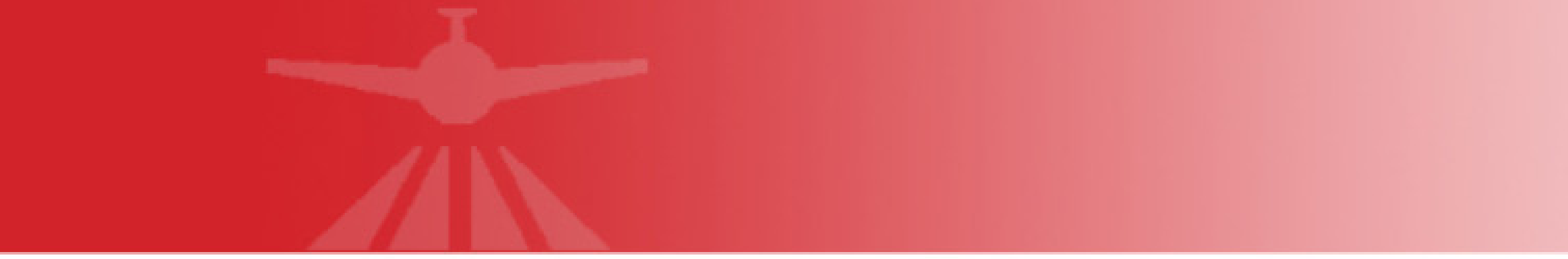

REGION 11

Davao River Basin:
DREAM Flood Forecasting and Flood Hazard Mapping

TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY
2015

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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.

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.

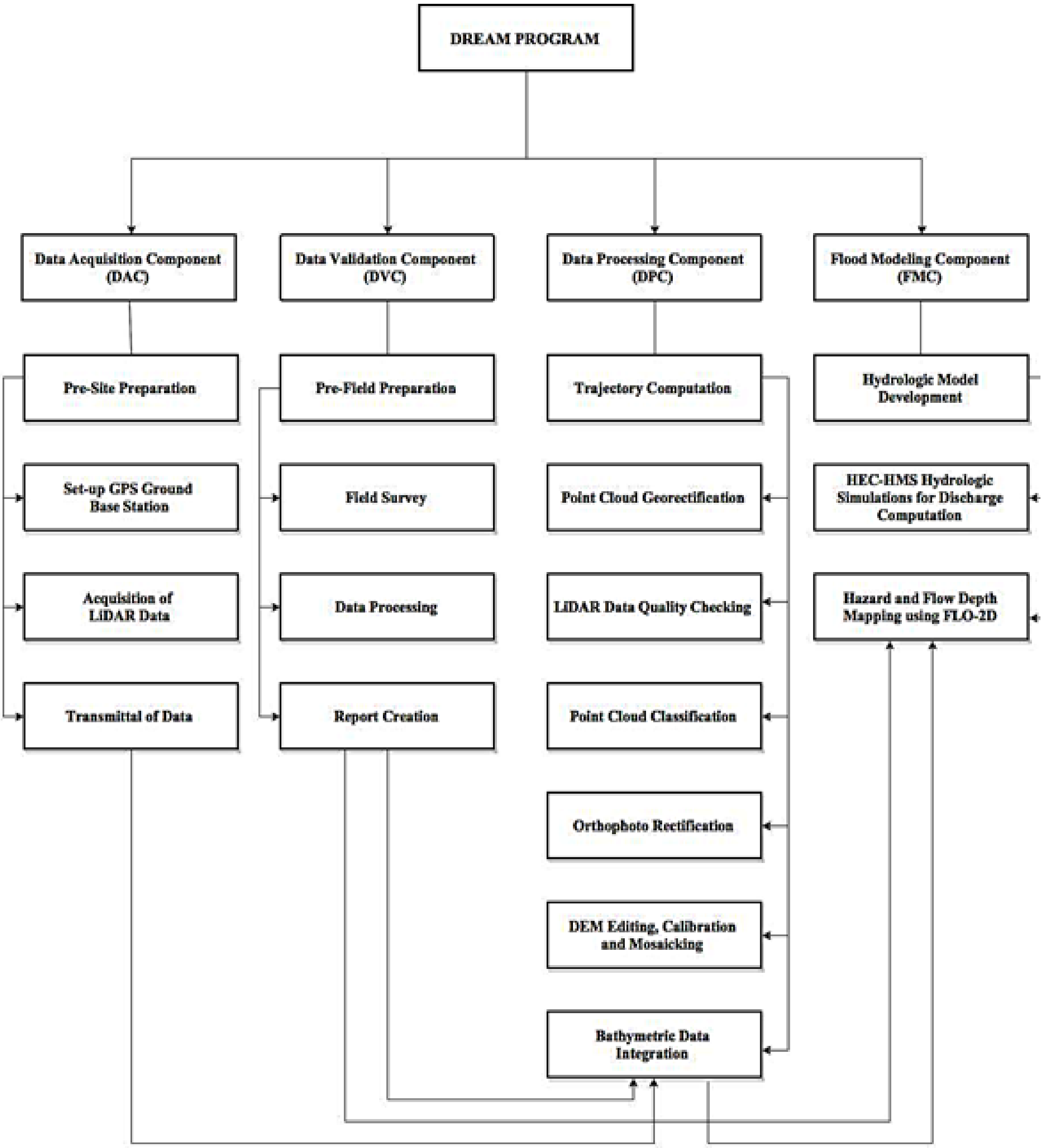


Figure 1. The general methodological framework of the program

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 Davao 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 Davao floodplain using FLO-2D GDS Pro; and
d) To prepare the static flood hazard and flow depth maps for the Davao 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.

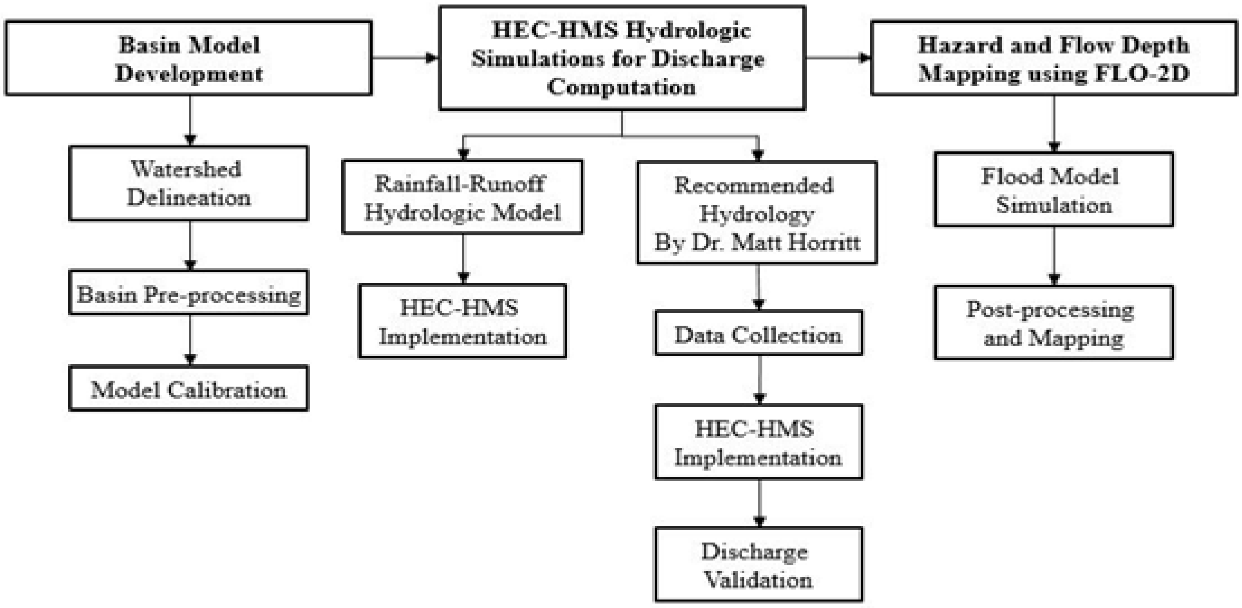


Figure 2. The operational framework and specific work flow of the Flood Modeling Component

The Davao River Basin

The Davao River Basin

The Davao River Basin is located in the southern part of Mindanao. It is considered as the 15th largest river basin in the Philippines. It is also considered as the largest of Davao City's nine (9) principal catchments, namely Lasang, Bunawan, Panacan, Matina, Davao, Talomo, Lipadas and portions of Inawayan and Sibulan. It covers an estimated basin area of 1,623 square kilometers.

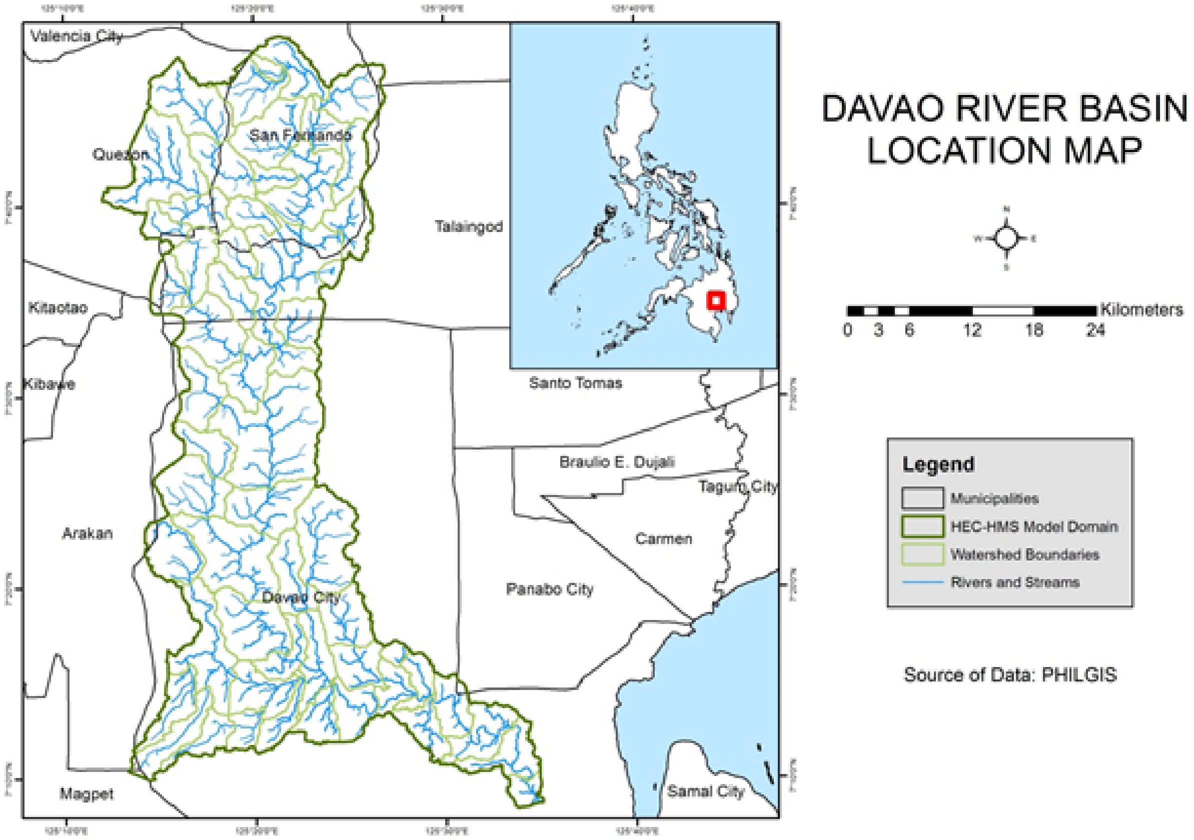
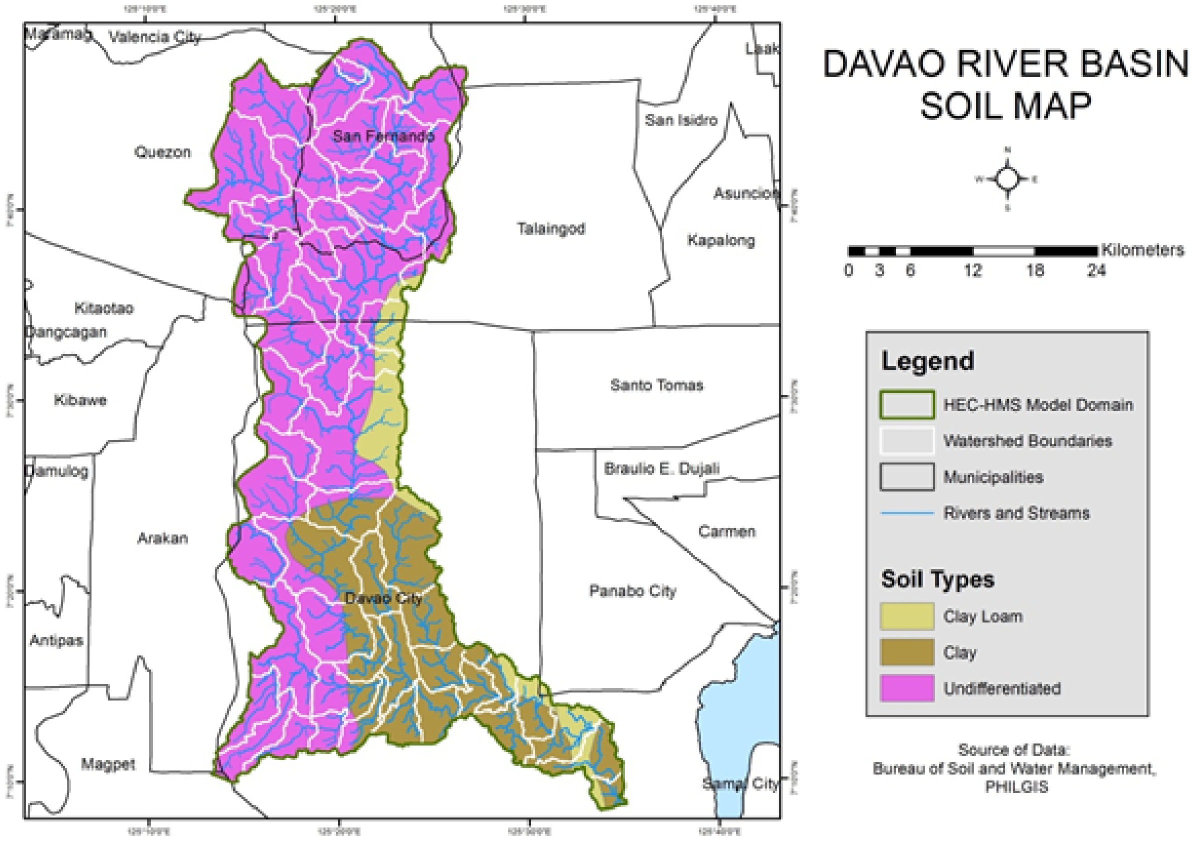


Figure 3. Davao River Basin Location Map

It traverses from as far as the Salug River in San Fernando, Bukidnon and flows outward through the provinces of Bukidnon, Davao del Sur, Davao del Norte and North Cotabato. It opens eastward and drains into Gulf of Davao.

