Guam Comprehensive Flood Study – Part 1

Flood Frequency Estimates for Streams on Guam

Final Report
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EXEUCTIVE 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 Manell River, Guam

Part 4 – Flood Hazard Study for Upper Namo River, Guam

This document presents information on Part 1, the objective of which is to 1) provide estimates of the magnitudes of the 50%, 20%, 10%, 4%, 2%, 1%, 0.4%, and 0.2% Annual Exceedance Probability (AEP) peak stream discharges at gaged sites on Guam, using recorded annual peak discharges through water year 2019, and 2) develop regression equations that can be used to estimate the magnitude of the 50%, 20%, 10%, 4%, 2%, 1%, 0.4%, and 0.2% AEP peak stream discharges at ungaged, unregulated sites in southern Guam.

Generalized-skew coefficients and peak-discharge magnitude and frequency at gaged sites were determined using guidelines documented in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). A summary of the steps completed to determine these regression equations is provided below, with greater detail provided in the sections that follow.

1. Identify all stream gaging stations within the region of Southern Guam that have at least 10 years of valid (usable and unregulated) annual peak flow data.

2. Select and quantify various basin characteristic parameters (e.g. mean basin slope, drainage area) for each station to be used in the study.
3. Perform a flood frequency (Bulletin 17B) analysis on each stream gaging station with 25 years or more of usable peak flow record to determine the individual station skew and mean square error (MSE).
4. Compute the overall mean station skew and MSE, which corresponds to the generalized (regional) skew and MSE.
5. Perform another flood frequency (Bulletin 17B) analysis on each stream gaging station with 10 years or more of unregulated peak flow data using a weighted skew to determine the flood frequency estimates at each site.
6. Compare the statistical relationships between the flood frequency estimates and the basin parameters.

The final regression equations determined by this study use two basin characteristics: drainage area (DRNAREA) and the maximum 24-hour precipitation that occurs on average once in 2 years (I24H2Y). These equations are presented in Table 6-3.

For each streamflow gaging station in Guam that had at least 10 years of valid (usable and unregulated) annual peak flow data, flood frequency estimates are provided in Appendix A. The results of this flood frequency analysis provide peak flow estimates computed in three different ways: 1) following Bulletin 17B methodology and based solely on the station's independent record, 2) from using the regional regression equations determined in this study, and 3) following Bulletin 17B methodology and using a weighted skew, based on both the individual station record and regional skew.

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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
- 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.

1.3.1 **Other Key Agencies**

Other agencies and partners that may have influence or interest in this study include the following:

- Federal Emergency Management Agency (FEMA)
- Federal Highway Administration (FHWA)
  - US Department of Transportation (USDOT)
- Government of Guam
  - Department of Land Management
    - Chamorro Land Trust Commission
  - Department of Public Works (DPW)
    - Guam Transportation Program
  - Homeland Security / Civil Defense (OHS/OCD)
- University of Guam
  - Water and Environmental Research Institute (WERI)

2. Watershed Description

2.1 Location

This study considers the entire island of Guam within its study area, although the flood frequency regression equations are being developed specific to southern Guam. The island of Guam is the southernmost and largest island in the Marianas Chain and lies 13°28'30"N latitude and 144°45'09"E longitude at Hagatña (formerly known as Agana), the capital village on the central western coast. The island is approximately 48.3 kilometers (km) [30 miles (mi)] in length with a northern width of 13.7 km (8.5 mi) and a maximum southern width of 18.5 km (11.5 mi). Northern and southern island areas taper at the central waist to a width of 6.44 km (4 mi). Excluding reef areas, the land area is 549 km^2 (212 mi^2). The axis of the island is in a northeast-southeast direction (Google Earth).

2.2 Topography and Geology

Geologically, the central waist of Guam from Hagatña Bay to Pago Bay represents a transitional zone between the northern limestone and southern volcanic formations. The limestone in this area is argillaceous or yellowish in color from the volcanic sediments that were mixed with the white reef coral during the later development of the northern reef adjacent to the older southern volcanics. The relief features are characterized by sloping hills, intersected by low-lying basins that are periodically flooded during the wet season. They appear as grassy flats and are important for recharge of the central aquifer. This aquifer reaches the surface at Hagatña Springs and disperses water into the Agana Swamp, which eventually flows into Hagatña Bay via Hagatña River – the northernmost river on Guam.

