

REGION 11

Tagum River Basin:

DREAM Flood Forecasting
and Flood Hazard Mapping



TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY

2015





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Table of Contents

INTRODUCTION	1
1.1 About the DREAM Program	2
1.2 Objectives and Target Outputs	2
1.3 General Methodological Framework	3
1.4 Scope of Work of the Flood Modeling Component	4
1.5 Limitations	4
1.6 Operational Framework	4
THE TAGUM RIVER BASIN	5
METHODOLOGY	9
3.1 Pre-processing and Data Used	10
3.1.1 Elevation Data	10
3.1.1.1 Hydro-corrected SRTM DEM	10
3.1.1.2 LiDAR DEM	10
3.1.2 Land Cover and Soil Type	12
3.1.3 Hydrometry and Rainfall Data	12
3.1.3.1 Mahayahay Bridge – Asuncion Davao del Norte	12
3.1.3.2 Nanaga Bridge – Talainod, Davao del Norte	13
3.1.4 Rainfall Intensity Duration Frequency (RIDF)	14
3.1.5 Rating Curves	16
3.1.5.1 Mahayahay Bridge – Asuncion, Davao del Norte Rating Curve	16
3.1.5.2 Nanaga Bridge, Talainod, Davao del Norte Rating Curve	17
3.2 Rainfall-Runoff Hydrologic Model Development	18
3.2.1 Watershed Delineation and Basin Model Pre-processing	18
3.2.2 Basin Model Calibration	20
3.3 HEC-HMS Hydrologic Simulations for Discharge Computations using PAGASA RIDF Curves	22
3.3.1 Discharge Computation using Rainfall-Runoff Hydrologic Model ...	22
3.3.2 Discharge Computation using Dr. Horritt’s Recommended Hydrological Method	23
3.4 Hazard and Flow Depth Mapping using FLO-2D	27
3.4.1 Floodplain Delineation	27
3.4.2 Flood Model Generation	27
3.4.3 Flow Depth and Hazard Map Simulation	31
3.4.4 Hazard Map and Flow Depth Map Creation	33
RESULTS AND DISCUSSION	35
4.1 Efficiency of HEC-HMS Rainfall-Runoff Models calibrated based on field survey and gauges data	36
4.1.1 Mahayahay Bridge – Asuncion, Davao del Norte HEC-HMS Calibration Results	36
4.1.2 Nanaga Bridge – Talainod, Davao del Norte HEC-HMS Calibration Results	37
4.2 Application	37
4.3 Calculated Outflow hydrographs and Discharge Values for different Rainfall Return Periods	38



Table of Contents

4.3.1	Hydrograph using the Rainfall-Runoff Model	38
4.3.1.1	Mahayahay, Asuncion Tagum	38
4.3.1.2	Nanaga, Talaingon Tagum	42
4.3.2	Discharge Data using Dr. Horritt’s Recommended Hydrological Method	46
4.4	Flood Hazard and Flow Depth Maps	49
BIBLIOGRAPHY		54
APPENDICES		55
Appendix A. Asuncion Tagum Model Basin Parameters		56
Appendix B. Asuncion Tagum Reach Parameters		58
Appendix C. Talaingod Tagum Model Basin Parameters		59
Appendix D. Talaingod Tagum Model Reach Parameters		60
Appendix E. Tagum HEC-HMS Discharge Simulation		61



List of Figures

Figure 1.	The general methodological framework of the program	3
Figure 2.	The operational framework and specific work flow of the Flood Modeling Component	4
Figure 3.	The Tagum River Basin Location Map	6
Figure 4.	Tagum River Basin Soil Map.....	7
Figure 5.	Tagum River Basin Land Cover Map.....	8
Figure 6.	Summary of data needed for the purpose of flood modeling	10
Figure 7.	Digital Elevation Model (DEM) of the Tagum River Basin using Light Detection and Ranging (LiDAR) technology	11
Figure 8.	The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted	11
Figure 9.	Stitched Quickbird images for the Tagum floodplain	12
Figure 10.	Asuncion Rainfall and outflow data used for modeling	13
Figure 11.	Rainfall and Outflow Data used for Modeling (Panit-an)	13
Figure 12.	Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines	15
Figure 13.	Davao Rainfall Intensity Duration Frequency Curves	16
Figure 14.	Water level vs. Discharge Curve for Mahayahay Bridge, Asuncion, Davao del Norte	17
Figure 15.	Water level vs. Discharge Curve for Nanaga Bridge, Talaingod, Davao del Norte	17
Figure 16.	The Rainfall-Runoff Basin Model Development Scheme	18
Figure 17.	Tagum HEC-HMS Model domain generated by WMS	19
Figure 18.	The location map of rain gauges used for the calibration of the Tagum HEC-HMS model	21
Figure 19.	Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt’s recommended hydrology method	22
Figure 20.	Delineation upper watershed for Tagum floodplain discharge computation	24
Figure 21.	HEC-HMS simulation discharge results using Dr. Horritt’s Method	26
Figure 22.	Screenshot showing how boundary grid elements are defined by line	28
Figure 23.	Screenshots of PTS files when loaded into the FLO-2D program	28
Figure 24.	Areal image of Tagum floodplain	29
Figure 25.	Screenshot of Manning’s n-value rendering	30
Figure 26.	FLO-2D Mapper Pro General Procedure	31
Figure 27.	Tagum floodplain Generated Hazard Maps using FLO-2D Mapper	32
Figure 28.	Tagum floodplain generated flow depth map using FLO-2D Mapper	32
Figure 29.	Basic Layout and Elements of the hazard maps	33
Figure 30.	Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow at Asuncion Bridge	36
Figure 31.	Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow at Nanaga Bridge	37
Figure 32.	Sample DREAM Water Level Forecast	38
Figure 33.	Outflow hydrograph generated using the Davao 5-Year RIDF inputted in HEC-HMS	39
Figure 34.	Outflow hydrograph generated using the Davao 10-Year RIDF inputted in HEC-HMS	39



List of Figures

Figure 35.	Outflow hydrograph generated using the Davao 25-Year RIDF inputted in HEC-HMS	40
Figure 36.	Outflow hydrograph generated using the Davao 50-Year RIDF inputted in HEC-HMS	40
Figure 37.	Outflow hydrograph generated using the Davao 100-Year RIDF inputted in HEC-HMS	41
Figure 38.	Outflow hydrograph generated using the Davao 5-Year RIDF inputted in HEC-HMS	42
Figure 39.	Outflow hydrograph generated using the Davao 10-Year RIDF inputted in HEC-HMS	43
Figure 40.	Outflow hydrograph generated using the Davao 25-Year RIDF inputted in HEC-HMS	43
Figure 41.	Outflow hydrograph generated using the Davao 50-Year RIDF inputted in HEC-HMS	44
Figure 42.	Outflow hydrograph generated using the Davao 100-Year RIDF inputted in HEC-HMS	44
Figure 43.	Outflow hydrograph generated for Tagum using the Malaybalay and Davao Stations' 5-, 25-, and 100-year Rainfall Intensity Duration Frequency (RIDF) in HEC-HMS	46
Figure 44.	100-year Flood Hazard Map for Tagum River Basin	48
Figure 45.	100-year Flow Depth Map for Tagum River Basin	49
Figure 46.	25-year Flood Hazard Map for Tagum River Basin	50
Figure 47.	25-year Flow Depth Map for Tagum River Basin	51
Figure 48.	5-year Flood Hazard Map for Tagum River Basin	52
Figure 49.	5-year Flow Depth Map for Tagum River Basin	53



List of Tables

Table 1.	Methods used for the different calculation types for the hydrologic elements	19
Table 2.	Summary of peak values of the Asuncion Tagum outflow using the Davao RIDF	41
Table 3.	Summary of peak values of the Talaingod Tagum outflow using the Davao RIDF	45
Table 4.	Summary of Tagum river discharge using the recommended hydrological method by Dr. Horritt	46
Table 5.	Validation of river discharge estimate using the bankful method	47



List of Equations

Equation 1.	Rating Curve	16
Equation 2.	Determination of maximum potential retention using the average curve number of the catchment	25
Equation 3.	Lag Time Equation Calibrated for Philippine Setting	25
Equation 4.	Ratio of river discharge of a 5-year rain return to a 2-year rain return scenario from measured discharge data	26
Equation 5.	Discharge validation equation using bankful method	26
Equation 6.	Bankful discharge equation using measurable channel parameters	27



LIST OF ABBREVIATIONS

ACDP	Acoustic Doppler Current Profiler
AOI	Area of Interest
ARG	Automated Rain Gauge
AWLS	Automated Water Level Sensor
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DOST	Department of Science and Technology
DPC	Data Processing Component
DREAM	Disaster Risk Exposure and Assessment for Mitigation
DTM	Digital Terrain Model
DVC	Data Validation Component
FMC	Flood Modelling Component
GDS	Grid Developer System
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
LiDAR	Light Detecting and Ranging
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
RIDF	Rainfall Intensity Duration Frequency
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
UP-TCAGP	UP Training Center for Applied Geodesy and Photogrammetry





Introduction

Introduction

1.1 About the DREAM Program

The UP Training Center for Applied Geodesy and Photogrammetry (UP TCAGP) conducts a research program entitled “Nationwide Disaster Risk and Exposure Assessment for Mitigation (DREAM) Program” funded by the Department of Science and Technology (DOST) Grants-in-Aid Program. The DREAM Program aims to produce detailed, up-to-date, national elevation dataset for 3D flood and hazard mapping to address disaster risk reduction and mitigation in the country.

The DREAM Program consists of four components that operationalize the various stages of implementation. The Data Acquisition Component (DAC) conducts aerial surveys to collect Light Detecting and Ranging (LiDAR) data and aerial images in major river basins and priority areas. The Data Validation Component (DVC) implements ground surveys to validate acquired LiDAR data, along with bathymetric measurements to gather river discharge data. The Data Processing Component (DPC) processes and compiles all data generated by the DAC and DVC. Finally, the Flood Modeling Component (FMC) utilizes compiled data for flood modeling and simulation.

Overall, the target output is a national elevation dataset suitable for 1:5000 scale mapping, with 50 centimeter horizontal and vertical accuracies. These accuracies are achieved through the use of state-of-the-art airborne Light Detection and Ranging (LiDAR) technology and appended with Synthetic-aperture radar (SAR) in some areas. It collects point cloud data at a rate of 100,000 to 500,000 points per second, and is capable of collecting elevation data at a rate of 300 to 400 square kilometers per day, per sensor

1.2 Objectives and Target Outputs

The program aims to achieve the following objectives:

- a) To acquire a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management,
- b) To operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country,
- c) To develop the capacity to process, produce and analyze various proven and potential thematic map layers from the 3D data useful for government agencies,
- d) To transfer product development technologies to government agencies with geospatial information requirements, and,
- e) To generate the following outputs:
 - 1) flood hazard map
 - 2) digital surface model
 - 3) digital terrain model and
 - 4) orthophotograph.



Introduction

1.3 General Methodological Framework

The methodology to accomplish the program's expected outputs are subdivided into four (4) major components, as shown in Figure 1. Each component is described in detail in the following section.

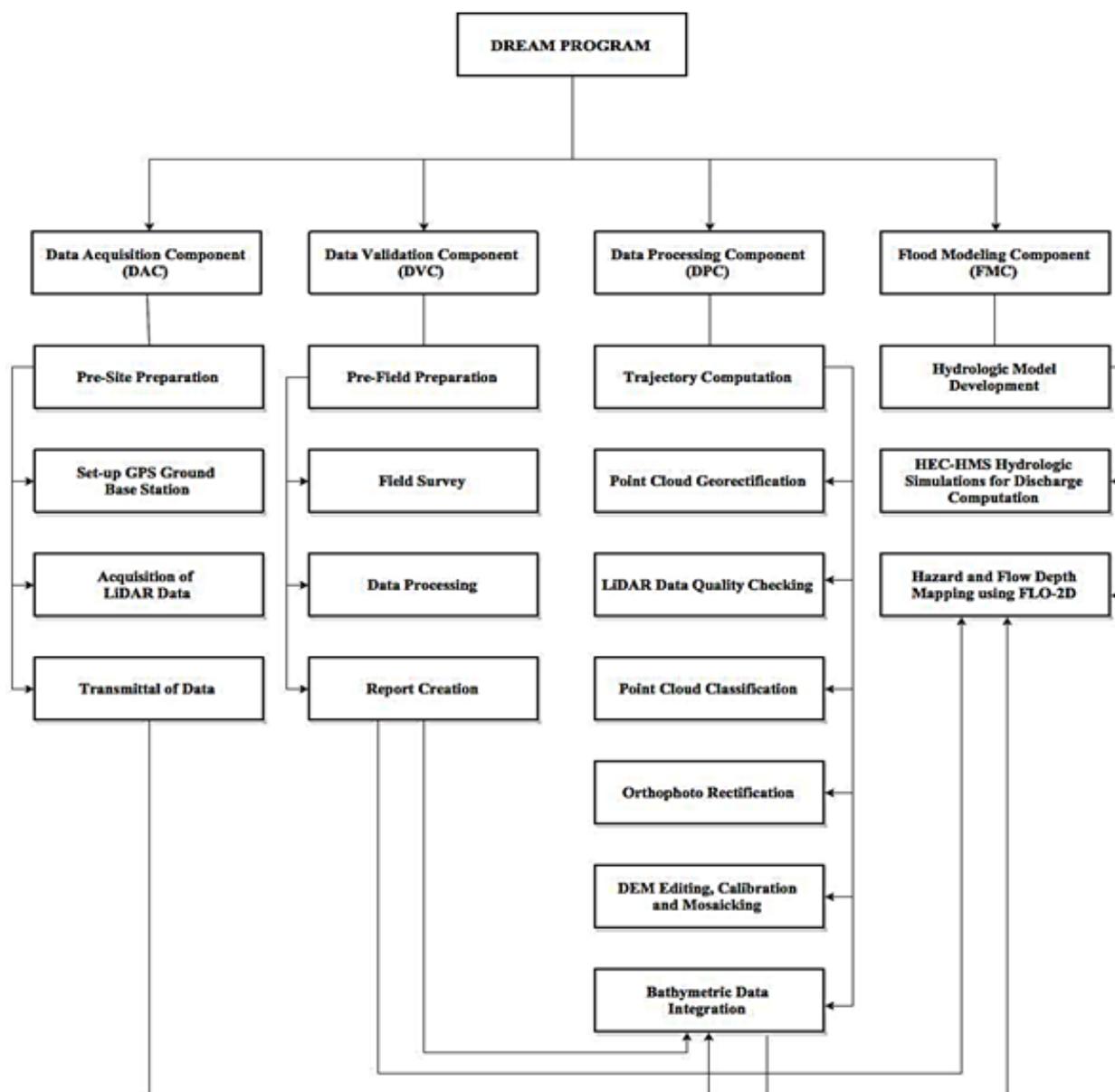


Figure 1. The general methodological framework of the program

Introduction

1.4 Scope of Work of the Flood Modeling Component

The scope of work of the Flood Modeling Component is listed as the following:

- a) To develop the watershed hydrologic model of the Tagum River Basin;
- b) To compute the discharge values quantifying the amount of water entering the floodplain using HEC-HMS;
- c) To create flood simulations using hydrologic models of the Tagum floodplain using FLO-2D GDS Pro; and
- d) To prepare the static flood hazard and flow depth maps for the Tagum river basin.

1.5 Limitations

This research is limited to the usage of the available data, such as the following:

1. Digital Elevation Models (DEM) surveyed by the Data Acquisition Component (DAC) and processed by the Data Processing Component (DPC)
2. Outflow data surveyed by the Data Validation and Bathymetric Component (DVC)
3. Observed Rainfall from ASTI sensors

While the findings of this research could be further used in related-studies, the accuracy of such is dependent on the accuracy of the available data. Also, this research adapts the limitations of the software used: ArcGIS 10.2, HEC-GeoHMS 10.2 extension, WMS 9.1, HEC-HMS 3.5 and FLO-2D GDS Pro.

1.6 Operational Framework

The flow for the operational framework of the Flood Modeling Component is shown in Figure 2.

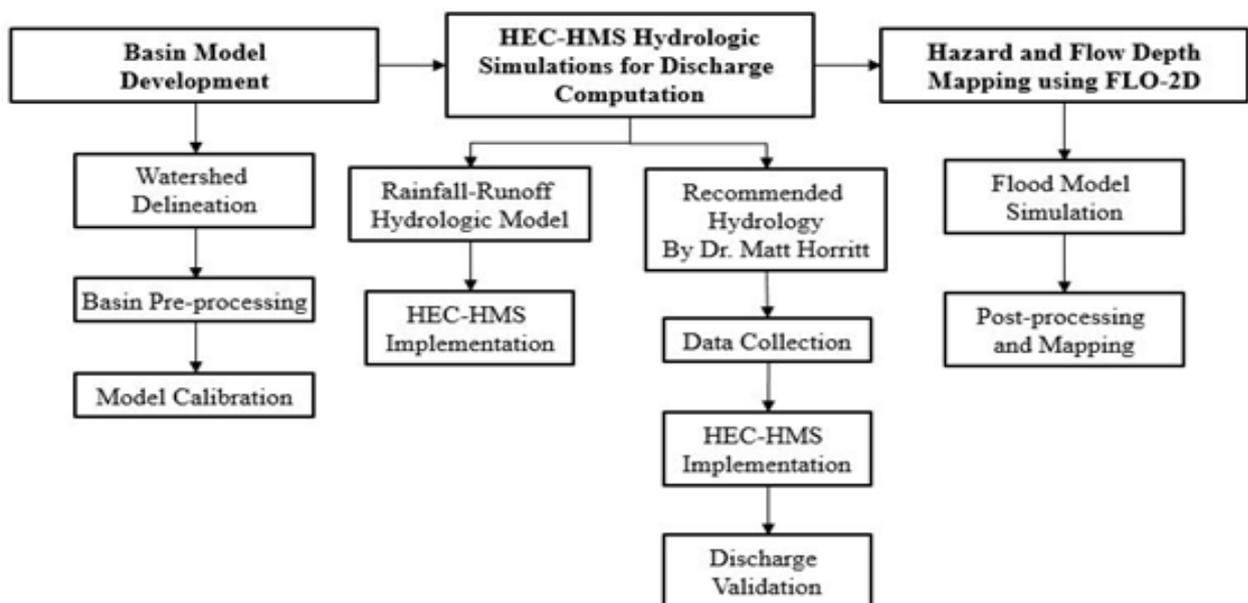
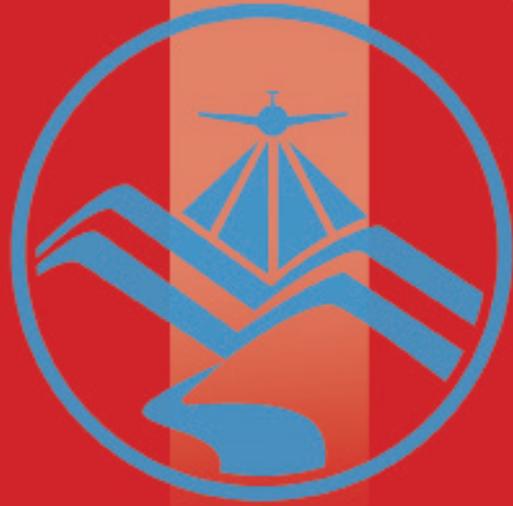


Figure 2. The operational framework and specific work flow of the Flood Modeling Component



The Tagum River Basin

The Tagum River Basin

The Tagum River Basin is located in Mindanao. It is considered as the tenth largest river basin in the Philippines. It covers an estimated basin area of 2,734 square kilometres. The location of Tagum River Basin is as shown in Figure 3.

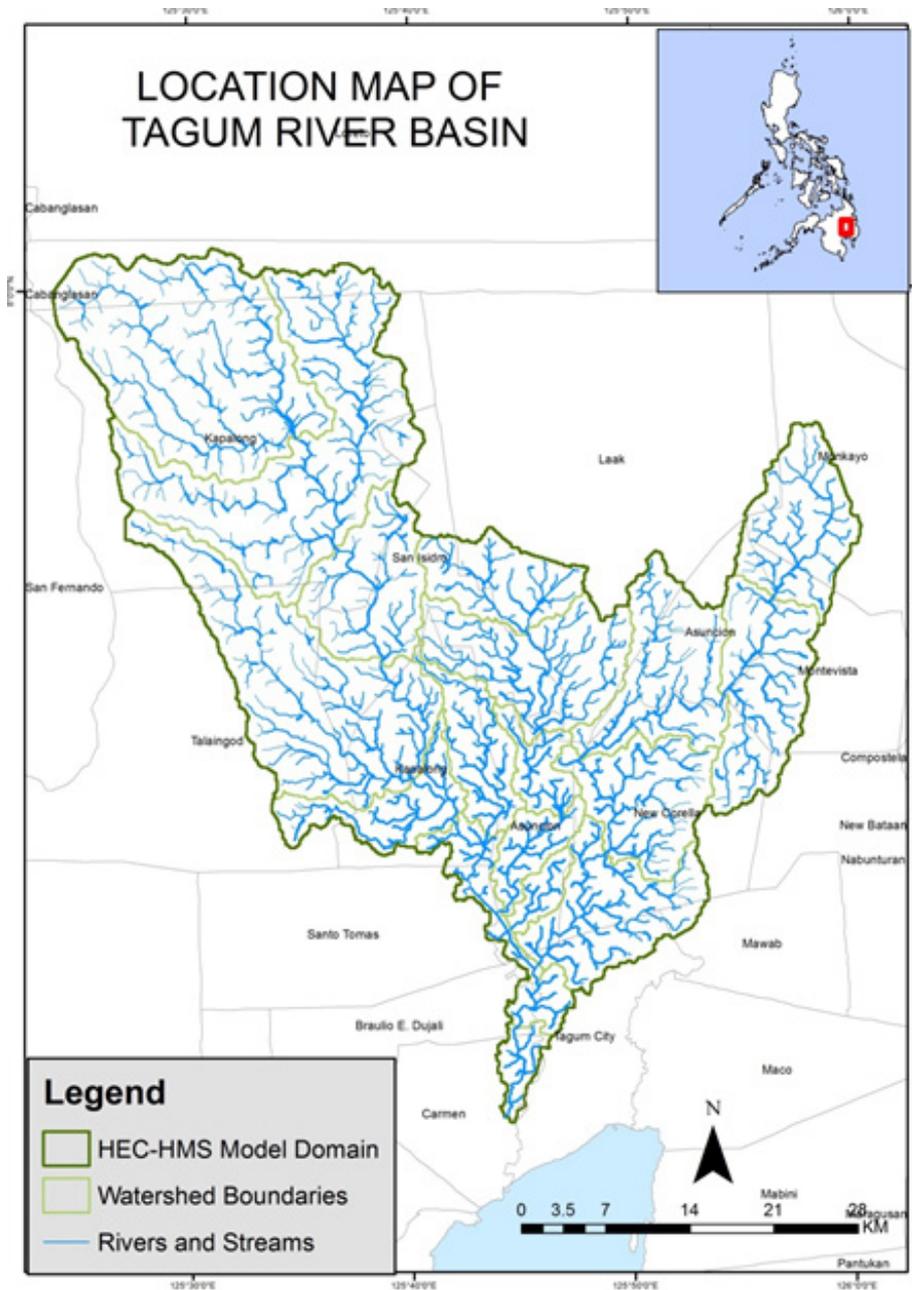


Figure 3. Tagum River Basin Location Map

It encompasses the provinces of Agusan del Sur, Compostella Valley and Davao del Norte. It drains the southern portion of the island and traverses through Tagum City and the towns of Laak, Monkayo, Monte Vista, and Nabunturan in Compostela Valley; Kapalong, San Isidro, Talaingod, Asuncion, New Corella, Santo Tomas, Braulio E. Dujali, Carmen, and Mawab in Davao del Norte; and Veruela in Agusan del Sur.

The land and soil characteristics are important parameters used in assigning the roughness coefficient for different areas within the river basin. The roughness coefficient, also called

The Tagum River Basin

Manning's coefficient, represents the variable flow of water in different land covers (i.e. rougher, restricted flow within vegetated areas, smoother flow within channels and fluvial environments).