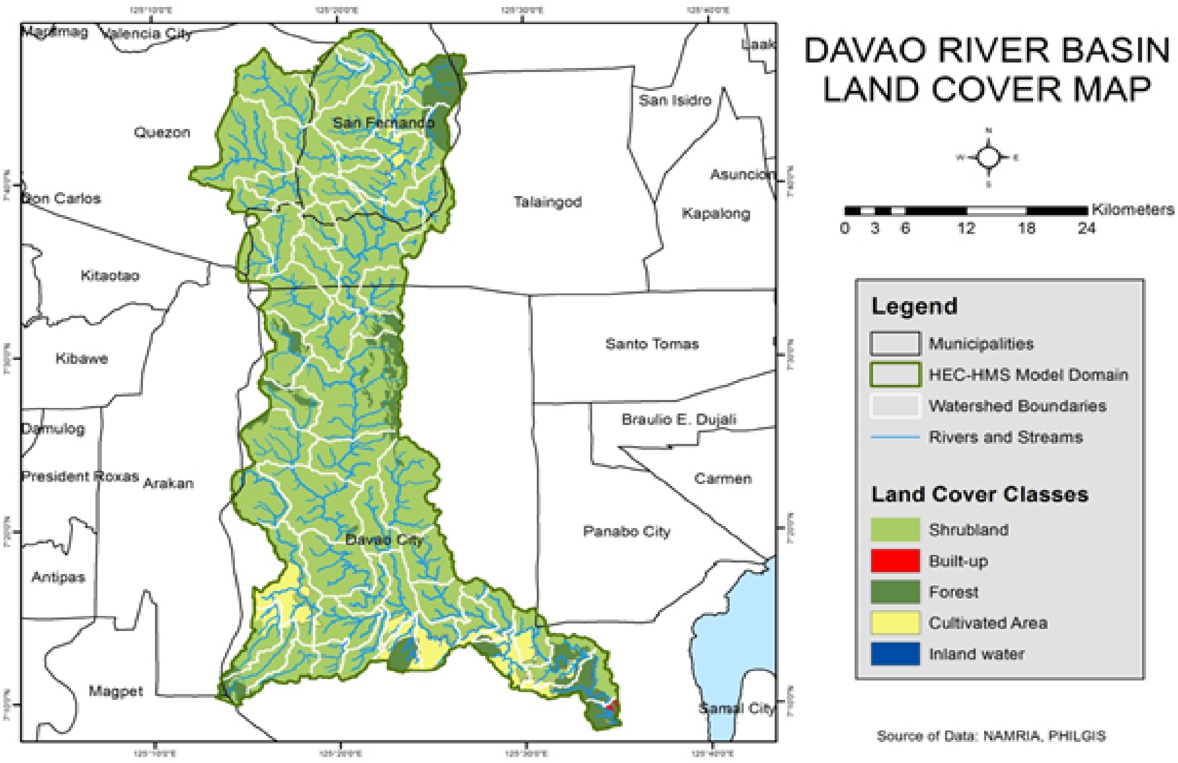
The land and soil characteristics are important parameters used in assigning the roughness coefficient for different areas within the river basin. The roughness coefficient, also called Manning's coefficient, represents the variable flow of water in different land covers (i.e. rougher, restricted flow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

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 Davao River Basin are shown in Figures 4 and 5, respectively.



Source of Data:
Bureau of Soil and Water Management,
PHILGIS

Figure 4. Davao River Basin Soil Map



Source of Data: NAMRIA, PHILGIS

Figure 5. Davao 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.

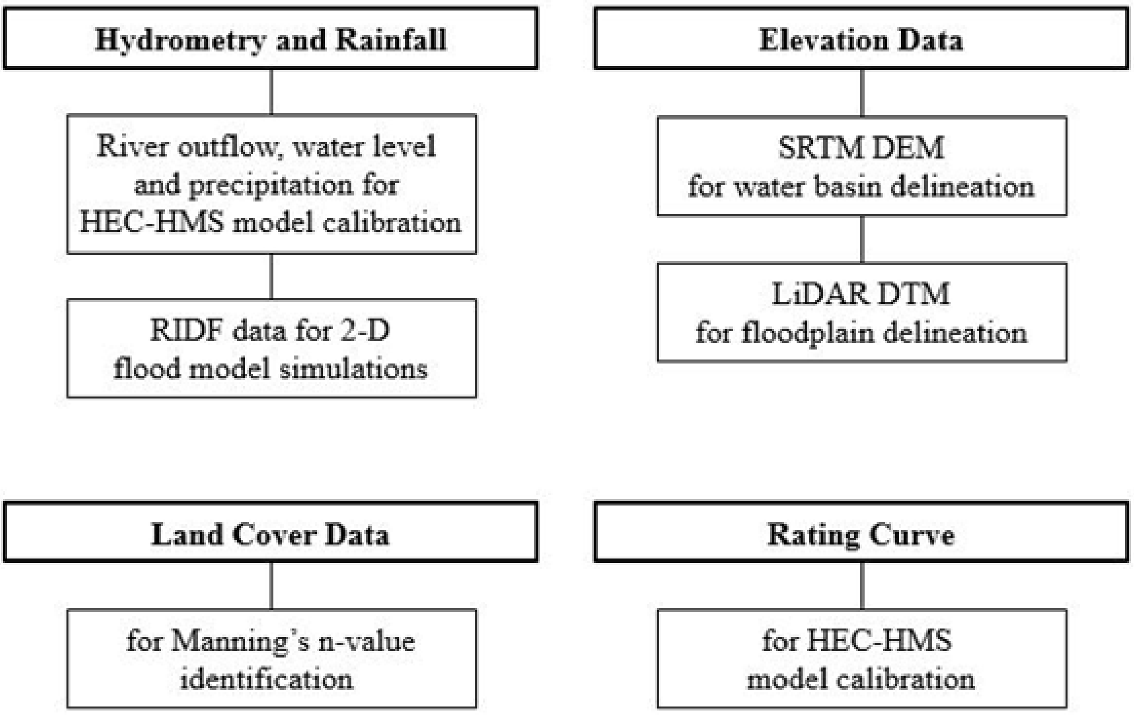


Figure 6. Summary of data needed for the purpose of flood modeling

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.

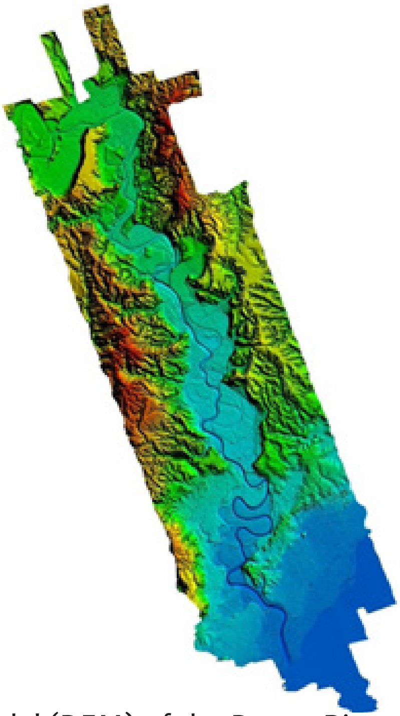


Figure 7. Digital Elevation Model (DEM) of the Davao River Basin using Light Detection and Ranging (LiDAR) technology

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.

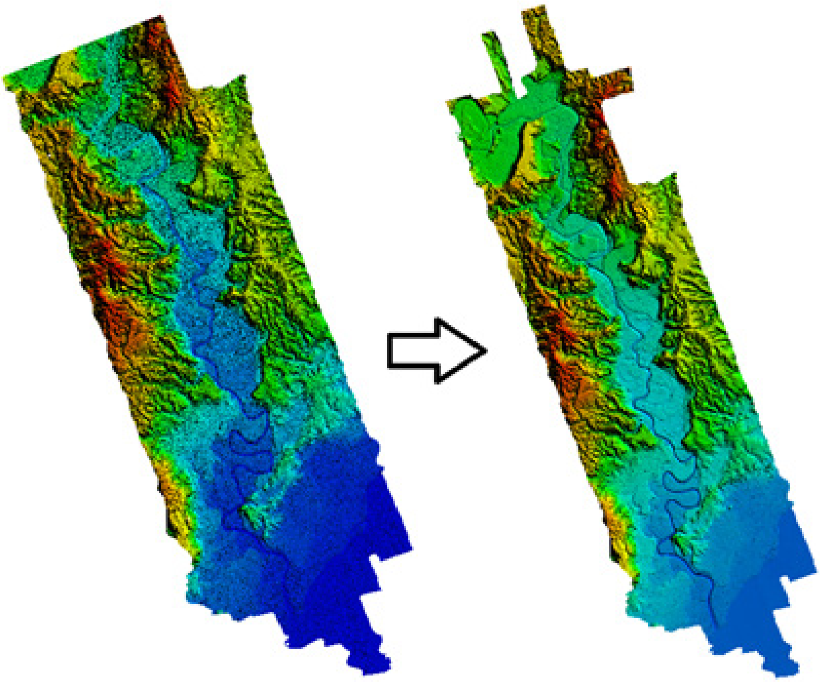


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted

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 Davao 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 Hydrometry for Waan Bridge, Davao City

River outflow from Waan Bridge (9° 07' 54.72233" N, 125° 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.

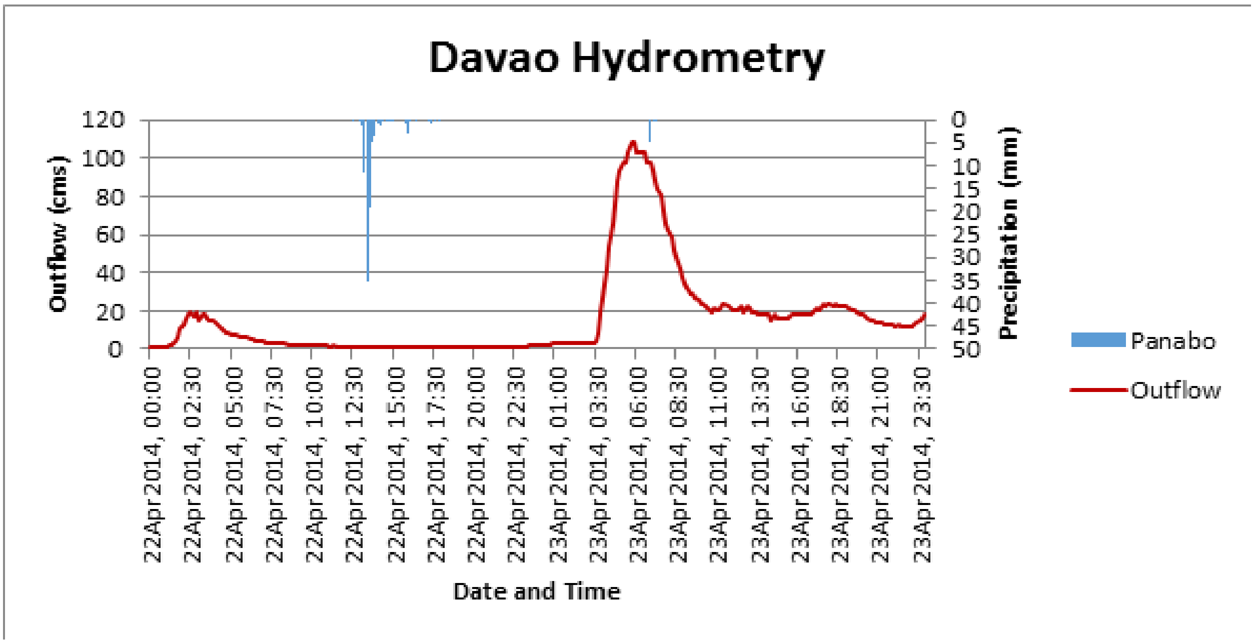


Figure 10. Waan Bridge, Davao rainfall and outflow data used for modeling

3.1.3.2 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.

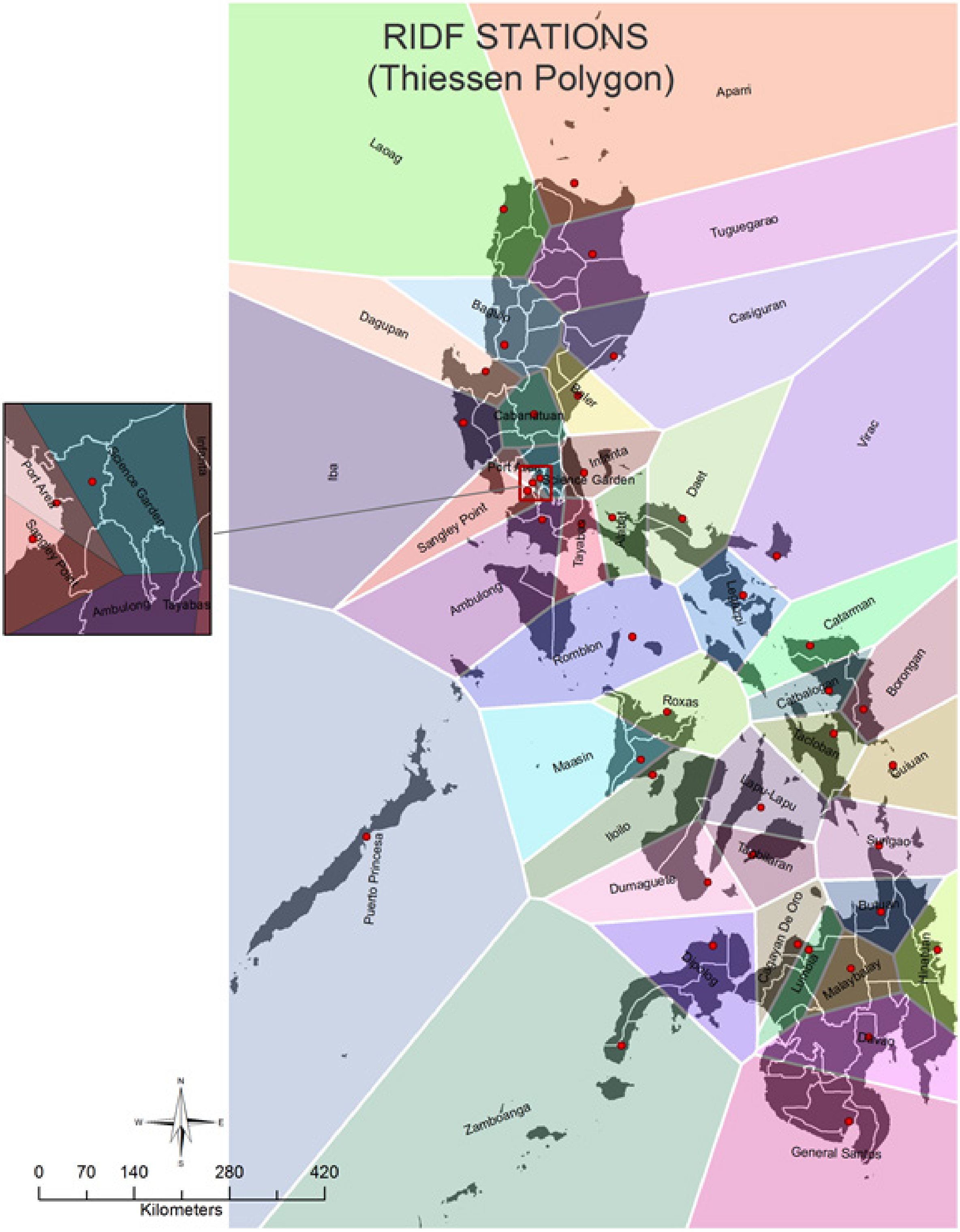


Figure 11. Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines

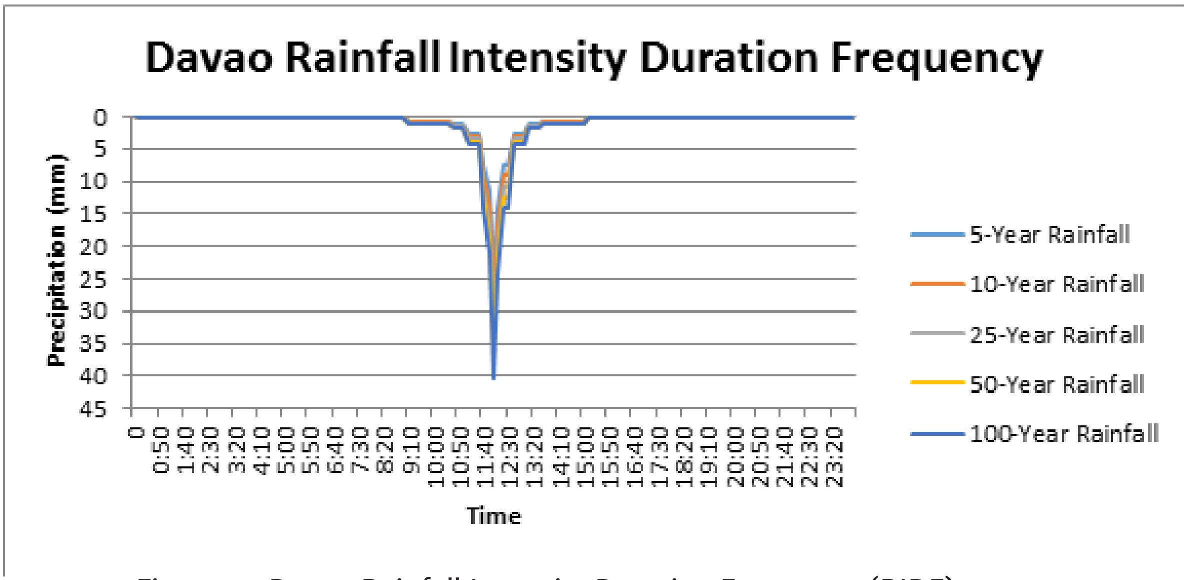


Figure 12. Davao Rainfall-Intensity Duration Frequency (RIDF) curves

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

3.1.4 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

For Waan Bridge, the rating curve is expressed as $Q = 3.4405e^{0.7363x}$ as shown in Figure 13.