Despite the small land area, geologic characteristics and unique ecology of central Guam, it is a major concentration of urban development on the island. Approximately 30% of the island's population resides in this small land area. Commercial, industrial and residential development has expanded from Hagåtña, the major trade center and seat of Guam's government and religion.

The northern section of Guam is geologically characterized by a raised limestone plateau with a maximum elevation of about 150 meters (m) [492 feet (ft)]. which gently slopes downward in a southwestern trend to less than 30 m (98 ft) in the central mid-section of the island. The northern limestone is composed of the consolidated remains of reef coral and sediments. The northern limestone terraces and cliffs represent an ancient barrier reef, with the inland limestone terrain comprised of the sedimentary remains of the lagoon sediments. The coastal limestone is extremely permeable; thus rainfall quickly soaks into the ground and recharges three main aquifer areas: lenses of fresh water which float upon salt water and provide the bulk of the island's freshwater supply.

The northern limestone plateau is interrupted by volcanic upthrusts at Barrigada Hill and Mt Santa Rosa. The volcanic basalt is exposed at Mt Santa Rosa and has resulted in the buildup of lateritic clay soil along an adjacent inland area. This region represents the best major sector of agriculturally developable land in the northern half of the island.

The southern portion of the island is geologically characterized by two distinct volcanic formations that developed in different geologic eras. The Alutom formation or mountainous ridge adjacent to Central Guam is the oldest formation. The highest peak is tion or mountainous ridge adjacent to Central Guam is the oldest formation. The highest peak is Mt. Alutom at 328 m (1,076 ft). The southern range, known as the Umatac formation, is characterized by high peaks or a coastal ridge that is steep on the seaward side and gently slopes inland toward the interior basin where the two formations merge. The highest peak is Mt. Lamlam at 407 m (1,334 ft). The rugged upland surfaces of volcanic areas are weathered. Exposed volcanic rock and conspicuous erosion scars are present. Major land areas, however, are covered with savannah grasslands that have adapted to the dry and nutrient deficient clay soils of the upper slopes. Water quickly drains from the sloped surfaces and forms a surface drainage pattern that comprises part of the freshwater resources of southern Guam. A relatively small amount of rainfall soaks into the underlying rock strata. More than 40 rivers and streams form a surface drainage pattern that dissects the volcanic region. These rivers flow into the sea of coastal embankments where floodplains and wetlands typify the estuarine areas.

2.3 **Vegetation**

A very thin soil layer covers most of the northern limestone and hosts forest vegetation known as the limestone forest. The limestone forest is comprised of mediumsize trees that form a canopy for understory shrubs, herbs, epiphytes, and lianas. Many of the plants grow from bare limestone. Large areas of limestone forest have been cleared by wartime efforts and postwar urban and military developments. The remaining areas are concentrated along coastal slopes and represent the critical habitat for many of Guam's endangered plants and animals.

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 savannah grasslands and ravine forest provide particularly aesthetic contrasts in Southern Guam. The southern uplands are some of the island's only expanses of unspoiled terrain.

2.4 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.).

2.4.1 **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).

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 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 North American Datum of 1983 (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 and Hydraulic Data

4.1 Peak Flow Data

Since 1951, the USGS has operated and maintained approximately 22 continuous streamflow gaging stations in Guam. During the 1990s, matching support from the Government of Guam was discontinued. The monitoring program was restored after legislation was passed in 1998 directing and providing funds to WERI to establish a permanent monitoring program in partnership with USGS.

For this study, only gaging stations with at least 10 years of usable record through water year 2019 were considered for estimating the magnitude and frequency of peak discharges, and gaging stations with at least 25 years of usable record were used to estimate the generalized skew (Interagency Advisory Committee on Water Data, 1982). There are a total of 14 gaging stations on Guam that have at least 10 years of usable annual peak-discharge data, and 9 gaging stations with at least 25 years of usable record (Table 4-1; Figure 4-1). Only one station contained at least 50 years of usable data (Figure 4-2). The longest available record through water year 2019 is 53 years at gaging station 16847000 Imong River near Agat, Guam. Out of 430 total annual peak flow records, 116 (27 percent) peak flow events occurred in September and 382 (89 percent) occurred during the wet season (July through December). The complete distribution is presented in Figure 4-3.