The shape files of the soil and land cover were taken from the Bureau of Soils, which is under the Department of Environment and Natural Resources Management, and National Mapping and Resource Information Authority (NAMRIA). The soil and land cover of the Tagum River Basin are shown in Figures 4 and 5, respectively

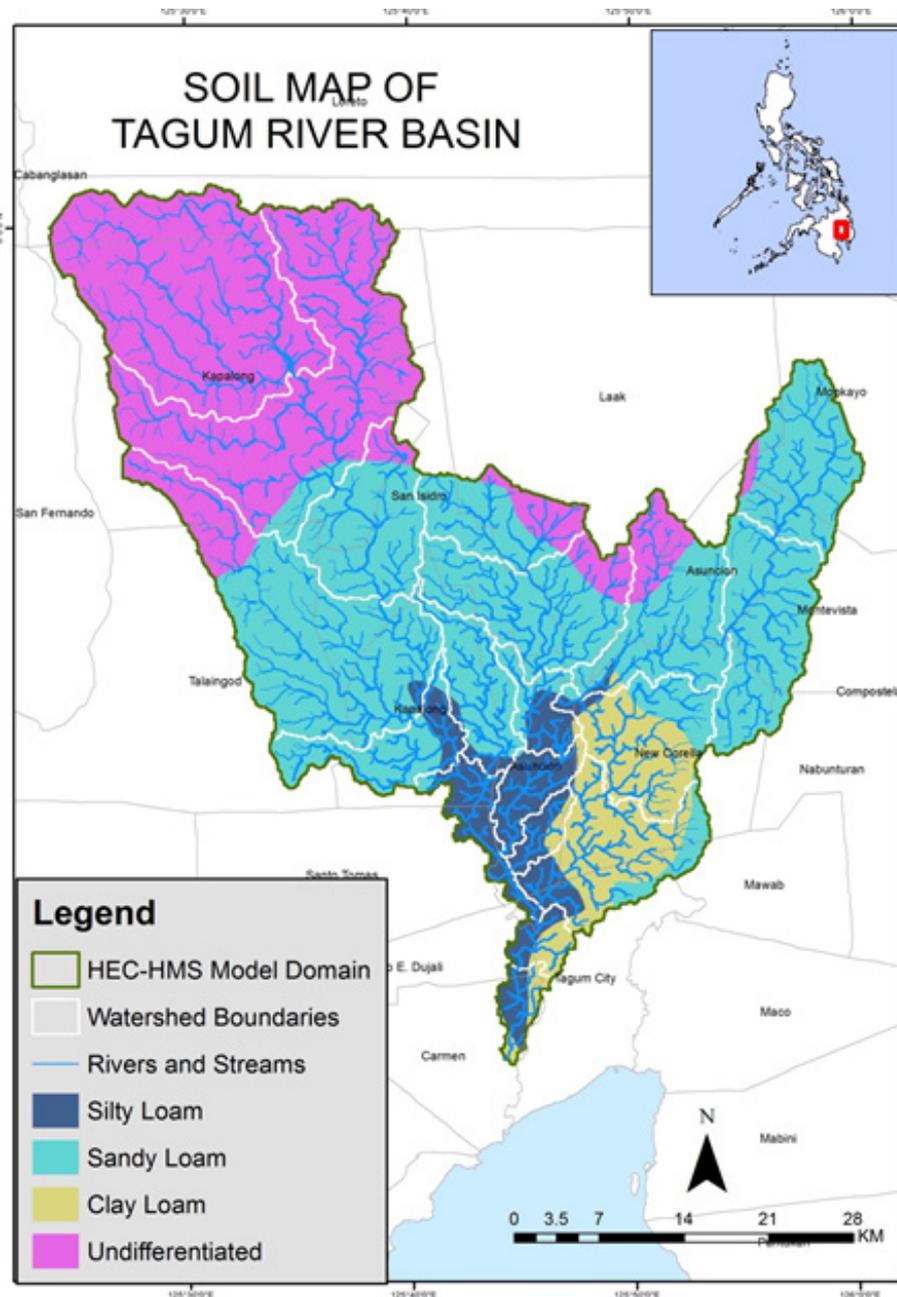


Figure 4. Tagum River Basin Soil Map

The Tagum River Basin

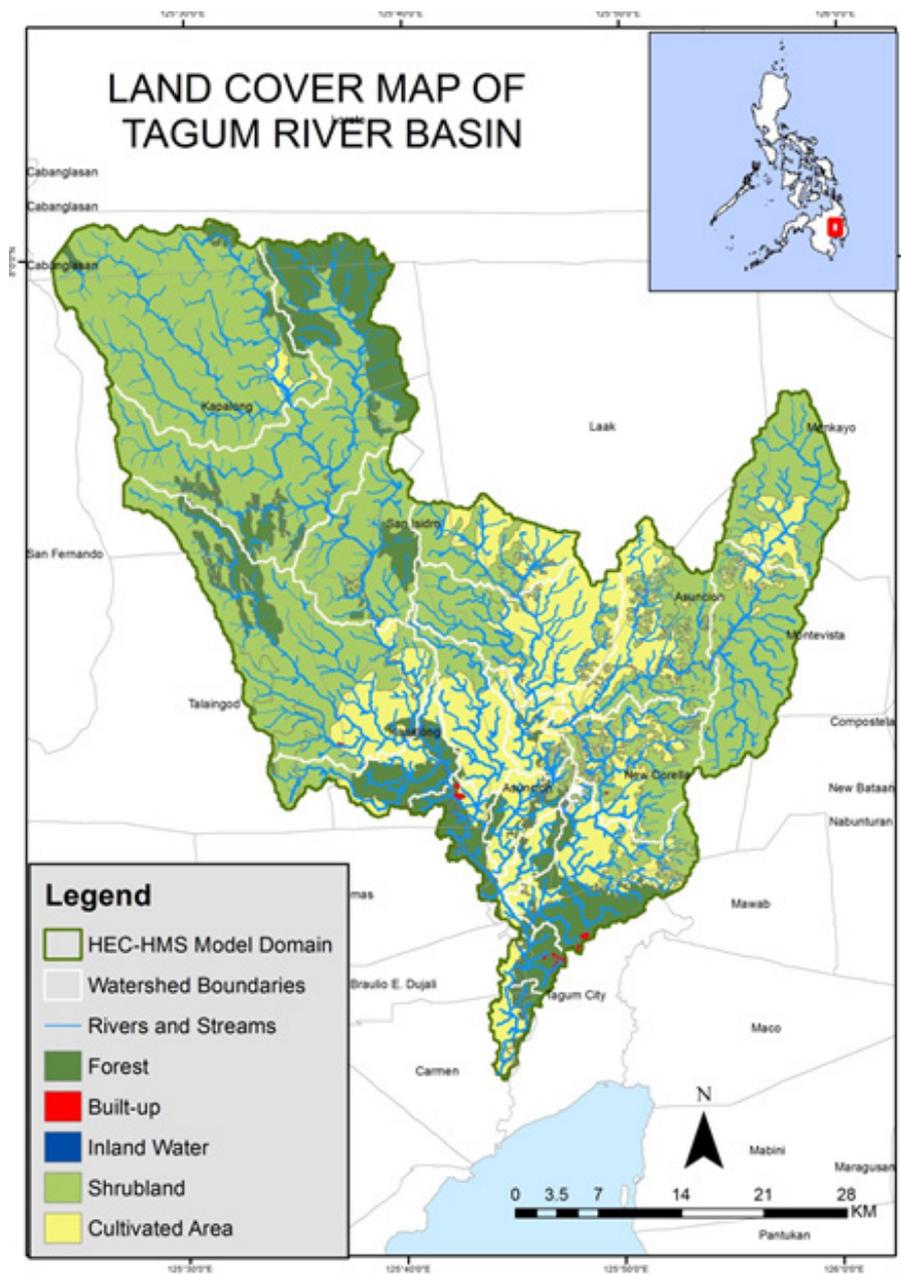


Figure 5. Tagum River Basin Land Cover Map



Methodology

3.1 Pre-processing and Data Used

Flood modeling involved several data and parameters to achieve realistic simulations and outputs. Figure 6 shows a summary of the data needed to for the research.

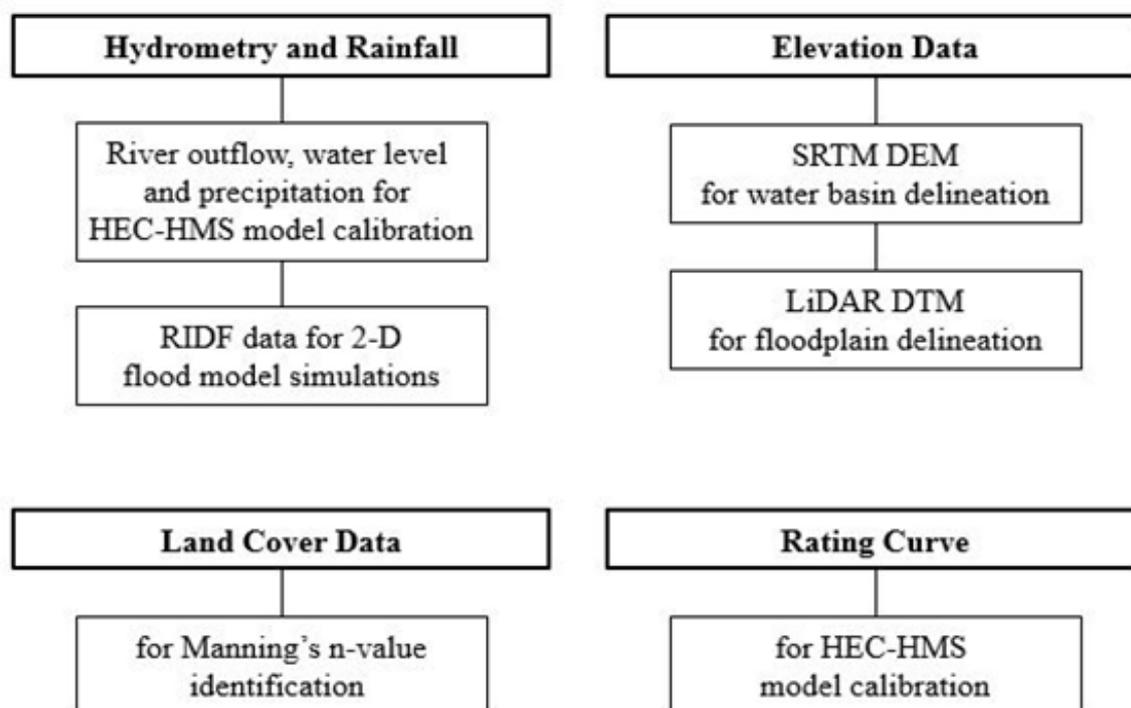


Figure 6. Summary of data needed for the purpose of flood modeling

3.1.1 Elevation Data

3.1.1.1 Hydro Corrected SRTM DEM

With the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) data as an input in determining the extent of the delineated water basin, the model was set-up. The Digital Elevation Model (DEM) is a set of elevation values for a range of points within a designated area. SRTM DEM has a 90 meter spatial mosaic of the entire country. Survey data of cross sections and profile points were integrated to the SRTM DEM for the hydro-correction.

3.1.1.2 LiDAR DEM

LiDAR was used to generate the Digital Elevation Model (DEM) of the different floodplains. DEMs used for flood modeling were already converted to digital terrain models (DTMs) which only show topography, and are thus cleared of land features such as trees and buildings. These terrain features would allow water to flow realistically in the models.

Figure 7 shows an image of the DEM generated through LiDAR.

Methodology

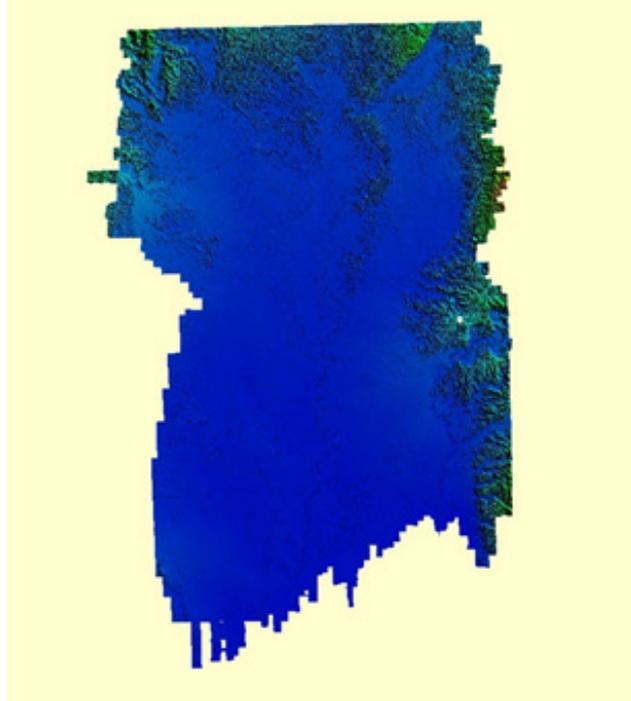


Figure 7. Digital Elevation Model (DEM) of the Tagum River Basin using Light Detection and Ranging (LiDAR) technology

Elevation points were created from LiDAR DTMs. Since DTMs were provided as 1-meter spatial resolution rasters (while flood models for Davao were created using a 10-meter grid), the DTM raster had to be resampled to a raster grid with a 10-meter cell size using ArcGIS.

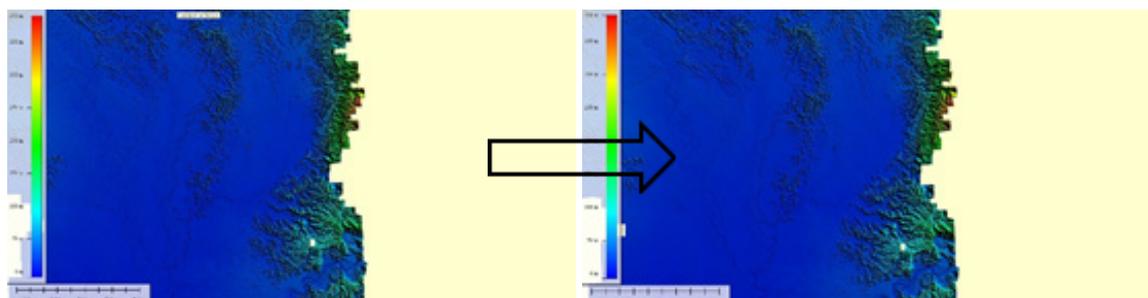


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted.

Methodology

3.1.2 Land Cover and Soil Type

The land and soil characteristics are important parameters used in assigning the roughness coefficient for different areas within the river basin. The roughness coefficient, also called Manning's coefficient, represents the variable flow of water in different land covers (i.e. rougher, restricted flow within vegetated areas, smoother flow within channels and fluvial environments).

A general approach was done for the Tagum floodplain. Streams were identified against built-up areas and rice fields. Identification was done visually using stitched Quickbird images from Google Earth. Areas with different land covers are shown on Figure 9. Different Manning n-values are assigned to each grid element coinciding with these main classifications during the modeling phase.



Figure 9. Stitched Quickbird images for the Davao floodplain.

3.1.3 Hydrometry and Rainfall Data

3.1.3.1 Mahayahay Bridge – Asuncion Davao del Norte

River outflow from Waan Bridge ($9^{\circ} 07' 54.72233''$ N, $125^{\circ} 34' 58.22592''$ E) water level sensor was used to calibrate the HEC-HMS model. This was recorded during 22-23 April, 2014. Peak discharge of 107.99 cms occurred on 23 April, 2014 at 5:40.

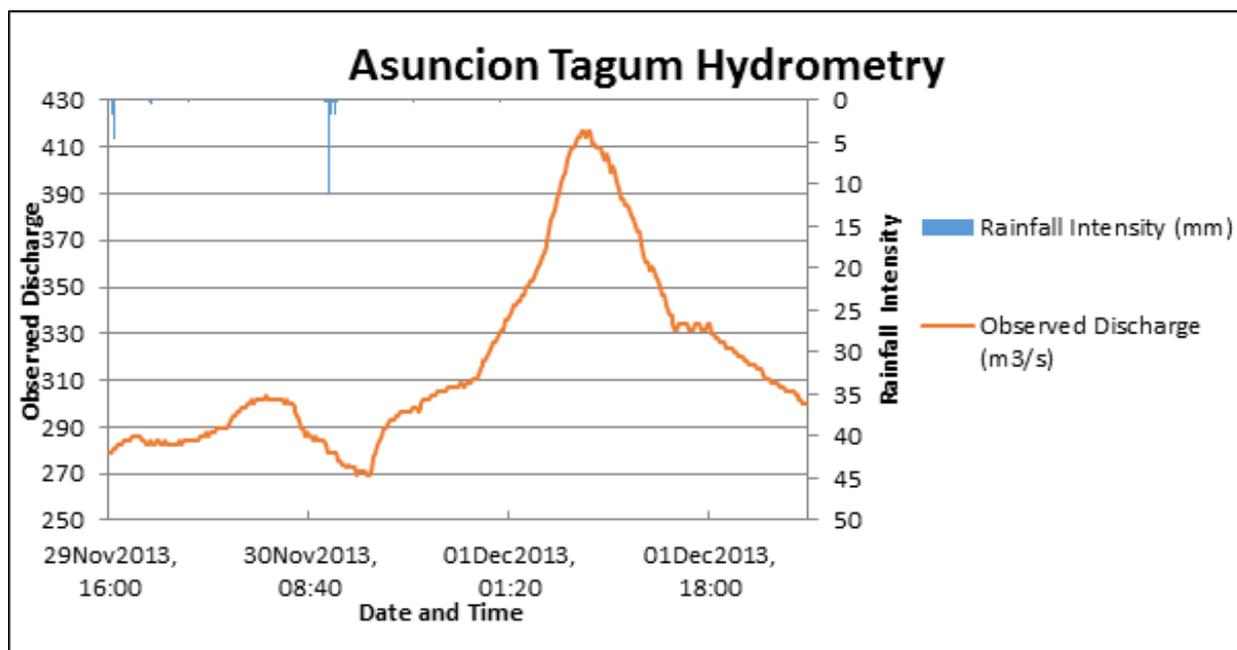


Figure 10. Asuncion Rainfall and outflow data used for modeling

3.1.3.2 Nanaga Bridge – Talaingod, Davao del Norte

This was taken from Nanaga Bridge Talaingod, Davao del (7°38'45.02"N, 125°37'1.29"E). This was recorded January 11, 2014 until January 12, 2014. Peak discharge is 41.4 cms at 3:20 AM, January 12, 2014.

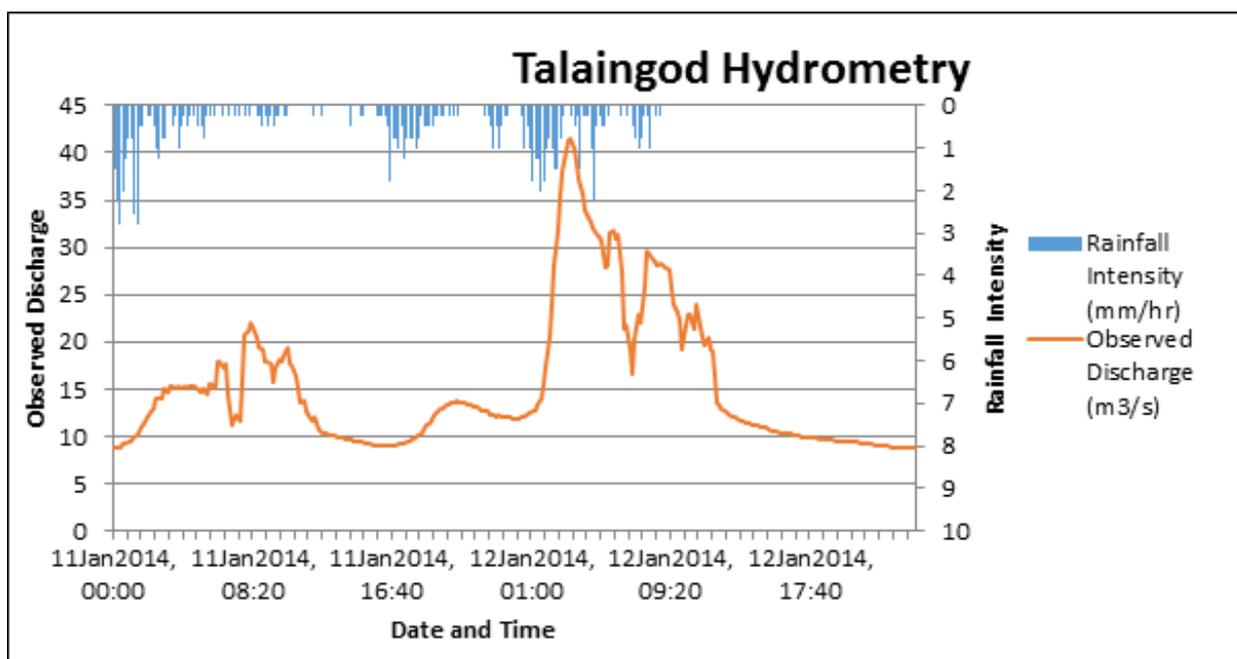


Figure 11. Rainfall and Outflow Data used for Modeling (Talaingod)

Methodology

3.1.4 Rainfall Intensity Duration Frequency

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Davao Rain Gauge. This station was chosen based on its proximity to the Davao watershed. The extreme values for this watershed were computed based on a 26-year record.

Five return periods were used, namely, 5-, 10-, 25-, 50-, and 100-year RIDFs. All return periods are 24 hours long and peaks after 12 hours.



Methodology

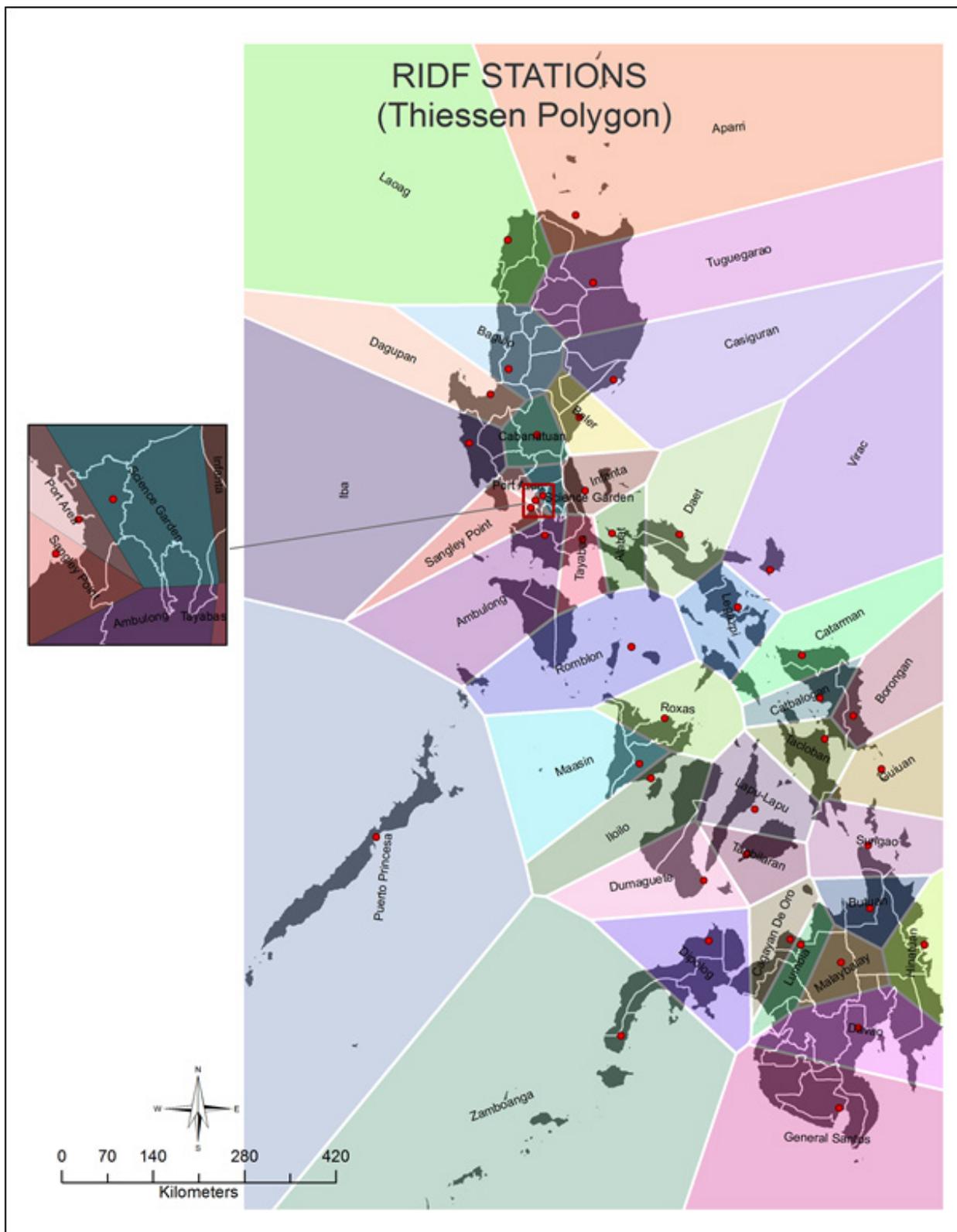


Figure 12. Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines.

