by overtopping the road. Based on computed discharges and water surface elevations in RAS, this culvert should be large enough to pass the 4% AEP (25 year) event without causing the road to overtop during the 1% AEP (100 year) event. However, debris and sediment can cause obstructions that reduce the culvert's capacity. This alternative, therefore, makes recommendations to reduce the amount of debris obstructing the culvert by installing three 1.5 m (5.0 ft) high posts approximately 8 m (26 ft) upstream of the culvert and road. Three posts would be installed at each tributary (six total; see Figure 6-1). The estimated cost of construction to restore the natural flow path of the channel is approximately $22,100 with a 35% contingency for a total estimated construction contract cost of $29,900.

The second alternative focuses on adding bank protection to the road and banks near Namo Falls Park Street / Sgt E Cruz Street. As mentioned previously, this road is frequently eroded by overland runoff. The proposed alternative is to cover the bank and road with a gravel bedding; and provide additional riprap on the banks and road abutments. The estimated cost of construction to restore the natural flow path of the channel is approximately $158,000 with a 35% contingency for a total estimated construction contract cost of $214,000.

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- % – percent
- A – area; drainage area
- AEP – annual exceedance probability
- BSP – Bureau of Statistics and Plans
- CN – curve number
- D – depth; bank-full depth
- DEM – digital elevation model
- DPW – Department of Public Works
- FCP – flood control project
- FHWA – Federal Highway Administration
- FPMS – Flood Plain Management Services
- ft - feet
- GCMP – Guam Coastal Management Program
- GIS – geographical information systems
- GUVD04 – Guam Vertical Datum of 2004
- HEC – Hydrologic Engineering Center
- HMS – Hydrologic Modeling Software

- IREI – Island Research & Education Initiative
- JALBTCX – Joint Airborne Lidar Bathymetry Technical Center of Expertise
- km – kilometer
- L – length; length of flow path; length of space between cross sections
- LiDAR – Light Detection and Ranging
- m – meter
- mi – miles
- MHHW – mean higher high water
- MLLW – mean lower low water
- MSL – mean sea level
- *n* – Manning's coefficient
- NAD83 – North American Datum of 1983
- NCDC – National Climatic Data Center
- NOAA – National Oceanic and Atmospheric Administration
- NRCS – National Resources Conservation Service
- NSE – Nash-Sutcliffe model efficiency
- OCD – Office of Civil Defense
- OHS – Office of Homeland Security
- PFDS - Precipitation-Frequency Data Server
- R – storage coefficient
- RAS - River Analysis System
- S_0 = mean channel slope
- SSP – Statistical Software Package
- T_c - time of concentration
- TR-55 - Technical Release 55
- U.S. – United States
- USACE – U.S. Army Corps of Engineers
- USDA – U.S. Department of Agriculture
- USGS – U.S. Geological Survey
- UTM – Universal Transverse Mercator
- WERI – Water and Environmental Research Institute of the Western Pacific
- WGS – World Geodetic System
- W.S. – water surface
- 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 Guam Comprehensive Flood Study represents a collaborative approach between the US Army Corps of Engineers (USACE) and the Government of Guam to understand flooding hazards across the island. The technical work done by USACE is meant to serve as the planning framework that the Government of Guam will use to work toward reducing flood risk for its communities.

The purpose of the study is to provide the Government of Guam with 1) an update of the regional flood frequency analysis for southern Guam; 2) site-specific hydrologic and hydraulic analysis of two to four flood prone areas within the inventory; and 3) preliminary flood mitigation design concepts for the aforementioned sites. Documentation for the study was divided into four parts:

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1.3 **Partner Agency**

The Government of Guam, Bureau of Statistics and Plans (BSP), Guam Coastal Management Program (GCMP) is designated as the proponent of the study because of their broad coordination authorities and comprehensive planning mandates. Responsible for land and natural resource planning, GCMP is often involved with issues concerning natural hazards that impact the daily lives of Guam’s communities. A common issue faced by Guam residents and Government agencies is flooding. What started out as GCMP’s work to provide a basic characterization of flooding problems in the village of Merizo, has now grown to a comprehensive technical assessment of major flood prone areas on the Island because of the partnership and resources provided by USACE Honolulu District.

1.4 **Site Visit**

In October 2018, USACE personnel conducted a site visit to measure bridge crossings, take photographs of the channel, and investigate the three priority sites included in the Guam Comprehensive Flood Study. They also met with BSP representatives to understand the unique challenges at each priority site and overall flood history. Several photos included in this report are from that site visit. Bridge and channel measurements were incorporated into the hydraulic model. Site-specific information provided by BSP added value to the development of alternatives for flood mitigation.

2. Watershed Description

2.1 Location

The Namo River begins in the village of Santa Rita, crosses into the village of Agat, and outflows into Agat Bay near Apaca Point.

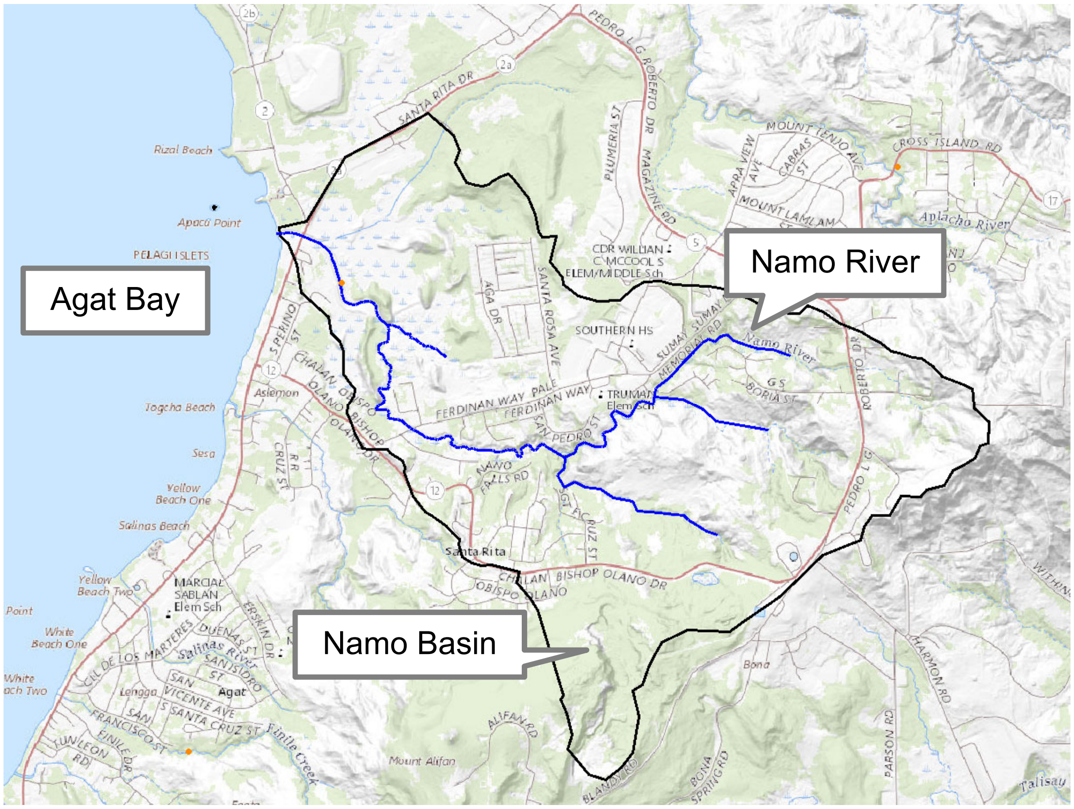

Figure 2-1: Delineated Subbasins of the Namo River and its Tributaries

2.2 Topography

The drainage basin for the Namo River has an area of about 4.56 square (sq) kilometers (km) [1.76 sq miles (mi)], is approximately 2.4 km (1.5 mi) wide, and 3.5 km (2.2 mi) long, extending from the hills of Santa Rita and Mt Alifan to Agat Bay. With the hills of Santa Rita approximately 210 meters (m) [689 feet (ft)] above sea level, the basin slope is a moderately-steep 6 percent (%). Steep land slopes and soils with a low permeability are often associated with greater stream incision. The longest watercourse in the basin is approximately 3.3 km (2.0 mi) with an approximate channel slope of 3.9% in the upper watershed and 0.5% in the lower watershed. Namo River is sometimes referred to as the *Ayuja River* on older topographic maps.