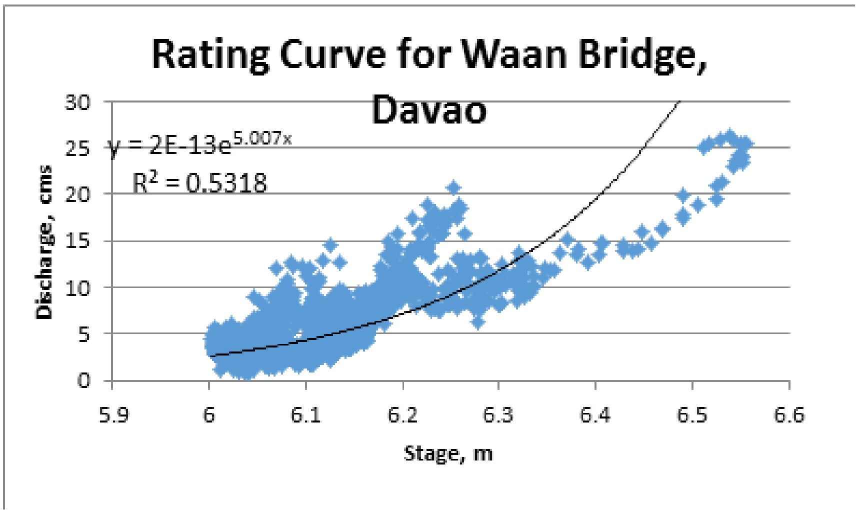


Figure 13. Water level vs. Discharge Curve for Waan Bridge, Davao

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Davao 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 14.

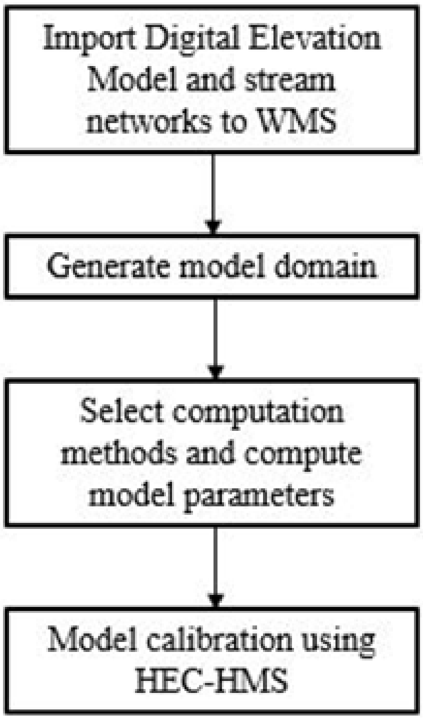


Figure 14. The Rainfall-Runoff Basin Model Development Scheme

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.

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.

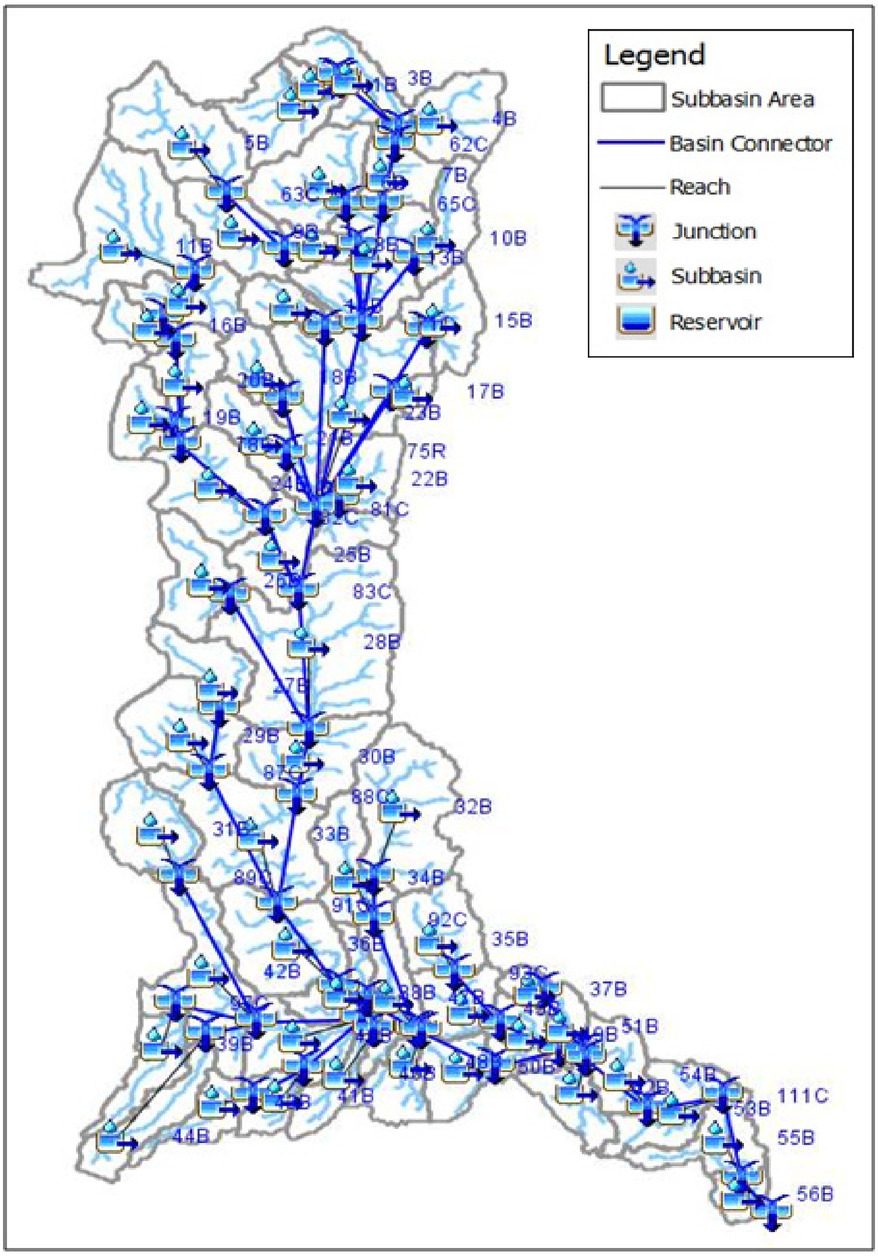


Figure 15. Davao HEC-HMS Model domain generated by WMS

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

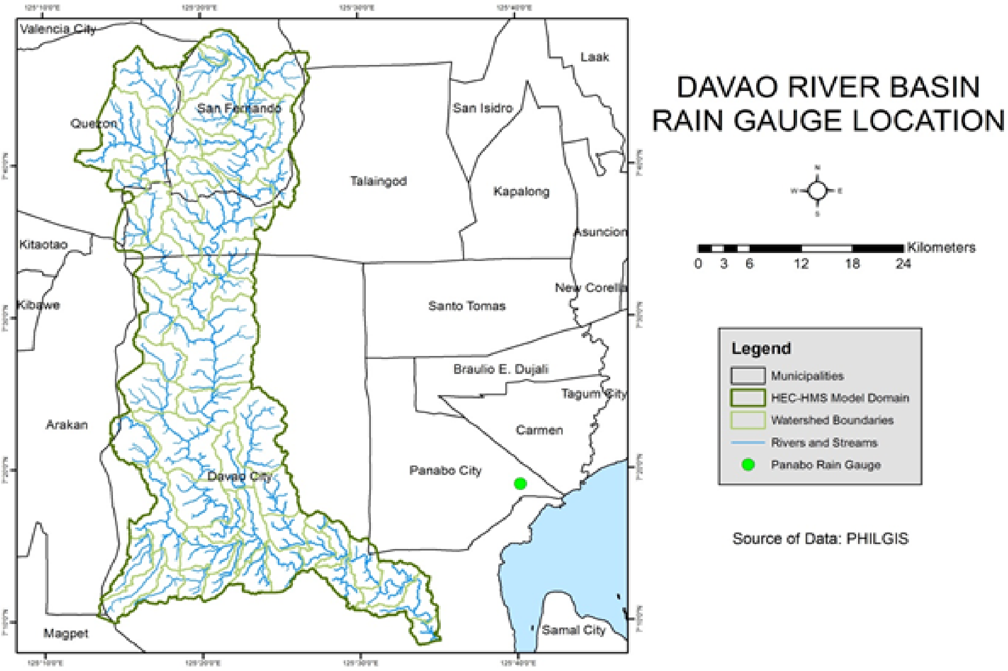
Hydrologic Element	Calculation Type	Method
Subbasin	Loss Rate	SCS Curve Number
	Transform	Clark's unit hydrograph
	Baseflow	Bounded recession
Reach	Routing	Muskingum-Cunge

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 Panabo sensor, an automatic rain gauge (ARGs) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). The location of the ARG is seen in Figure 16.

Total rainfall from Panabo rain gauge is 92.456 mm. Its peak rainfall is 35.052 mm which happened on 22 April, 2014 at 20:15. The lag time between the peak rainfall and peak discharge is nine hours and 25 minutes.



Source of Data: PHILGIS

Figure 16. Location of rain gauge used for the calibration of Davao 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.

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 Davao River Basin using WMS and HEC-HMS was used to simulate the flow 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 Waan 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. Horrit's method is shown on Figure 17.

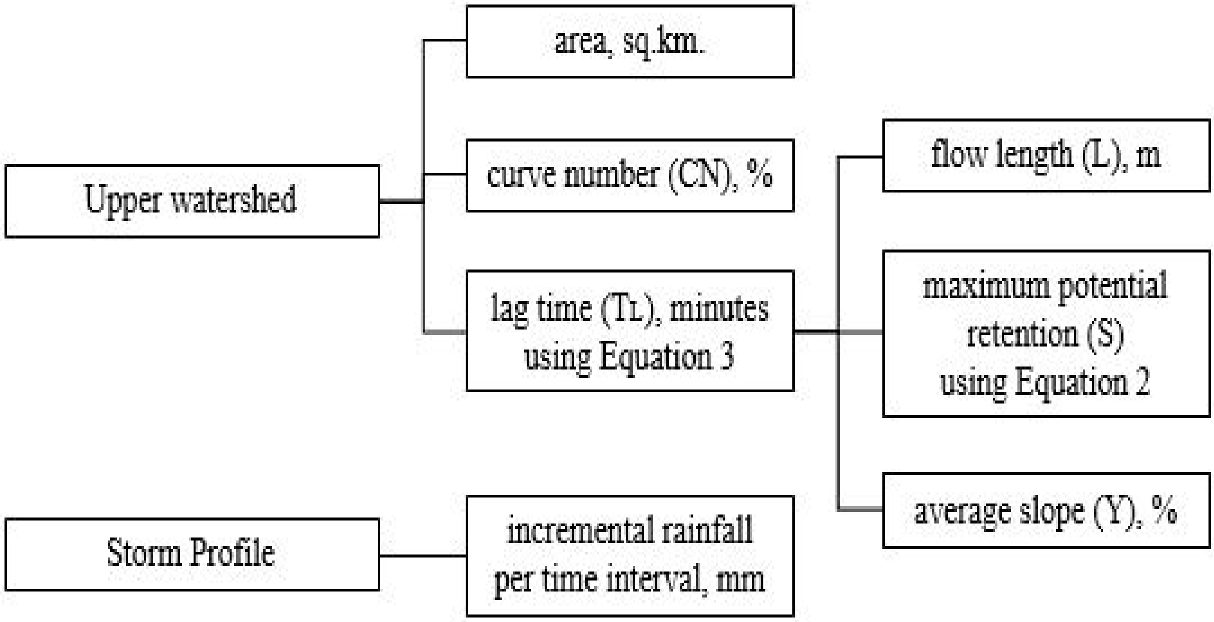


Figure 17. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method

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.

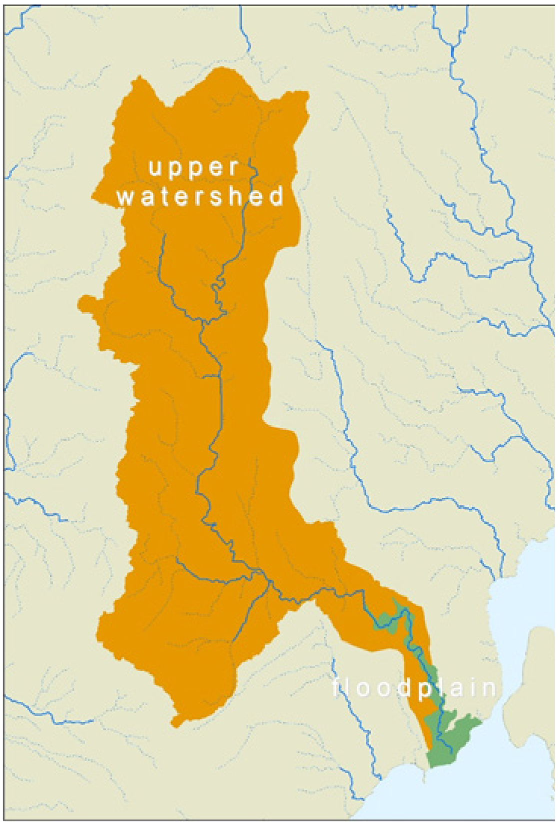


Figure 18. Delineation of upper watershed for Davao floodplain discharge computation

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.

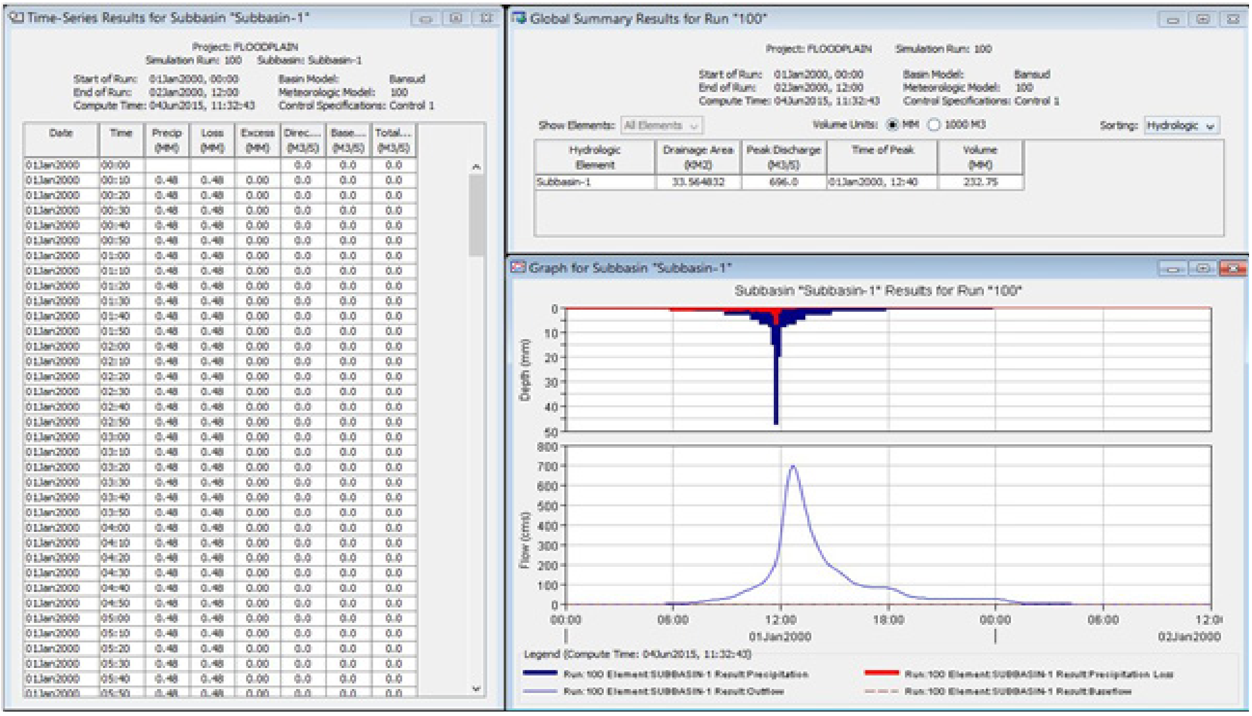
$$T_L = \frac{L^{0.8}(S+1)^{0.7}}{560Y^{0.5}}$$

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.