Methodology

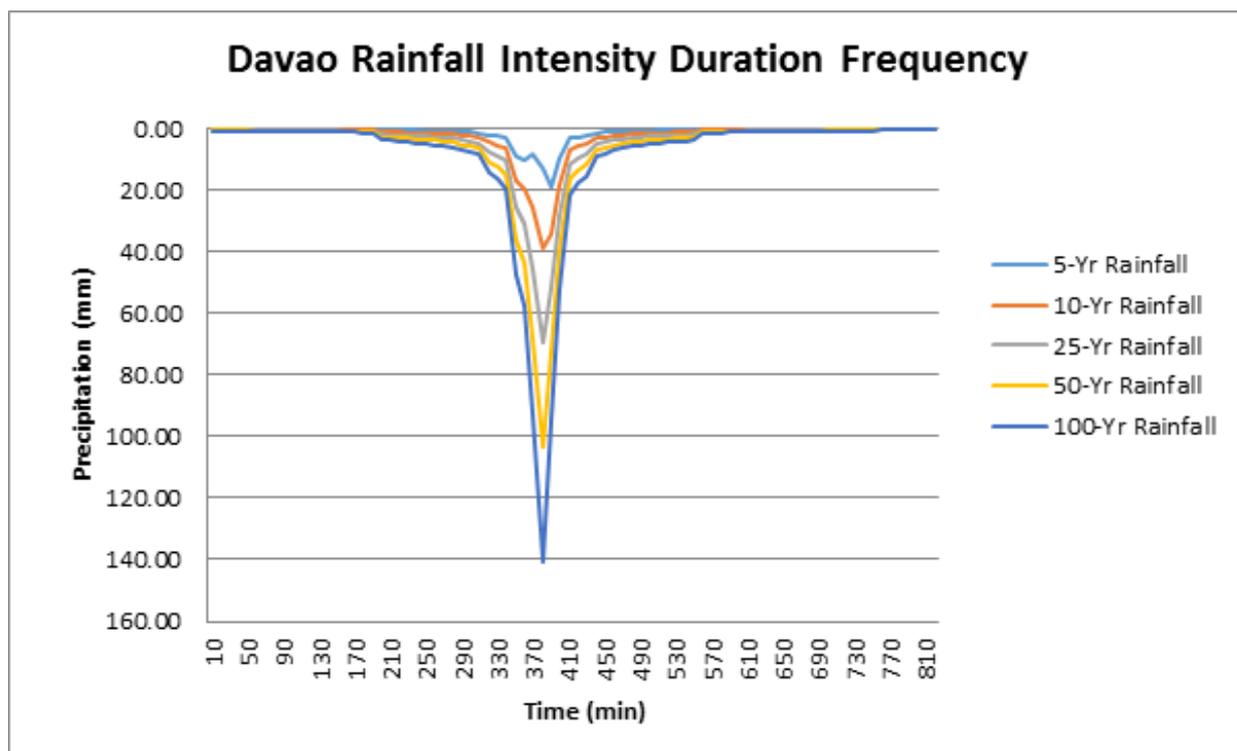


Figure 13. Davao Rainfall-Intensity Duration Frequency (RIDF) curves.

The Tagum River outflow was computed for the five return periods, namely, 5-, 10-, 25-, 50-, and 100-year RIDFs.

3.1.5 Rating Curves

Rating curves were provided by DVC. This curve gives the relationship between the observed water levels from the AWLS used and outflow watershed at the said locations.

Rating curves are expressed in the form of Equation 1 with the discharge (Q) as a function of the gauge height (h) readings from CDO Bridge AWLS and constants (a and n).

$$Q = a^{nh}$$

Equation 1. Rating Curve

3.1.5.1 Mahayahay Bridge – Asuncion, Davao del Norte Rating Curve

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Davao Rain Gauge. This station was chosen based on its proximity to the Davao watershed. The extreme values for this watershed were computed based on a 26-year record.

Five return periods were used, namely, 5-, 10-, 25-, 50-, and 100-year RIDFs. All return periods are 24 hours long and peaks after 12 hours.



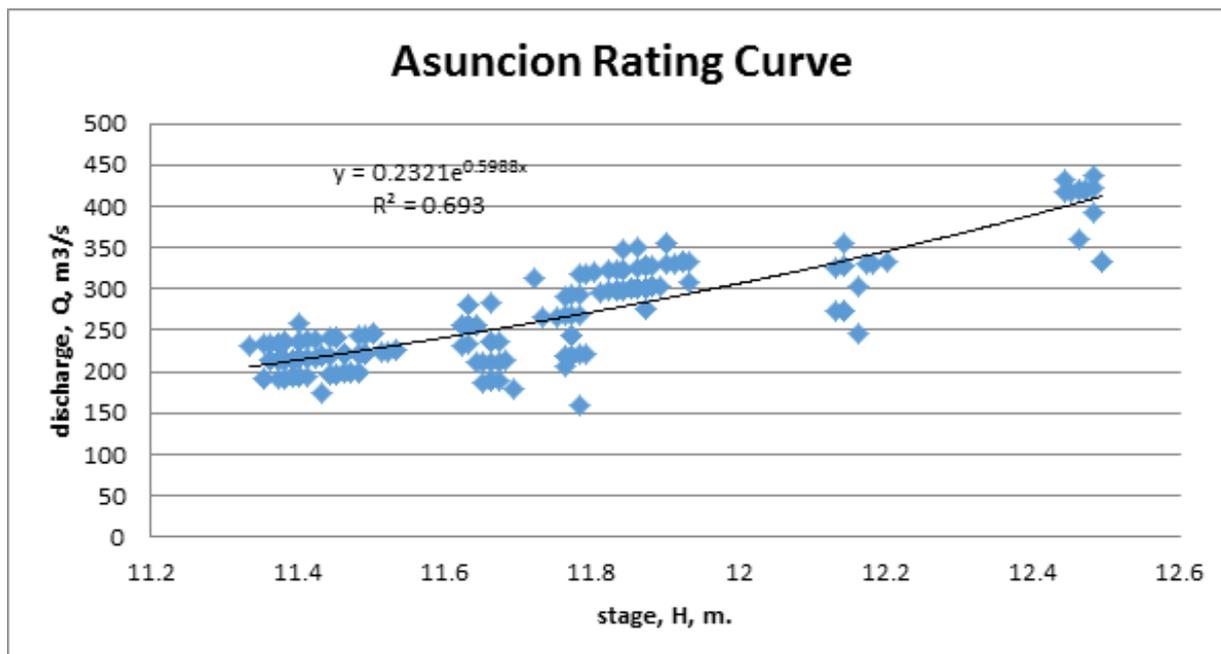


Figure 14. Water level vs. Discharge Curve for Mahayahay Bridge, Asuncion, Davao del Norte

3.1.5.2 Nanaga Bridge, Talaingod, Davao del Norte Rating Curve

A rating curve was developed at Nanaga Bridge (11.11961, 122.5386). The rating curve is ex-

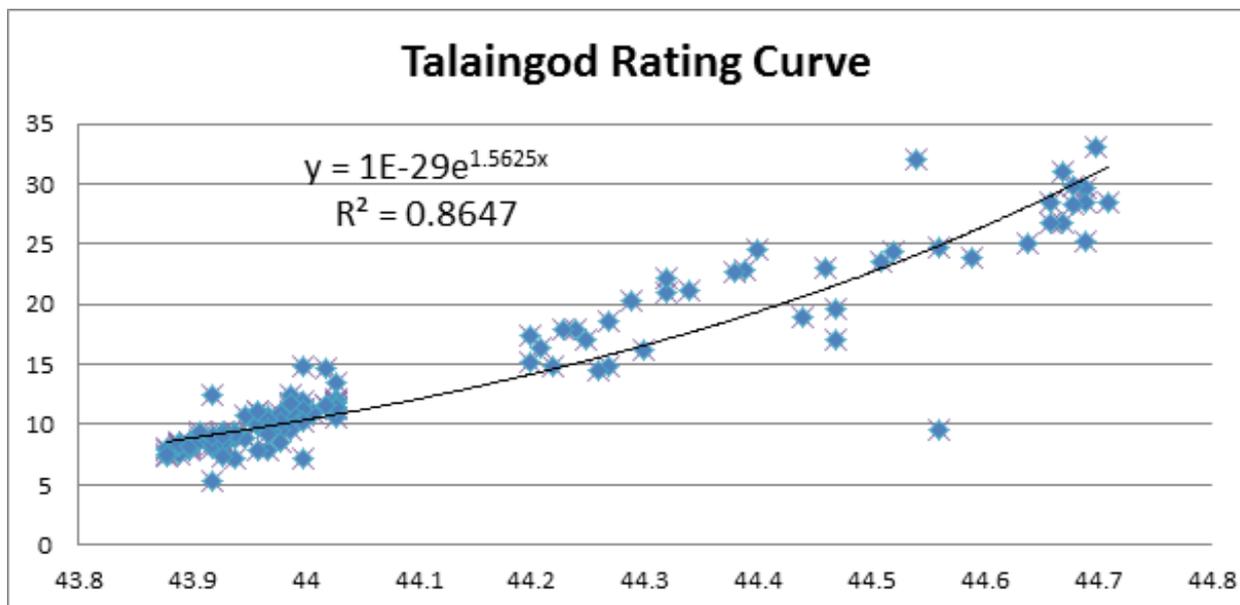


Figure 15. Water level vs. Discharge Curve for Nanaga Bridge, Talaingod, Davao del Norte

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Tagum River Basin was developed using Watershed Modeling System (WMS) version 9.1. The software was developed by Aquaveo, a water resources engineering consulting firm in United States. WMS is a program capable of various watershed computations and hydrologic simulations. The hydrologic model development follows the scheme shown in the Figure 16.

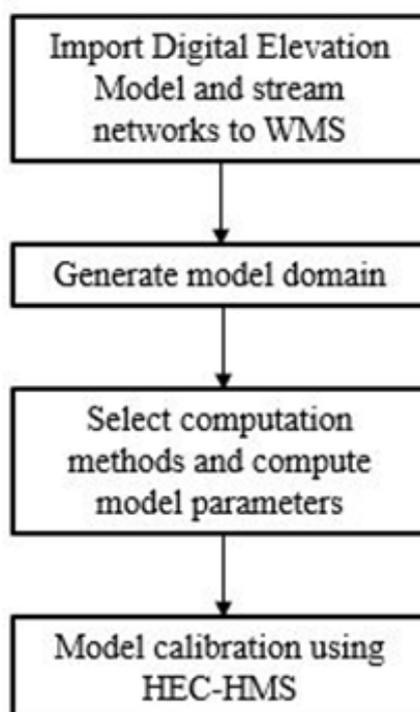


Figure 16. The Rainfall-Runoff Basin Model Development Scheme

Hydro-corrected SRTM DEM was used as the terrain for the basin model. The watershed delineation and its hydrologic elements, namely the subbasins, junctions and reaches, were generated using WMS after importing the elevation data and stream networks. An illustration of the Tagum HEC-HMS domain is shown in Figure 17.

The parameters for the subbasins and reaches were computed after the model domain was created. There are several methods available for different calculation types for each subbasin and reach hydrologic elements. The methods used for this study is shown in Table 1. The necessary parameter values are determined by the selected methods. The initial abstraction, curve number, percentage impervious and manning's coefficient of roughness, n , for each subbasin were computed based on the soil type, land cover and land use data. The subbasin time of concentration and storage coefficient were computed based on the analysis of the topography of the basin.

Methodology

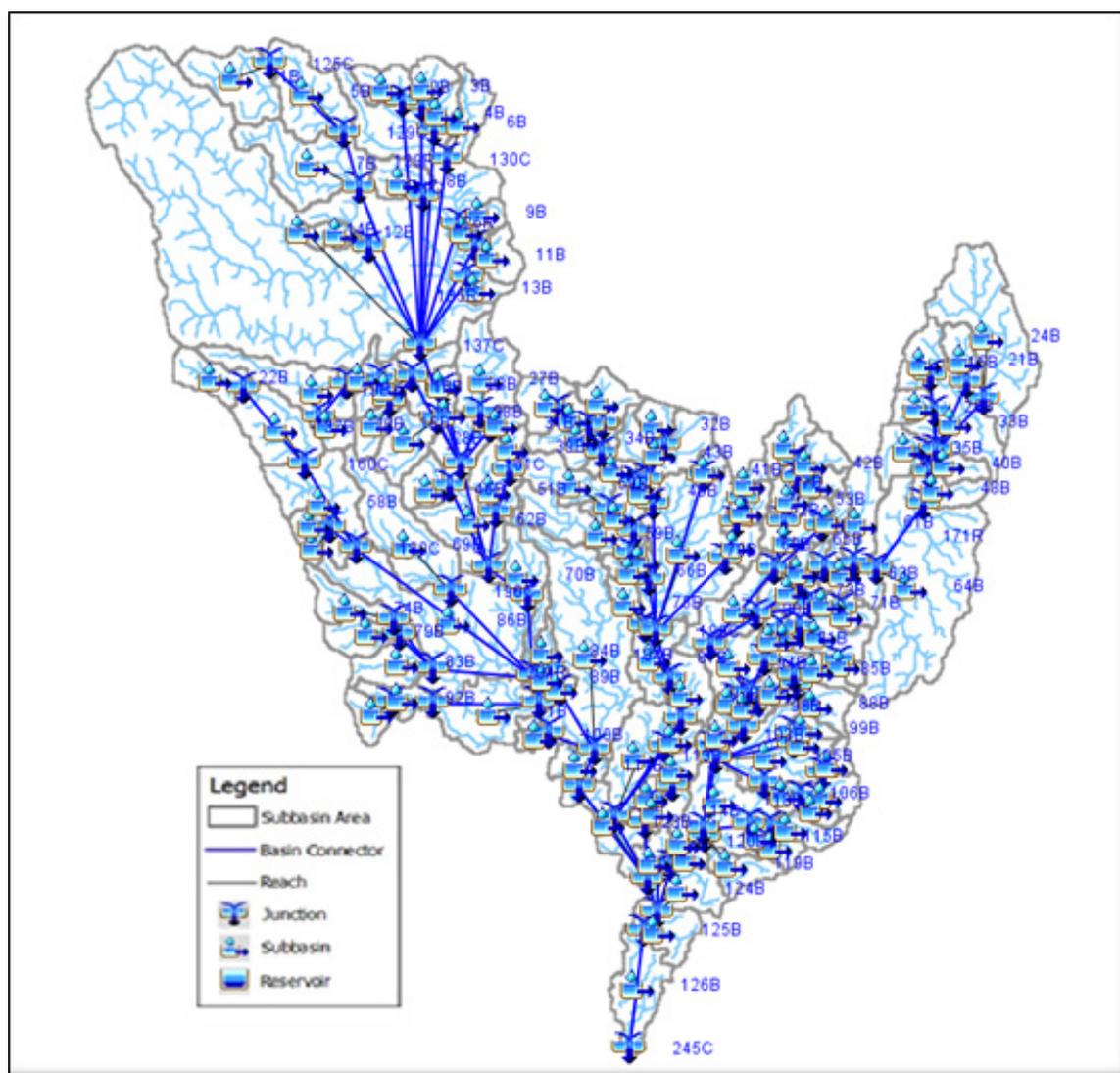


Figure 17. Tagum HEC-HMS Model domain generated by WMS

Table 1. Methods used for the different calculation types for the hydrologic elements

Hydrologic Element	Calculation Type	Method
Subbasin	Loss Rate	SCS Curve Number
	Transform	Clark's unit hydrograph
	Baseflow	Bounded recession
Reach	Routing	Muskingum-Cunge

Methodology

3.2.2 Basin Model Calibration

The basin model made using WMS was exported to Hydrologic Modeling System (HEC-HMS) version 3.5, a software made by the Hydrologic Engineering Center of the US Army Corps of Engineers, to create the final rainfall-runoff model. The developers described HEC-HMS as a program designed to simulate the hydrologic processes of a dendritic watershed systems. In this study, the rainfall-runoff model was developed to calculate inflow from the watershed to the floodplain.

Precipitation data was taken from three automatic rain gauges (ARGs) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). These were the New Corella and Talaingod ARGs. The location of the rain gauges is seen in Figure 18.

For the calibration of Asuncion, the total rain from New Corella rain gauge is 23.876 mm. It peaked to 11.176 mm. on 30 November 2013 16:30. The lag time between the peak rainfall and discharge is 15 hours. For the calibration of Talaingod, the total rain for this event is 87.46 mm. Peak rain of 2.79 mm. was recorded on 11 January 2014 1:20. The lag time between the peak rainfall and discharge is 1 day and 2 hours.



Methodology

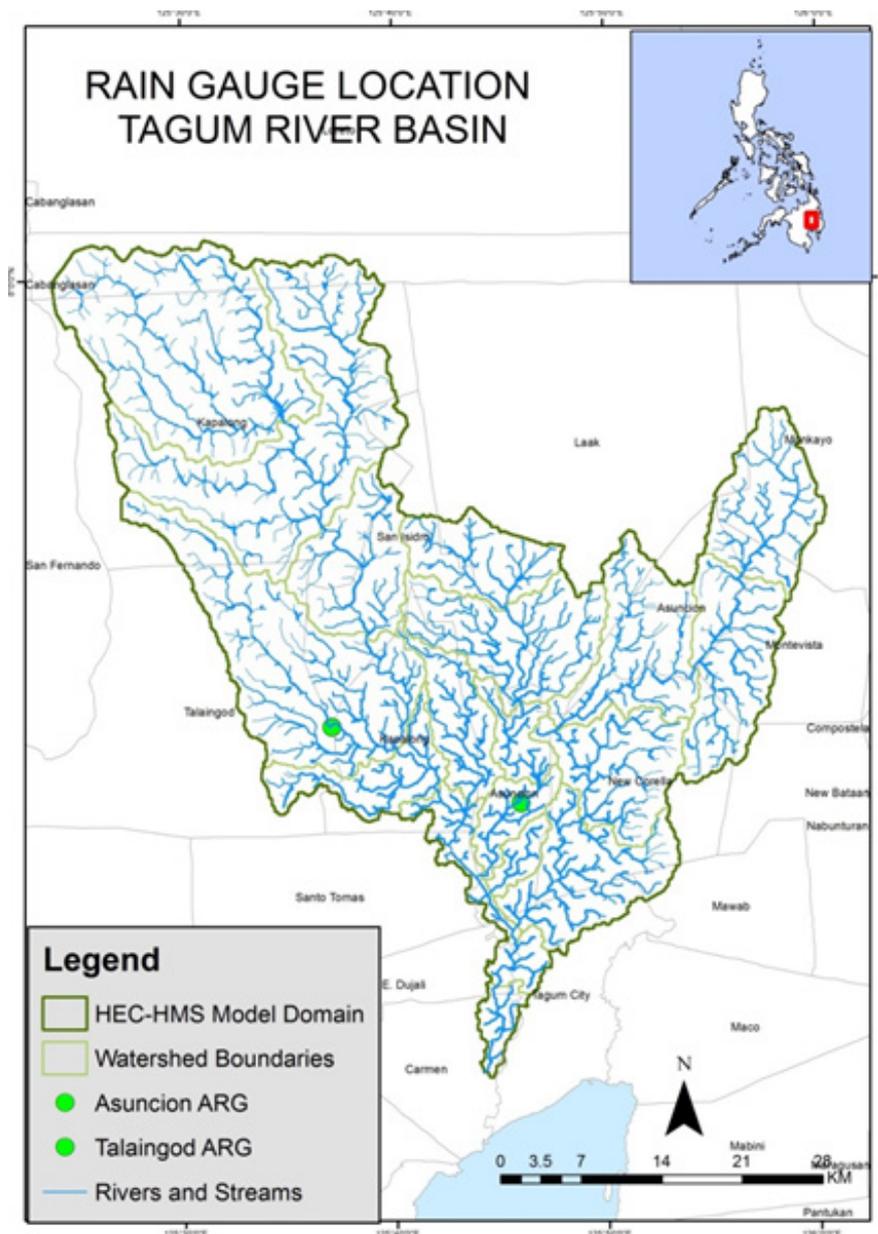


Figure 18. The location map of rain gauges used for the calibration of the Tagum HEC-HMS model

The outflow hydrograph for the downstream-most discharge point with field data was also encoded to the model as a basis for the calibration. Using the said data, HEC-HMS could perform rainfall-runoff simulation and the resulting outflow hydrograph was compared with the observed hydrograph. The values of the parameters were adjusted and optimized in order for the calculated outflow hydrograph to appear like the observed hydrograph. Acceptable values of the subbasin and reach parameters from the manual and past literatures were considered in the calibration.

After the calibration of the downstream-most discharge point, model calibration of the discharge points along the major tributaries of the main river/s were also performed (see Applications).

Methodology

3.3 HEC-HMS Hydrologic Simulations for Discharge Computations using PAGASA RIDF Curves

3.3.1 Discharge Computation using Rainfall-Runoff Hydrologic Model

The calibrated rainfall-Runoff Hydrologic Model for the Tagum River Basin using WMS and HEC-HMS was used to simulate the flow for for the five return periods, namely, 5-, 10-, 25-, 50-, and 100-year RIDFs. Time-series data of the precipitation data using the Davao RIDF curves were encoded to HEC-HMS for the aforementioned return periods, wherein each return period corresponds to a scenario. This process was performed for all discharge points – Mahayahay Bridge and Nanaga Bridge. The output for each simulation was an outflow hydrograph from that result, the total inflow to the floodplain and time difference between the peak outflow and peak precipitation could be determined.

3.3.2 Discharge Computation using Dr. Horritt’s Recommended Hydrological Method

The required data to be accumulated for the implementation of Dr. Horritt’s method is shown on Figure 19.

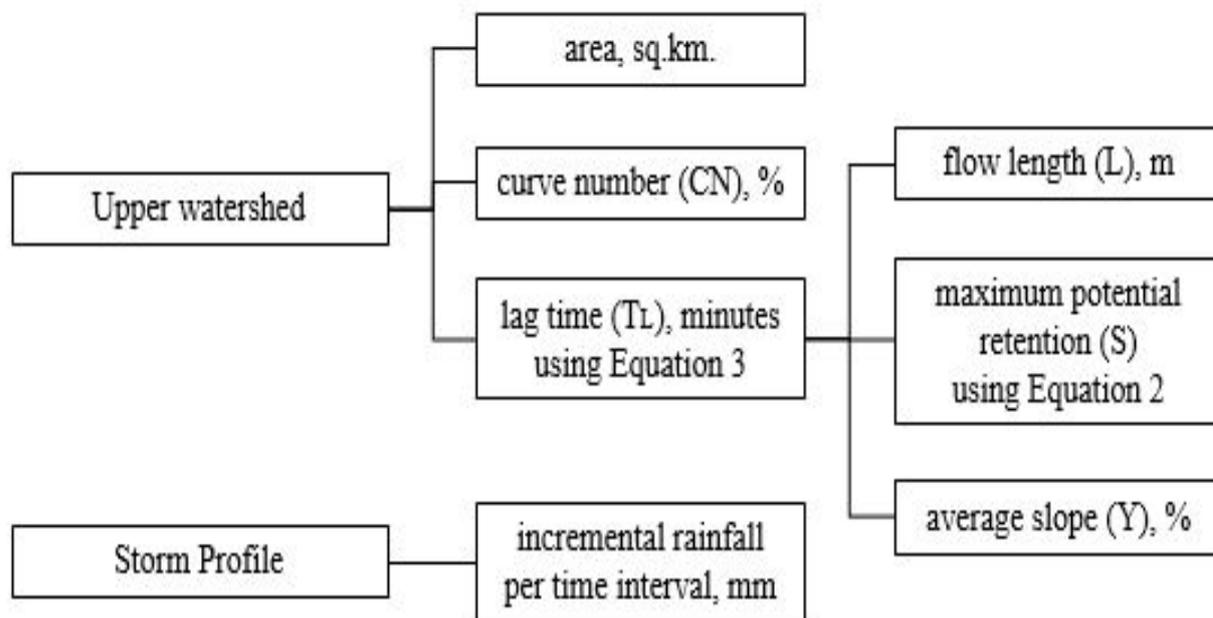


Figure 19. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt’s recommended hydrology method.