2.3 **Geology**

The basin of the Namo River (study area) is characterized by rolling to mountainous land that is underlain by breccia, conglomerate, sandstone, and shale derived from volcanic rock. These rocks and the alluvial deposits in the stream valley have a low permeability (Ward, Hoffard, & Davis, 1965).

2.4 **Soils**

The soils within the study area primarily belongs to the Akina and Agfayan series, especially in the volcanic uplands (Soil Conservation Service, 1985). These soils are classified as silty clay, volcanic in origin. The soils have moderately slow permeability, resulting in rapid runoff. Erosion is a serious concern for Akina soils, which are characteristically dark reddish brown to dark red in color compared to the Agfayan soils which are black, yellow, or brown (University of Guam, 2016).

Near the coast and lower elevations, the soil primarily belongs to the Inarajan series, which is also a silty clay of volcanic origins. It has a slow permeability rate, seasonal high water table, and is typically a dark gray color. Erosion is not a problem for this soil type (University of Guam, 2016).

2.5 **Vegetation**

In the southern section of Guam, a heavy growth of tropical vegetation borders the inland areas of rivers and represents a plant community known as the ravine forest. Sharp divisions between the non-native savannah grasslands and ravine forest provide particularly aesthetic contrasts in the study area. Fires occur frequently and are often intentionally set by people to draw deer and pigs out when hunting, to clear fields for farming, or as wildfire arson. The spatial extent of the savannah grasslands has increased in size as the fire-adapted grasslands quickly replace the burned forest edge. The southern uplands are some of the island’s only expanses of unspoiled terrain.

2.6 **Climate**

Guam’s climate is tropical marine, reflecting the nearness of the equator and the influence of warm surrounding waters. Wind and rainfall are the most variable elements; humidity, temperature and pressure remain fairly constant. The year is divided into a wet

(July through December) and a dry (January through June) season with pronounced differences in rainfall.

Two principal kinds of storms contribute to the climatic character of Guam: small-scale storms, consisting of thunderstorms and squalls, and large systems of tropical storms and typhoons. The small-scale disturbances may dominate an area of only a few square miles. Larger cyclonic storm systems may dominate an area as large as 300,000 square miles and can persist for a week or more.

Major tropical cyclonic disturbances of these kinds occur in all months, but they are prevalent during the rainy season with the greatest probability in the months of October and November. These typhoons are actually tropical storms accompanied by winds of 65 knots (120 kilometers per hour) or greater. Based on the information provided by the Digital Atlas of Southern Guam website, “an average of three tropical storms and one typhoon pass within 180 nautical miles (330 km) of Guam each year” with the most intense typhoon to pass over Guam recently being Super Typhoon Pongsona on December 8, 2002 (WERI and IREI, n.d.).

2.6.1 **El Niño Years**

The term *El Niño* refers to a periodic warming (every two to seven years) of the Pacific Ocean surface waters. These conditions often result in tropical rains shifting eastward across the Pacific and an increased risk of typhoons from March through July and October through December. Rainfall is characteristically greater at the start of El Niño conditions (beginning in May or June), near normal by December, and well below average by the following February. (NOAA Pacific RISA 2015). The duration, strength, and impacts of El Niño events vary, but three periods are universally accepted as having produced very strong conditions: 1982-83, 1997-98, and 2015-16 (NOAA Climate Prediction Center 2018).

2.7 **Site Visit**

In October 2018, U.S. Army Corps of Engineers (USACE) personnel conducted a site visit to measure bridge crossings, take photographs of the channel, and investigate the three priority sites included in Phase I of this study. They also met with Government of Guam, Bureau of Statistics and Plans (BSP) representatives to understand the unique challenges at each priority site and overall flood history. Several photos included in this report are from that site visit. Bridge and channel measurements were incorporated into the hydraulic model. Site-specific information provided by BSP added value to the development of alternatives for flood mitigation.

One of the primary concerns within this study area is the massive amounts of erosion and loss of private property caused by the Namo River in the upper watershed. During the site visit, USACE personnel spoke with a resident, Mr. Frank Borhof, who lost approximately four acres of land from erosion and uncontrolled runoff sent through his property. The road near Mr. Borhof’s property, identified as either Namo Falls Park Street or Sgt E Cruz Street on street maps, requires backfilling every six months or so by the Government of Guam, Department of Public Works to keep it from washing out.

3. Geographic Information Systems Data

Several terrain models and data layers were used to perform the hydrologic and hydraulic analysis of the study area. The Geographical Information Systems (GIS) data, sources, and description are summarized in the following sections.

3.1.1 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: World Geodetic System 1984 (WGS84)

Vertical Datum: Guam Vertical Datum of 2004 (GUVD04)

Tidal Epoch: 1983 – 2001

3.1.2 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
2012 – 2013	USGS	LiDAR	Island of Guam
2007	JALBTCX	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 North Atlantic Datum 1983 (NAD83) MA11, vertically referenced to GUVD04, has a vertical accuracy of +/- 8 centimeters (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.

LiDAR data were also collected by USACE and the Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX) in 2007 for the Government of Guam. This data includes hydrographic and topographic data depicting the elevations above and below the immediate coastal water. The topographic lidar data are vertically referenced to Mean Sea Level (MSL) and the bathymetric lidar data are referenced to Mean Lower Low Water (MLLW). The data set has a horizontal accuracy of +/- 0.75 m and a vertical accuracy of

+/- 20 cm. The data was collected so that the horizontal and vertical datum could be specified by the user. For this project, the selected projection was the Universal Transverse Mercator (UTM) coordinate system, zone 55N. Horizontal coordinates reference the NAD83 in meters. The vertical control datum is the Guam Vertical Datum of 2004 (GUVD04), in meters.

3.1.3 **Imagery**

High resolution imagery used for background mapping of the study area is from 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 Guam.

3.1.4 **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.

4. Hydrologic 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-, 250-, and 500-year) flood events (8 profiles) include the following:

1. Stream Gage Analysis
2. Regional Regression Equations
3. Rainfall-Runoff Modeling

Other peak flow estimates previously published (for reference):

1. 2007 FEMA FIS

4.1 Stream Gage Analysis

There is one streamflow gaging station located within the Namo River basin: *16808120 Namo River above weir at Santa Rita, Guam* (USGS 8120). This gaging station is actively operated and maintained by the U.S. Geological Survey (USGS) and has an annual peak flow record data of 23 events.

4.1.1 Bulletin 17B

Annual peak flow data from the USGS Stream Gage 16808120 (USGS 8120), located along the lower reach of the Namo River, was 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 0.220 and mean-square error of 0.169 was adopted as determined in Part 1 – Flood Frequency Estimates for Streams on Guam.

Table 4-1: Peak Flow Data from Gaged Data by Bulletin 17B Analysis in HEC-SSP

Location	Peak Flow (m^3/s)[1]							
	2-yr (50%)	5-yr (20%)	10-yr (10%)	25-yr (4%)	50-yr (2%)	100-yr (1%)	250-yr (0.4%)	500-yr (0.2%)
USGS 8120	16.1	25.6	33.2	44.7	54.6	65.8	82.9	97.7
[1]: rounded to three significant figures								

4.2 Regional Regression Equations

In Part 1 of this study, regional regression equations were developed for estimating various peak flow magnitudes at ungaged, unregulated sites in southern Guam. These equations were used to estimate peak flow at USGS 8120 to show how the different methodologies compare. The results are presented in Table 4-2. Overall, the difference is within an acceptable range of tolerance.

Table 4-2: Peak Flow Data from Regional Regression Equations

Location	Peak Flow (m^3/s)[1]							
	2-yr (50%)	5-yr (20%)	10-yr (10%)	25-yr (4%)	50-yr (2%)	100-yr (1%)	250-yr (0.4%)	500-yr (0.2%)
USGS 8120	15.3	15.9	32.4	40.4	53.5	61.9	70.1	83.8
[1]: rounded to three significant figures								

4.3 **Rainfall-Runoff Modeling**

Hydrologic models were created using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) software (version 4.2, HEC, 2016). This section describes rainfall, riverine, and basin characteristics that were used to create the models, as well as the resulting flow estimates for different probability events.