Table 4-1: Stream Gaging Stations Used in this Study

Site Number	Site Name (as it appears in NWIS database)	No. years of usable record	Period of record used in analysis
16809600	La Sa Fua River near Umatac, Guam	32	1954-58, 1960, 1977-83, 2001-19
16808120	Namo River above weir at Santa Rita, Guam	23	1985-89, 2002-19
16848100	Almagosa River near Agat, Guam	39	1972-79, 1981-91, 1998-2003, 2005-18
16848500	Maulap River near Agat, Guam	40	1972-86, 1988-93, 1998-2015, 2018
16847000	Imong River near Agat, Guam	53	1961-93, 1998-99, 2001-04, 2006-19
16854500	Ugum River above Talofofo Falls, nr Talofofo, Guam	40	1977-94, 1998-2019
16865000	Pago River near Ordot, Guam	48	1952-55, 1957-60, 1962-66, 1968-82, 1999-2018
16808300	Finile Creek at Agat, Guam	22	1961-82
16816000	Umatac River at Umatac, Guam	33	1954-76, 2002-11
16835000	Inarajan River nr Inarajan, Guam	11	1954-59, 1965, 1973, 1975, 1977, 1981
16855000	Ugum River nr Talofofo, Guam	19	1953-1971
16840000	Tinaga River nr Inarajan, Guam	31	1953-66, 1969-85
16858000	Ylig River near Yona, Guam	39	1953-55, 1957-85, 1988-90, 1999-2002