Methodology

Flows from streams were computed using the hydrology method developed by the flood modeling component with Dr. Matt Horritt, a British hydrologist that specializes in flood research. The methodology was based on an approach developed by CH2M Hill and Horritt Consulting for Taiwan which has been successfully validated in a region with meteorology and hydrology similar to the Philippines. It utilizes the SCS curve number and unit hydrograph method to have an accurate approximation of river discharge data from measurable catchment parameters.

3.3.2.1 Determination of Catchment Properties

RADARSAT DTM data for the different areas of the Philippines were compiled with the aid of ArcMap. RADARSAT satellites provide advance geospatial information and these were processed in the forms of shapefiles and layers that are readable and can be analyzed by ArcMap. These shapefiles are digital vectors that store geometric locations.

The watershed flow length is defined as the longest drainage path within the catchment, measured from the top of the watershed to the point of the outlet. With the tools provided by the ArcMap program and the data from RADARSAT DTM, the longest stream was selected and its geometric property, flow length, was then calculated in the program.

The area of the watershed is determined with the longest stream as the guide. The compiled RADARSAT data has a shapefile with defined small catchments based on mean elevation. These parameters were used in determining which catchments, along with the area, belong in the upper watershed.

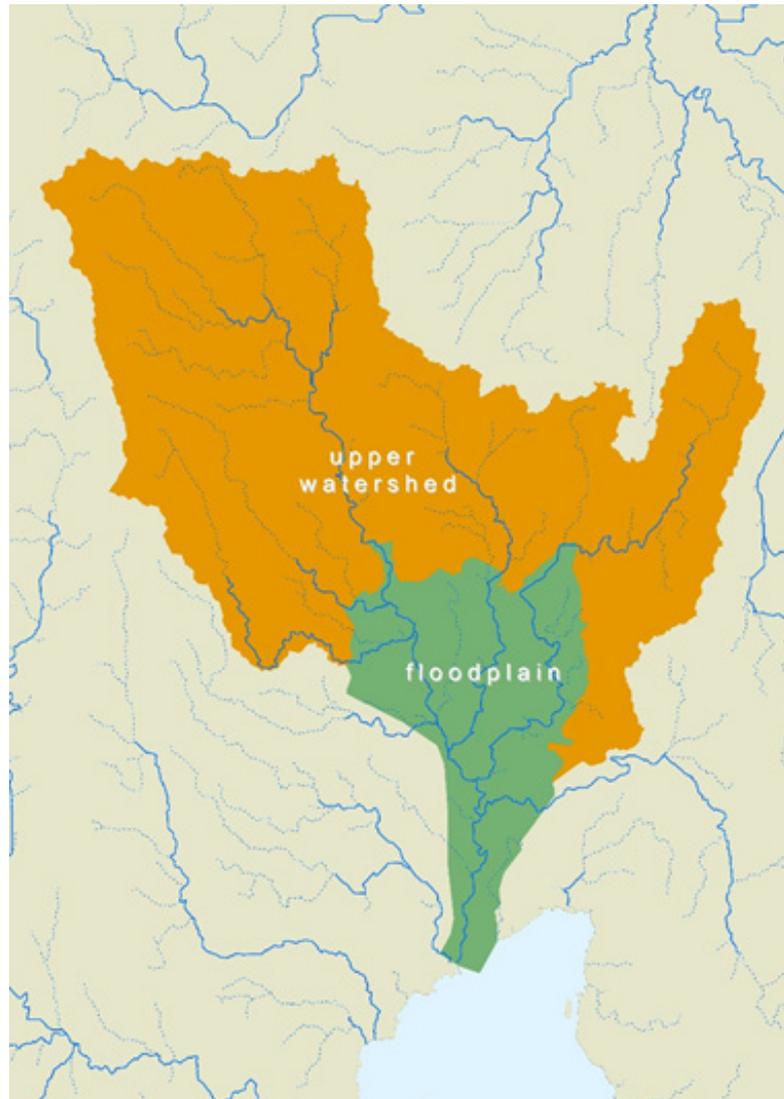


Figure 20. Delineation upper watershed for Tagum floodplain discharge computation

Methodology

The value of the curve number was obtained using the RADARSAT data that contains information of the Philippine national curve number map. An ArcMap tool was used to determine the average curve number of the area bounded by the upper watershed shapefile. The same method was implemented in determining the average slope using RADARSAT with slope data for the whole country.

After determining the curve number (CN), the maximum potential retention (S) was determined by Equation 2.

$$S = \frac{1000}{CN} - 10$$

Equation 2. Determination of maximum potential retention using the average curve number of the catchment

The watershed length (L), average slope (Y) and maximum potential retention (S) are used to estimate the lag time of the upper watershed as illustrated in Equation 3.

$$T_L = \frac{L^{0.8}(S + 1)^{0.7}}{560Y^{0.5}}$$

Equation 3. Lag Time Equation Calibrated for Philippine Setting

Finally, the final parameter that will be derived is the storm profile. The synoptic station which covers the majority of the upper watershed was identified. Using the RIDF data, the incremental values of rainfall in millimeter per 0.1 hour was used as the storm profile.

3.3.2.2 HEC-HMS Implementation

With all the parameters available, HEC-HMS was then utilized. Obtained values from the previous section were used as input and a brief simulation would result in the tabulation of discharge results per time interval. The maximum discharge and time-to-peak for the whole simulation as well as the river discharge hydrograph were used for the flood simulation process. The time series results (discharge per time interval) were stored as HYD files for input in FLO-2D GDS Pro.

Methodology

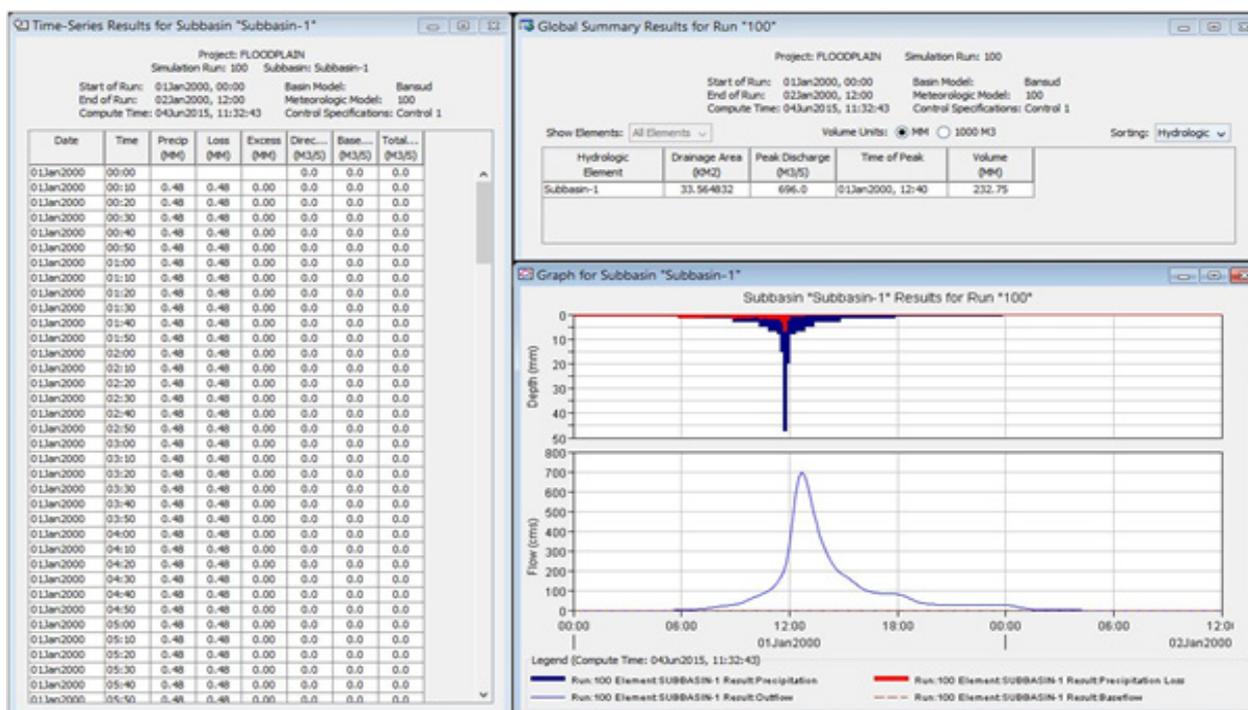


Figure 21. HEC-HMS simulation discharge results using Dr. Horritt’s Method

3.3.2.3 Discharge validation against other estimates

As a general rule, the river discharge of a 2-year rain return, Q_{MED} , should approximately be equal to the bankful discharge, $Q_{bankful}$, of the river. This assumes that the river is in equilibrium, with its deposition being balanced by erosion. Since the simulations of the river discharge are done for 5-, 25-, and 100-year rainfall return scenarios, a simple ratio for the 2-year and 5-year return was computed with samples from actual discharge data of different rivers. It was found out to have a constant of 0.88. This constant, however, should still be continuously checked and calibrated when necessary.

$$Q_{MED} = 0.88Q_{5yr}$$

Equation 4. Ratio of river discharge of a 5-year rain return to a 2-year rain return scenario from measured discharge data

For the discharge calculation to pass the validation using the bankful method, Equation 5 must be satisfied.

$$50\% Q_{bankful} \leq Q_{MED} \leq 150\% Q_{bankful}$$

Equation 5. Discharge validation equation using bankful method

The bankful discharge was estimated using channel width (w), channel depth (h), bed slope (S) and Manning’s constant (n). Derived from the Manning’s Equation, the equation for the bankful discharge is by Equation 6.



$$Q_{bankful} = \frac{(wh)^{\frac{5}{3}} S^{\frac{1}{2}}}{n(w + 2h)^{\frac{2}{3}}}$$

Equation 6. Bankful discharge equation using measurable channel parameters

3.4 Hazard and Flow Depth Mapping using FLO-2D

3.4.1 Floodplain Delineation

The boundaries of subbasins within the floodplain were delineated based on elevation values given by the DEM. Each subbasin is marked by ridges dividing catchment areas. These catchments were delineated using a set of ArcMap tools compiled by Al Duncan, a UK Geomatics Specialist, into a single processing model. The tool allows ArcMap to compute for the flow direction and acceleration based on the elevations provided by the DEM.

Running the tool creates features representing large, medium-sized, and small streams, as well as large, medium-sized, and small catchments. For the purpose of this particular model, the large, medium-sized, and small streams were set to have an area threshold of 100,000sqm, 50,000sqm, and 10,000sqm respectively. These thresholds define the values where the algorithm refers to in delineating a trough in the DEM as a stream feature, i.e. a large stream feature should drain a catchment area totalling 100,000 sqm to be considered as such. These values differ from the standard values used (10,000sqm, 1,000 sqm and 100sqm) to limit the detail of the project, as well as the file sizes, allowing the software to process the data faster.

The tool also shows the direction in which the water is going to flow across the catchment area. This information was used as the basis for delineating the floodplain. The entire area of the floodplain was subdivided into several zones in such a way that it can be processed properly. This was done by grouping the catchments together, taking special account of the inflows and outflows of water across the entire area. To be able to simulate actual conditions, all the catchments comprising a particular computational domain were set to have outflows that merged towards a single point. The area of each subdivision was limited to 250,000 grids or less to allow for an optimal simulation in FLO-2D GDS Pro. Larger models tend to run longer, while smaller models may not be as accurate as a large one.

3.4.2 Flood Model Generation

The software used to run the simulation is FLO-2D GDS Pro. It is a GIS integrated software tool that creates an integrated river and floodplain model by simulating the flow of the water over a system of square grid elements.

After loading the shapefile of the subcatchment onto FLO-2D, 10 meter by 10 meter grids that encompassed the entire area of interest were created.

The boundary for the area was set by defining the boundary grid elements. This can either be

Methodology

done by defining each element individually, or by drawing a line that traces the boundaries of the subcatchment. The grid elements inside of the defined boundary were considered as the computational area in which the simulation will be run.

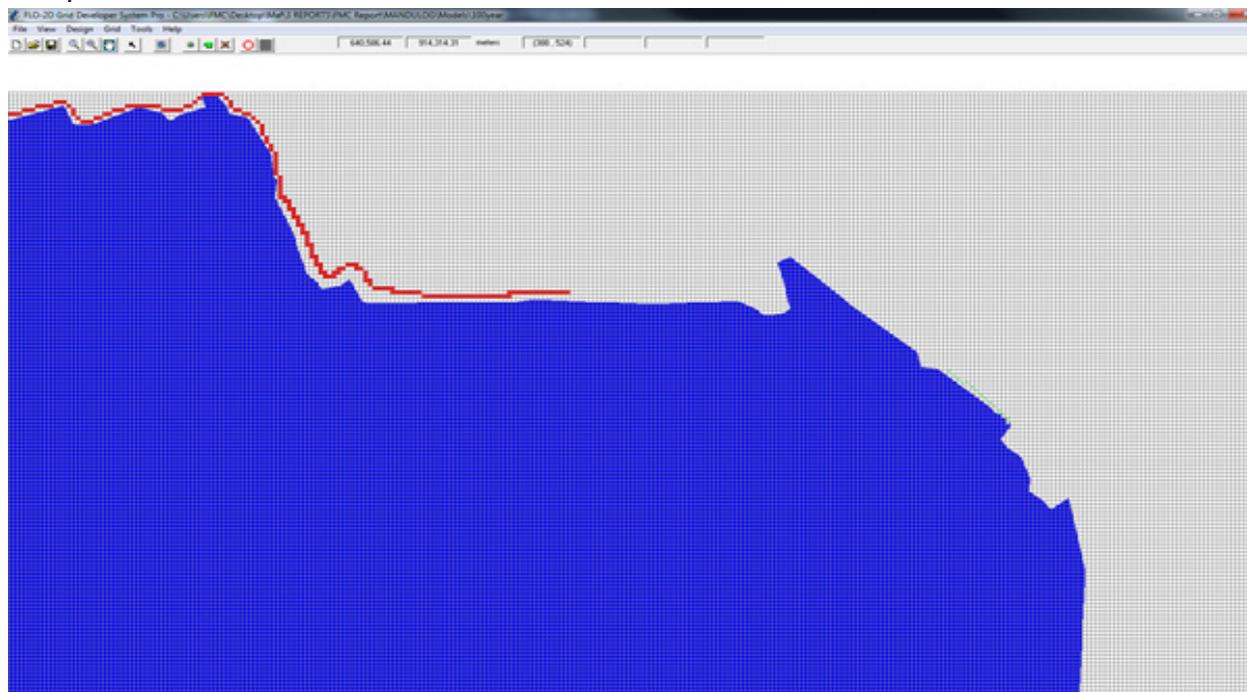


Figure 22. Screenshot showing how boundary grid elements are defined by line Elevation data was imported in the form of the DEM gathered through LiDAR. These elevation points in PTS format were extrapolated into the model, providing an elevation value for each grid element.

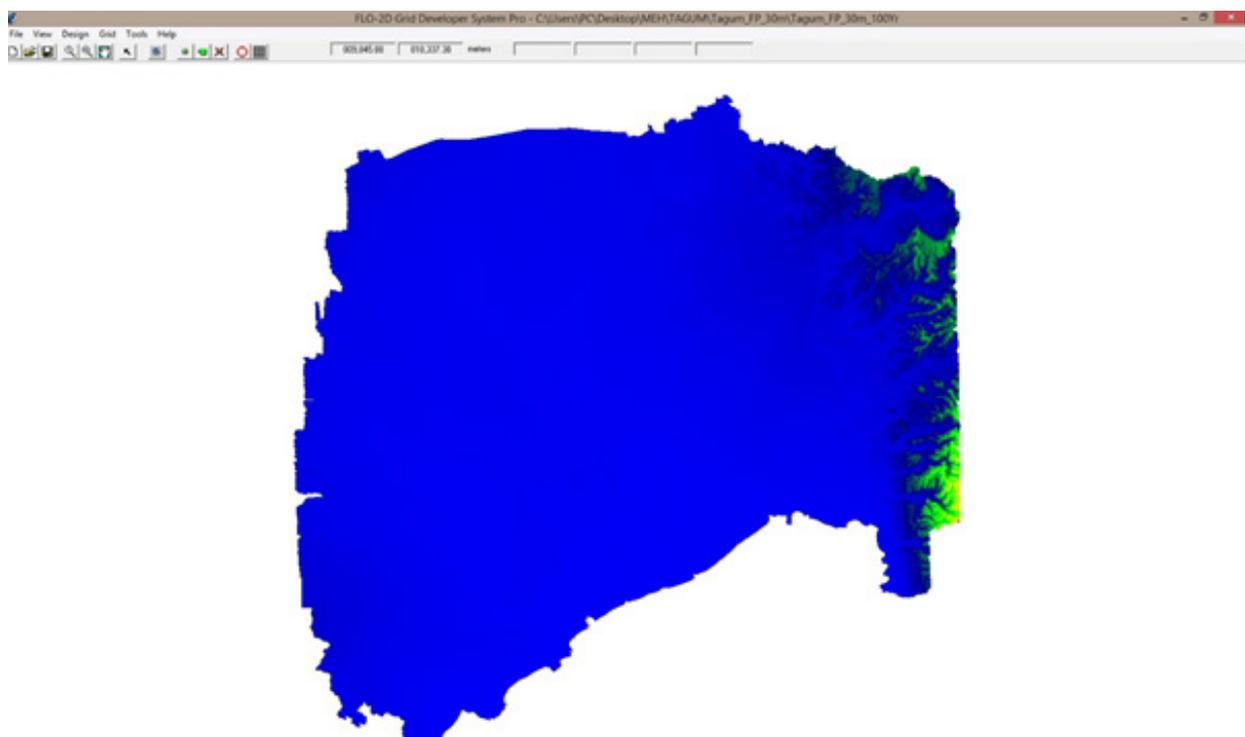


Figure 23. Screenshots of PTS files when loaded into the FLO-2D program

Methodology

The floodplain is predominantly composed of rice fields, which have a Manning coefficient of 0.15. All the inner grid elements were selected and the Manning coefficient of 0.15 was assigned. To differentiate the streams from the rest of the floodplain, a shapefile containing all the streams and rivers in the area were imported into the software. The shapefile was generated using Al Duncan's catchment tool for ArcMap. The streams were then traced onto their corresponding grid elements.

These grid elements were all selected and assigned a Manning coefficient of 0.03. The DEM and aerial imagery were also used as bases for tracing the streams and rivers.

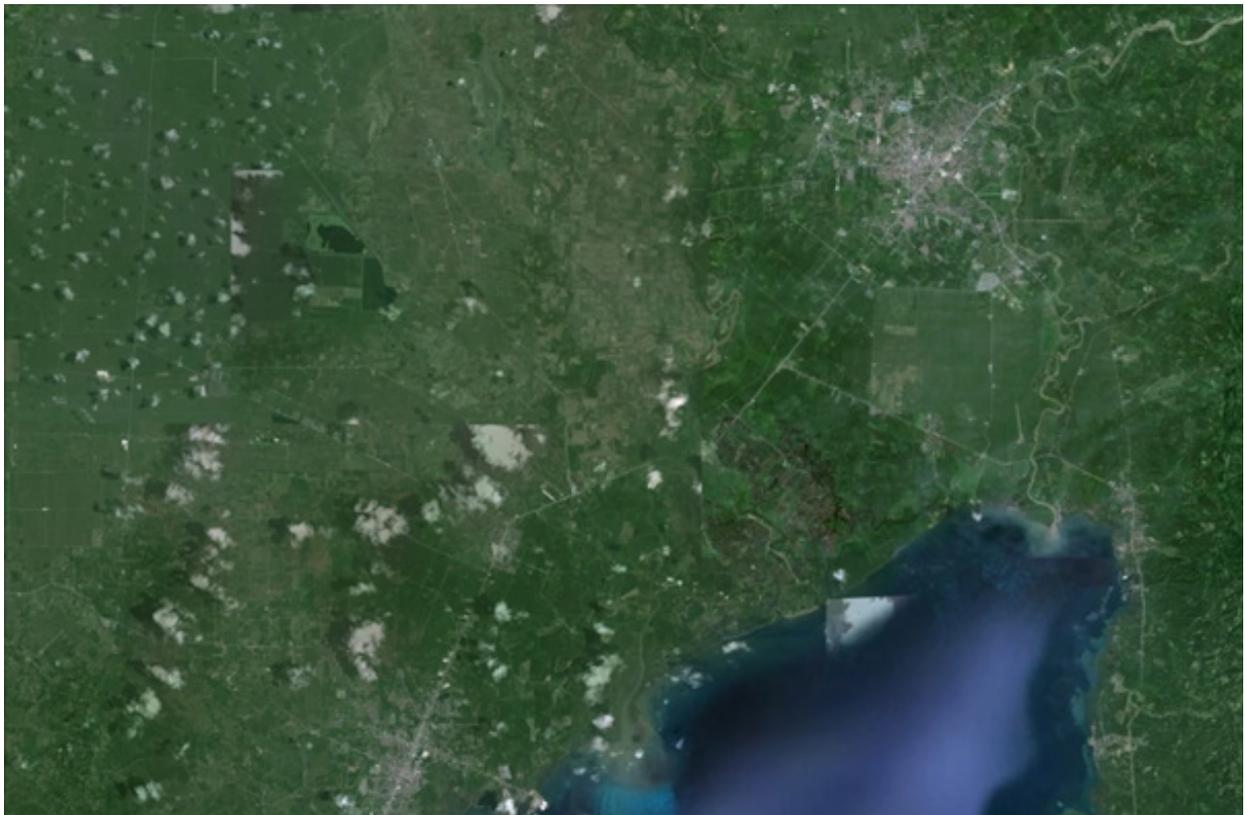


Figure 24. Areal image of Tagum floodplain

Methodology

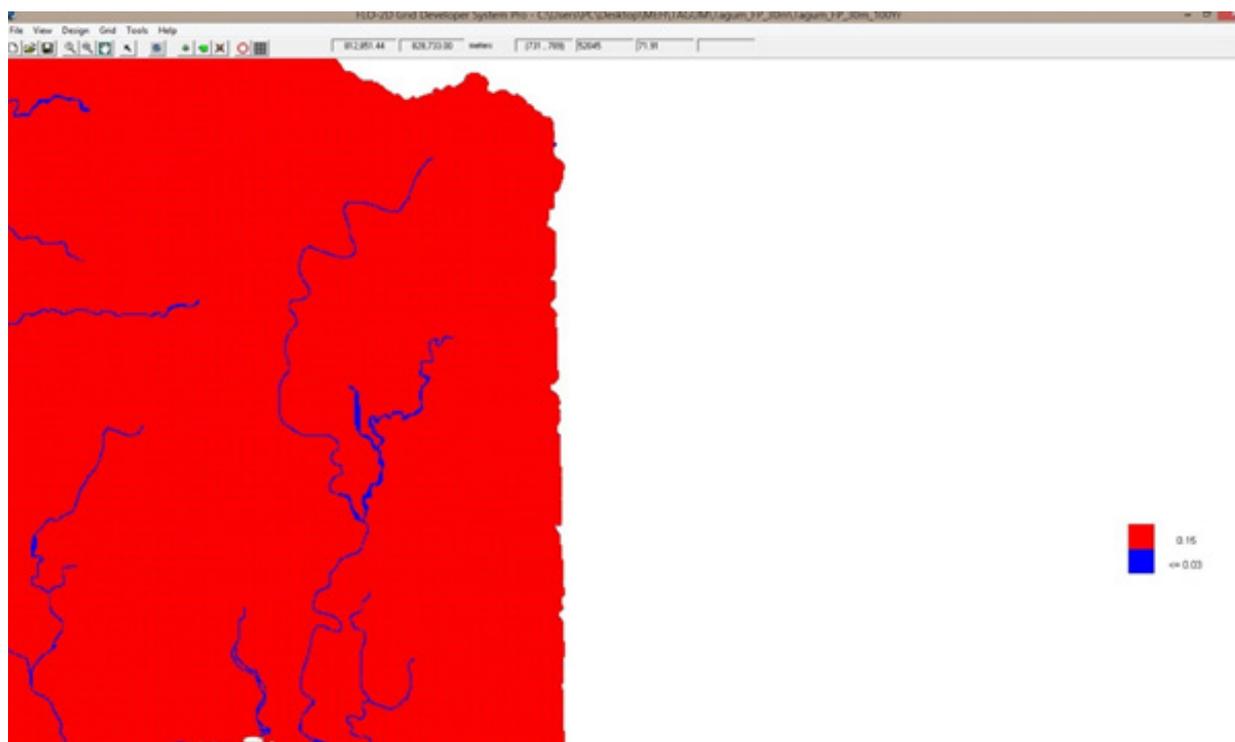


Figure 25. Screenshot of Manning’s n-value rendering

After assigning Manning coefficients for each grid, the infiltration parameters were identified. Green-Ampt infiltration method by W. Heber Green and G.S Ampt were used for all the models. The initial saturations applied to the model were 0.99, 0.8, and 0.7 for 100-year, 25-year, and 5-year rain return periods respectively. These initial saturations were used in the computation of the infiltration value.