4.3.1 **River Delineation**

Namo River and its tributaries were delineated in GIS, extending from the upper watershed to the bay outlet. The Namo River Flood Control Project, a federally constructed project, is located at the downstream end, extending 6.1 km (0.38 mi) upstream from the bay outlet. Typical channel characteristics for upper, middle, and lower reaches of Namo River are provided in Table 4-3. Photos of Namo River, taken during the October 2018 site visit, are also provided (see Photos 4-1, 4-2, and 4-3).

Table 4-3: Channel Characteristics

River	Reach	Length (m) [1]	Slope (m/m) [1]	Manning's *n*	Bottom Width (m)	Side Slopes (xH:1V)
Namo	Upper	1,510	0.032	0.055	4	2
Namo	Middle	1,750	0.005	0.045	8	5
Namo	Lower	1,660	0.004	0.035	18	2

Photo 4-1: Namo River, Upper Watershed

Photo 4-2: Namo River, Middle Watershed


2018/10/23

Photo 4-3: Namo River, Lower Watershed

4.3.2 **Subbasin Delineation**

The corresponding drainage areas that contribute flow to Namo River and its tributaries were also delineated in GIS. These are referred to as the *Upper*, *Middle*, and *Lower* subbasins in the HEC-HMS model and this chapter, respectively. The HEC-HMS basin model is provided as Figure 4-1.

Table 4-4 identifies the total drainage area and centroid coordinates for each subbasin.

Table 4-4: Basin Characteristics

HEC-HMS Subbasin Name	Area (km^2)	Centroid	
		Latitude	Longitude
Upper	2.41	13.390	144.682
Middle	1.17	13.395	144.673
Lower	0.853	13.402	144.668

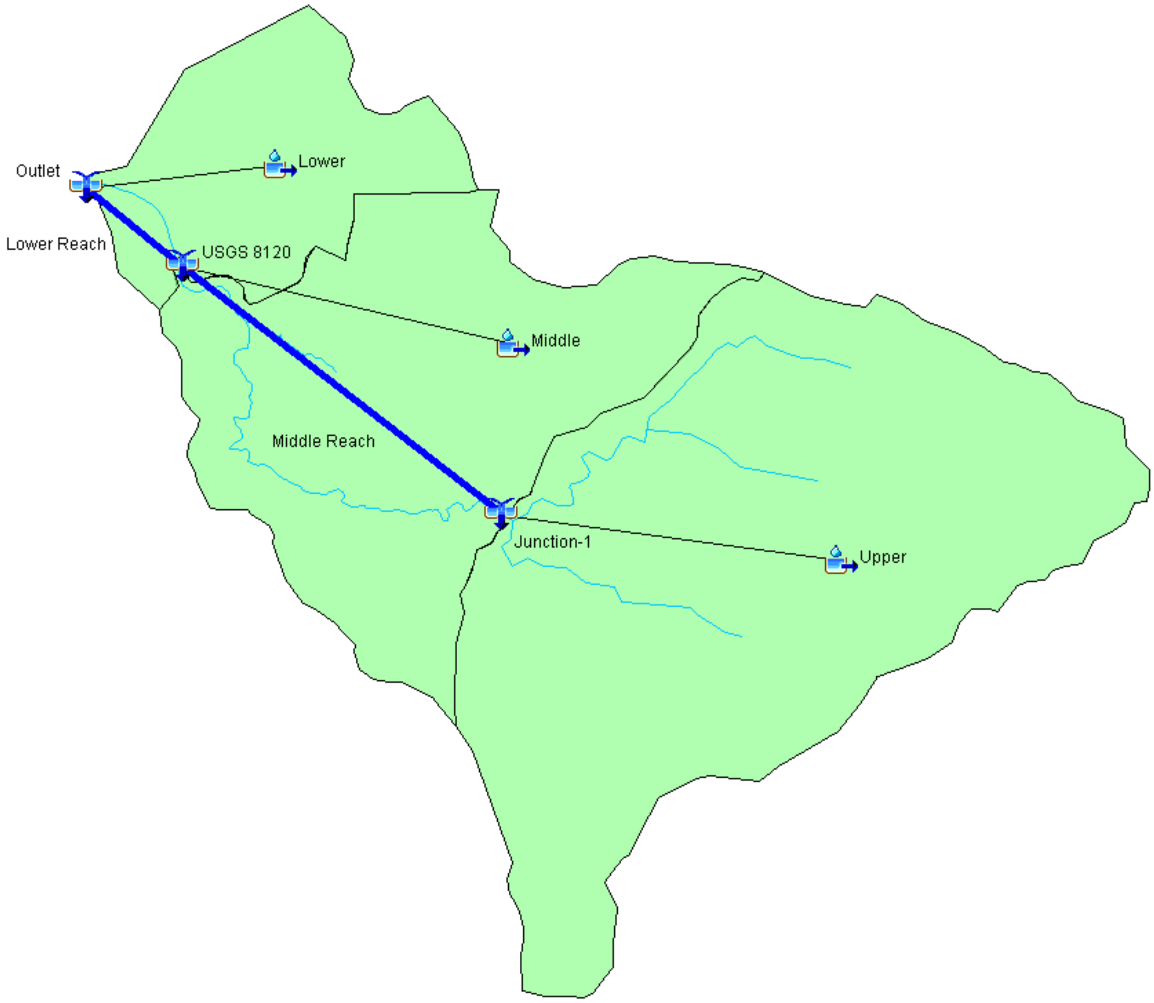

Figure 4-1: HEC-HMS Basin Model

4.3.3 **Subbasin Loss Parameterization**

As described in Section 0, The drainage basin for the Namo River has an area of about 4.56 square (sq) kilometers (km) [1.76 sq miles (mi)], is approximately 2.4 km (1.5 mi) wide, and 3.5 km (2.2 mi) long, extending from the hills of Santa Rita and Mt Alifan to Agat Bay. With the hills of Santa Rita approximately 210 meters (m) [689 feet (ft)] above sea level, the basin slope is a moderately-steep 6 percent (%). Steep land slopes and soils with a low permeability are often associated with greater stream incision. The longest watercourse in the basin is approximately 3.3 km (2.0 mi) with an approximate channel slope of 3.9% in the upper watershed and 0.5% in the lower watershed. Namo River is sometimes referred to as the *Ayuja River* on older topographic maps.

Geology, the low-permeability volcanic rocks and alluvial deposits along the streambed slow the infiltration of rainwater. Initial loss was set to 0.1 millimeters (mm), the lowest value accepted by the HEC-HMS program. Constant loss was estimated to be 30 mm/hr across the entire watershed. The percent impervious was approximated in GIS to be between 6 and 38 percent.

Table 4-5: Subbasin Loss Parameters

HEC-HMS Subbasin Name	Initial Loss (mm)	Constant Rate (mm/hr)	Impervious (%)
Upper	0.1	30	6
Middle	0.1	30	38
Lower	0.1	30	14

4.3.4 **Subbasin Transform Parameterization**

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, Conservation Engineering Division, 1986). As water travels along the longest flow path in the subbasin, it is transformed from sheet flow (Table 4-6) to shallow concentrated flow (Table 4-7) to open channel flow (Table 4-8).

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 or measured in the field. Additional data required for the TR-55 method, such as the 2-year, 24-hour rainfall, were entered based on published data from National Oceanic and Atmospheric Administration (NOAA)'s Atlas 14 Precipitation-Frequency Data Server (PFDS) for the centroid locations listed in Table 4-4. The computed times of concentration are presented in Table 4-9.