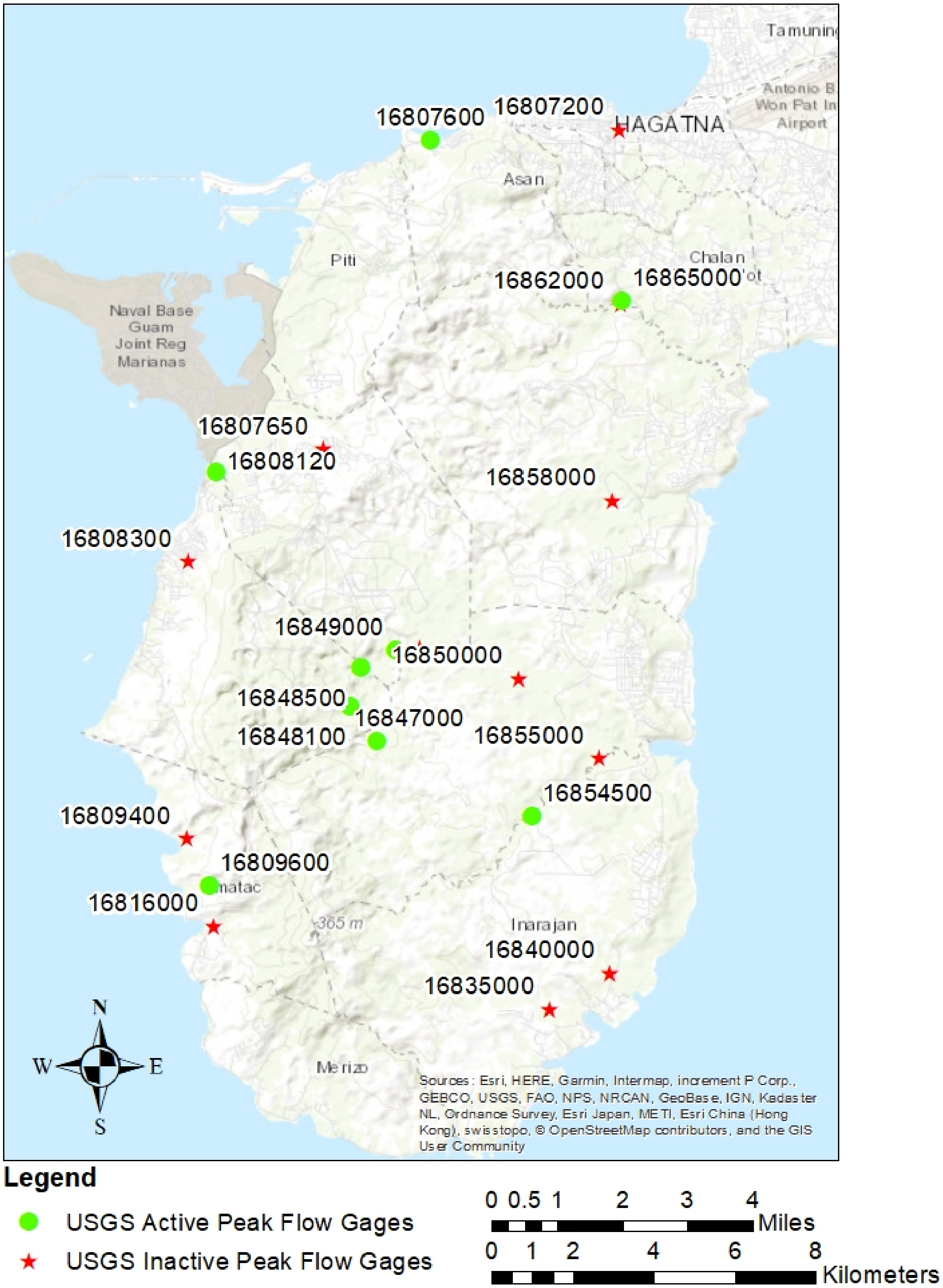

Figure 4-1: USGS Stream Flow Gaging Stations on Guam

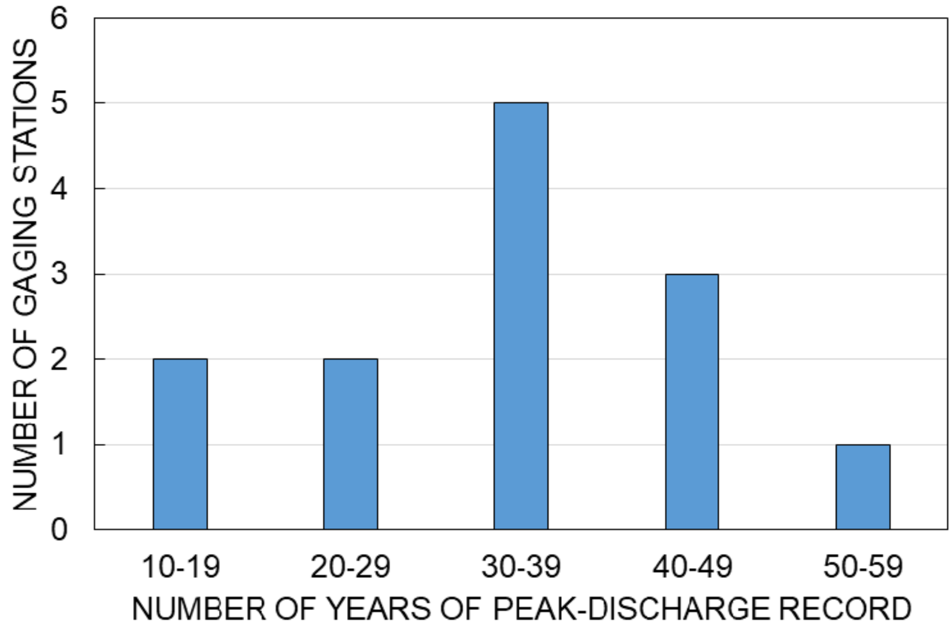

Figure 4-2: Distribution of record lengths for stream gaging stations with at least 10 years of usable peak discharge data