The Green-Ampt infiltration method by W. Heber Green and G.S Ampt method is based on a simple physical model in which the equation parameter can be related to physical properties of the soil. Physically, Green and Ampt assumed that the soil was saturated behind the wetting front and that one could define some “effective” matric potential at the wetting front (Kirkham, 2005). Basically, the system is assumed to consist of a uniformly wetted near-saturated transmission zone above a sharply defined wetting front of constant pressure head (Diamond & Shanley, 2003).

The next step was to allocate inflow nodes based on the locations of the outlets of the streams from the upper watershed. The inflow values came from the computed discharges that were input as hyd files.

Outflow nodes were allocated for the model. These outflow nodes show the locations where the water received by the watershed is discharged. The water that will remain in the watershed will result to flooding on low lying areas.

For the models to be able to simulate actual conditions, the inflow and outflow of each computational domain should be indicated properly. In situations wherein water flows from one subcatchment to the other, the corresponding models are processed one after the other. The

Methodology

outflow generated by the source subcatchment was used as inflow for the subcatchment area that it flows into.

The standard simulation time used to run each model is the time-to-peak (TP) plus an additional 12 hours. This gives enough time for the water to flow into and out of the model area, illustrating the complete process from entry to exit as shown in the hydrograph. The additional 12 hours allows enough time for the water to drain fully into the next subcatchment. After all the parameters were set, the model was run through FLO-2D GDS Pro.

3.4.3 Flow Depth and Hazard Map Simulation

After running the flood map simulation in FLO-2D GDS Pro, FLO-2D Mapper Pro was used to read the resulting hazard and flow depth maps. The standard input values for reading the simulation results are shown on Figure 24.

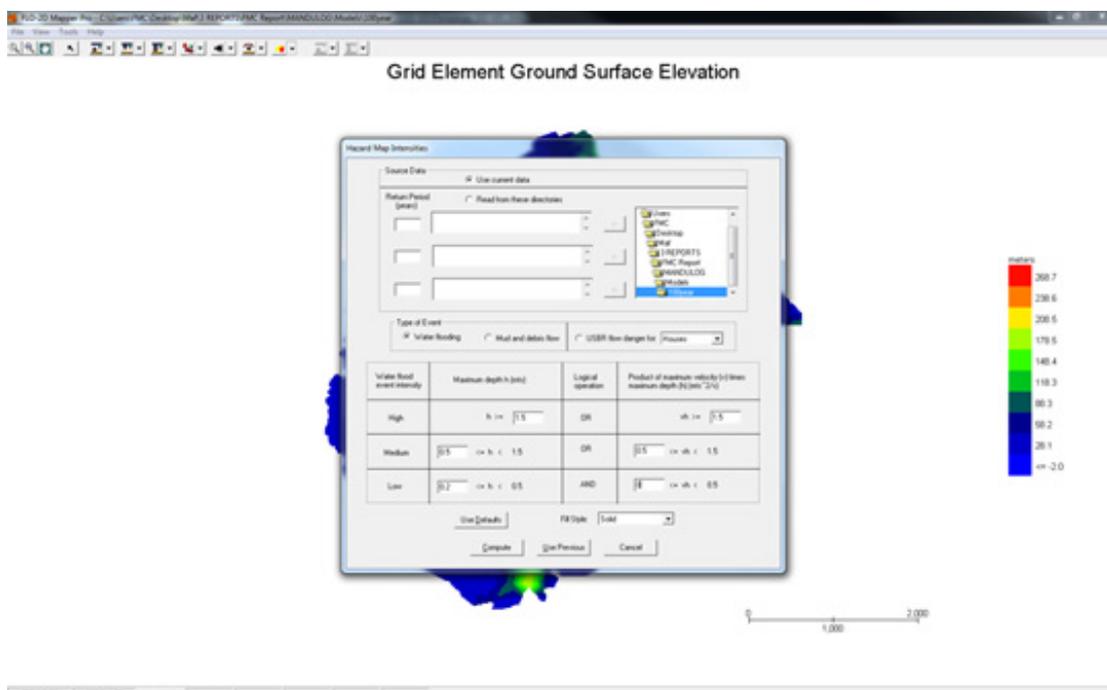


Figure 26. Flo-2D Mapper Pro General Procedure

In order to produce the hazard maps, set input for low maximum depth as 0.2 m, and vh , product of maximum velocity and maximum depth (m^2/s), as greater than or equal to zero. The program will then compute for the flood inundation and will generate shapefiles for the hazard and flow depth scenario.

Methodology

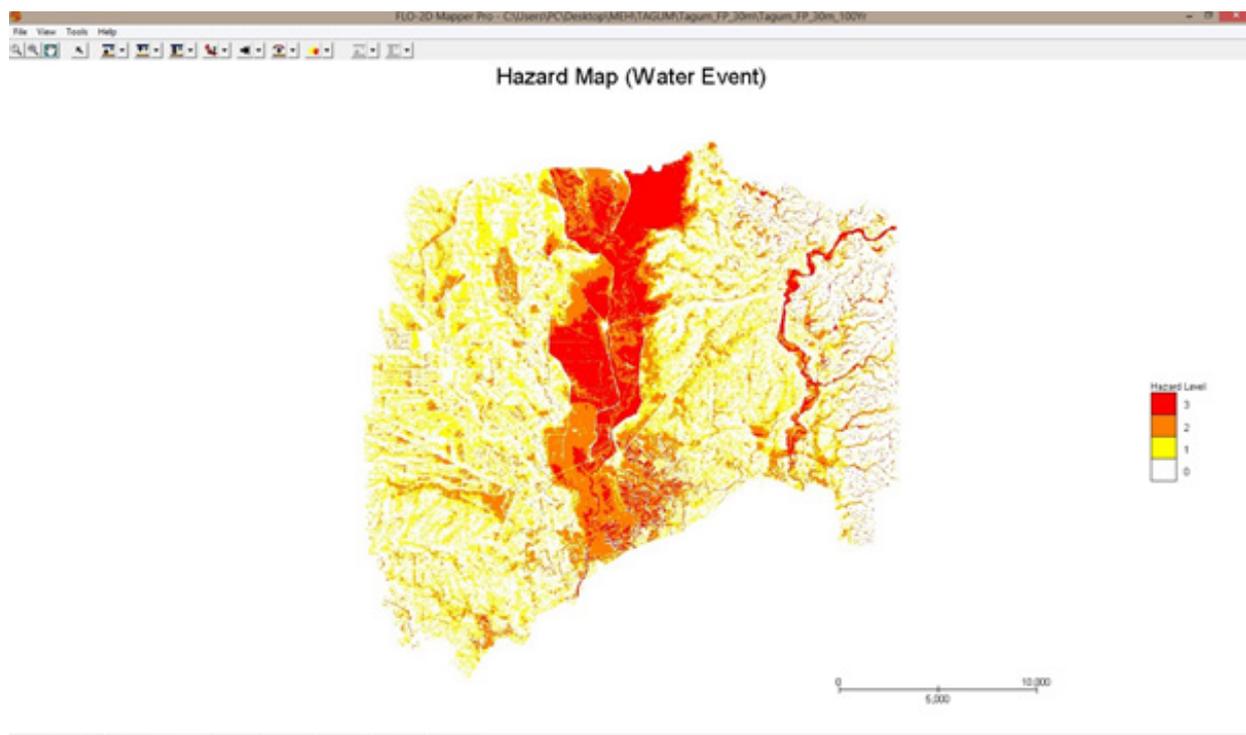


Figure 27. Tagum Floodplain Generated Hazard Maps using FLO-2D Mapper

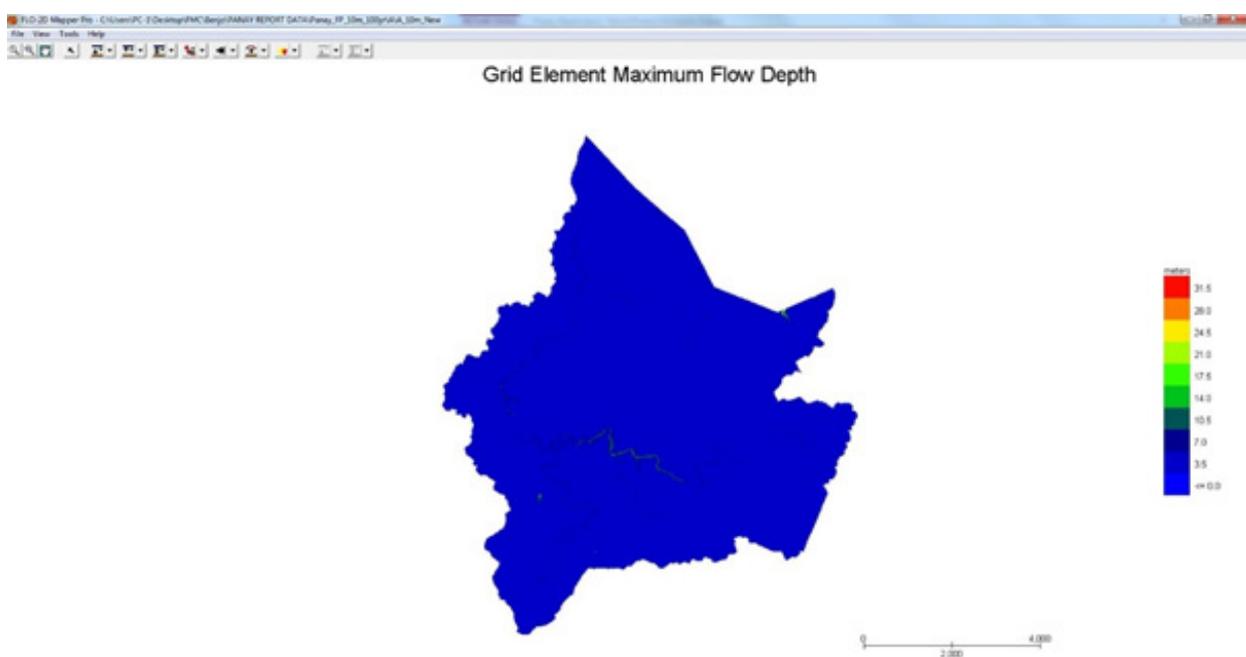
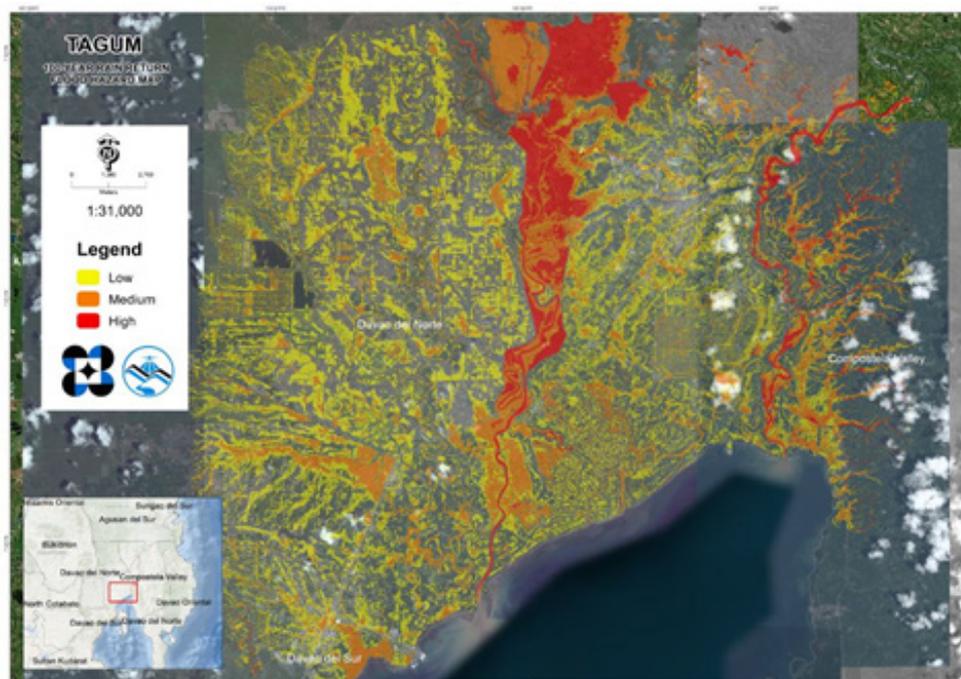


Figure 28. Tagum floodplain generated flow depth map using FLO-2D Mapper

Methodology

3.4.4 Hazard Map and Flow Depth Map Creation

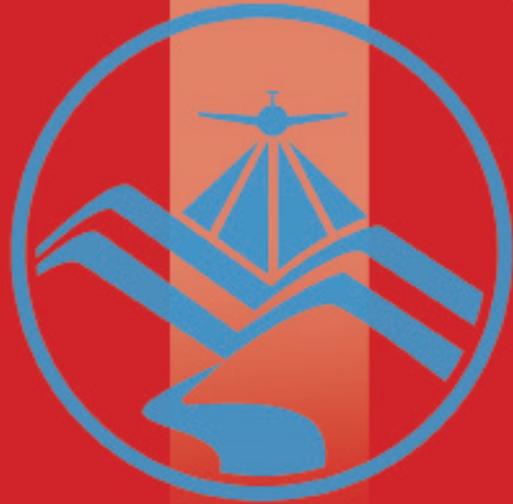
The final procedure in creating the maps is to prepare them with the aid of ArcMap. The generated shapefiles from FLO-2D Mapper Pro were opened in ArcMap. The basic layout of a hazard map is shown in Figure 27. The same map elements are also found in a flow depth map.



ELEMENTS:

1. River Basin Name
2. Hazard/Flow Depth Shapefile
3. Provincial Inset
4. Philippine Inset
5. Hi-Res image of the area
6. North Arrow
7. Scale Text and Bar

Figure 29. Basic Layout and Elements of the Hazard Maps



Results and Discussion

Results and Discussion

4.1 Efficiency of HEC-HMS Rainfall-Runoff Models calibrated based on field survey and gauges data

4.1.1 Mahayahay Bridge – Asuncion, Davao del Norte HEC-HMS Calibration Results

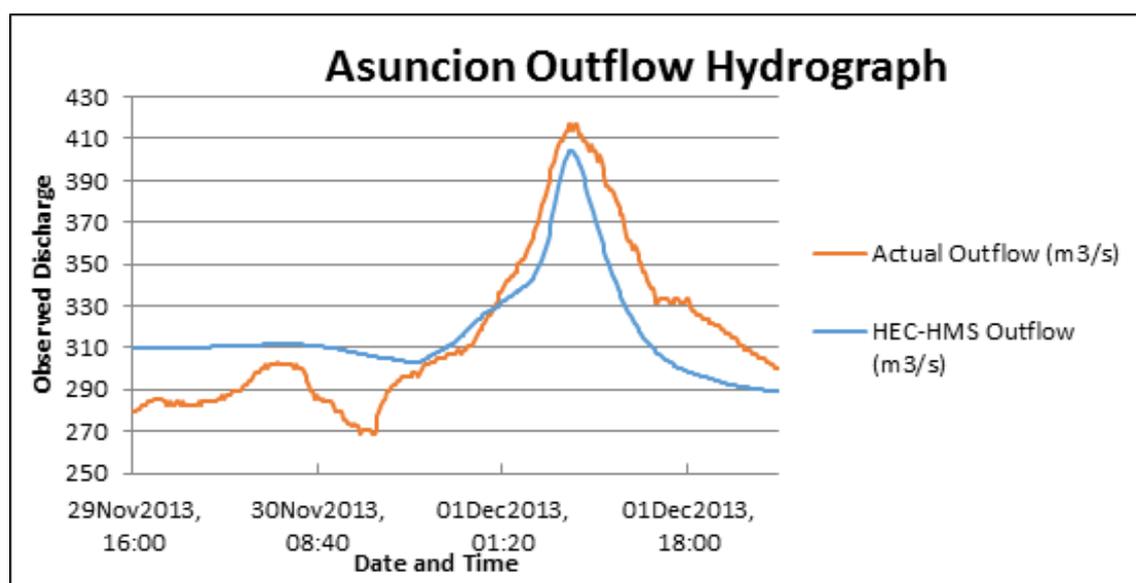


Figure 30. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow at Asuncion Bridge

After calibrating the Davao HEC-HMS river basin model, its accuracy was measured against the observed values. The comparison between the two discharge data are shown in Figure 30.

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 16.68.

The Pearson correlation coefficient (r^2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.998.

The Nash-Sutcliffe (E) method was also used to assess the predictive power of the model. Here the optimal value is 1. The model attained an efficiency coefficient of 0.84.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 0.41.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.4.

Results and Discussion

4.1.2 Nanaga Bridge – Talainod, Davao del Norte HEC-HMS Calibration Results

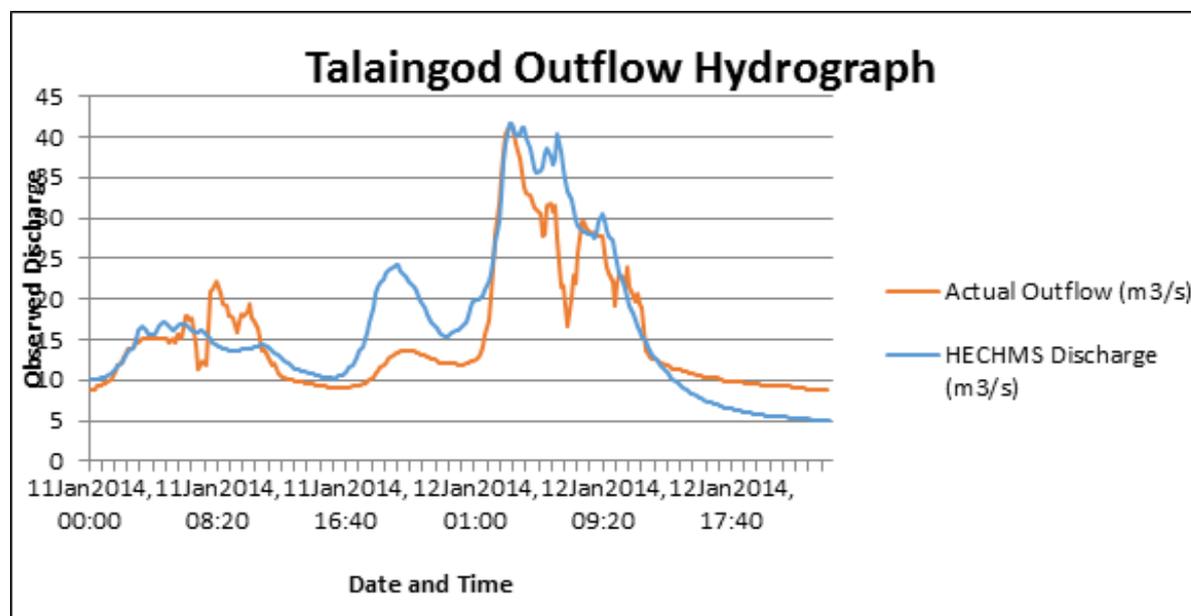


Figure 31. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow at Nanaga Bridge

After calibrating the Nanaga Bridge HEC-HMS river basin model, its accuracy was measured against the observed values and is shown in Figure 31.

For Talaingod, the RMSE is 4.7, the Pearson correlation coefficient, r_2 , is 0.866, it has a Nash-Sutcliffe E value of 0.6, PBIAS of -7.51 and RSR value of 0.63.

4.2 Application

The calibrated models of the other discharge points are used in flood forecasting. DREAM project offers the LGUs and other disaster mitigation agencies a water level forecast tool, which can be found on the DREAM website.

Results and Discussion

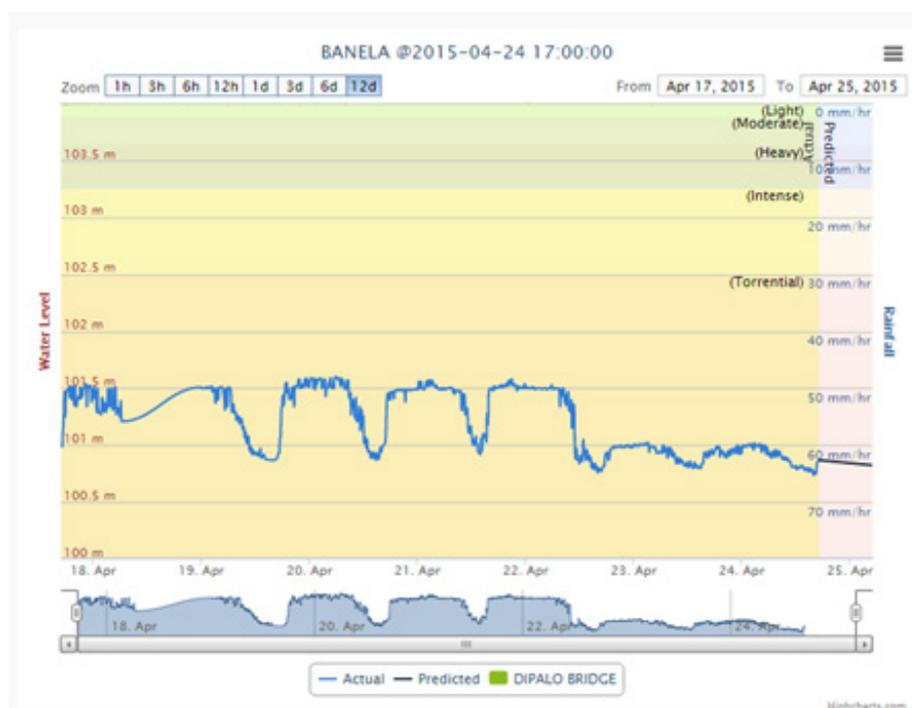


Figure 32. Sample DREAM Water Level Forecast

Given the predicted and real-time actual water level on specific AWLS, possible river flooding can be monitored and information can be disseminated to LGUs. This will help in the early evacuation of the probable affected communities. The calibrated models can also be used for flood inundation mapping.

4.3 Calculated Outflow hydrographs and Discharge Values for different Rainfall Return Periods

4.3.1 Hydrograph using the Rainfall-Runoff Model

4.3.1.1 Mahayahay, Asuncion Tagum

In the 5-year return period graph (Figure 33), the peak outflow is 1155.9 cms. This occurs after 11 hours and 40 minutes, and a precipitation of 19.30 mm.