Time-Series Results for Subbasin "Subbasin-1"

Project: FLOODPLAIN
Simulation Run: 100 Subbasin: Subbasin-1

Start of Run: 01Jan2000, 00:00
End of Run: 02Jan2000, 12:00
Compute Time: 04Jun2015, 11:32:43
Basin Model: Bansud
Meteorologic Model: 100
Control Specifications: Control 1

Date	Time	Precip (MM)	Loss (MM)	Excess (MM)	Direc... (M3/S)	Base... (M3/S)	Total... (M3/S)
01Jan2000	00:00				0.0	0.0	0.0
01Jan2000	00:10	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	00:20	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	00:30	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	00:40	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	00:50	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	01:00	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	01:10	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	01:20	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	01:30	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	01:40	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	01:50	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	02:00	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	02:10	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	02:20	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	02:30	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	02:40	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	02:50	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	03:00	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	03:10	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	03:20	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	03:30	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	03:40	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	03:50	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	04:00	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	04:10	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	04:20	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	04:30	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	04:40	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	04:50	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	05:00	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	05:10	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	05:20	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	05:30	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	05:40	0.48	0.48	0.00	0.0	0.0	0.0
01Jan2000	05:50	0.48	0.48	0.00	0.0	0.0	0.0

Global Summary Results for Run "100"

Project: FLOODPLAIN Simulation Run: 100

Start of Run: 01Jan2000, 00:00
End of Run: 02Jan2000, 12:00
Compute Time: 04Jun2015, 11:32:43
Basin Model: Bansud
Meteorologic Model: 100
Control Specifications: Control 1

Show Elements: All Elements
Volume Units: ● MM ○ 1000 M3
Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
Subbasin-1	33.564832	696.0	01Jan2000, 12:40	232.75

Graph for Subbasin "Subbasin-1"

Figure 19. 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 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.

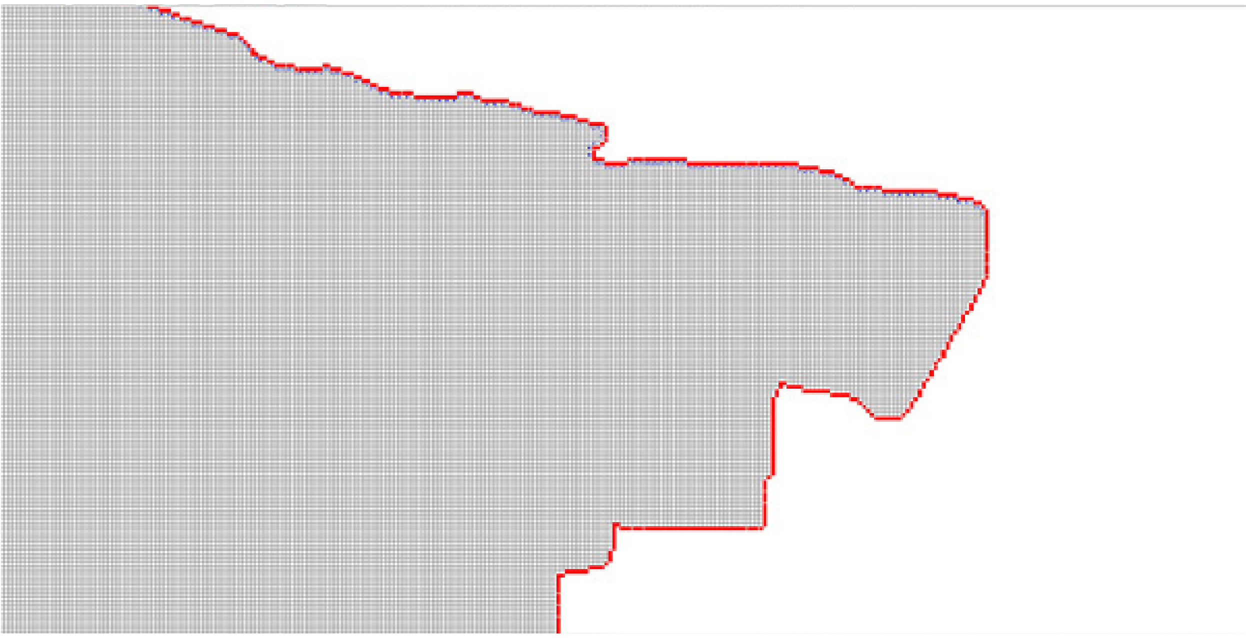


Figure 20. Screenshot showing how boundary grid elements are defined by line

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.

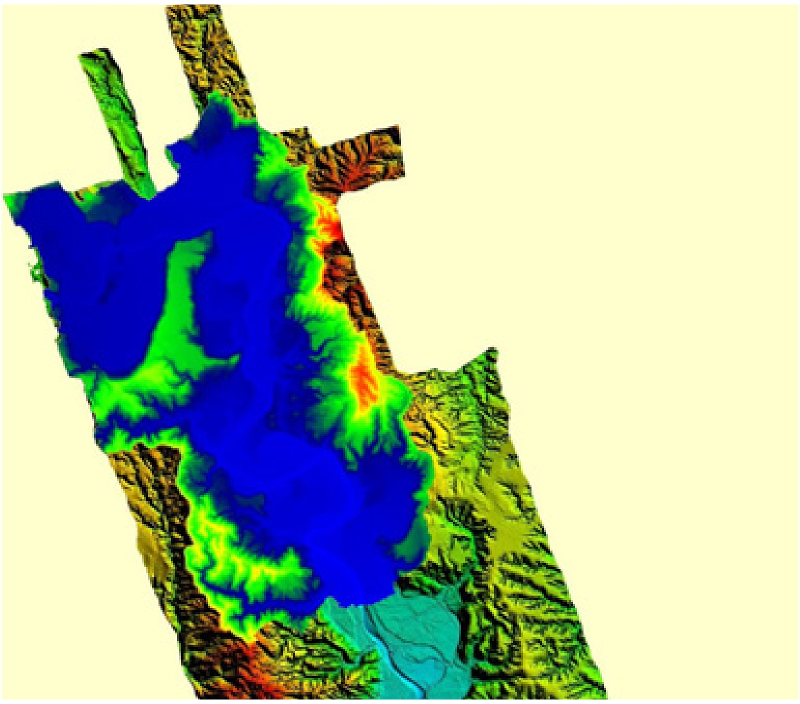


Figure 21. Screenshots of PTS files when loaded into the FLO-2D program

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 22. Areal image of Davao floodplain

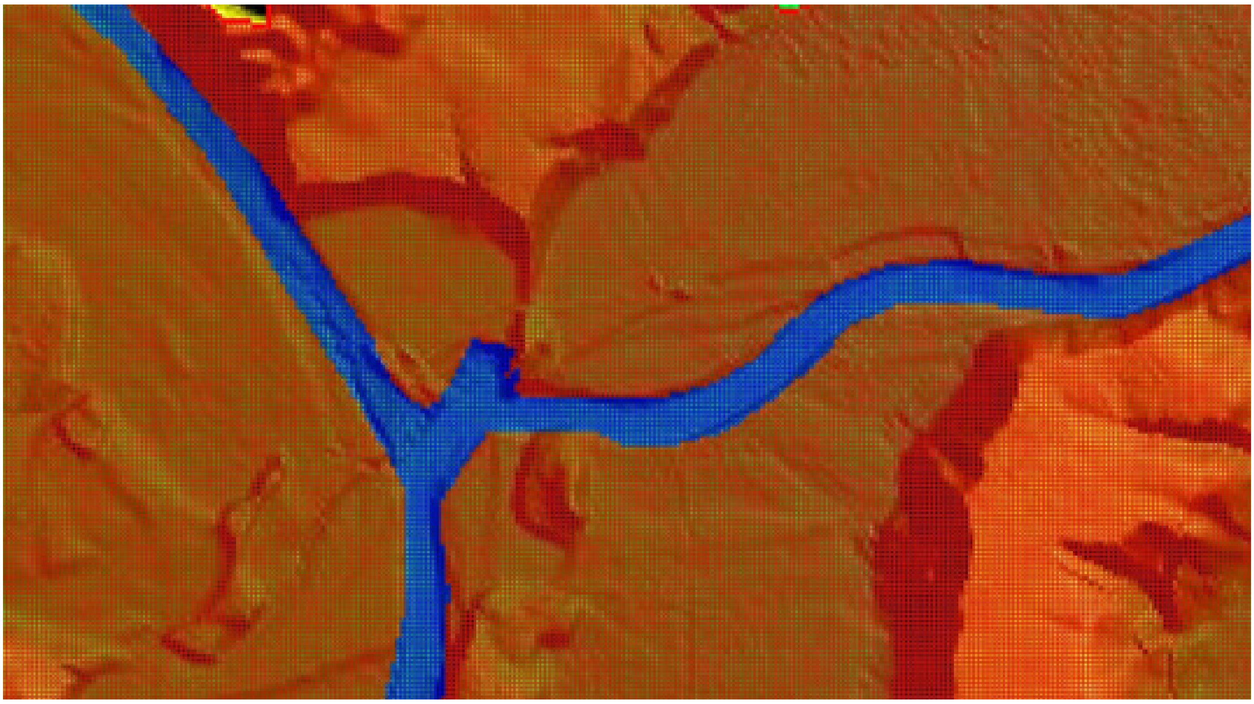


Figure 23. Screenshot of Manning's n-value rendering

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 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.

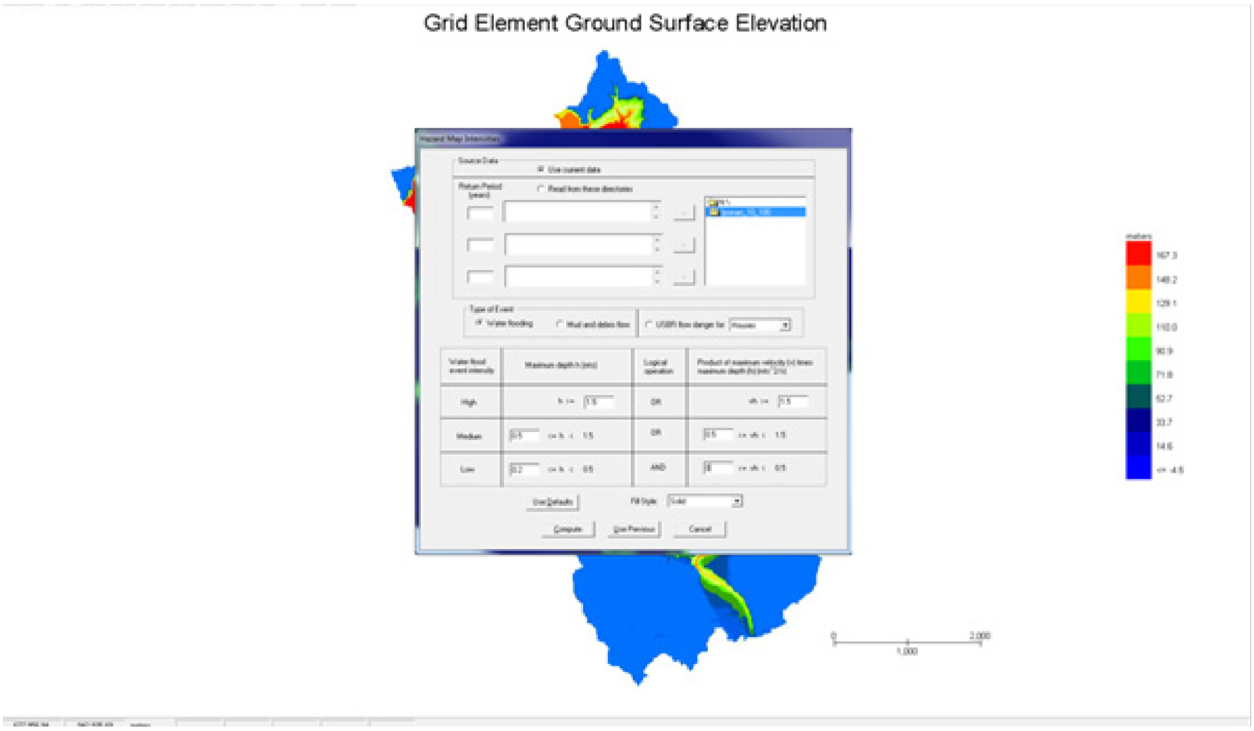


Figure 24. Flo-2D Mapper Pro General Procedure

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.