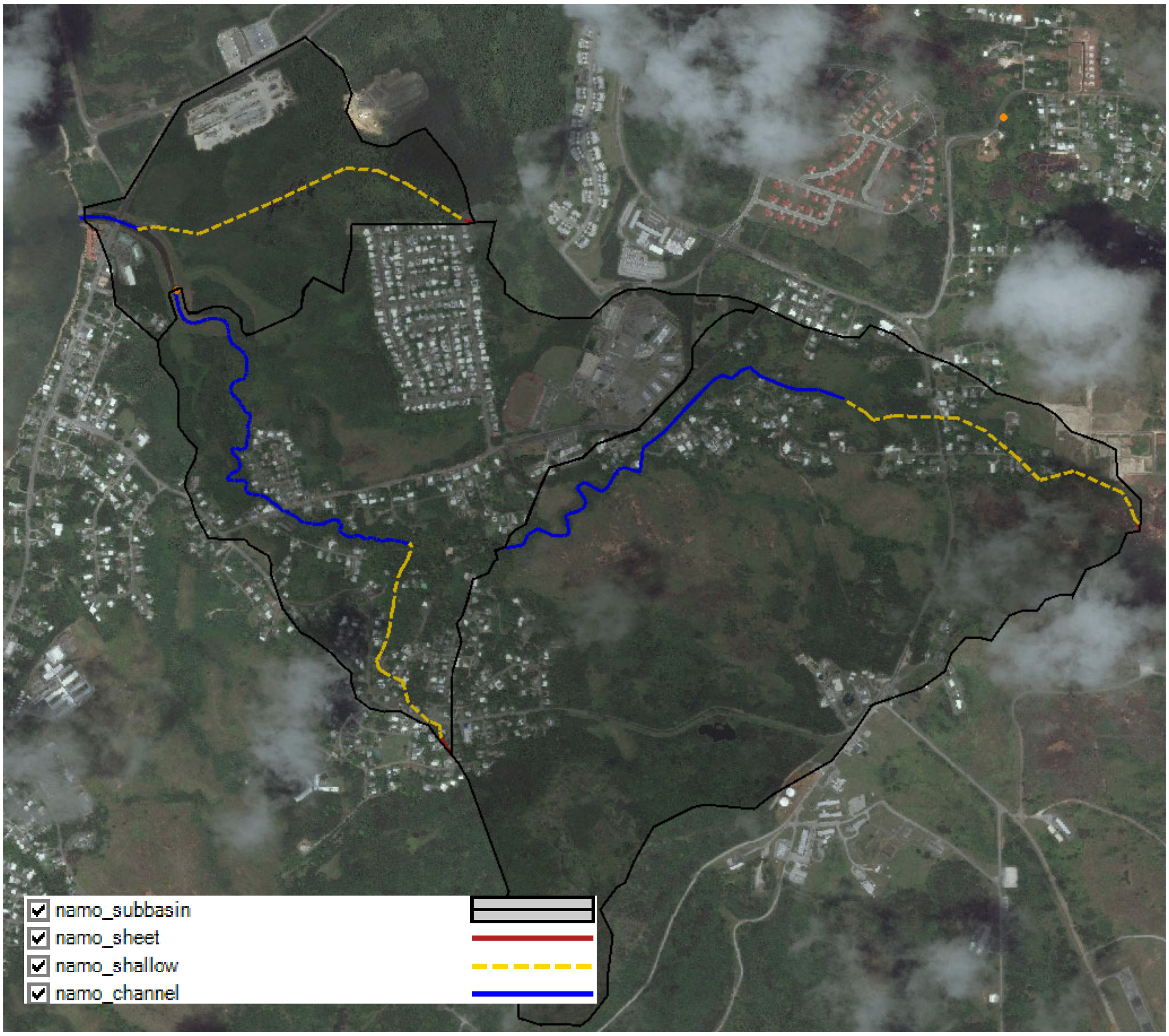

Figure 4-2: Sheet Flow, Shallow Concentrated Flow, and Channel Flow Delineated, Namo River, Agat Watershed

Table 4-6: Sheet Flow Characteristics for each Subbasin

HEC-HMS Subbasin Name	Manning's *n*	Sheet Flow Length (m)	Land Slope (m/m)	2-yr, 24-hr Rainfall (mm)	Tc, sheet (hrs)
Upper	0.035	21.6	0.165	152	0.012
Middle	0.1	64.0	0.070	141	0.098
Lower	0.16	37.5	0.217	137	0.060

Table 4-7: Shallow Concentrated Flow Characteristics for each Subbasin

HEC-HMS Subbasin Name	Surface Description	Shallow Flow Length (m)	Watercourse Slope (m/m)	Average Velocity (m/s)	Tc, shallow (hrs)
Upper	Unpaved	1,090	0.123	1.75	0.173
Middle	Unpaved	736	0.103	0.610	0.335
Lower	Unpaved	1,110	0.024	0.762	0.405

Table 4-8: Channel Flow Characteristics for each Subbasin

HEC-HMS Subbasin Name	Hydraulic Radius (m)	Channel Slope (m/m)	Manning's *n* Channel	Velocity (m/s)	Flow Length (m)	Tc, channel (hrs)
Upper	1.86	0.032	0.055	7.33	1,510	0.057
Middle	2.80	0.005	0.045	4.65	1,570	0.093
Lower	7.00	0.004	0.035	9.85	191	0.005

Table 4-9: Initial Time of Concentration for each Subbasin

HEC-HMS Subbasin Name	Time of Concentration, Tc (hrs)
Upper	0.242
Middle	0.526
Lower	0.470

The Clark Unit Hydrograph storage coefficient, R, accounts for storage in the watershed. This parameter was determined using a mathematical relationship between the longest flow path, drainage area, and time of concentration. An equation was adopted from the “Drainage Design Manual for Maricopa County” (Flood Control District of Maricopa County, 2013) for use in this study. This relationship was used to make an initial estimate of the storage coefficient of each sub-basin. These estimates were adjusted during the hydrologic model calibration. The equation used is as follows:

$$R = 0.37{T_c}^{1.11}A^{-0.57}L^{0.80}$$

R: Storage Coefficient
Tc: Time of Concentration (hrs)
A: Drainage Area (square miles)
L: Length of flow path (miles)

The initial values for the storage coefficient parameter are summarized in Table 4-10.

Table 4-10: Initial Storage Coefficients for each Subbasin

HEC-HMS Subbasin Name	Time of Concentration (hrs)	Area (mi^2)	Length of Flow (mi)	Storage Coefficient, R
Upper	0.242	0.931	1.63	0.118
Middle	0.526	0.452	1.47	0.388
Lower	0.470	0.329	0.895	0.276

4.3.5 **Subbasin Baseflow**

Baseflow was considered negligible for the Namo River.

4.3.6 **Model Calibration**

Although there is no instantaneous (hourly) stream flow data within the study area, gaged data from a nearby watershed with similar characteristics was used for calibration purposes. Rainfall and stream flow data from the Maulap River, located approximately 2.7 km south of the study area, was used to calibrate the sub-basin parameters within the basin of the Namo River. As part of the 2013 dam break analysis of Fena Dam, the Maulap River hydrologic model was calibrated to the July 2002 and December 2002 typhoon events. The initial parameters for the Maulap River Basin were computed using the same loss and transform methods used for the Namo River Basin. The initial and final parameters for the Maulap River Basin are presented in Table 4-11.

Table 4-11: Initial and Calibrated Parameters for the Maulap River Basin

Calibration Status	Drainage Area (km)	Initial Loss (mm)	Constant Loss Rate (mm/hr)	Time of Concentration (hr)	Storage Coefficient (hr)
Initial	3.42	0.508	3.05	0.78	0.78
Calibrated	3.42	7.62	3.05	0.75	0.24
% Change	**0**	**1400**	**0**	**-3.85**	**-69.2**

Based on the resulting increase in loss parameters and decrease in transform parameters, the initial parameters computed for the Namo River Basin were similarly adjusted. The final calibrated parameters for the Namo River Basin are shown in Table 4-12.