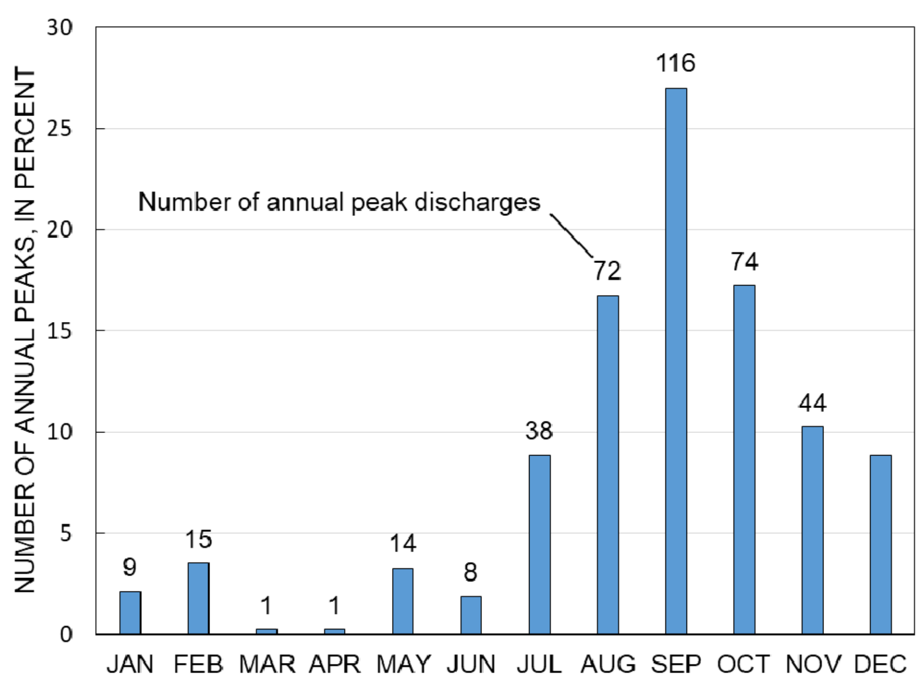

Figure 4-3: Distribution by month of the 430 annual peak discharges

4.2 **Basin Characteristics**

For each gaging station with at least 10 years of usable record, drainage basins were initially delineated using ArcHydro Tools and the 2012-2013 DEM (Section 3.1.2). In some instances, manual adjustments were necessary to correct the boundary outline.

Site-specific drainage basin characteristics were quantified by GIS methods. These basin characteristics are needed to develop regression equations for regionalizing flood estimates. Seven different characteristics were brought into consideration for this analysis: mean basin slope (BLSDEM10M), drainage area (DRNAREA), mean basin elevation (ELEV), length of longest flow path (LFPLENGTH), basin perimeter (PERIMMI), the maximum 24-hour precipitation that occurs on average once in 2 years (I24H2Y), and the mean annual precipitation (PRECIP). I24H2Y was found using NOAA’s Atlas 14 Precipitation Frequency Data Server (PFDS). PRECIP was found by taking the mean annual rainfall at the basin centroid location, using a 2015 precipitation raster created by L.F. Heitz and available on the *Digital Atlas of Southern Guam*. Other parameters were derived in GIS. A summary of each quantified parameter is provided in Table 4-2.

Table 4-2: Basin Characteristics

Station No.	River	BSLDEM10M	DRNAREA	ELEV	LFPLENGTH	PERIMMI	I24H2Y	PRECIP
		percent	km^2	m	km	km	mm	mm
16808120	Namo	70.6	3.86	76.2	0.743	6.87	149	2,530
16808300	Finile Creek	92.4	0.679	131	0.681	5.76	139	2,560
16809600	La Sa Fua	163.0	2.65	172	1.62	12.3	177	2,790
16816000	Umatac	167.4	5.36	121	1.36	14.9	168	2,690
16835000	Inarajan	84.5	11.0	108	2.48	25.6	148	2,610
16840000	Tinaga	44.2	4.93	77.4	2.01	19.8	142	2,550
16847000	Imong	157.8	4.95	187	1.65	15.0	187	2,910
16848100	Almagosa	109.4	3.42	225	1.64	13.4	179	2,870
16848500	Maulap	107.6	3.17	166	1.55	13.5	172	2,770
16854500	Ugum	100.9	15.3	30.8	3.27	28.7	170	2,730
16855000	Ugum	97.85	18.2	130	4.53	36.9	168	2,710
16858000	Ylig	101.4	16.9	106	4.30	34.9	186	2,550
16865000	Pago	116.5	14.4	124	3.45	27.7	187	2,490

BSLDEM10M = Mean basin slope computed from 2-meter DEM
DRNAREA = Drainage area
ELEV = Mean basin elevation
LFPLENGTH = Length of the longest flow path
PERIMMI = Basin perimeter
I24H2Y = Maximum 24-hour precipitation that occurs on average once in 2 years
PRECIP = mean annual precipitation

5. Frequency Analysis at Gaged Sites

A flood frequency analysis was performed to determine the individual station skew and mean square error (MSE) for each stream gaging station with 25 years or more of usable record. The overall mean station skew and MSE was then determined, which corresponds to the generalized (regional) skew and MSE.

A second flood frequency analysis was performed on each stream gaging station with 10 years or more of usable record, using a weighted skew based on both the individual station skew and regional skew. This data was used for the regression analysis (Section 6) to compare the statistical relationships between the flood frequency estimates (Appendix A) and basin characteristics (Section 4.2).