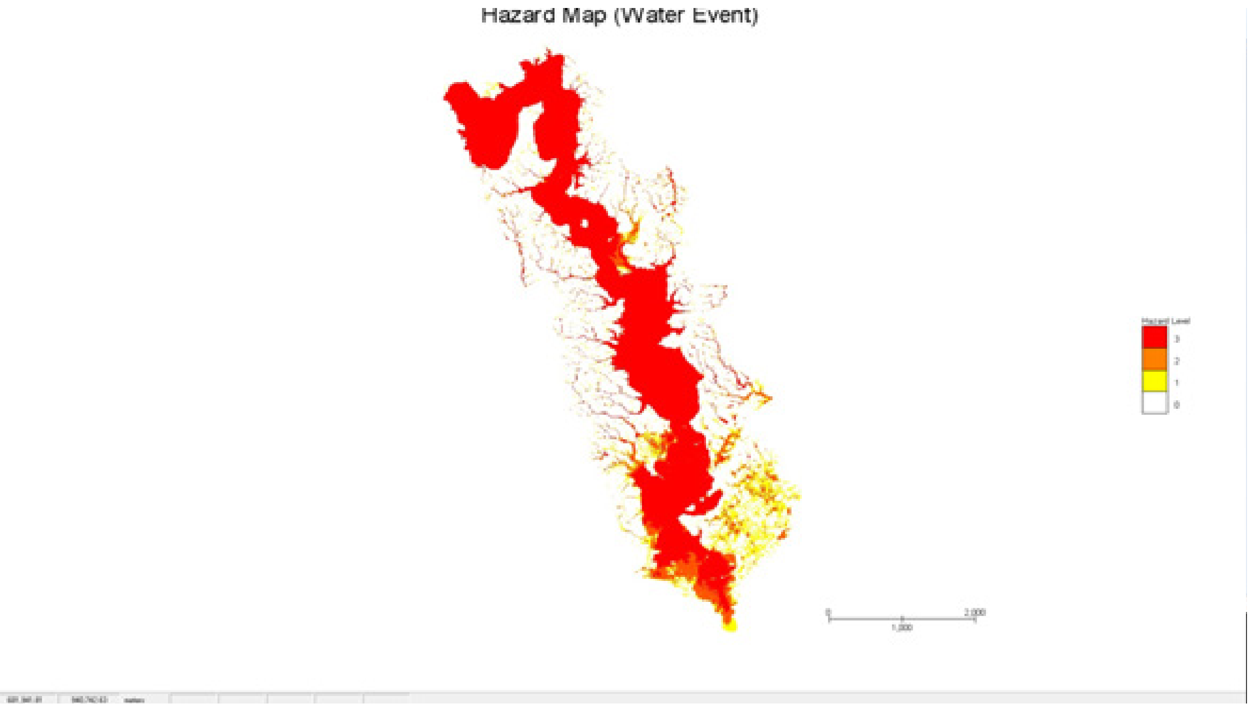


Figure 25. Davao Floodplain Generated Hazard Maps using FLO-2D Mapper

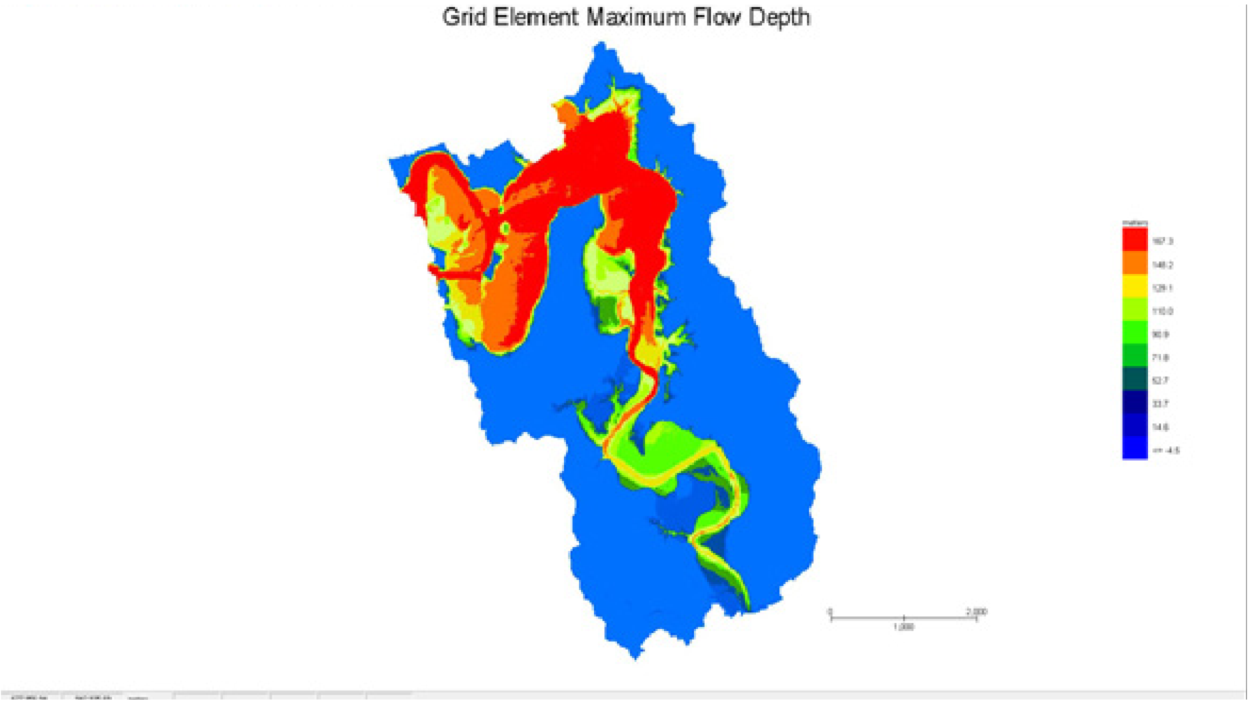
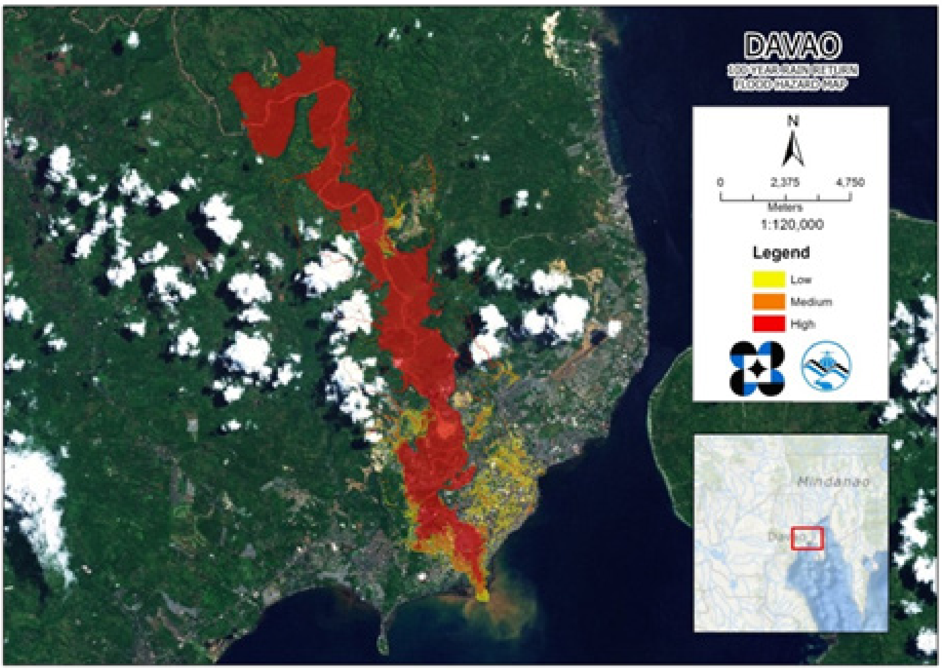


Figure 26. Davao floodplain generated flow depth map using FLO-2D Mapper

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 27. 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

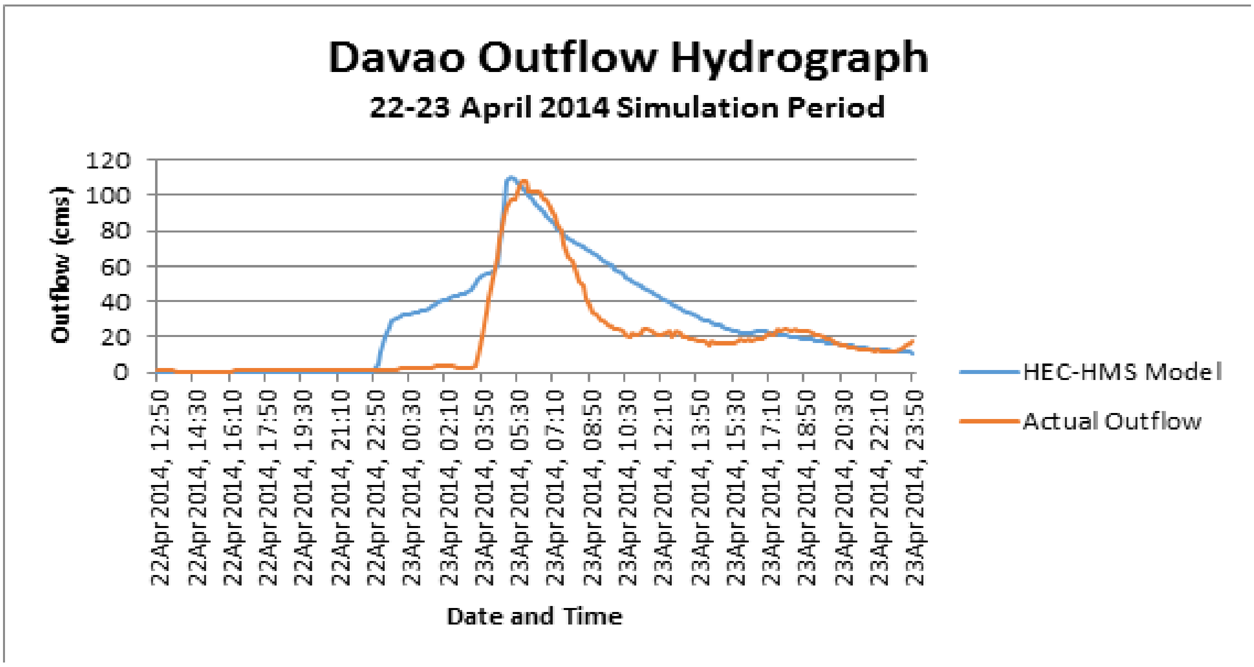


Figure 28. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow

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 28.

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 15.11924.

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 0.604049.

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 -25.30.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0. The model has an RSR value of 0.63.

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

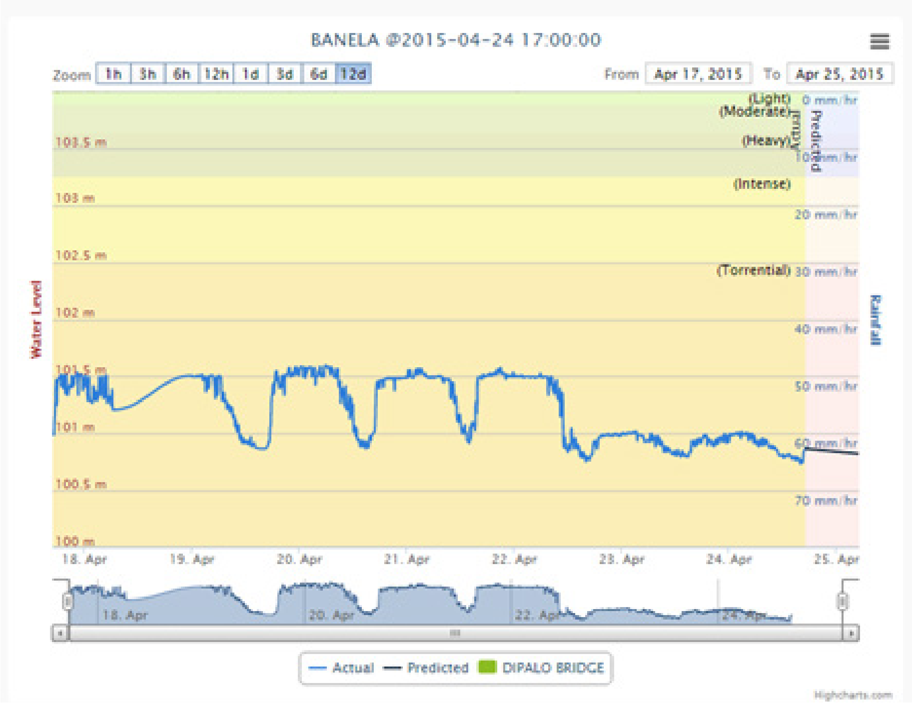


Figure 29. Sample DREAM Water Level Forecast

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.

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

4.2.1 Hydrograph using the Rainfall-Runoff Model

The outflow of Davao using the Davao station Rainfall Intensity-Duration-Frequency curves (RIDF) in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on PAGASA data are shown in Figures 30-34. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

In the 5-year return period graph, the peak outflow is 357.5 cms. This occurs 7 hours and 30 minutes after the peak precipitation of 25.1 mm, as shown on Figure 30.

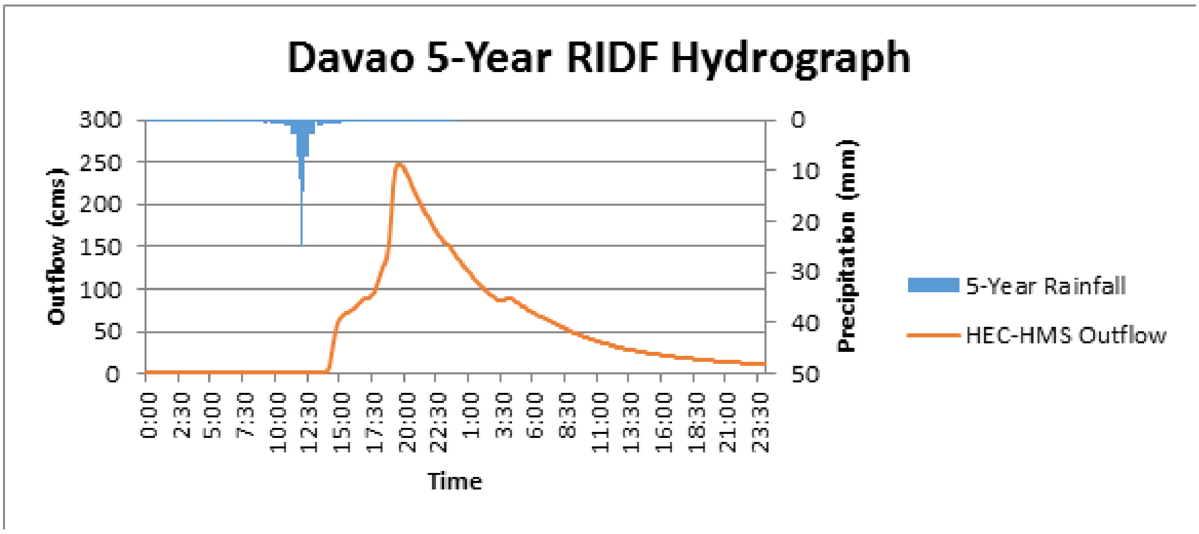


Figure 30. Outflow hydrograph generated using the Davao 5-Year RIDF in HEC-HMS

In the 10-year return period graph, the peak outflow is 357cms. This occurs 7 hours after the peak precipitation of 28.8 mm, as shown on Figure 31.

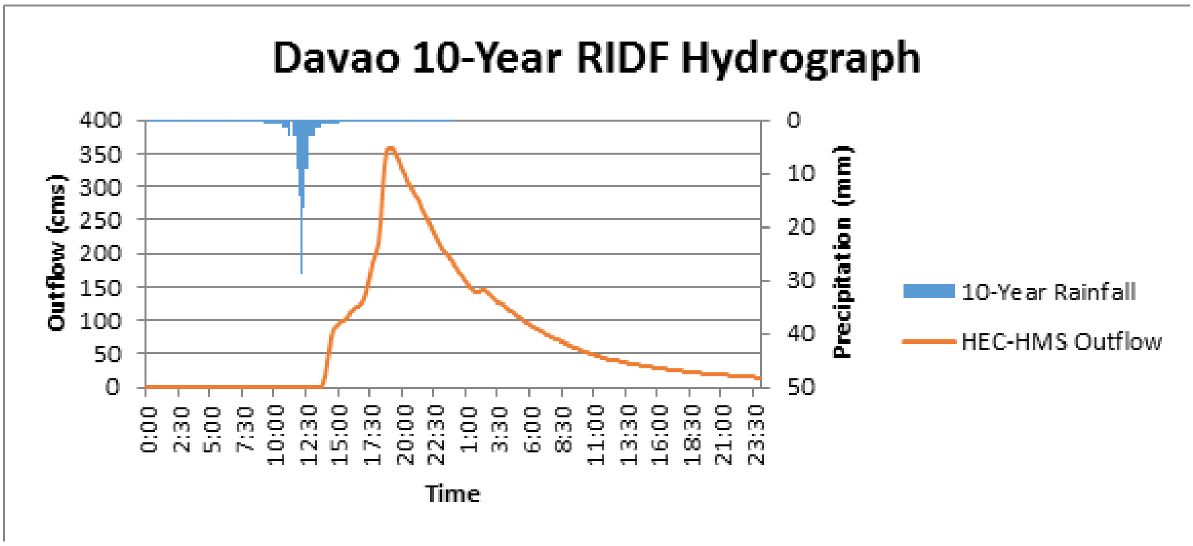


Figure 31. Outflow hydrograph generated using the Davao 10-Year RIDF in HEC-HMS

Results and Discussion

In the 25-year return period graph, the peak outflow is 527.5 cms. This occurs 6 hours and 30 minutes after the peak precipitation of 33.5 mm, as shown on Figure 32.

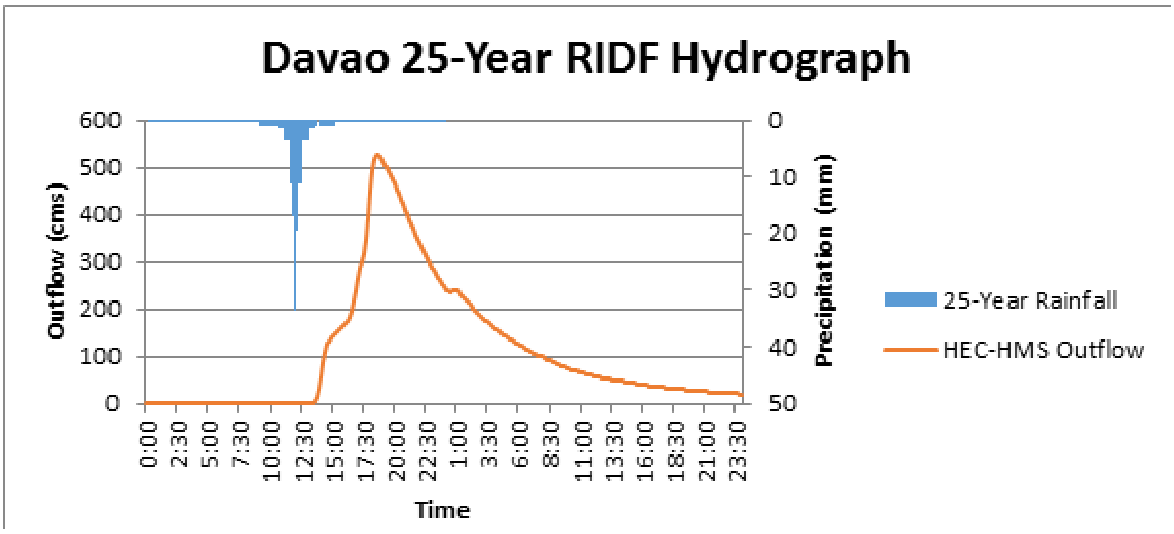


Figure 32. Outflow hydrograph generated using the Davao 25-Year RIDF in HEC-HMS

In the 50-year return period graph, the peak outflow is 673 cms. This occurs 6 hours and 20 minutes after the peak precipitation of 37 mm, as shown on Figure 33.