Table 4-12: Initial and Calibrated Parameters for the Namo River Basin

Calibration Status	Drainage Area (km)	Initial Loss (mm)	Constant Loss Rate (mm/hr)	Time of Concentration (hr)	Storage Coefficient (hr)
Upper Subbasin					
Initial	2.41	0.1	30	0.242	0.118
Calibrated	2.41	26	30	0.233	0.036
Middle Subbasin					
Initial	1.17	0.1	30	0.526	0.388
Calibrated	1.17	26	30	0.506	0.120
Lower Subbasin					
Initial	0.853	0.1	30	0.470	0.276
Calibrated	0.853	26	30	0.452	0.085
% Change	**0**	**1400**	**0**	**-3.85**	**-69.2**

4.3.7 **Rainfall Frequency Data**

Point precipitation frequency data were taken from the NOAA's Atlas 14 Precipitation-Frequency Data Server (PFDS) (NOAA, NOAA Atlas 14 Point Precipitation Frequency Estimates, 2017). This source presents rainfall frequencies from recurrence intervals of 1 to 500 years (100% to 0.2% chance exceedance) for sites in Guam. The location point used to extract PFDS data was the approximate centroid locations for the entire Namo River Basin. The latitude and longitude for this centroid is 13.393, 144.67. The point precipitation frequency estimates at this location are presented in Table 4-12.

Table 4-13: Point Precipitation Frequency Estimates (in inches)

Duration	Average recurrence interval (years)							
	2	5	10	25	50	100	200	500
5 Minutes	0.510	0.636	0.736	0.872	0.979	1.09	1.20	1.36
15 Minutes	1.02	1.27	1.47	1.75	1.96	2.18	2.41	2.72
1 Hour	2.04	2.55	2.94	3.49	3.92	4.36	4.82	5.44
2 Hours	2.60	3.25	3.77	4.47	5.03	5.60	6.19	7.01
3 Hours	3.03	3.83	4.46	5.31	5.99	6.68	7.40	8.38
6 Hours	3.75	4.91	5.83	7.08	8.06	9.07	10.1	11.6
12 Hours	4.41	6.10	7.42	9.24	10.7	12.1	13.7	15.8
1 Day	5.45	7.59	9.27	11.6	13.4	15.2	17.1	19.8

4.3.8 **Hydrologic Model Results**

The HEC-HMS model was used to simulate the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2% AEP flood frequency events. The resulting peak discharges for the two subbasins are presented in Table 4-14.

Table 4-14: Calibrated Peak Flow Data from HEC-HMS

HEC-HMS Element Name	Drainage Area (km2)	Peak Flow (m3/s)1						
		2-yr (50%)	5-yr (20%)	10-yr (10%)	25-yr (4%)	50-yr (2%)	100-yr (1%)	500-yr (0.2%)
Upper	2.41	53.4	71.2	84.2	104	120	136	174
Middle	1.17	19.1	25.2	29.7	36.4	42.1	47.5	60.8
USGS 8120	3.58	63.3	84.5	99.2	124	145	165	212
Lower	0.853	14.0	18.9	22.5	27.8	32.4	36.7	47.4
Outlet	4.43	63.1	91.4	109	137	159	180	236
1: rounded to three significant figures								

4.4 **Adopted Flows**

As the HMS model used site-specific information and was calibrated to historical streamflow data, these peak flows are the most reliable and should be used as the flow input for the hydraulic model (Table 4-14). For comparison, all three methods of estimating the peak flow at the two gage sites are presented in Figure 4-3.

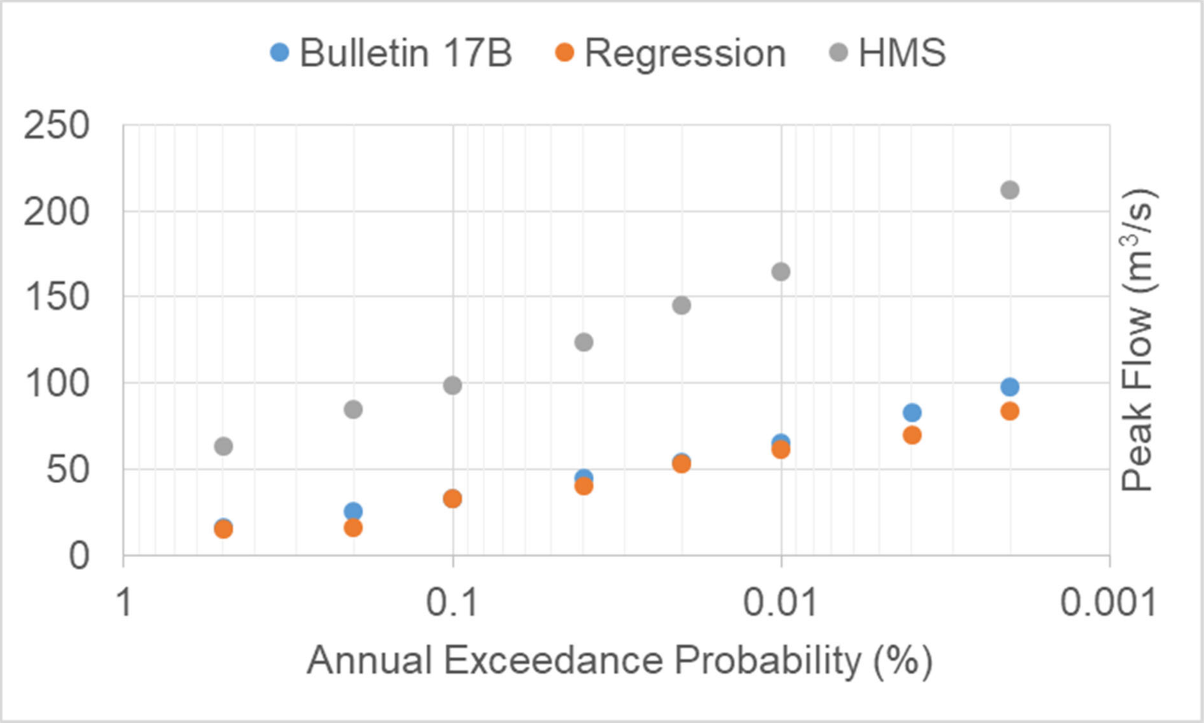

Figure 4-3: Comparison of Peak Flows at USGS 6000 Using Various Methods

5. Development of the Hydraulic Model

The hydraulic model was created using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software (version 5.0.5, HEC, 2018). The peak flow values determined in Section 4, Hydrologic Analysis were used to represent the amount of water entering the system. Field measurements and observations made during the October 2018 site visit were incorporated into the geometry of the HEC-RAS model. As a result of these efforts, a summary of flood impacts to the site are provided at the end of this section.

5.1 Flow Data

As the HMS model used site-specific information and was calibrated to historical streamflow data, the peak flows computed by the model (Table 4-14) are the most reliable and were used as the flow input for the HEC-RAS model.

5.1.1 Boundary Conditions

"Critical Depth" was the selected upstream boundary condition for the main river as cross sections begin just downstream of a waterfall. "Normal Depth" was the selected upstream boundary condition for the tributary as flow was considered to be uniform. The upstream slope used for normal depth computation was 0.03.

"Known W.S" was the selected downstream boundary condition. The mean higher high water (MHHW) from NOAA tidal stations 1630000 Apra Harbor, Guam was used as the known water surface (Known W.S) representing the downstream boundary condition. The MHHW above MSL (as the terrain data is in m above MSL) at this station is 0.26 m above MSL (or 0.85 ft MSL) (NOAA, Datums for 1630000, Apra Harbor, Guam , 2018).

5.2 Geometry Data

5.2.1 Reach

The extent of the Namo River included in the HEC-RAS model is from the ocean outlet to 2,310 m upstream. The extent of the Tributary River is from the junction with the Namo River to 330 m upstream. The delineated river is shown in Figure 5-1.