Results and Discussion

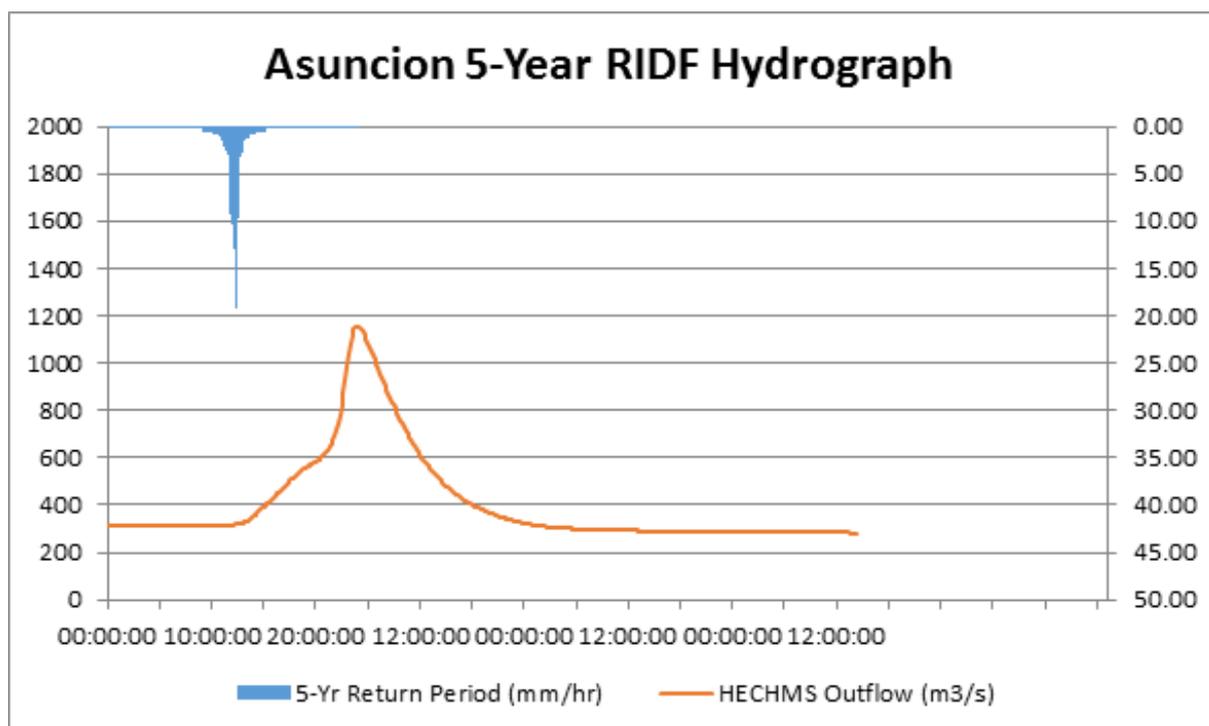


Figure 33. Outflow hydrograph generated using the Davao 5-Year RIDF inputted in HEC-HMS

In the 10-year return period graph (Figure 34), the peak outflow is 1314.7 cms. This occurs after 11 hours and 30 minutes, and a precipitation of 26.18 mm.

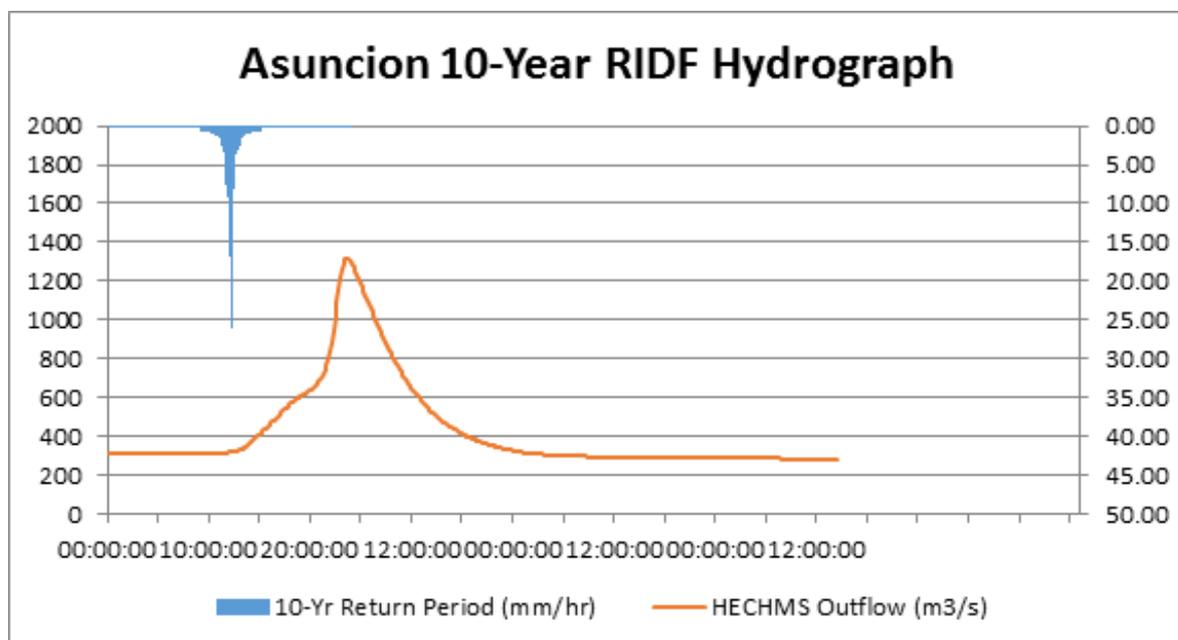


Figure 34. Outflow hydrograph generated using the Davao 10-Year RIDF inputted in HEC-HMS

Results and Discussion

In the 25-year return period graph (Figure 35), the peak outflow is 1515.6 cms. This occurs after 11 hours and 10 minutes, and a precipitation of 30.61 mm.

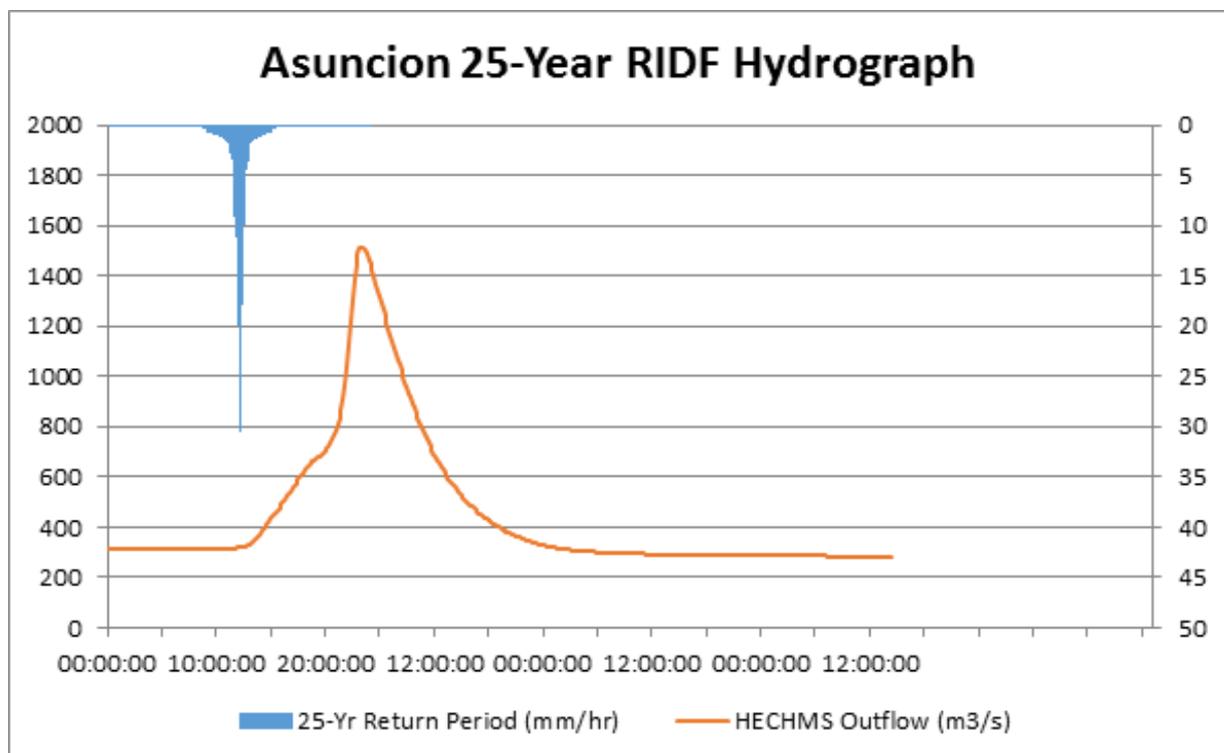


Figure 35. Outflow hydrograph generated using the Davao 25-Year RIDF inputted in HEC-HMS

In the 50-year return period graph (Figure 36), the peak outflow is 1666.1 cms. This occurs after 11 hours, and a precipitation of 33.82 mm.

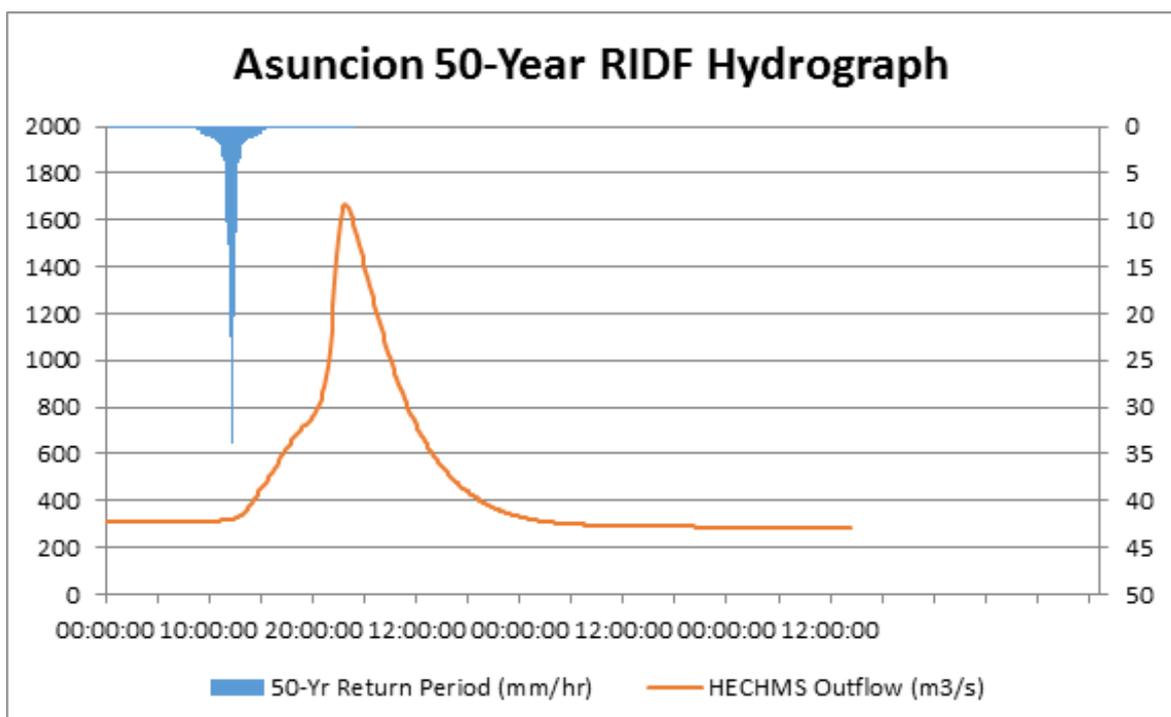


Figure 36. Outflow hydrograph generated using the Davao 50-Year RIDF inputted in HEC-HMS



Results and Discussion

In the 100-year return period graph (Figure 37), the peak outflow is 1816.5 cms. This occurs after 10 hours and 50 minutes, and a precipitation of 37.04 mm.

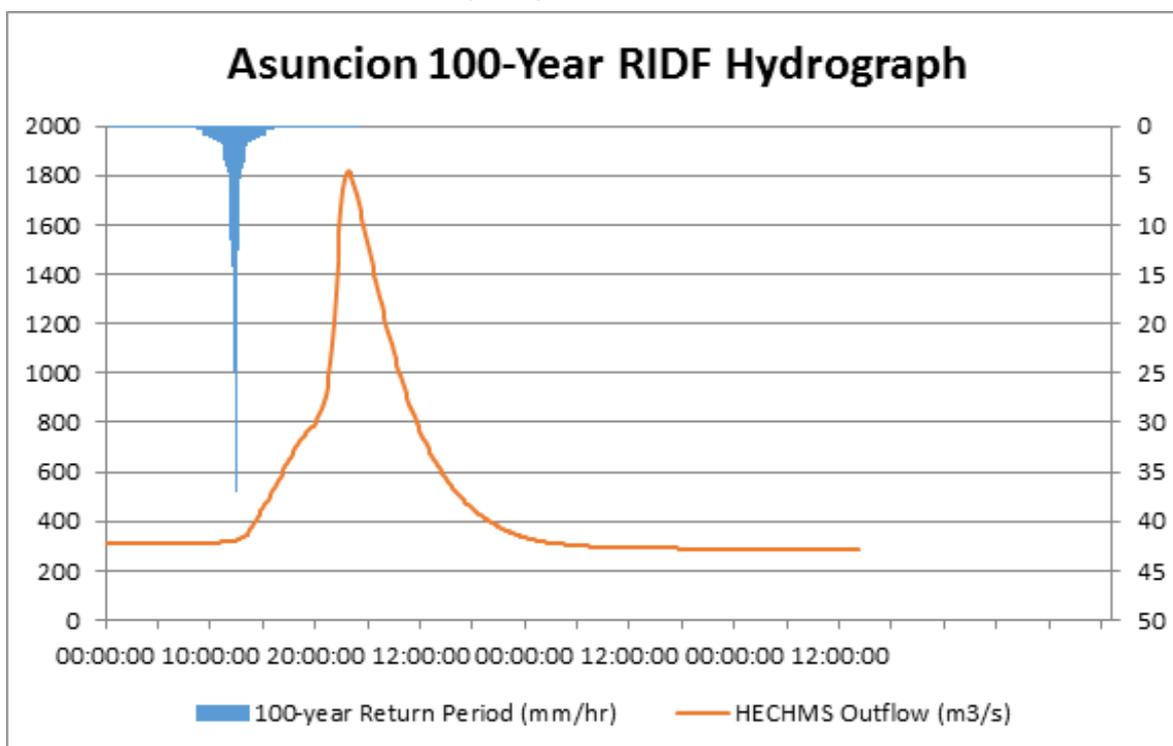


Figure 37. Outflow hydrograph generated using the Davao 100-Year RIDF inputted in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of Asuncion Tagum discharge using the Davao Rainfall Intensity Duration Frequency curves (RIDF) in five different return periods is shown in Table 2.

Table 2. Summary of peak values of the Asuncion Tagum outflow using the Davao RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	119.78	19.30	1155.9	11 hours
10-Year	139.17	26.18	1263.7	11 hours
25-Year	163.70	30.61	1445.7	10 hours, 40 minutes
50-Year	181.90	33.82	1597.2	10 hours, 40 minutes
100-Year	199.90	37.04	1787.9	10 hours, 40 minutes

Results and Discussion

4.3.1.2 Nanaga, Talaingon Tagum

In the 5-year return period graph (Figure 38), the peak outflow is 193 cms. This occurs after 1 hour, and a precipitation of 19.30 mm.

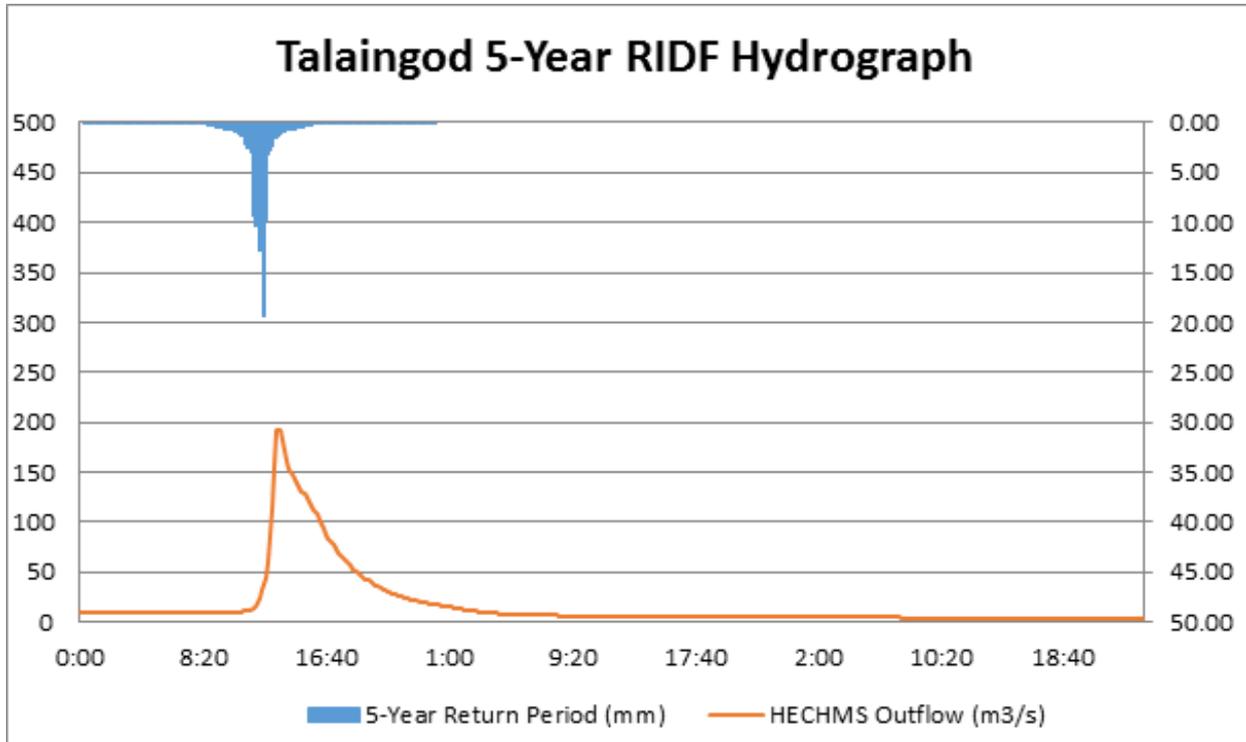


Figure 38. Outflow hydrograph generated using the Davao 5-Year RIDF inputted in HEC-HMS

In the 10-year return period graph (Figure 39), the peak outflow is 247.7 cms. This occurs after 1 hour, and a precipitation of 26.18 mm.

Results and Discussion

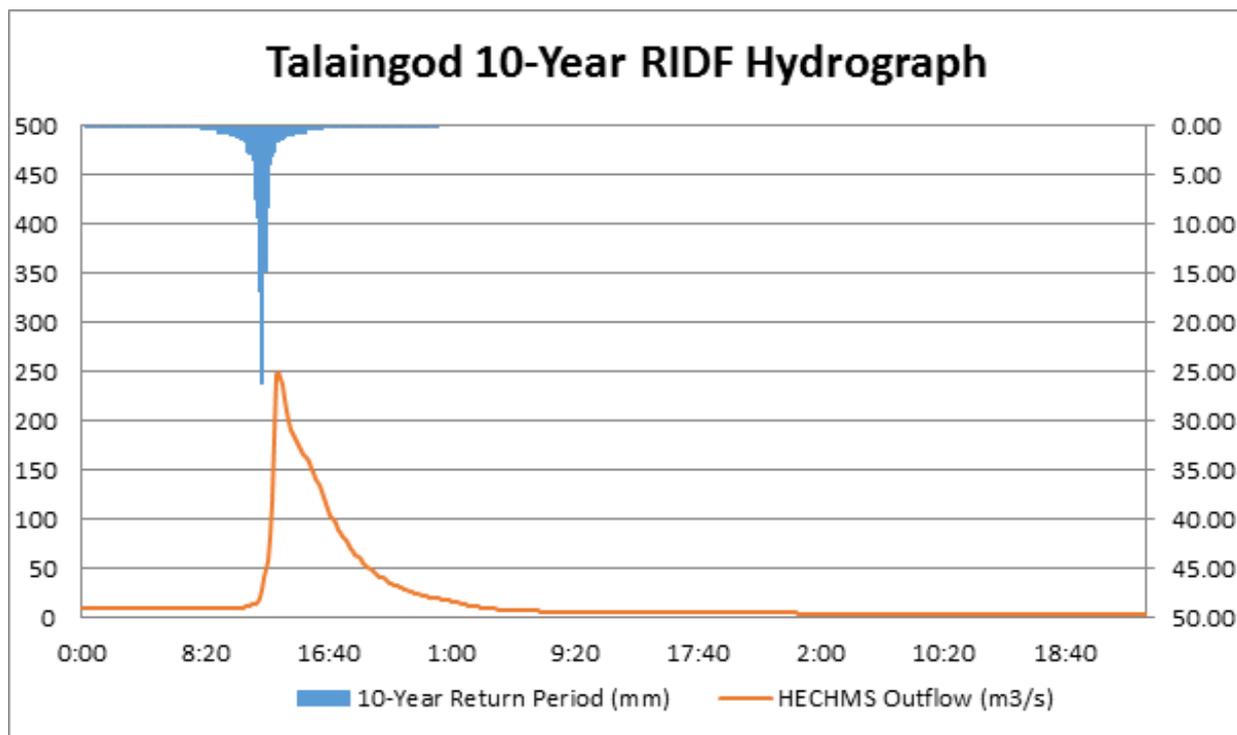


Figure 39. Outflow hydrograph generated using the Davao 10-Year RIDF inputted in HEC-HMS

In the 25-year return period graph (Figure 40), the peak outflow is 324.7 cms. This occurs after 1 hour, and a precipitation of 30.61 mm.

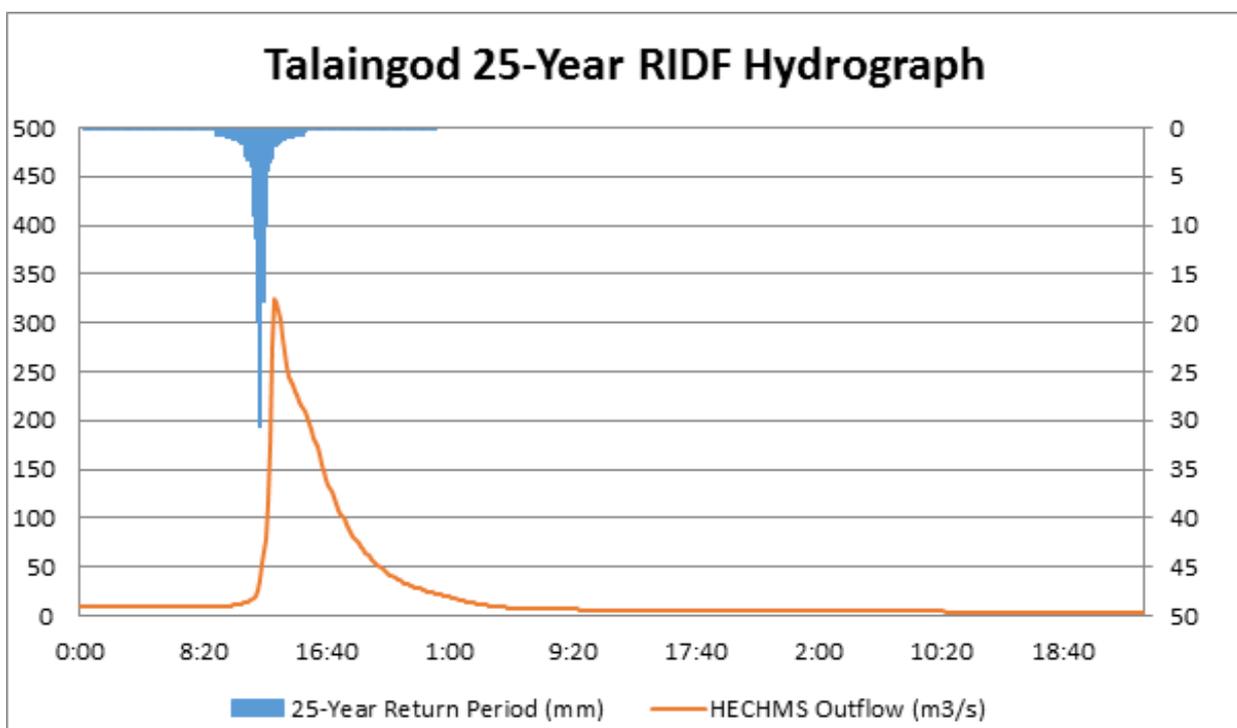


Figure 40. Outflow hydrograph generated using the Davao 25-Year RIDF inputted in HEC-HMS

Results and Discussion

In the 50-year return period graph (Figure 41), the peak outflow is 386.2 cms. This occurs after 50 minutes, and a precipitation of 33.82 mm.