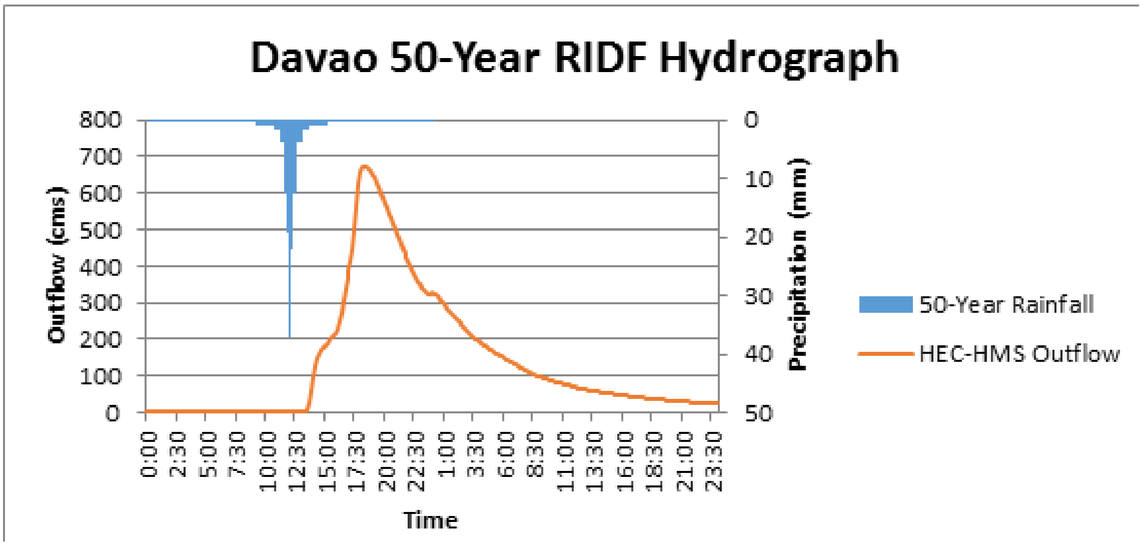


Figure 33. Outflow hydrograph generated using the Davao 50-Year RIDF in HEC-HMS

In the 100-year return period graph, the peak outflow is 850.7 cms. This occurs 6 hours and 10 minutes after the peak precipitation of 40.5 mm, as shown on Figure 34.

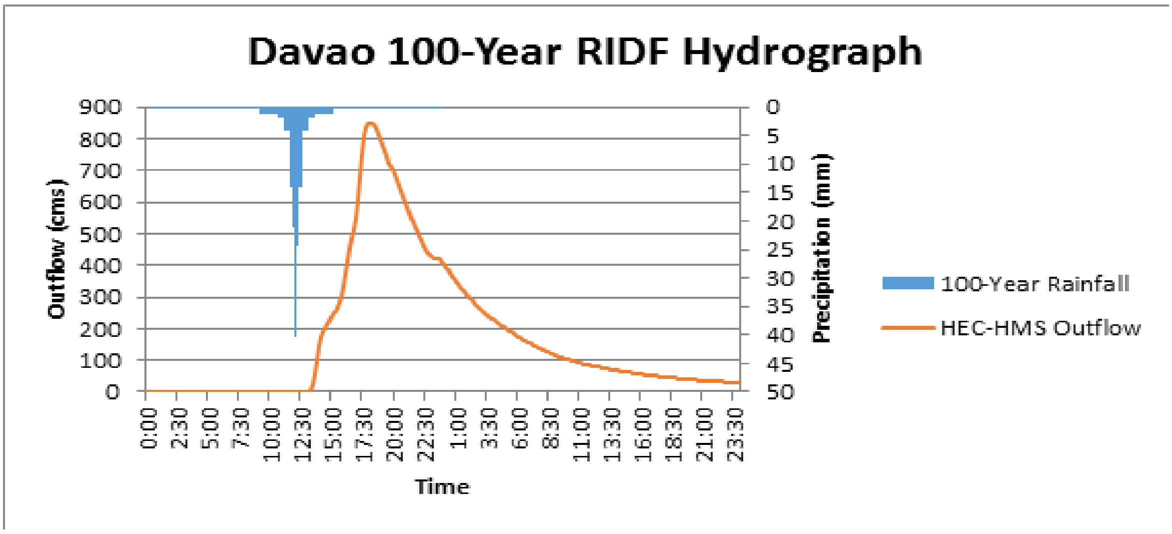


Figure 34. Outflow hydrograph generated using the Davao 100-Year RIDF in HEC-HMS

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

Table 2. Summary of Davao discharge using Davao Station Rainfall Intensity Duration Frequency (RIDF)

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	121.26	25.1	247.2	7 hours, 30 minutes
10-Year	140.49	28.8	357.5	7 hours
25-Year	165.65	33.5	527	6 hours, 30 minutes
50-Year	183.55	37	673	6 hours, 20 minutes
100-Year	202.15	40.5	850.7	6 hours, 10 minutes

4.2.2 Discharge Data using Dr. Horritt's Recommended Hydrological Method

The river discharge values using Dr. Horritt's recommended hydrological method are shown in Figure 35 and the peak discharge values are summarized in Table 3.

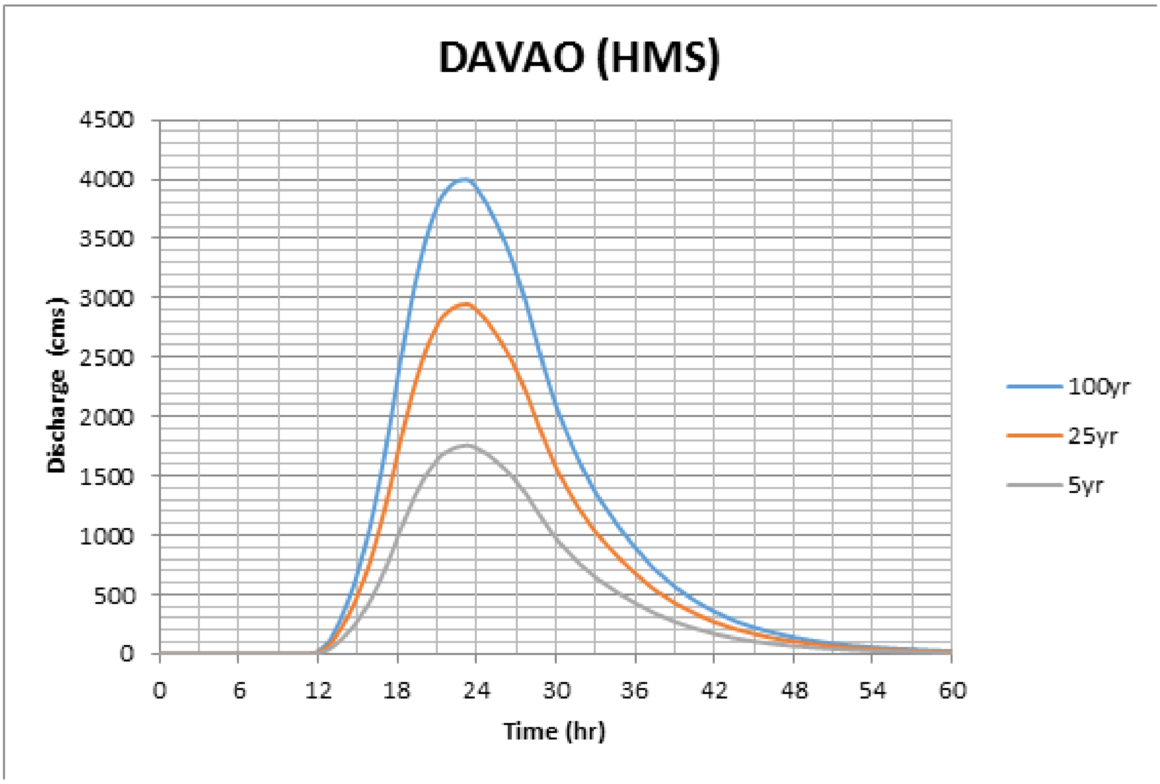


Figure 35. Outflow hydrograph generated using the Davao 5-, 25-, 100-Year RIDF in HEC-HMS

Table 3. Summary of Davao river discharge using the recommended hydrological method by Dr. Horritt

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	1758.6	23 hours, 20 minutes
25-Year	2947.5	23 hours, 10 minutes
100-Year	3997.1	23 hours, 10 minutes

The comparison of discharge values obtained from HEC-HMS, QMED, and from the bankful discharge method, Qbankful, are shown in Table 4. Using values from the DTM of Davao, the bankful discharge for the river was computed.

Table 4. Validation of river discharge estimate using the bankful method

Discharge Point	Qbankful, cms	QMED, cms	Validation
Davao (1)	1501.82	1758.6	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.

4.3 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 Davao river basin.