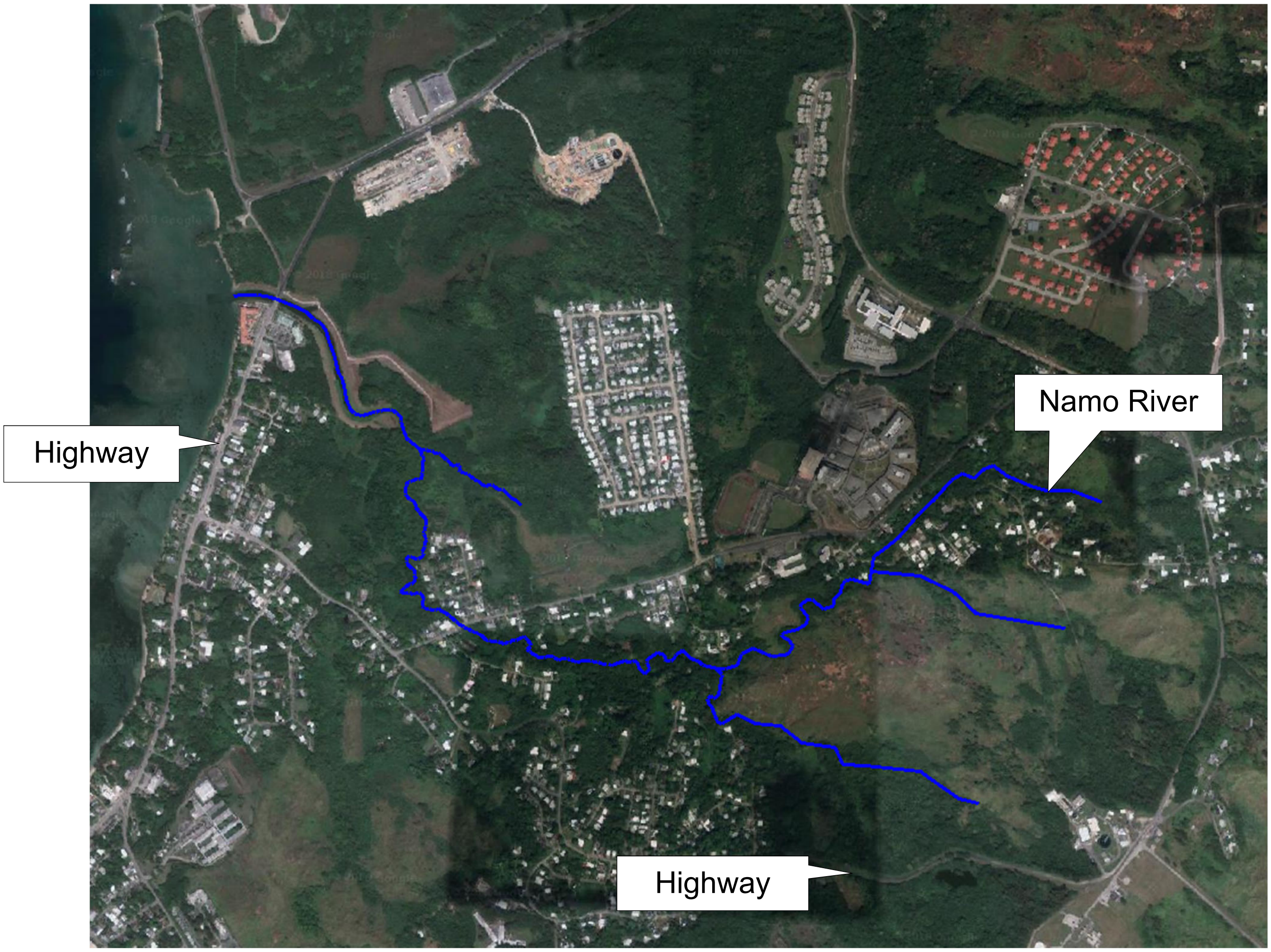

Figure 5-1: Delineated Rivers in HEC-RAS, Namo River Basin, Agat and Santa Rita Villages

5.2.2 **Cross-Sections**

Cross-sections were drawn at varying intervals along the river to characterize the flow carrying capability of the river and its adjacent floodplain (see Figure 5-2). A terrain was created in HEC-RAS based on the Light Detection and Ranging (LiDAR) data collected in 2007. Initial elevations for each cross-section were extracted from this terrain and then adjusted, as needed, to reflect measurements taken in the field during the October 2018 site visit. Such measurements include typical channel dimensions as previously presented in Table 4-3, as well as bridge and culvert dimensions, presented in Section

5.2.3. An average cross-section spacing of 15 meters was used to represent the numerous bends along the Namo River.

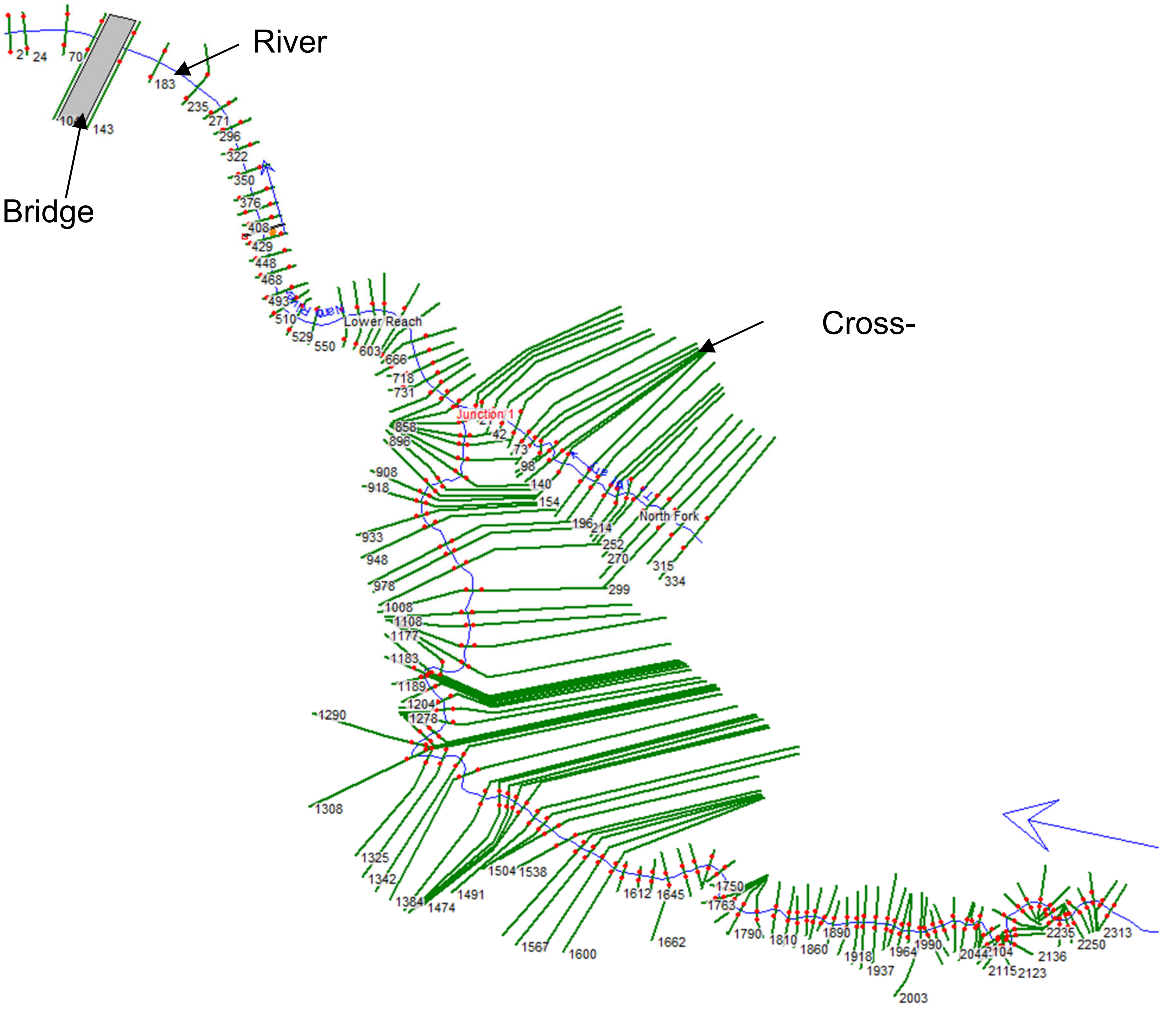

Figure 5-2: HEC-RAS River and Cross-Section Layout

5.2.3 **Bridges**

Two bridges were included in the model, one in the upper watershed where Sumay Memorial Street crosses Namo River, and one in the lower watershed where Highway 2 crosses Namo River. Bridge data, as presented in as-built drawings for the Highway 2

Bridge and as measured in the field during the October 2018 site visit for the Sumay Memorial Street Bridge, are presented in Table 5-1.