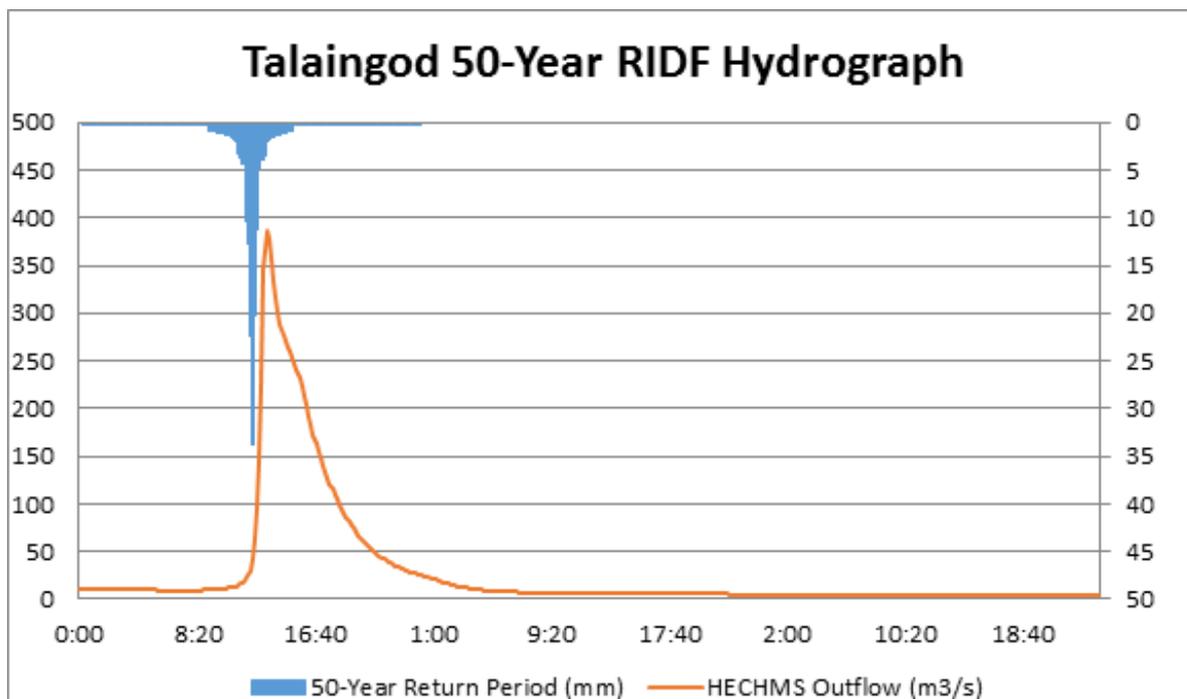


Figure 41. Outflow hydrograph generated using the Davao 50-Year RIDF inputted in HEC-HMS

In the 100-year return period graph (Figure 42), the peak outflow is 434.7 cms. This occurs after 50 minutes, and a precipitation of 37.04 mm.

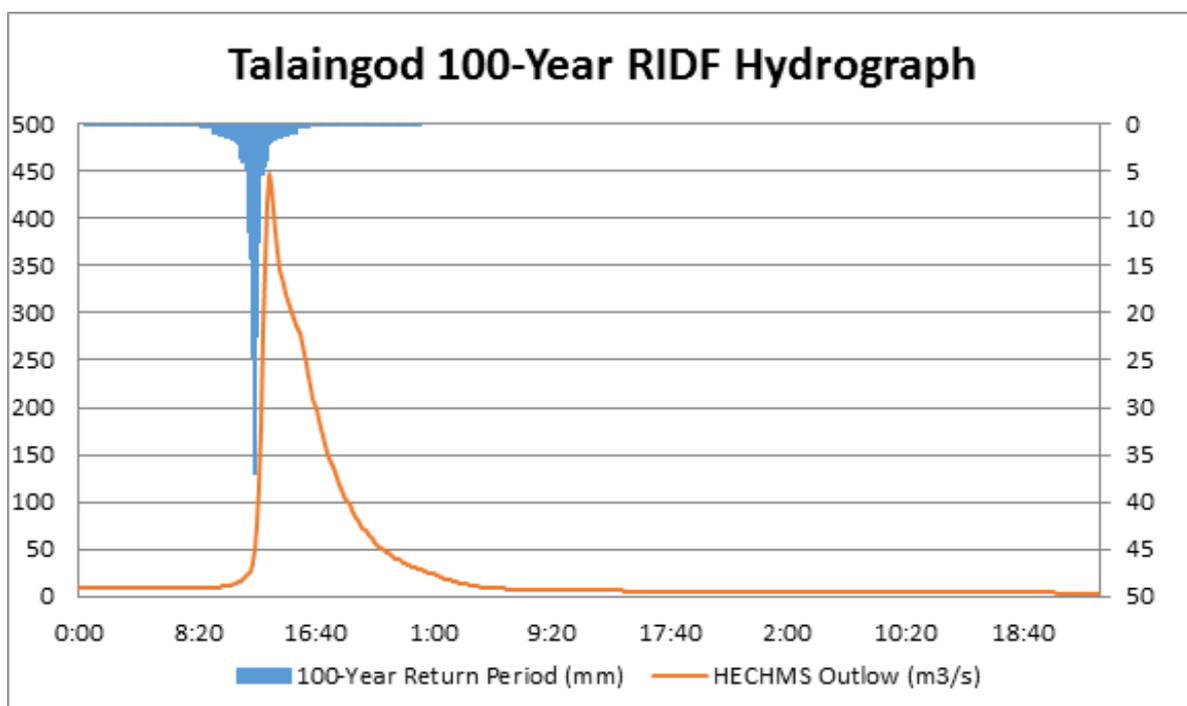


Figure 42. Outflow hydrograph generated using the Davao 100-Year RIDF inputted in HEC-HMS



Results and Discussion

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of Talaingod Tagum discharge using the Davao Rainfall Intensity Duration Frequency curves (RIDF) in five different return periods is shown in Table 3.

Table 3. Summary of peak values of the Talaingod Tagum outflow using the Davao RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	119.78	19.30	193	1 hour
10-Year	139.17	26.18	247.7	1 hour
25-Year	163.70	30.61	324.7	1 hour
50-Year	181.90	33.82	386.2	50 minutes
100-Year	199.90	37.04	434.7	50 minutes

Results and Discussion

4.3.2 Discharge Data using Dr. Horritt’s Recommended Hydrological Method

The river discharge values using Dr. Horritt’s recommended hydrological method are shown in Figure 43 and summarized in Table 4.

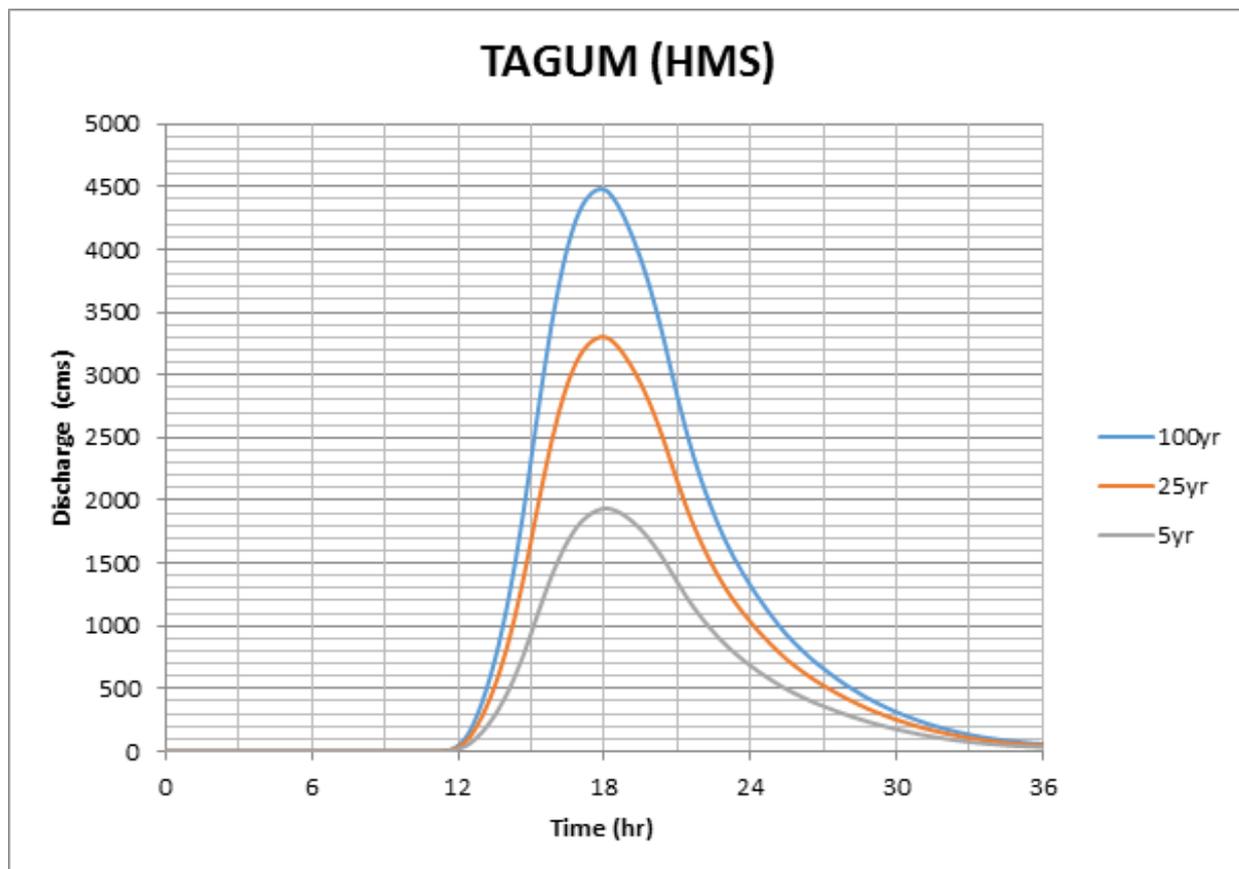


Figure 43. Outflow hydrograph generated for Tagum using the Malaybalay and Davao Stations’ 5-, 25-, and 100-year Rainfall Intensity Duration Frequency (RIDF) in HEC-HMS

Table 4. Summary of Tagum river discharge using the recommended hydrological method by Dr. Horritt

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	1,936.1	18 hours
25-Year	3,302.9	18 hours
100-Year	4,480.9	17 hours, 50 minutes

The comparison of discharge values obtained from HEC-HMS, QMED, and from the bankful discharge method, Qbankful, are shown in Table 5. Using values from the DTM of Tagum, the bankful discharge for the river was computed.



Results and Discussion

Table 5. Validation of river discharge estimate using the bankful method

Discharge Point	Qbankful, cms	QMED, cms	Validation
Tagum (1)	1,436.69	1,703.8	Pass

The value from the HEC-HMS discharge estimate was able to satisfy the condition for validating the computed discharge using the bankful method. Since the computed value is based on theory, the actual discharge values were still used for flood modeling but will need further investigation for the purpose of validation. It is recommended, therefore, to use the actual value of the river discharge for higher-accuracy modeling.

4.4 Flood Hazard and Flow Depth Maps

The following images are the hazard and flow depth maps for the 5-, 25-, and 100-year rain return scenarios of the Tagum river basin.