Results and Discussion

Flood Hazard Maps and Flow Depth Maps

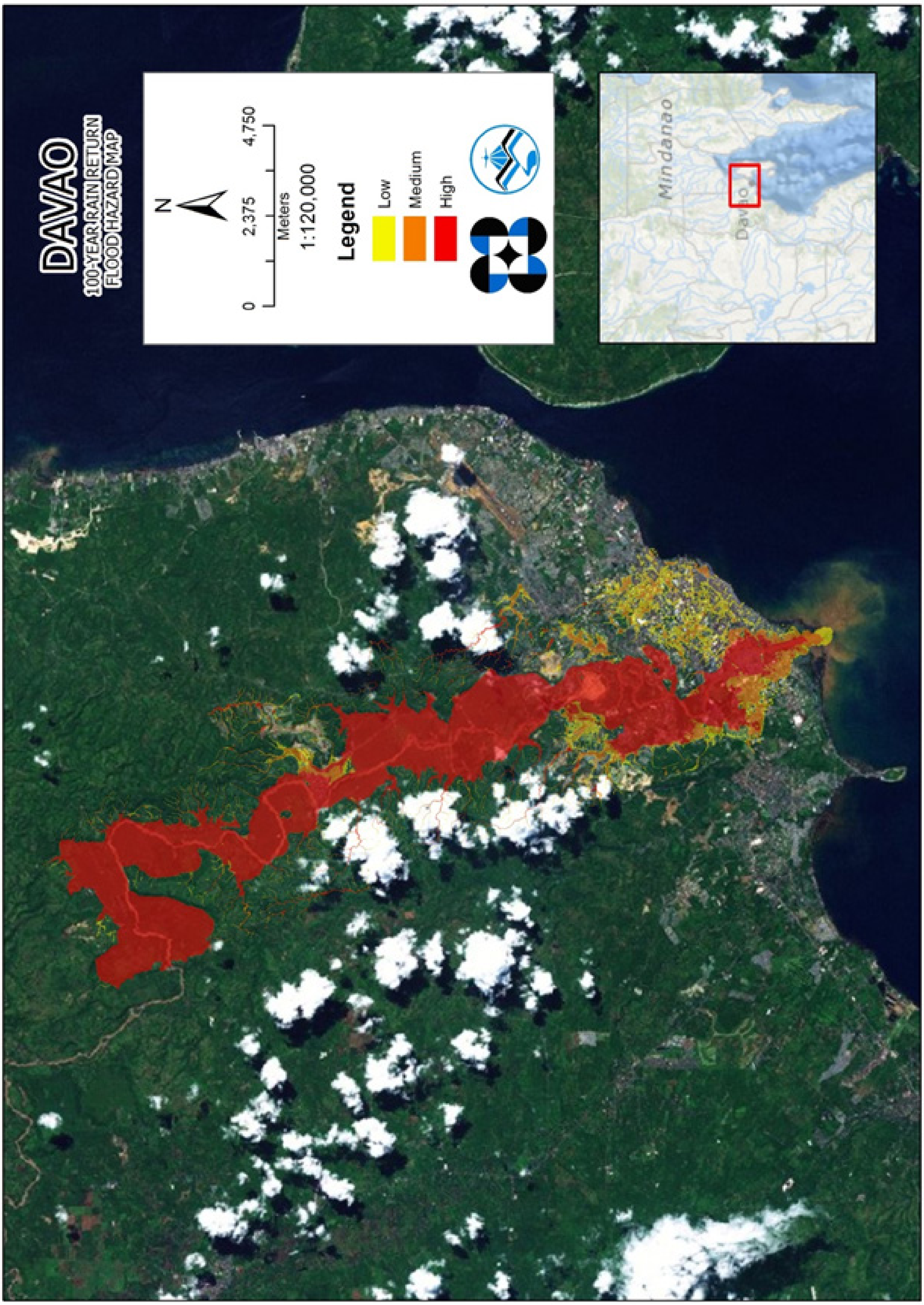


Figure 36. 100-year Flood Hazard Map for Davao River Basin

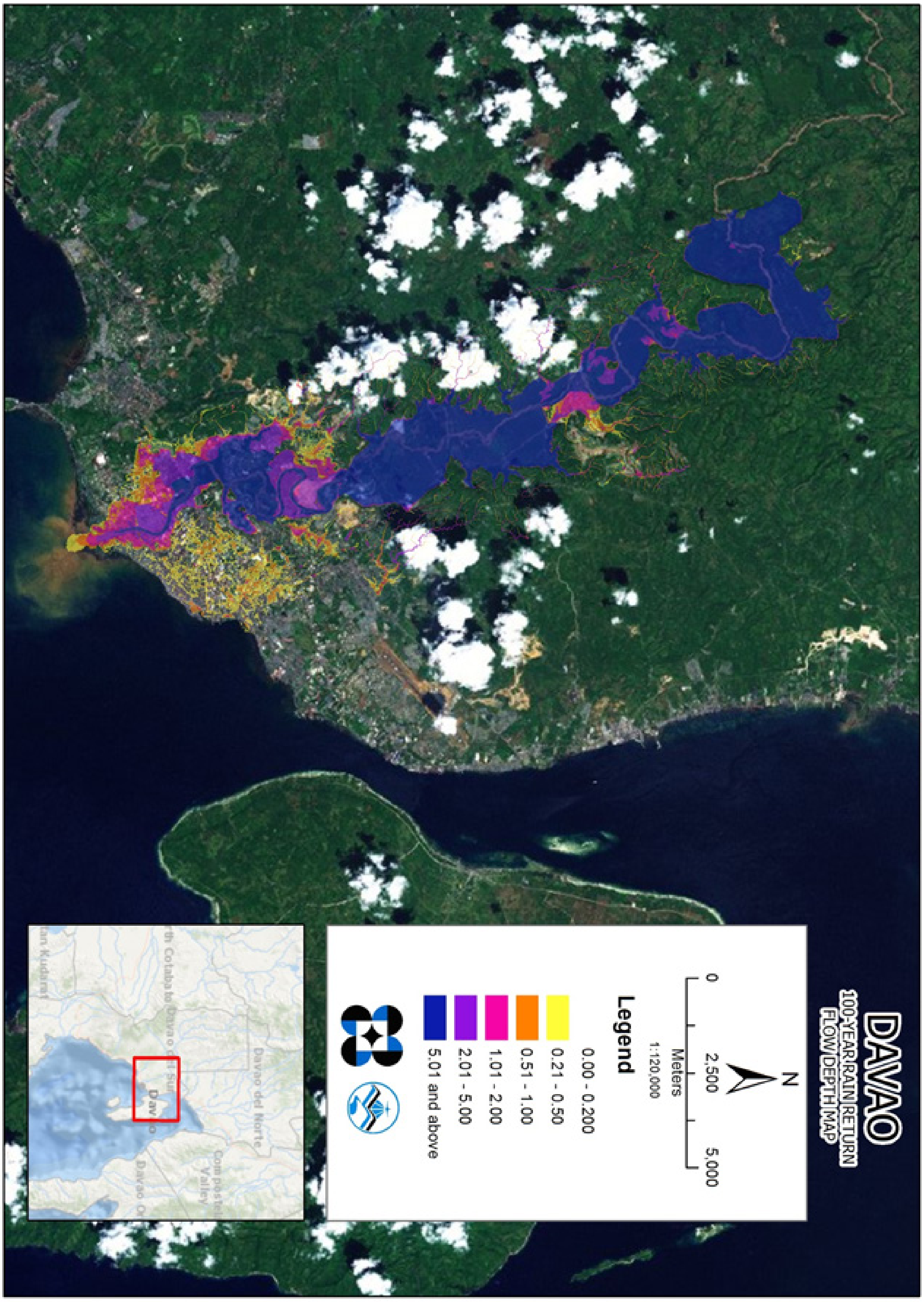


Figure 37. 100-year Flow Depth Map for Davao River Basin

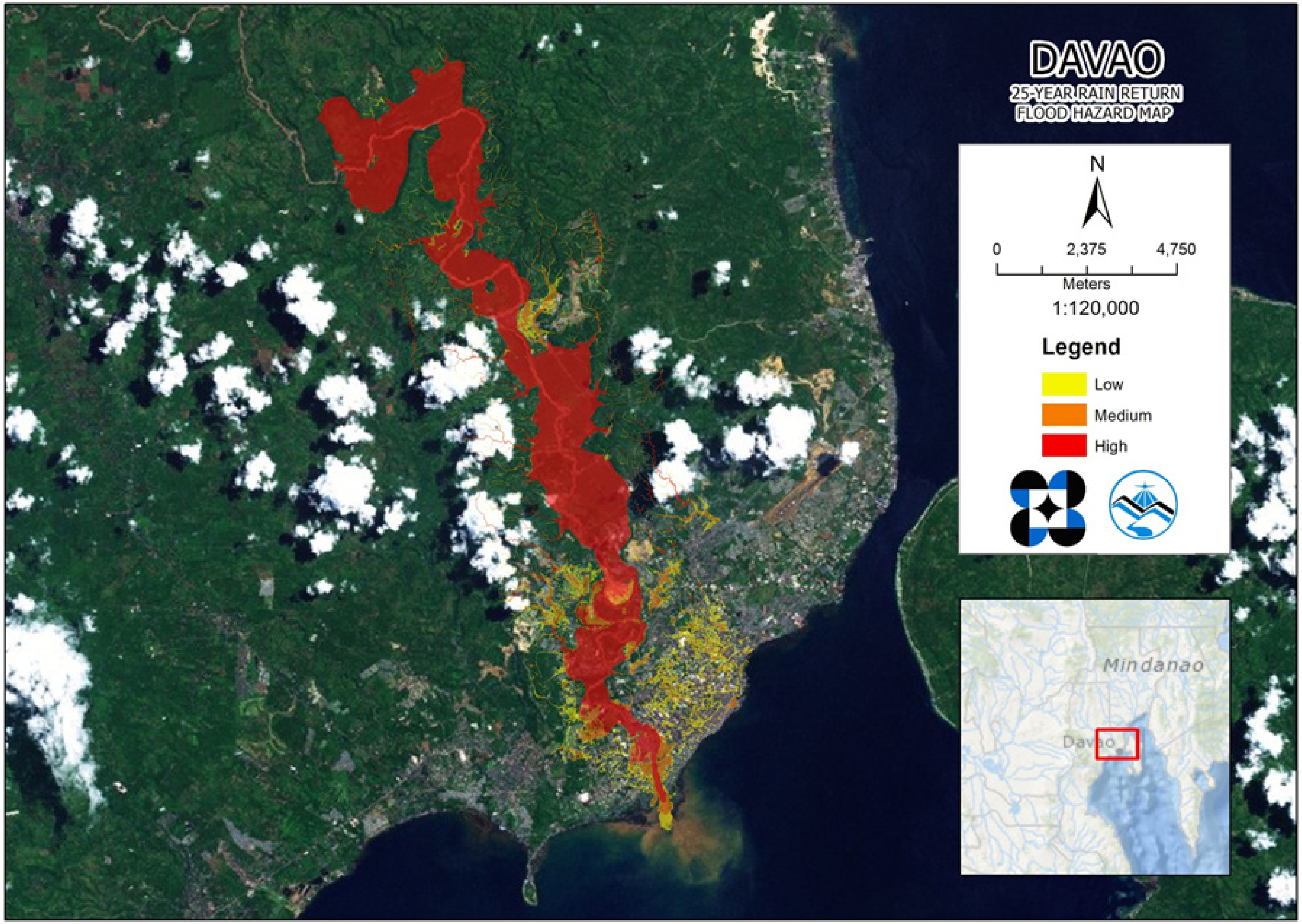


Figure 38. 25-year Flood Hazard Map for Davao River Basin

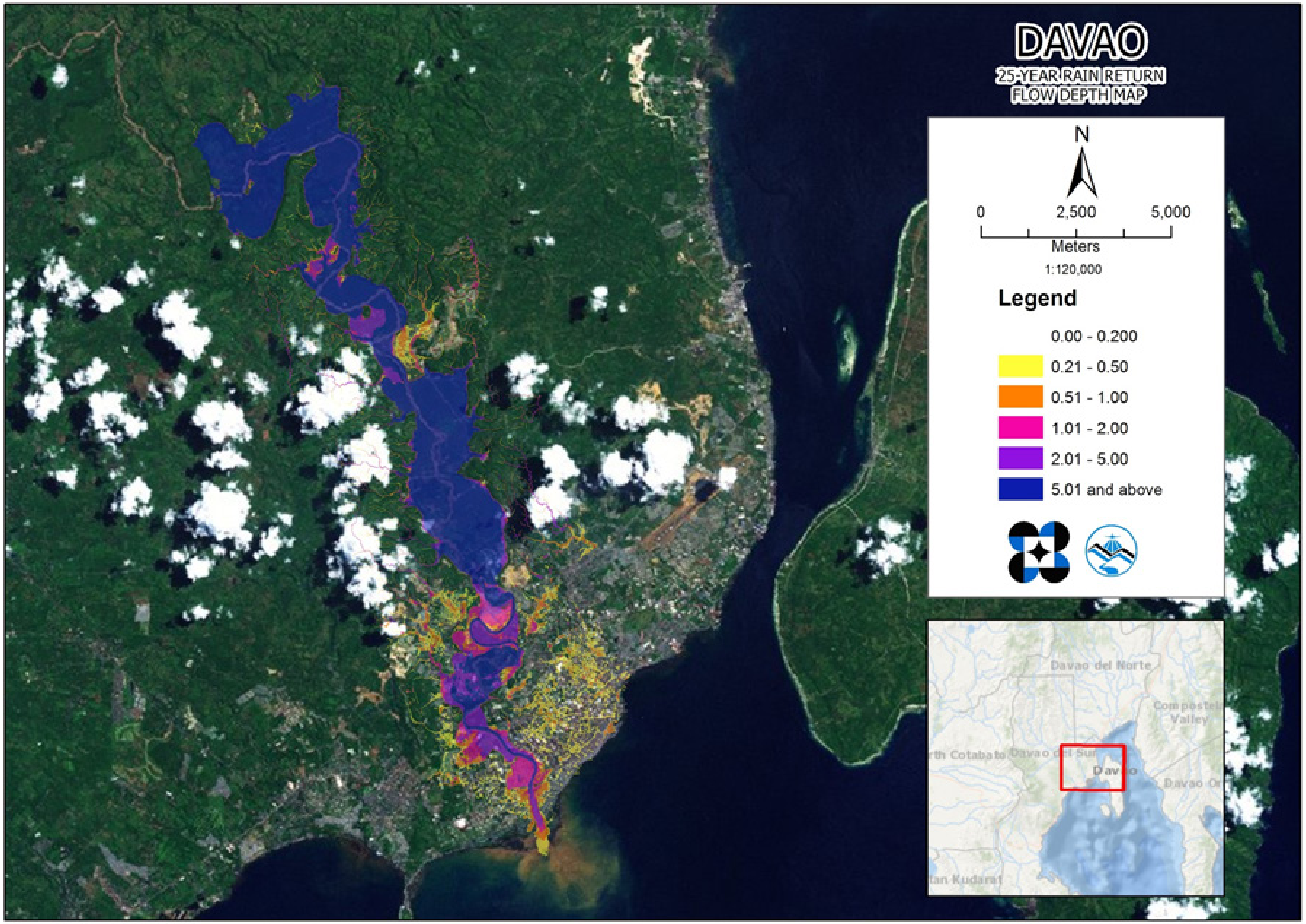


Figure 39. 25-year Flow Depth Map for Davao River Basin

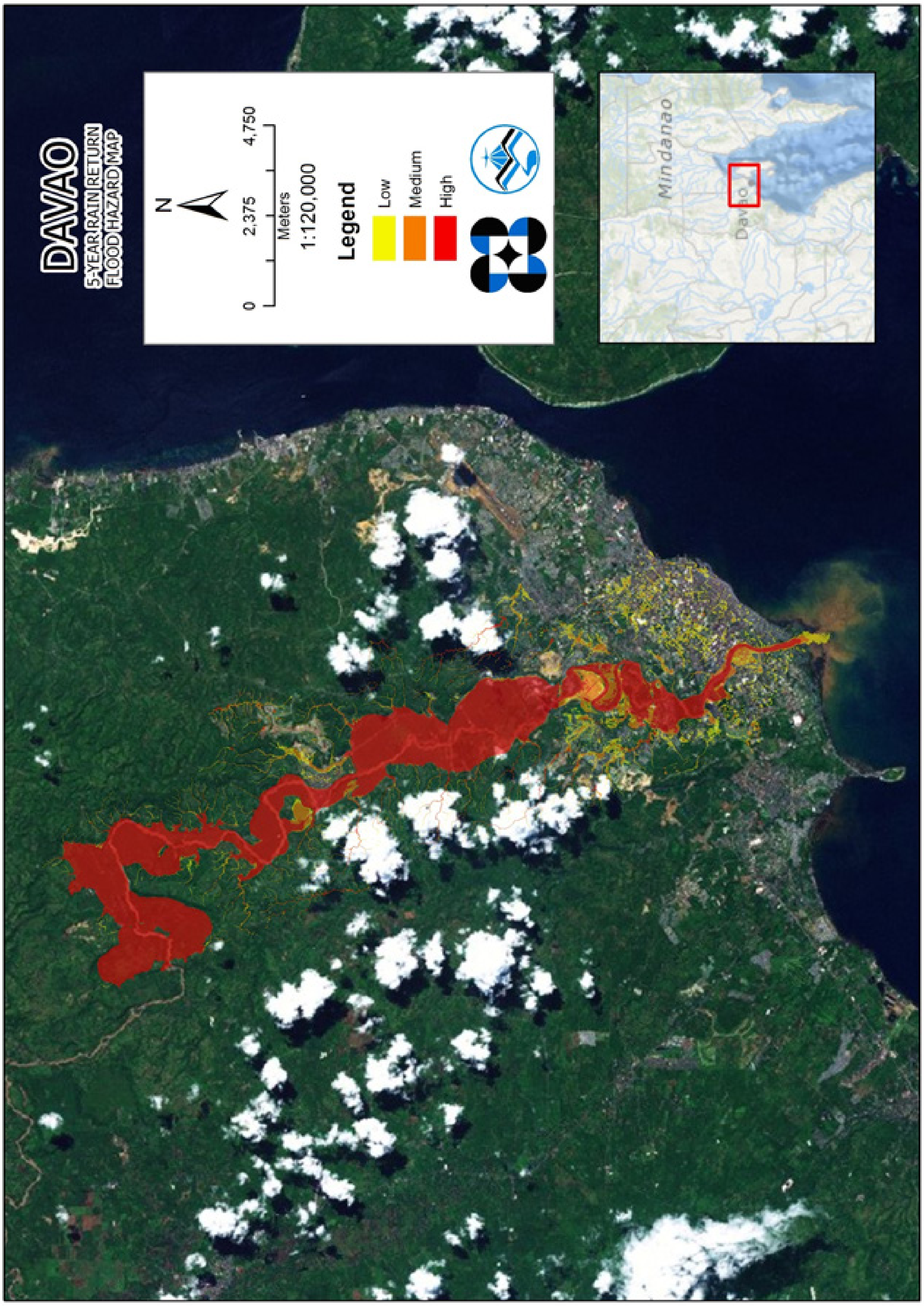


Figure 40. 5-year Flood Hazard Map for Davao River Basin

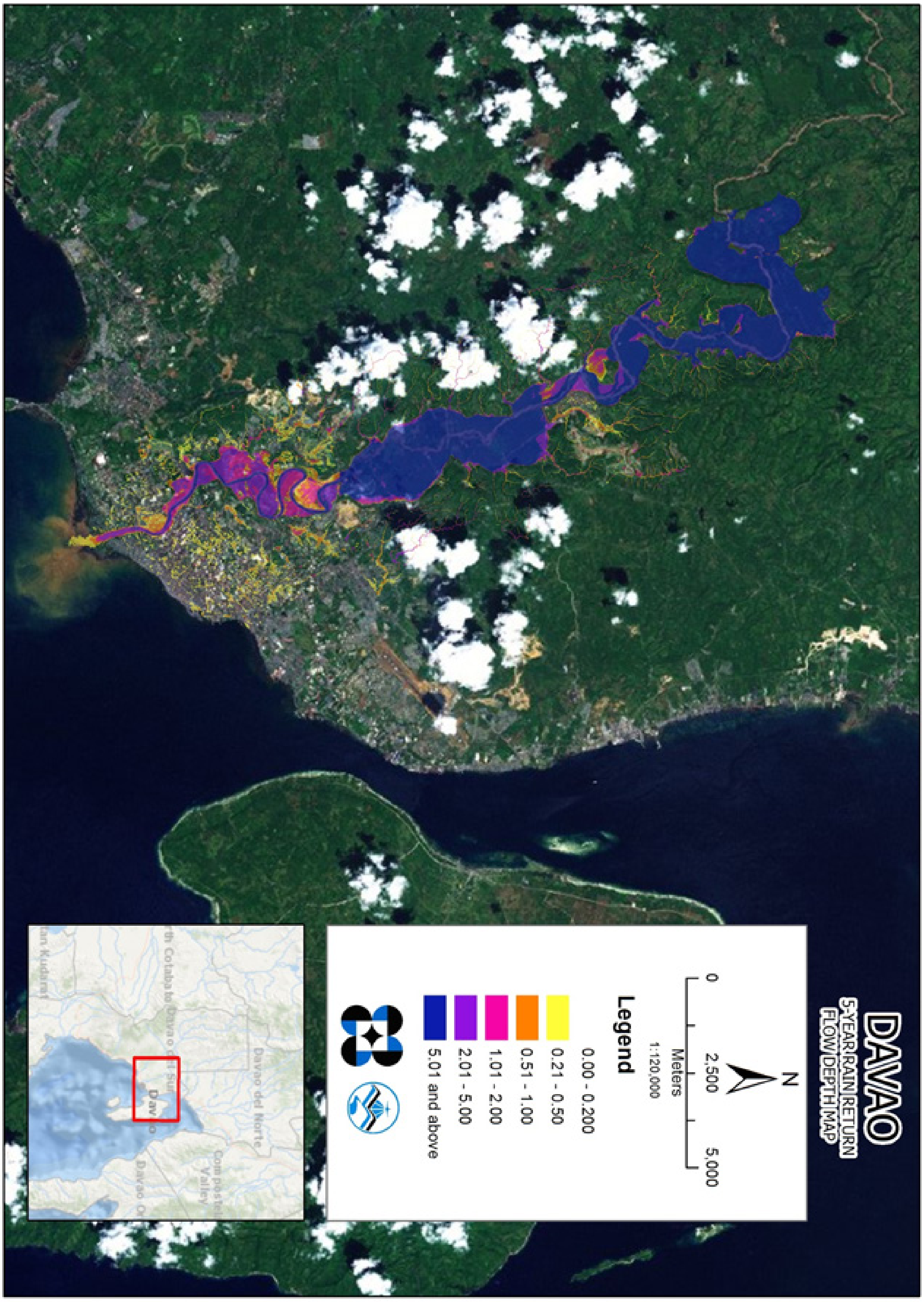


Figure 41. 5-year Flow Depth Map for Davao River Basin

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Appendix

Appendix A. Davao Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
10B	18.721	69.986	0	1.6317	3.0776	Discharge	0.0181412	0.0240899	Ratio to Peak	0.01
11B	154.22	49.133	0	3.3634	3.9275	Discharge	0.0559617	0.0361349	Ratio to Peak	0.01
12B	204.87	73.143	0	1.0068	3.4463	Discharge	0.0201226	0.0780847	Ratio to Peak	0.01
13B	228.27	70.461	0	1.578	4.0667	Discharge	0.0406689	0.0361349	Ratio to Peak	0.01
14B	499.00	46.366	0	0.66865	1.7528	Discharge	0.0126843	0.0361349	Ratio to Peak	0.01
15B	41.812	46.27	0	1.6286	3.0206	Discharge	0.0207894	0.0361349	Ratio to Peak	0.01
16B	255.12	73.143	0	0.33979	1.2357	Discharge	0.0117811	0.053117	Ratio to Peak	0.01
17B	80.399	72.086	0	0.15754	0.60883	Discharge	0.0045867	0.0361349	Ratio to Peak	0.01
18B	499.00	42.289	0	0.57605	1.5099	Discharge	0.0142640	0.0361349	Ratio to Peak	0.01
19B	94.017	73.143	0	0.7432	1.2473	Discharge	0.0153315	0.0361349	Ratio to Peak	0.01
1B	335.59	69.302	0	0.6485	1.707	Discharge	0.0046062	0.0361349	Ratio to Peak	0.01

Appendix

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
20B	176.37	33.016	0	1.5041	2.703	Discharge	0.0214370	0.0361349	Ratio to Peak	0.01
21B	40.898	30.116	0	1.0347	2.7207	Discharge	0.0178965	0.0361349	Ratio to Peak	0.01
22B	27.412	49.098	0	0.93985	1.645	Discharge	0.0192448	0.0361349	Ratio to Peak	0.01
23B	50.051	47.611	0	3.5547	21.382	Discharge	0.0778584	0.18293	Ratio to Peak	0.01
24B	499.00	49.133	0	1.8488	5.0041	Discharge	0.0347289	0.0531184	Ratio to Peak	0.01
25B	244.42	49.089	0	1.8276	4.7867	Discharge	0.0237172	0.18293	Ratio to Peak	0.01
26B	32.000	49.082	0	2.6675	5.9384	Discharge	0.0248798	0.12691	Ratio to Peak	0.01
27B	51.219	49.138	0	0.7742	3.0636	Discharge	0.0183919	0.0361349	Ratio to Peak	0.01
28B	110.01	32.966	0	2.2861	6.1157	Discharge	0.0893548	0.18293	Ratio to Peak	0.01
29B	146.47	46.282	0	0.53045	1.3937	Discharge	0.0327274	0.18293	Ratio to Peak	0.01
2B	83.539	46.35	0	3.3269	2.5325	Discharge	0.0248253	0.1269	Ratio to Peak	0.01