Photo 5-1: Looking upstream at the Highway 2 Bridge over Namo River at XS 120

Photo 5-2: Looking downstream through the Sumay Memorial Street Bridge over Namo River at XS 1520

Table 5-1: Bridge Data as Measured in the Field

Road Name	River	XS	Culvert Data			Pier Width (m)	Headwall Height (m)	Deck Width (m)
			#	Span (m)	Rise (m)			
Highway 2	Namo	120	2	25.6	3.66	0.305	0.80	30
Sumay Memorial	Namo	1520	0	5.2 (bottom) – 15.5 (top)	3.60	--	2.44	10.4

5.2.4 **Manning’s n**

In the HEC-RAS model, a Manning’s roughness coefficient, *n*, is required for the main channel, left overbank, and right overbank areas. As presented in Section 4.3.1, the Manning’s *n* for the natural channel varies between 0.035 in the lower watershed to 0.055 in the more heavily vegetated upper watershed. Overbank areas were represented by four types of land cover: evergreen forest (0.16), forested wetland (0.12), grassland (0.035), and developed open spaces (0.04).

5.3 **Results**

The results of the hydraulic model indicate that the Namo River is able to contain the 1% AEP (100 year) flood event without inundating residential structures. However, the October 2018 site visit identified overland runoff as a potential source of erosive flows across Namo Falls Park Street / Sgt E Cruz Street. Modeling results support this theory as the inundation limits created by the main river do not extend to the identified problem area. The inundation map generated by the HEC-RAS model for the 1% AEP (100-yr) event is provided in Appendix A.

6. Flood Mitigation Alternatives

6.1 Debris Structure along Namo Falls Park Street

This alternative is intended to address the erosion along Namo Falls Park Street / Sgt E Cruz Street caused by overland runoff. This problem was introduced in Section 2.7, Site Visit and mentioned previously in Section 5.3, Results. The source of erosive flows along this road are two small, unnamed tributaries that enter Namo River by either crossing underneath the road through a small culvert or by overtopping the road. The amount of flow for each tributary was estimated by determining the drainage areas for these two rivers (0.065 km^2 and 0.051 km^2), taking it as a percentage of the total drainage area for the Middle subbasin (5.6% and 4.4%), and using the same percentage on the total estimated peak flow for the Middle subbasin for the 4% AEP (25 year) event (16.4 m^3/s or 579 ft^3/s) and the 1% AEP (100 year) event (21.4 m^3/s or 756 ft^3/s). The approximate flow for the two tributaries crossing Namo Falls Park Street / Sgt E Cruz Street is 0.911 m^3/s and 0.715 m^3/s, from west to east (32.2 ft^3/s and 25.2 ft^3/s, respectively) for the 4% AEP (25 year) event and 1.19 m^3/s and 0.933 m^3/s (42.0 ft^3/s and 32.9 ft^3/s, respectively) for the 1% AEP (100 year) event. Generally, culverts are designed for the 4% AEP (25 year) event and roads are designed to withstand the 1% AEP (100 year) event without overtopping.

During the October 2018 site visit, a 0.762 m (30 inch) culvert was observed and measured in the field (see Photo 6-1). Based on computed discharges and water surface elevations in RAS, this culvert should be large enough to pass the 4% AEP (25 year) event without causing the road to overtop during the 1% AEP (100 year) event. However, debris and sediment can cause obstructions that reduce the culvert’s capacity. This alternative, therefore, makes recommendations to reduce the amount of debris obstructing the culvert by installing three 1.5 m (5.0 ft) high posts approximately 8 m (26 ft) upstream of the culvert and road. Each of the posts have a concrete base, approximately 0.61 (2.0 ft) deep, 1.2 m (4.0 ft) wide, and 3.7 m (12 ft) long (see Figure 6-2). Three posts would be installed at each tributary (six total; see Figure 6-1).

The estimated cost of construction to restore the natural flow path of the channel is approximately $22,100 with a 35% contingency for a total estimated construction contract cost of $29,900.