5.1 Generalized Skew

A flood frequency analysis following Bulletin 17B methodology (Interagency Advisory Committee on Water Data, 1982) was performed using the Hydrologic Engineering Center's Statistical Software Package (HEC-SSP, version 2.2) for each stream gaging station with 26 years or more of usable record. The generalized skew coefficient and MSE for the region were based on the arithmetic mean of the skew coefficients and MSE of individual station records. 9 USGS stream gages met the requirements of having 25 or more years of record and not being influenced by regulation. These stations, along with their station skew and MSE, are presented in Table 5-1. The computed mean station skew and MSE, which corresponds to the generalized skew and MSE are 0.220 and 0.169, respectively.

Table 5-1: Station Skew and Variance for 9 USGS Gaging Stations, Guam

Station ID	Station Name	Number of Years of Usable Record	Station Skew	Mean Square Error
16809600	La Sa Fua River near Umatac, Guam	30	-0.267	0.237
16816000	UMATAC RIVER AT UMATAC, GUAM	33	-0.094	0.099
16840000	TINAGA RIVER NR INARAJAN, GUAM	31	0.154	0.004
16847000	Imong River near Agat, Guam	50	0.179	0.002
16848100	Almagosa River near Agat, Guam	37	0.006	0.046
16848500	Maulap River near Agat, Guam	41	0.529	0.095
16854500	Ugum River above Talofofo Falls, nr Talofofo, Guam	37	0.940	0.518
16858000	Ylig River near Yona, Guam	35	-0.240	0.212
16865000	Pago River near Ordot, Guam	46	0.775	0.308
		Mean:	0.220	0.169

5.2 **Flood Frequency Estimates at Gaged Sites**

A flood frequency analysis using a weighted skew was performed for each stream gaging station in Guam that had 10 or more years of record. As station skews tend to be sensitive to extreme events, it accuracy can be improved by weighing it with the generalized skew (Interagency Advisory Committee on Water Data, 1982, page 10). 13 USGS stream gages met the requirements of having 10 or more years of usable record. The resulting flood frequency estimates are presented in Appendix A.

6. Regression Analysis

The statistical relationships between basic characteristics (Table 4-2) and flood frequency estimates (Appendix A) were evaluated using a Microsoft Excel statistics add-in, StatTools (version 7.5).

6.1 Independent Variable Correlation

Seven different characteristics were brought into consideration for this analysis: mean basin slope (BLSDEM10M), drainage area (DRNAREA), mean basin elevation (ELEV), length of longest flow path (LFPLENGTH), basin perimeter (PERIMMI), the maximum 24-hour precipitation that occurs on average once in 2 years (I24H2Y), and the mean annual precipitation (PRECIP). When there are two or more independent variables, it is possible to have redundancies caused by a correlation between the variables. A correlation matrix was created using the StatTools software and presented in Table 6-1. The results of the analysis show a high correlation between the DRNAREA, LFPLENGTH, and PERIMMI variables. When there is a high correlation between variables, typically only one is included in development of the regression equations.

Table 6-1: Linear Correlation Table for Independent Variables Representing Basin Characteristics

	BSLDEM10M	DRNAREA	ELEV	LFPLENGTH	PERIMMI	I24H2Y	PRECIP
BSLDEM10M	1.000	-0.140	0.513	-0.112	-0.147	0.643	0.579
DRNAREA	-0.140	1.000	-0.432	0.958	0.964	0.341	-0.251
ELEV	0.513	-0.432	1.000	-0.265	-0.337	0.432	0.642
LFPLENGTH	-0.112	0.958	-0.265	1.000	0.983	0.426	-0.156
PERIMMI	-0.147	0.964	-0.337	0.983	1.000	0.345	-0.172
I24H2Y	0.643	0.341	0.432	0.426	0.345	1.000	0.458
PRECIP	0.579	-0.251	0.642	-0.156	-0.172	0.458	1.00

6.2 **Simple Linear Regression**

A simple linear regression uses only one independent variable. The portion of variability in the dependent variable (e.g. the 1% AEP peak flow) that is explained by the independent variable (e.g. DRNAREA) is represented by the coefficient of determination, R^2. In general, if a linear model is appropriate, a higher R^2 implies a better fit. R^2 ranges from 0 to 1.