Results and Discussion

Flood Hazard Maps and Flow Depth Maps

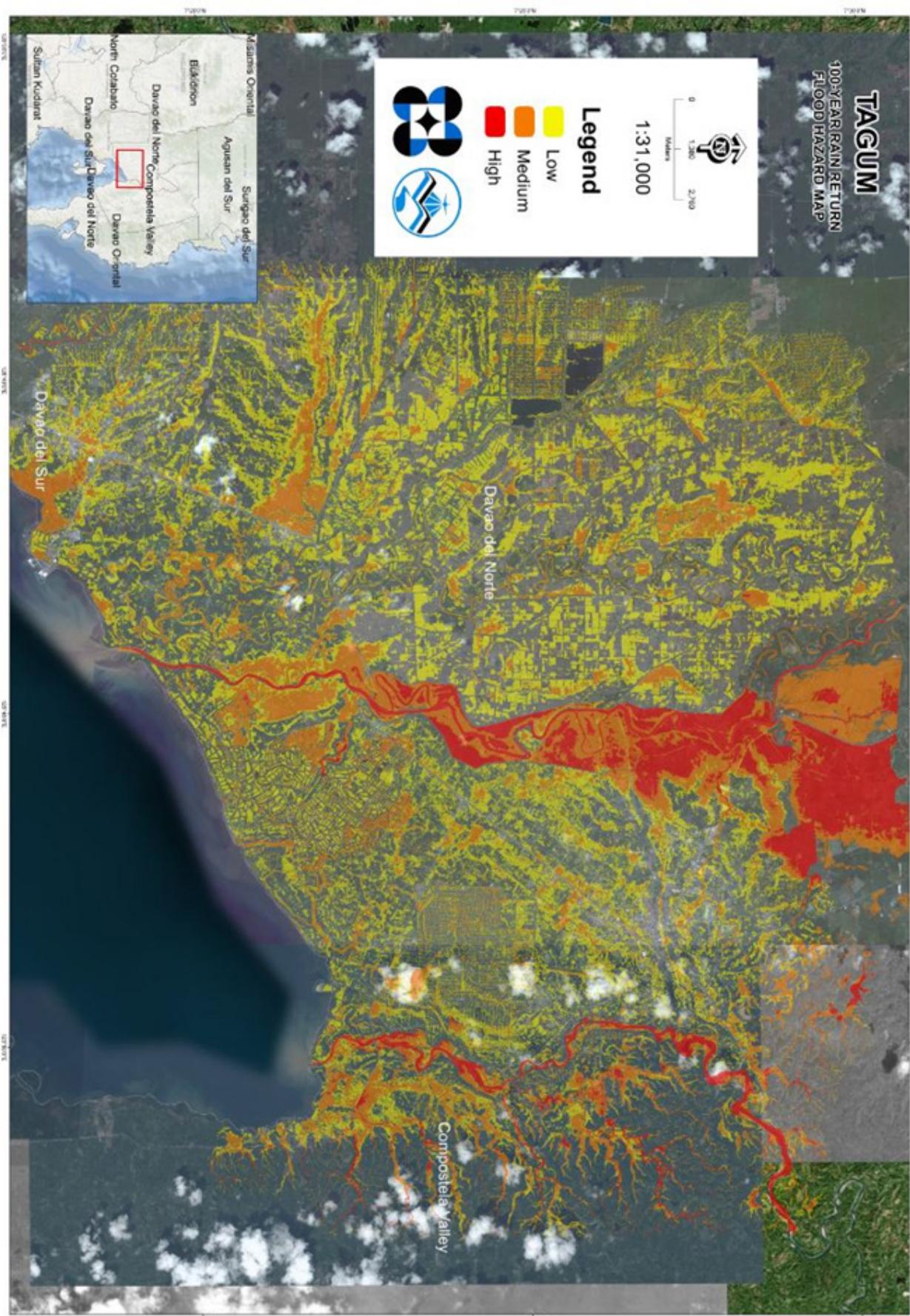


Figure 44. 100-year Flood Hazard Map for Tagum River Basin

Results and Discussion

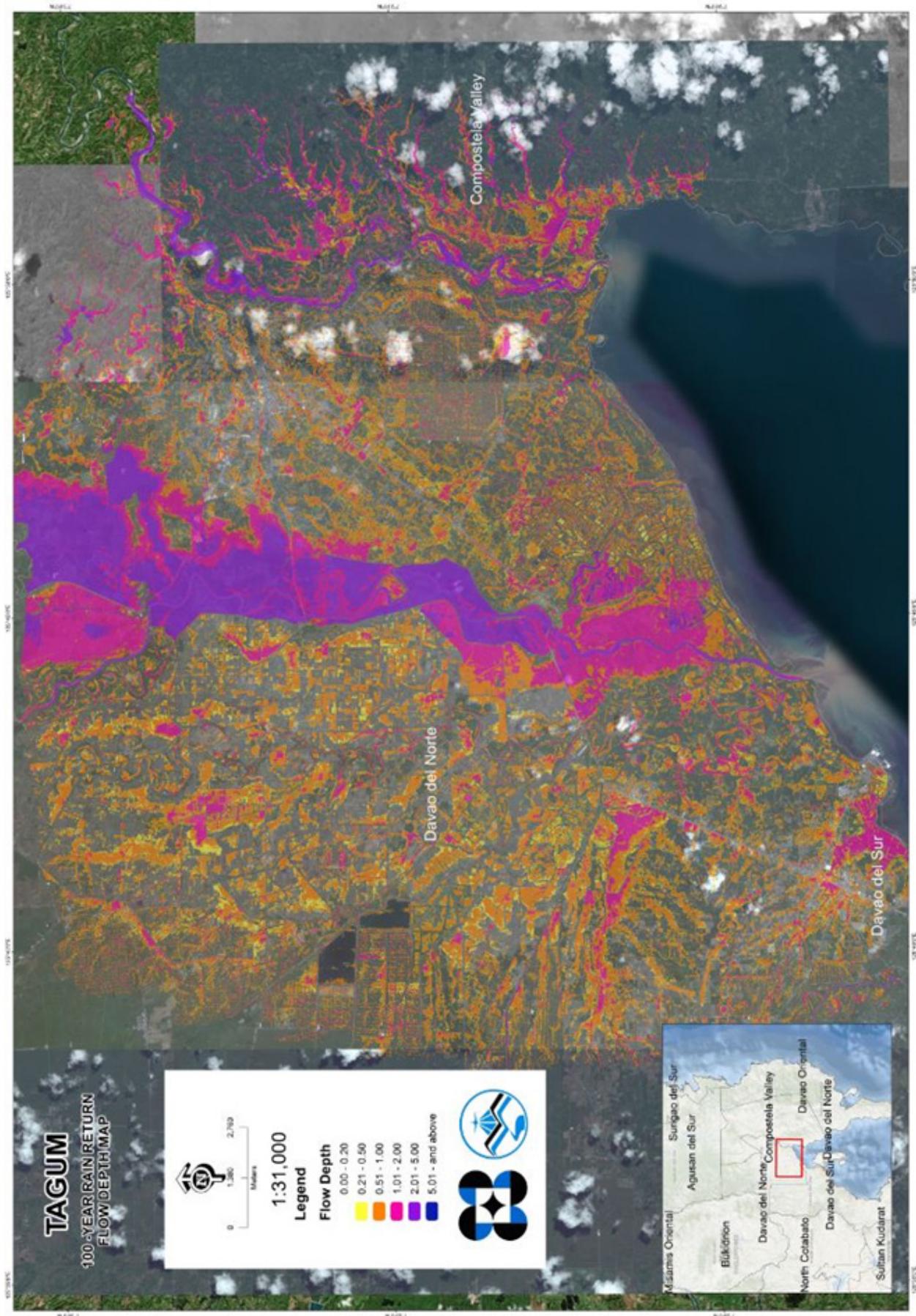


Figure 45. 100-year Flow Depth Map for Tagum River Basin

Results and Discussion

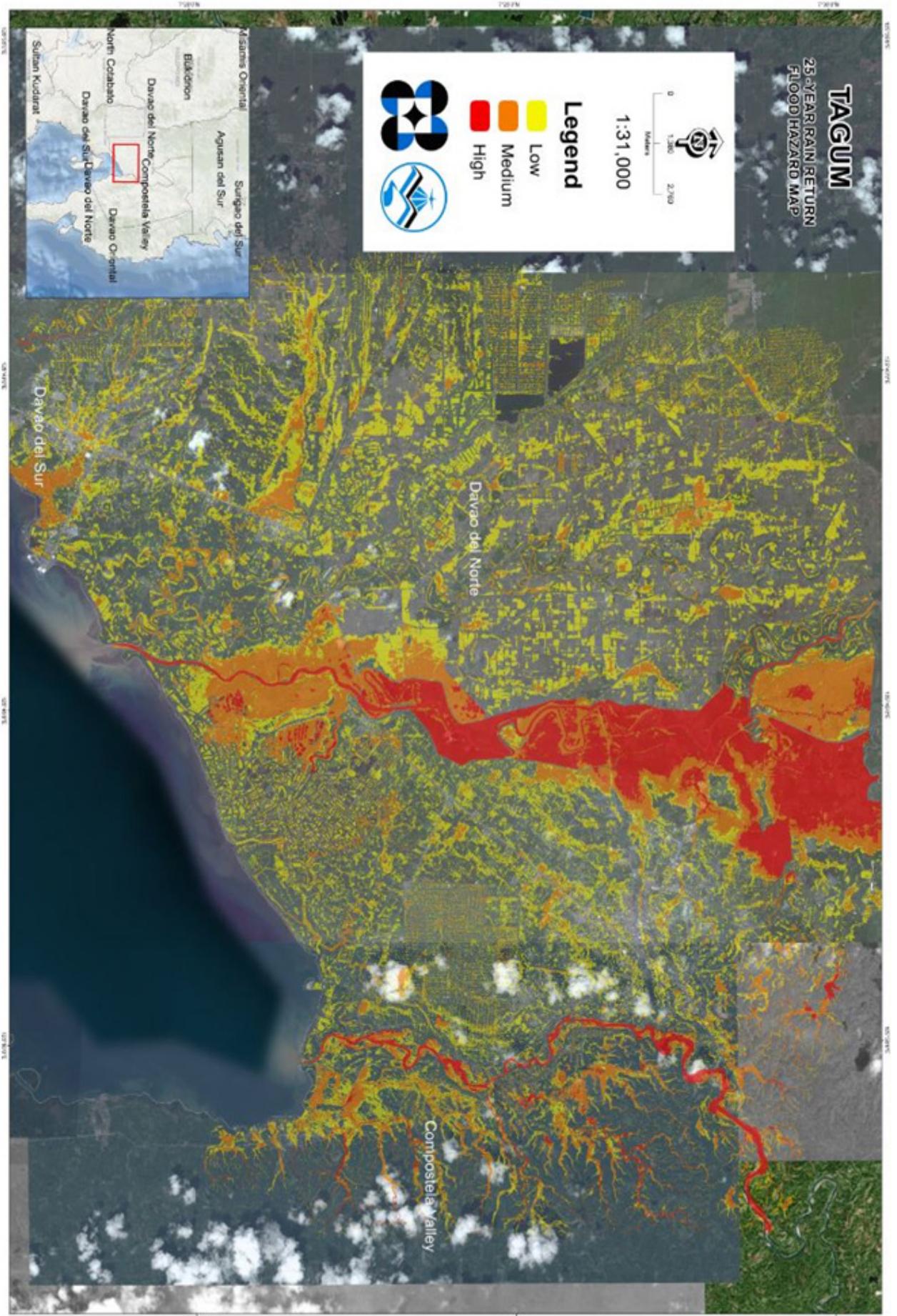


Figure 46. 25-year Flood Hazard Map for Tagum River Basin



Results and Discussion

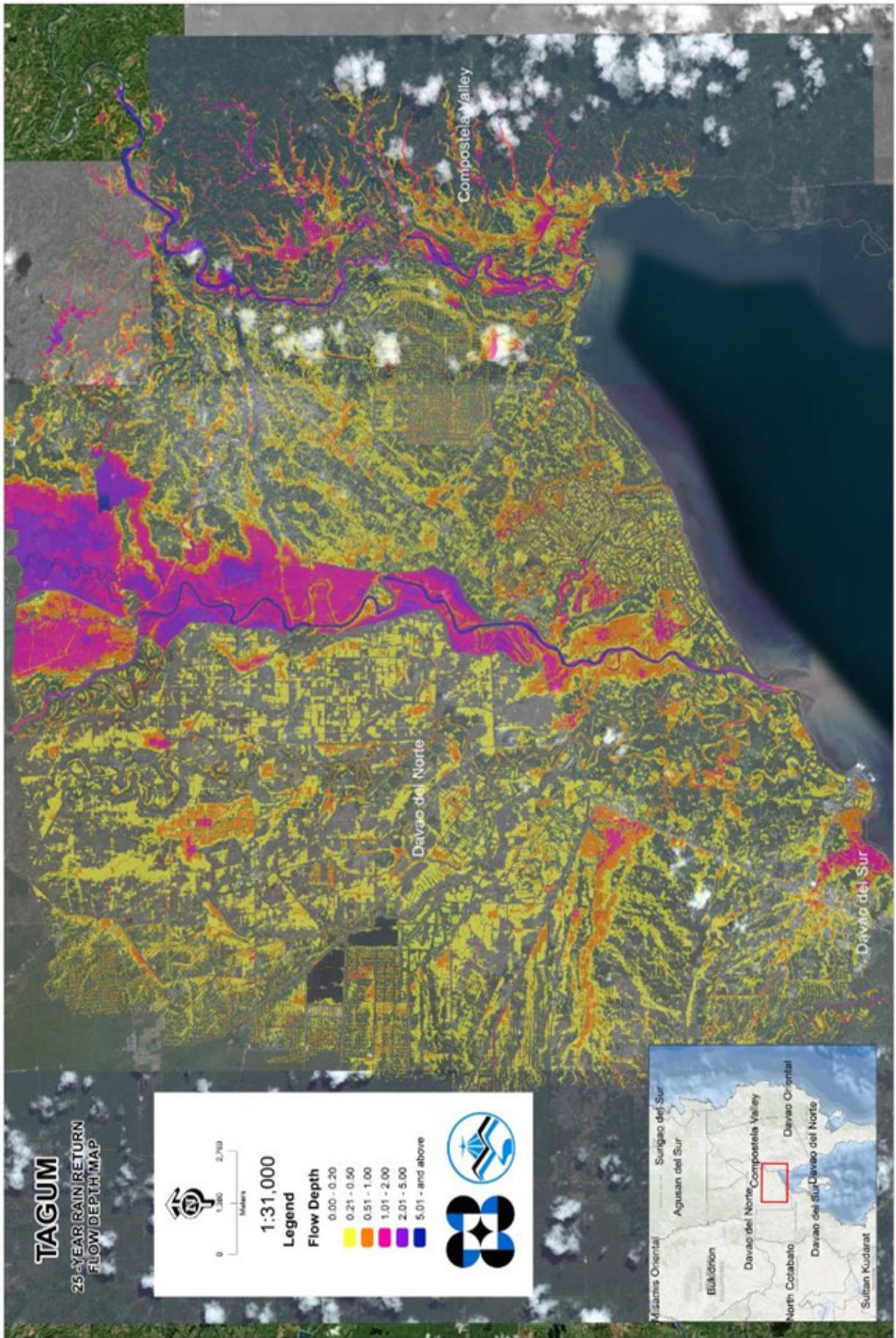


Figure 47. 25-year Flow Depth Map for Tagum River Basin

Results and Discussion

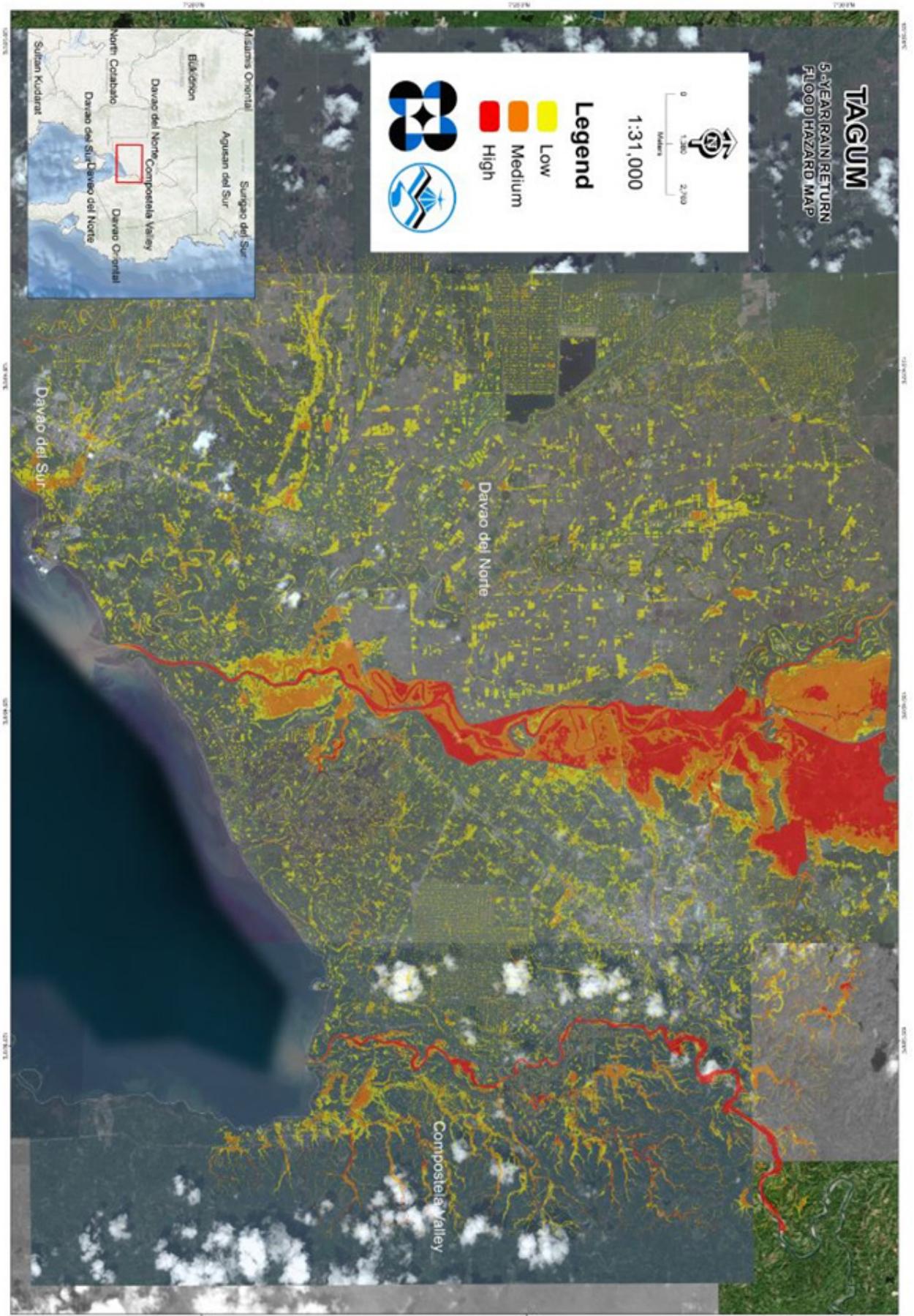


Figure 48. 5-year Flood Hazard Map for Tagum River Basin

Results and Discussion

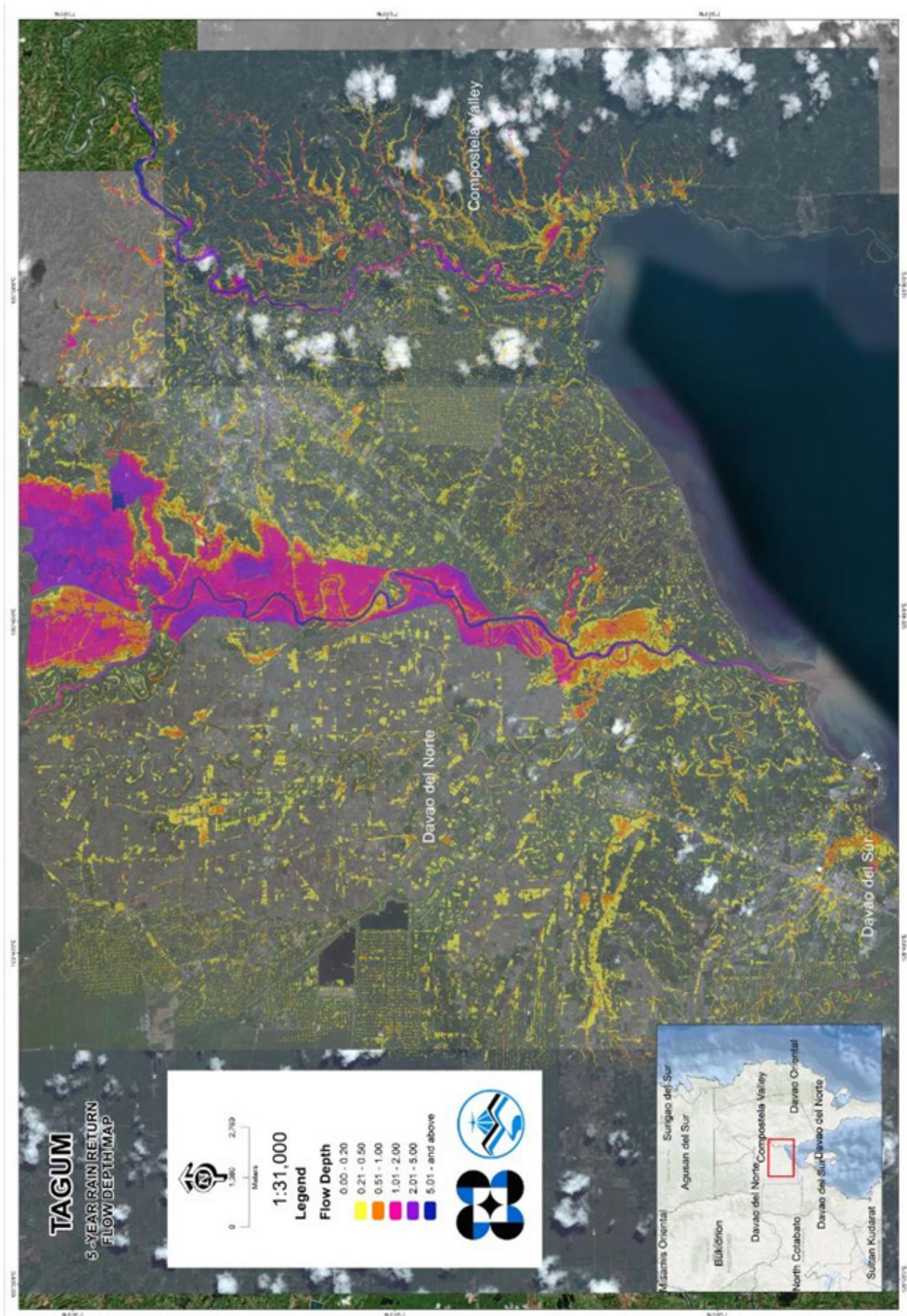


Figure 49. 5-year Flow Depth Map for Tagum River Basin

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Appendix



Appendix A. Asuncion Tagum Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow Initial Type	Initial Discharge (M ³ /S)	Recession Constant	Threshold Type	Ratio to Peak
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)					
25B	0.0150747	99	0	2.3734	1.5248	Discharge	6.9648	0.97	Ratio to Peak	0.00
29B	0.0150745	99	0	1.6338	2.007	Discharge	20.915	0.97	Ratio to Peak	0.00
30B	0.0225	99	0	1.766	2.0789	Discharge	10.514	0.97	Ratio to Peak	0.00
32B	0.0150739	99	0	4.0851	3.4524	Discharge	27.326	0.97	Ratio to Peak	0.00
34B	0.0225	99	0	3.2081	2.523	Discharge	3.9696	0.97	Ratio to Peak	0.00
41B	0.0150746	99	0	4.0081	2.1514	Discharge	4.5440	0.97	Ratio to Peak	0.00
43B	0.0150739	99	0	6.6354	2.7163	Discharge	5.0364	0.97	Ratio to Peak	0.00
44B	0.0150747	99	0	4.4838	2.3688	Discharge	8.1239	0.97	Ratio to Peak	0.00
47B	0.0150745	99	0	4.6007	2.4881	Discharge	9.2419	0.97	Ratio to Peak	0.00
49B	0.0150746	99	0	8.1077	2.9208	Discharge	3.9594	0.97	Ratio to Peak	0.00
50B	0.0150747	99	0	3.2997	2.777	Discharge	8.1136	0.97	Ratio to Peak	0.00



Appendix

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)					
52B	0.0150745	99	0	8.6788	3.0833	Discharge	28.023	0.97	Ratio to Peak	0.00
57B	0.0150747	99	0	10.721	3.9127	Discharge	13.642	0.97	Ratio to Peak	0.00
59B	0.0150739	99	0	6.3511	3.804	Discharge	14.422	0.97	Ratio to Peak	0.00
60B	0.0150745	99	0	10.292	4.7391	Discharge	5.9903	0.97	Ratio to Peak	0.00
66B	0.0150748	99	0	3.8741	3.1967	Discharge	16.597	0.97	Ratio to Peak	0.00
67B	0.015071	99	0	10.481	4.2767	Discharge	7.4161	0.97	Ratio to Peak	0.00
75B	0.0150727	99	0	9.675	2.3745	Discharge	4.2773	0.97	Ratio to Peak	0.00
78B	0.0150742	99	0	8.035	2.9321	Discharge	75.566	0.97	Ratio to Peak	0.00
87B	0.0225	89.461	0	6.128	0.21384	Discharge	18.514	0.97	Ratio to Peak	0.00
97B	0.0150746	99	0	7.8099	4.3035	Discharge	16.843	0.97	Ratio to Peak	0.00

Appendix

Appendix B. Asuncion Tagum Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
148R	Automatic Fixed Interval	9444.025	0.010490	0.0111111	Trapezoid	30	45
152R	Automatic Fixed Interval	8185.224	0.003540	0.050625	Trapezoid	30	45
153R	Automatic Fixed Interval	7915.273	0.005700	0.0242921	Trapezoid	30	45
155R	Automatic Fixed Interval	9605.831	0.002790	0.0160067	Trapezoid	30	45
157R	Automatic Fixed Interval	11233.030	0.006900	0.0245	Trapezoid	30	45
164R	Automatic Fixed Interval	51472.695	0.010320	0.0235298	Trapezoid	30	45
166R	Automatic Fixed Interval	7027.931	0.011580	0.0553068	Trapezoid	30	45
167R	Automatic Fixed Interval	7777.687	0.008350	0.0288492	Trapezoid	30	45
170R	Automatic Fixed Interval	7002.965	0.006920	0.043125	Trapezoid	30	45
172R	Automatic Fixed Interval	40466.344	0.002310	0.025183	Trapezoid	30	45
173R	Automatic Fixed Interval	8721.774	0.008330	0.0248686	Trapezoid	30	45
175R	Automatic Fixed Interval	11886.436	0.007110	0.0232707	Trapezoid	30	45
179R	Automatic Fixed Interval	6620.881	0.006900	0.0243771	Trapezoid	30	45
181R	Automatic Fixed Interval	11003.286	0.003820	0.0246064	Trapezoid	30	45
182R	Automatic Fixed Interval	34857.843	0.009260	0.0223762	Trapezoid	30	45
188R	Automatic Fixed Interval	19533.011	0.002610	0.03675	Trapezoid	30	45
196R	Automatic Fixed Interval	20600.266	0.001450	0.0248566	Trapezoid	30	45
199R	Automatic Fixed Interval	20617.449	0.001650	0.024831	Trapezoid	30	45
208R	Automatic Fixed Interval	12126.996	0.001690	0.0252393	Trapezoid	30	45



Appendix C. Talaingod Tagum Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow Initial Type	Initial Discharge (M ³ /S)	Recession Constant	Threshold Type	Ratio to Peak
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)					
22B	1	50	0	0.19756	0.3379125	Discharge	1.6564	0.7	Ratio to Peak	0.00
37B	1	50	0	2.8069	2.53195	Discharge	3.3823	0.7	Ratio to Peak	0.00
55B	1	50	0	0.83255	2.6816	Discharge	0.61012	0.7	Ratio to Peak	0.00
56B	1	50	0	1.0056	3.28535	Discharge	0.43394	0.7	Ratio to Peak	0.00
58B	1	50	0	1.1622	2.5488	Discharge	4.0055	0.7	Ratio to Peak	0.00

Appendix

Appendix D. Talaingod Tagum Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
145R	Automatic Fixed Interval	29469.465	0.026850	0.00294	Trapezoid	30	45
160R	Automatic Fixed Interval	28606.468	0.012460	0.003	Trapezoid	30	45
178R	Automatic Fixed Interval	9388.882	0.022430	0.002	Trapezoid	30	45



Appendix

Appendix E. Tagum HEC-HMS Discharge Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	6	0	0	0
0.166666667	0	0	0	6.166666667	0	0	0
0.333333333	0	0	0	6.333333333	0	0	0
0.5	0	0	0	6.5	0	0	0
0.666666667	0	0	0	6.666666667	0	0	0
0.833333333	0	0	0	6.833333333	0	0	0
1	0	0	0	7	0	0	0
1.166666667	0	0	0	7.166666667	0	0	0
1.333333333	0	0	0	7.333333333	0	0	0
1.5	0	0	0	7.5	0	0	0
1.666666667	0	0	0	7.666666667	0	0	0
1.833333333	0	0	0	7.833333333	0	0	0
2	0	0	0	8	0	0	0
2.166666667	0	0	0	8.166666667	0	0	0
2.333333333	0	0	0	8.333333333	0	0	0
2.5	0	0	0	8.5	0	0	0
2.666666667	0	0	0	8.666666667	0	0	0
2.833333333	0	0	0	8.833333333	0	0	0
3	0	0	0	9	0	0	0
3.166666667	0	0	0	9.166666667	0	0	0
3.333333333	0	0	0	9.333333333	0	0	0
3.5	0	0	0	9.5	0	0	0
3.666666667	0	0	0	9.666666667	0	0	0
3.833333333	0	0	0	9.833333333	0	0	0
4	0	0	0	10	0	0	0
4.166666667	0	0	0	10.166666667	0	0	0
4.333333333	0	0	0	10.333333333	0	0	0
4.5	0	0	0	10.5	0.1	0.1	0.1
4.666666667	0	0	0	10.666666667	0.2	0.2	0.1
4.833333333	0	0	0	10.833333333	0.6	0.5	0.3
5	0	0	0	11	1.2	0.9	0.6
5.166666667	0	0	0	11.166666667	2.4	1.8	1.1
5.333333333	0	0	0	11.333333333	4.5	3.3	2
5.5	0	0	0	11.5	7.6	5.6	3.3
5.666666667	0	0	0	11.666666667	13.2	9.6	5.5
5.833333333	0	0	0	11.833333333	24	17.1	9.6



Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
12	45.3	32.2	17.9	18.33333333	4419.1	3268.5	1928.1
12.16666667	76.8	54.7	30.2	18.5	4370.4	3237	1915.8
12.33333333	116.3	82.7	45.4	18.66666667	4312.4	3198.7	1899.4
12.5	169.3	120.5	66.1	18.83333333	4247	3154.6	1879.3
12.66666667	236.1	168.3	92.4	19	4175.3	3105.7	1856.2
12.83333333	313.2	223.6	122.8	19.16666667	4097.4	3052.1	1830.1
13	400.1	285.9	157.2	19.33333333	4012.9	2993.5	1800.8
13.16666667	497.6	356.1	196.1	19.5	3922.2	2930.1	1768.6
13.33333333	604.8	433.3	239	19.66666667	3825.7	2862.4	1733.7
13.5	721.5	517.4	285.8	19.83333333	3721.6	2789	1695.3
13.66666667	851.2	611	338.1	20	3609.9	2709.9	1653.4
13.83333333	993.4	713.8	395.6	20.16666667	3492.4	2626.4	1608.7
14	1146.1	824.1	457.4	20.33333333	3368.6	2538.1	1561.2
14.16666667	1312.7	944.5	524.9	20.5	3237.2	2444.1	1510.1
14.33333333	1494.2	1076	598.9	20.66666667	3100.8	2346.3	1456.5
14.5	1687.3	1215.9	677.8	20.83333333	2964	2247.6	1402.1
14.66666667	1890.5	1363.3	760.9	21	2830.5	2151.2	1348.4
14.83333333	2106.3	1520.1	849.7	21.16666667	2701.8	2057.8	1296
15	2331.1	1683.7	942.6	21.33333333	2576.8	1966.8	1244.4
15.16666667	2557.2	1848.7	1036.8	21.5	2459	1880.7	1195.2
15.33333333	2779.3	2011.1	1129.9	21.66666667	2350.4	1801.1	1149.4
15.5	2993.6	2168.3	1220.6	21.83333333	2248.3	1726	1105.7
15.66666667	3201.1	2321	1309.4	22	2151	1654.2	1063.6
15.83333333	3397.1	2465.8	1394.2	22.16666667	2059.5	1586.4	1023.6
16	3576.1	2598.5	1472.6	22.33333333	1972.6	1521.9	985.2
16.16666667	3740.6	2721.1	1545.8	22.5	1889.5	1460	948.1
16.33333333	3892.2	2834.7	1614.4	22.66666667	1811.2	1401.5	912.8
16.5	4023	2933.4	1674.9	22.83333333	1737.2	1346.1	879.1
16.66666667	4135.2	3018.8	1728.3	23	1666.9	1293.2	846.7
16.83333333	4233.4	3094.3	1776.5	23.16666667	1600.9	1243.5	815.9
17	4312.4	3156.1	1817.2	23.33333333	1539.9	1197.3	787.2
17.16666667	4372.5	3204.1	1850.2	23.5	1482.6	1153.8	760
17.33333333	4418	3241.6	1877.4	23.66666667	1427.4	1112	733.8
17.5	4451	3270.1	1899.6	23.83333333	1373.9	1071.4	708.3
17.66666667	4471.6	3289.4	1916.5	24	1321.7	1031.8	683.5
17.83333333	4480.9	3300.5	1928.8	24.16666667	1271	993.4	659.4
18	4478	3302.9	1936.1	24.33333333	1222.6	956.6	636.3
18.16666667	4457.2	3292	1935.7	24.5	1176.6	921.7	614.2



Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
24.66666667	1132.3	888	593	31	238.3	192.5	134.8
24.83333333	1089	855.1	572.2	31.16666667	227.5	183.7	128.7
25	1046.4	822.7	551.8	31.33333333	217.2	175.4	122.8
25.16666667	1004.7	791	531.7	31.5	207.3	167.4	117.2
25.33333333	964.5	760.3	512.3	31.66666667	197.7	159.6	111.8
25.5	927.2	731.8	494.1	31.83333333	188.4	152.1	106.5
25.66666667	892.9	705.5	477.2	32	179.3	144.8	101.4
25.83333333	860.2	680.3	460.9	32.16666667	170.7	137.8	96.5
26	828.5	655.9	445.1	32.33333333	162.5	131.2	91.9
26.16666667	797.6	632.1	429.7	32.5	154.8	125	87.5
26.33333333	767.3	608.8	414.6	32.66666667	147.5	119.1	83.4
26.5	738.1	586.3	400	32.83333333	140.4	113.3	79.4
26.66666667	710.7	565	386.1	33	133.6	107.9	75.5
26.83333333	684.8	545	372.9	33.16666667	127.1	102.6	71.9
27	659.6	525.4	360	33.33333333	121	97.7	68.4
27.16666667	634.9	506.2	347.4	33.5	115.4	93.1	65.2
27.33333333	610.5	487.2	334.9	33.66666667	110.1	88.9	62.2
27.5	586.5	468.6	322.7	33.83333333	105.1	84.8	59.4
27.66666667	563.3	450.5	310.7	34	100.3	80.9	56.6
27.83333333	541.4	433.4	299.3	34.16666667	95.7	77.2	54
28	520.4	416.9	288.3	34.33333333	91.3	73.6	51.5
28.16666667	500	400.9	277.6	34.5	87.2	70.3	49.2
28.33333333	480	385.1	267	34.66666667	83.5	67.3	47
28.5	460.2	369.5	256.6	34.83333333	80	64.5	45
28.66666667	440.9	354.4	246.4	35	76.7	61.7	43.1
28.83333333	422.5	339.8	236.6	35.16666667	73.5	59.2	41.2
29	405.3	326.1	227.2	35.33333333	70.4	56.7	39.4
29.16666667	388.8	313	218.3	35.5	67.4	54.2	37.7
29.33333333	372.9	300.3	209.5	35.66666667	64.5	51.9	36.1
29.5	357.2	287.9	201	35.83333333	61.7	49.6	34.5
29.66666667	341.9	275.7	192.6	36	59	47.4	32.9
29.83333333	327.1	263.8	184.4				
30	312.9	252.4	176.6				
30.16666667	299.5	241.6	169.1				
30.33333333	286.6	231.2	161.8				
30.5	274	221.2	154.8				
30.66666667	261.8	211.3	147.9				
30.83333333	249.9	201.7	141.3				





D R E A M
Disaster Risk and Exposure Assessment for Mitigation