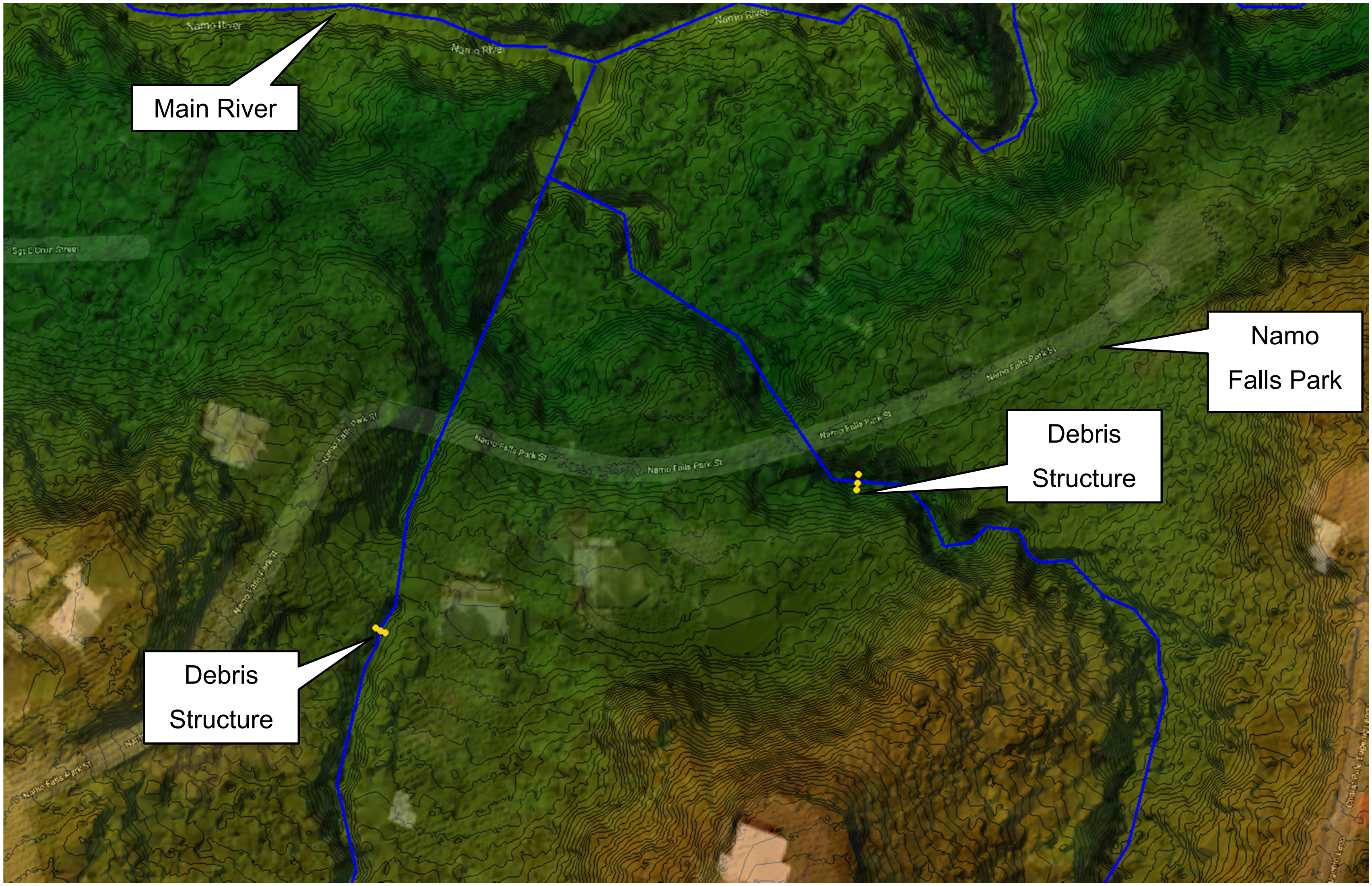

Figure 6-1: Proposed Locations of Debris Structures

Photo 6-1: Road Culvert, October 2018

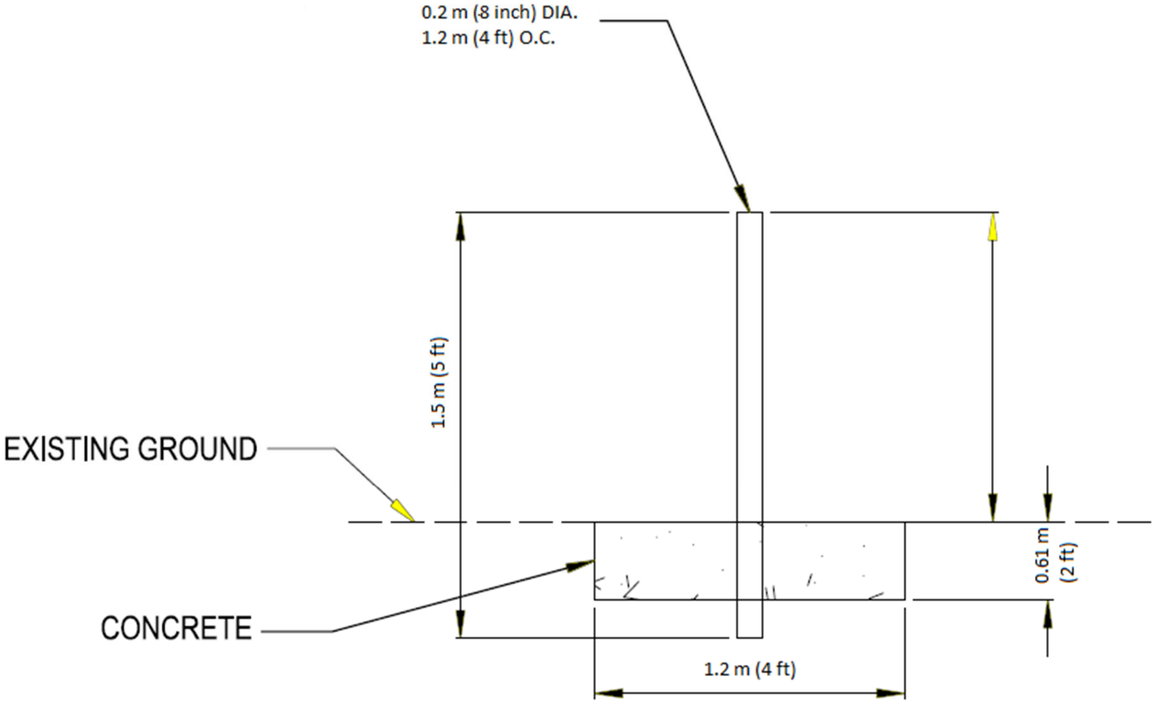

Figure 6-2: Debris Post Structure

6.2 Road and Bank Protection of Namo Falls Park Street

This alternative focuses on adding bank protection to the road and banks near Namo Falls Park Street / Sgt E Cruz Street. As mentioned previously, this road is frequently eroded by overland runoff. The proposed alternative is to cover the bank and road with a gravel bedding; and provide additional riprap on the banks and road abutments (not the crest). Riprap Class II, ranging from 4.1 m to 5.7 m (1.25 ft to 1.75 ft) in diameter, would be the appropriate size based on typical flow and velocities along the tributaries. A summary of pertinent data are provided below:

Typical Hydraulic Data (1% AEP, 100 year flood)
    Flow: < 1.2 m^3/s (< 42 ft^3/s)
    Velocities 2 – 4.5 m/s (6 – 15 ft/s)
Typical Channel Section (for both tributaries)
    Bottom width: 2 m (6.5 ft)
    Side slope: 2H:1V
    Height (streambed to top of bank): 4 m (13 ft)
    Length, upstream of road: 15 m (50 ft)
    Length, downstream of road: 15 m (50 ft)
    Bedding layer, thickness: 12 inches
    Riprap lining, thickness: 24 inches
Typical Road Section (for both tributaries)
    Height (streambed to crest): 2 m (6.5 ft)
    Crest width: 7.5 m (25 ft)
    Upstream slope: 2H:1V
    Downstream slope: 2H:1V
    Length: 23 m (75 ft)

The estimated cost of construction to restore the natural flow path of the channel is approximately $158,000 with a 35% contingency for a total estimated construction contract cost of $214,000.

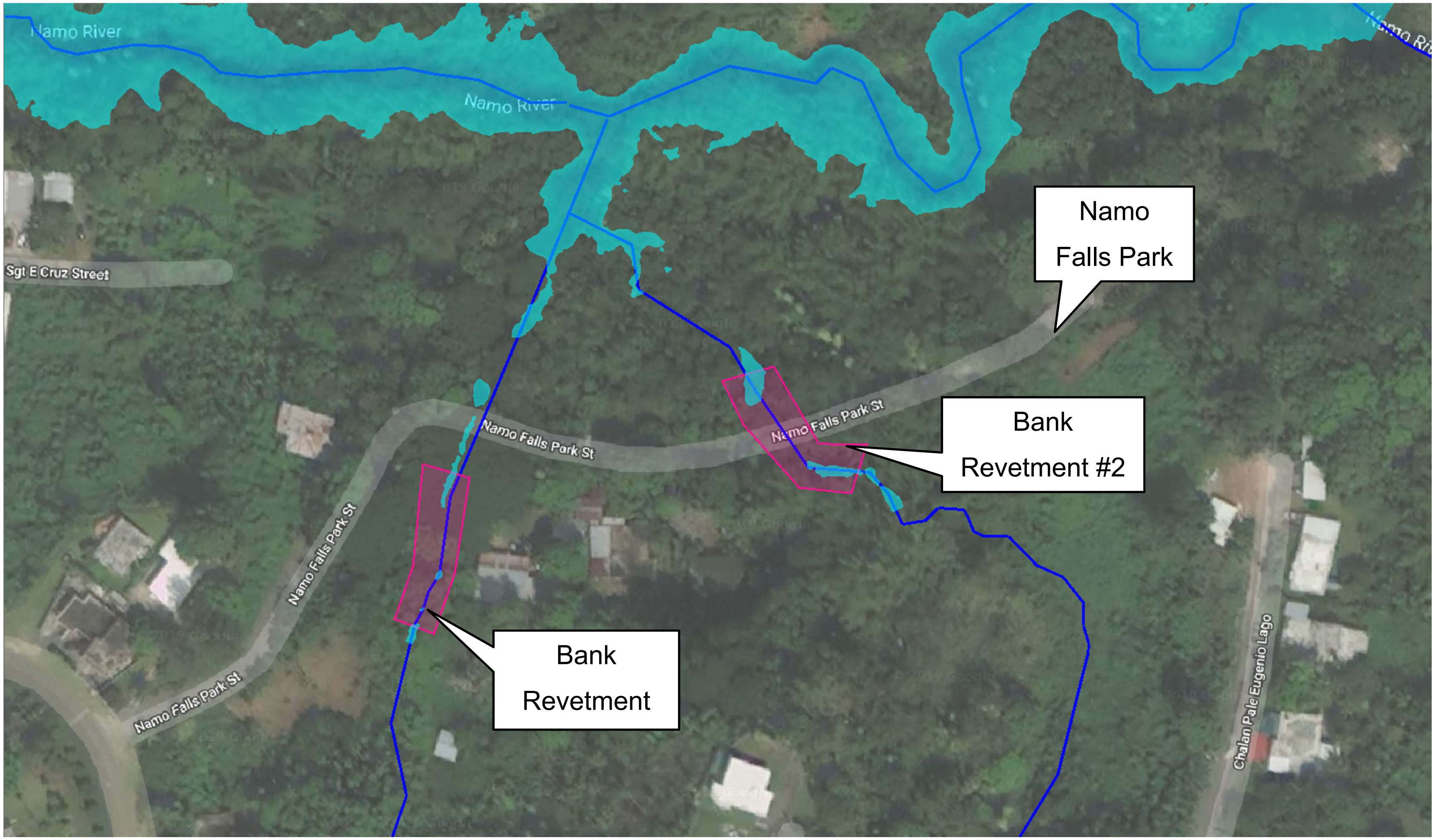

Figure 6-3: Location of Bank and Road Revetment

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