As presented in Table 6-2, DRNAREA has the highest R^2, followed by LFPLENGTH and PERIMMI. However, as these three variables were shown to be highly correlated (Table 6-1), only DRNAREA will be used. I24H2Y may also provide some value in the regression analysis with a moderate R^2

Table 6-2: Comparison of the Coefficient of Determination, R^2, for Different Independent Variables with the 1% AEP Peak Flow

Independent Variable	R^2
BLSDEM10M	0.059
DRNAREA	0.501
ELEV	0.021
LFPLENGTH	0.410
PERIMMI	0.434
I24H2Y	0.322
PRECIP	0.002

6.3 **Multiple Linear Regression**

When multiple independent variables are used, such as DRNAREA and I24H2Y, the R^2 must be adjusted to compare different models. Equations using these two independent variables (DRNAREA and I24H2Y) were selected for the final equations with consideration toward the adjusted R^2, correlation between the variables, and level of difficulty for the end user (a simpler equation is often more practical, especially if a more complex one does not add significant value). The final equations are presented in Table 6-3.

Table 6-3: Regional Regression Equations for Peak-Discharge Estimates, Southern Guam in cubic meters per second (m^3/s)

Q_X, peak discharge for X-year recurrence interval; DRNAREA, 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.

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

Table 6-4: Regional Regression Equations for Peak-Discharge Estimates, Southern Guam in cubic feet per second (ft^3/s)

Q_X, peak discharge for X-year recurrence interval; DRNAREA, drainage area, in square miles; I24H2Y, maximum 24-hour precipitation that occurs on average once in 2 years, in inches; 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.

Regression equation	Range of explanatory variables	R^2	Standard Error of Estimate
$Q_2 = 10^{0.038}(DRNAREA^{0.561})(I24H2Y^{3.37})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.839	0.142
$Q_5 = 10^{0.149}(DRNAREA^{0.575})(I24H2Y^{3.44})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.884	0.121
$Q_{10} = 10^{0.254}(DRNAREA^{0.596})(I24H2Y^{3.52})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.879	0.127
$Q_{25} = 10^{0.307}(DRNAREA^{0.609})(I24H2Y^{3.57})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.854	0.144
$Q_{50} = 10^{0.361}(DRNAREA^{0.626})(I24H2Y^{3.64})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.812	0.171
$Q_{100} = 10^{0.395}(DRNAREA^{0.637})(I24H2Y^{3.680})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.778	0.192
$Q_{250} = 10^{0.425}(DRNAREA^{0.649})(I24H2Y^{3.72})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.744	0.213
$Q_{500} = 10^{0.460}(DRNAREA^{0.664})(I24H2Y^{3.77})$	$0.681 \leq DRNAREA \leq 18.2$; $139 \leq I24H2Y \leq 187$	0.700	0.241

7. Summary

Generalized-skew coefficients and peak-discharge magnitude and frequency at gaged sites were determined using guidelines documented in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). A summary of the steps completed to determine these regression equations is provided below, with greater detail provided in the sections that follow.

7. Identify all stream gaging stations within the region of Southern Guam that have at least 10 years of valid (usable and unregulated) annual peak flow data.
8. Select and quantify various basin characteristic parameters (e.g. mean basin slope, drainage area) for each station to be used in the study.
9. Perform a flood frequency (Bulletin 17B) analysis on each stream gaging station with 25 years or more of usable peak flow record to determine the individual station skew and mean square error (MSE).
10. Compute the overall mean station skew and MSE, which corresponds to the generalized (regional) skew and MSE.
11. Perform another flood frequency (Bulletin 17B) analysis on each stream gaging station with 10 years or more of unregulated peak flow data using a weighted skew to determine the flood frequency estimates at each site.
12. Compare the statistical relationships between the flood frequency estimates and the basin parameters.

The final regression equations determined by this study use two basin characteristics: drainage area (DRNAREA) and the maximum 24-hour precipitation that occurs on average once in 2 years (I24H2Y). These equations are presented in Table 6-3.

For each streamflow gaging station in Guam that had at least 10 years of valid (usable and unregulated) annual peak flow data, flood frequency estimates are provided in Appendix A. The results of this flood frequency analysis provide peak flow estimates computed in three different ways: 1) following Bulletin 17B methodology and based solely on the station's independent record, 2) from using the regional regression equations determined in this study, and 3) following Bulletin 17B methodology and using a weighted skew, based on both the individual station record and regional skew.

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