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
30B	499.00	37.48	0	2.164	5.6727	Discharge	0.0328998	0.0531184	Ratio to Peak	0.01
31B	1.2484	73.143	0	3.5553	9.3422	Discharge	0.0269480	0.0361349	Ratio to Peak	0.01
32B	499.00	24.081	0	1.4386	3.7711	Discharge	0.0488904	0.268905	Ratio to Peak	0.01
33B	499.00	37.507	0	2.6642	4.2565	Discharge	0.0543686	0.268905	Ratio to Peak	0.01
34B	499.00	27.034	0	1.2079	2.154	Discharge	0.0239689	0.403368	Ratio to Peak	0.01
35B	499.00	35.745	0	1.2824	3.3617	Discharge	0.0247704	0.274407	Ratio to Peak	0.01
36B	499.00	41.752	0	2.0422	5.3479	Discharge	0.0386023	0.9261	Ratio to Peak	0.01
37B	499.00	53.436	0	0.74525	1.9534	Discharge	0.0046294	0.9261	Ratio to Peak	0.01
38B	499.00	23.225	0	1.0714	2.8085	Discharge	0.0149046	0.245721	Ratio to Peak	0.01
39B	41.965	49.107	0	0.41346	2.8877	Discharge	0.0193250	0.552888	Ratio to Peak	0.01
3B	18.832	31.623	0	1.9961	28.474	Discharge	0.0217283	0.18293	Ratio to Peak	0.01

Appendix

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
40B	499.00	41.48	0	1.1938	3.1183	Discharge	0.0247258	0.593628	Ratio to Peak	0.01
41B	301.47	72.086	0	0.28646	0.51081	Discharge	0.0109324	0.9261	Ratio to Peak	0.01
42B	18.843	32.87	0	5.4911	9.8709	Discharge	0.0423288	0.55566	Ratio to Peak	0.01
43B	187.05	32.611	0	0.5266	0.93907	Discharge	0.0144798	0.6174	Ratio to Peak	0.01
44B	18.712	49.082	0	0.31789	1.8758	Discharge	0.0223631	0.9261	Ratio to Peak	0.01
45B	499.00	33.053	0	1.7764	4.6565	Discharge	0.0187994	0.6174	Ratio to Peak	0.01
46B	499.00	37.732	0	0.23566	0.61772	Discharge	0.0133821	0.9261	Ratio to Peak	0.01
47B	499.00	34.643	0	2.1308	5.5857	Discharge	0.0224376	0.9261	Ratio to Peak	0.01
48B	499.00	37.584	0	1.2522	3.2827	Discharge	0.0160738	0.9261	Ratio to Peak	0.01
49B	499.00	51.298	0	1.9524	5.1178	Discharge	0.0135748	0.9261	Ratio to Peak	0.01
4B	62.617	47.348	0	1.7855	7.1856	Discharge	0.0269453	0.63	Ratio to Peak	0.01

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
50B	499.00	37.445	0	1.751	4.5898	Discharge	0.0189833	0.6174	Ratio to Peak	0.01
51B	499.00	49.964	0	0.96105	3.7603	Discharge	0.0126261	0.9261	Ratio to Peak	0.01
52B	499.00	49.964	0	1.6436	4.2024	Discharge	0.0167358	0.9261	Ratio to Peak	0.01
53B	499.00	42.8	0	2.5567	4.487	Discharge	0.0244345	0.605052	Ratio to Peak	0.01
54B	499.00	41.534	0	1.7719	4.6473	Discharge	0.0187666	0.9261	Ratio to Peak	0.01
55B	499.00	49.964	0	2.6384	6.916	Discharge	0.0216828	0.9261	Ratio to Peak	0.01
56B	499.00	49.964	0	0.47495	1.8302	Discharge	0.0086123	0.945	Ratio to Peak	0.01
5B	77.988	47.155	0	2.8441	7.308	Discharge	0.0388572	0.945	Ratio to Peak	0.01
6B	27.572	32.415	0	1.7756	1.5117	Discharge	0.0327418	0.940275	Ratio to Peak	0.01
7B	499.00	49.302	0	0.7193	1.8855	Discharge	0.0158473	0.940275	Ratio to Peak	0.01
8B	18.564	32.393	0	0.71065	2.8034	Discharge	0.0089763	0.945	Ratio to Peak	0.01

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
9B	18.557	48.191	0	1.4982	2.5145	Discharge	0.0260344	0.945	Ratio to Peak	0.01

Appendix B. Davao Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
100R	Automatic Fixed Interval	24484.7	0.02	0.0001	Trapezoid	15	45
101R	Automatic Fixed Interval	16253.5	0.05	0.0003	Trapezoid	15	45
102R	Automatic Fixed Interval	17290.7	0.03	0.0003	Trapezoid	15	45
103R	Automatic Fixed Interval	15096.5	0.01	0.0001	Trapezoid	15	45
104R	Automatic Fixed Interval	11920.7	0.01	0.0001	Trapezoid	15	45
105R	Automatic Fixed Interval	1149.8	0.01	0.0004	Trapezoid	15	45
106R	Automatic Fixed Interval	25128.0	0.01	0.0006	Trapezoid	15	45
107R	Automatic Fixed Interval	8421.8	0.01	0.0002	Trapezoid	15	45
108R	Automatic Fixed Interval	16731.5	0.01	0.0011	Trapezoid	15	45
109R	Automatic Fixed Interval	1699.9	0.01	0.0004	Trapezoid	15	45
110R	Automatic Fixed Interval	25087.1	0.01	0.0010	Trapezoid	15	45
111R	Automatic Fixed Interval	29730.3	0.00	0.0014	Trapezoid	15	45
112R	Automatic Fixed Interval	28981.5	0.00	0.0021	Trapezoid	15	45
113R	Automatic Fixed Interval	10859.7	0.00	0.0010	Trapezoid	15	45
59R	Automatic Fixed Interval	23132.4	0.00	0.0007	Trapezoid	15	45
60R	Automatic Fixed Interval	22573.7	0.00	0.0016	Trapezoid	15	45
61R	Automatic Fixed Interval	4018.9	0.01	0.0003	Trapezoid	15	45
62R	Automatic Fixed Interval	17129.8	0.01	0.0007	Trapezoid	15	45
63R	Automatic Fixed Interval	28333.1	0.04	0.0023	Trapezoid	15	45
64R	Automatic Fixed Interval	39848.7	0.00	0.0004	Trapezoid	15	45
65R	Automatic Fixed Interval	37115.6	0.00	0.0008	Trapezoid	15	45
66R	Automatic Fixed Interval	24949.5	0.00	0.0009	Trapezoid	15	45
67R	Automatic Fixed Interval	19712.5	0.01	0.0012	Trapezoid	15	45
68R	Automatic Fixed Interval	26948.9	0.01	0.0004	Trapezoid	15	45
69R	Automatic Fixed Interval	13407.1	0.02	0.0007	Trapezoid	15	45
70R	Automatic Fixed Interval	7228.6	0.04	0.0033	Trapezoid	15	45
71R	Automatic Fixed Interval	70560.7	0.00	0.0014	Trapezoid	15	45
72R	Automatic Fixed Interval	73641.0	0.01	0.0001	Trapezoid	15	45
73R	Automatic Fixed Interval	84336.1	0.00	0.0085	Trapezoid	15	45
74R	Automatic Fixed Interval	27936.0	0.03	0.0006	Trapezoid	15	45
75R	Automatic Fixed Interval	59845.6	0.01	0.0061	Trapezoid	15	45
76R	Automatic Fixed Interval	53166.0	0.01	0.0001	Trapezoid	15	45
77R	Automatic Fixed Interval	6061.8	0.02	0.0009	Trapezoid	15	45
78R	Automatic Fixed Interval	31457.7	0.01	0.0001	Trapezoid	15	45
79R	Automatic Fixed Interval	23476.4	0.00	0.0011	Trapezoid	15	45

Appendix

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
80R	Automatic Fixed Interval	5436.7	0.01	0.0022	Trapezoid	15	45
81R	Automatic Fixed Interval	32244.0	0.00	0.0017	Trapezoid	15	45
82R	Automatic Fixed Interval	20500.0	0.00	0.0003	Trapezoid	15	45
83R	Automatic Fixed Interval	32337.5	0.00	0.0012	Trapezoid	15	45
84R	Automatic Fixed Interval	43199.3	0.01	0.0033	Trapezoid	15	45
85R	Automatic Fixed Interval	15752.4	0.03	0.0012	Trapezoid	15	45
86R	Automatic Fixed Interval	19948.5	0.00	0.0013	Trapezoid	15	45
87R	Automatic Fixed Interval	40384.2	0.01	0.0003	Trapezoid	15	45
88R	Automatic Fixed Interval	34330.5	0.00	0.0011	Trapezoid	15	45
89R	Automatic Fixed Interval	45395.1	0.02	0.0009	Trapezoid	15	45
90R	Automatic Fixed Interval	10816.0	0.01	0.0004	Trapezoid	15	45
91R	Automatic Fixed Interval	33575.5	0.01	0.0032	Trapezoid	15	45
92R	Automatic Fixed Interval	28124.9	0.01	0.0021	Trapezoid	15	45
93R	Automatic Fixed Interval	17568.4	0.02	0.0006	Trapezoid	15	45
94R	Automatic Fixed Interval	7638.7	0.00	0.0006	Trapezoid	15	45
95R	Automatic Fixed Interval	17770.6	0.01	0.0004	Trapezoid	15	45
96R	Automatic Fixed Interval	13235.9	0.01	0.0004	Trapezoid	15	45
97R	Automatic Fixed Interval	25949.2	0.02	0.0008	Trapezoid	15	45
98R	Automatic Fixed Interval	3893.6	0.01	0.0002	Trapezoid	15	45
99R	Automatic Fixed Interval	17543.9	0.03	0.0003	Trapezoid	15	45

Appendix C. Davao Floodplain HEC-HMS Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	7.33333333	0	0	0
0.16666667	0	0	0	7.5	0	0	0
0.33333333	0	0	0	7.66666667	0	0	0
0.5	0	0	0	7.83333333	0	0	0
0.66666667	0	0	0	8	0	0	0
0.83333333	0	0	0	8.16666667	0	0	0
1	0	0	0	8.33333333	0	0	0
1.16666667	0	0	0	8.5	0	0	0
1.33333333	0	0	0	8.66666667	0	0	0
1.5	0	0	0	8.83333333	0	0	0
1.66666667	0	0	0	9	0	0	0
1.83333333	0	0	0	9.16666667	0	0	0
2	0	0	0	9.33333333	0	0	0
2.16666667	0	0	0	9.5	0	0	0
2.33333333	0	0	0	9.66666667	0	0	0
2.5	0	0	0	9.83333333	0	0	0
2.66666667	0	0	0	10	0	0	0
2.83333333	0	0	0	10.1666667	0	0	0
3	0	0	0	10.3333333	0	0	0
3.16666667	0	0	0	10.5	0	0	0
3.33333333	0	0	0	10.6666667	0.1	0	0
3.5	0	0	0	10.8333333	0.1	0	0
3.66666667	0	0	0	11	0.3	0.1	0
3.83333333	0	0	0	11.1666667	0.7	0.3	0
4	0	0	0	11.3333333	1.3	0.6	0.1
4.16666667	0	0	0	11.5	2.8	1.4	0.4
4.33333333	0	0	0	11.6666667	6.1	3.5	1.3
4.5	0	0	0	11.8333333	14	9	4.2
4.66666667	0	0	0	12	25	16.7	8.5
4.83333333	0	0	0	12.1666667	38	26	13.7
5	0	0	0	12.3333333	53.2	36.7	19.7
5.16666667	0	0	0	12.5	69.8	48.5	26.2
5.33333333	0	0	0	12.6666667	88.9	62	33.6
5.5	0	0	0	12.8333333	113.3	79.3	43.3
5.66666667	0	0	0	13	142.7	100.5	55.3
5.83333333	0	0	0	13.1666667	175.5	124.1	68.8

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
6	0	0	0	13.3333333	211.2	149.9	83.6
6.16666667	0	0	0	13.5	248.7	177	99.1
6.33333333	0	0	0	13.6666667	287.8	205.4	115.4
6.5	0	0	0	13.8333333	329.6	235.6	132.8
6.66666667	0	0	0	14	374.9	268.4	151.7
6.83333333	0	0	0	14.1666667	422.5	303	171.8
7	0	0	0	14.3333333	472.1	339.1	192.8
7.16666667	0	0	0	14.5	523.3	376.3	214.4
14.6666667	576.1	414.7	236.6	22.5	3981.9	2932.2	1743.8
14.8333333	631.4	454.8	259.8	22.6666667	3988.9	2938.4	1748.6
15	691.5	498.4	285.1	22.8333333	3993.7	2942.9	1752.5
15.1666667	755.3	544.9	312.2	23	3996.5	2946	1755.5
15.3333333	821.7	593.2	340.3	23.1666667	3997.1	2947.5	1757.7
15.5	890.7	643.4	369.5	23.3333333	3994	2946.5	1758.6
15.6666667	961.4	694.9	399.5	23.5	3983.4	2940	1756.2
15.8333333	1035	748.3	430.5	23.6666667	3966.9	2929	1751
16	1113.6	805.4	463.6	23.8333333	3946.5	2915	1744.1
16.1666667	1197.7	866.7	499.3	24	3922.5	2898.4	1735.6
16.3333333	1285.6	930.8	536.7	24.1666667	3896.6	2880.4	1726.1
16.5	1376.6	997.2	575.5	24.3333333	3868.8	2860.9	1715.9
16.6666667	1469.9	1065.3	615.3	24.5	3838.7	2839.8	1704.5
16.8333333	1565.3	1134.9	655.9	24.6666667	3806.7	2817.1	1692.2
17	1663.9	1206.8	697.9	24.8333333	3773.1	2793.3	1679.2
17.1666667	1767.6	1282.6	742.2	25	3738.4	2768.5	1665.5
17.3333333	1874.7	1360.9	788.2	25.1666667	3702.7	2743	1651.4
17.5	1984.1	1441.1	835.4	25.3333333	3665.9	2716.7	1636.8
17.6666667	2095.5	1522.9	883.6	25.5	3627.8	2689.5	1621.6
17.8333333	2207.3	1605	932.1	25.6666667	3587.7	2660.7	1605.6
18	2318.5	1686.9	980.7	25.8333333	3546.1	2630.9	1588.8
18.1666667	2426.8	1766.7	1028.1	26	3503.3	2600.1	1571.4
18.3333333	2532.2	1844.4	1074.3	26.1666667	3459.3	2568.5	1553.6
18.5	2635.7	1920.8	1119.9	26.3333333	3414.3	2536.1	1535.3
18.6666667	2737.7	1996.2	1164.9	26.5	3367.6	2502.5	1516.4
18.8333333	2838.5	2070.8	1209.6	26.6666667	3318	2466.8	1496.1
19	2937.2	2144	1253.6	26.8333333	3265.8	2429.1	1474.7
19.1666667	3031	2213.7	1295.8	27	3211.7	2390.1	1452.4
19.3333333	3118.1	2278.5	1334.9	27.1666667	3156.1	2349.9	1429.4
19.5	3200.7	2339.9	1372	27.3333333	3099.3	2308.8	1405.9

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
19.6666667	3280.1	2398.9	1407.8	27.5	3041.1	2266.6	1381.8
19.8333333	3356.8	2456.1	1442.5	27.6666667	2980.6	2222.8	1356.7
20	3431.2	2511.7	1476.5	27.8333333	2916.9	2176.6	1330.1
20.1666667	3501.7	2564.6	1509	28	2851.2	2128.8	1302.5
20.3333333	3564.1	2611.5	1537.9	28.1666667	2784.1	2079.9	1274.2
20.5	3620.7	2654.1	1564.2	28.3333333	2715.8	2030.1	1245.3
20.6666667	3673.6	2693.9	1588.9	28.5	2647.4	1980.2	1216.2
20.8333333	3722.7	2730.9	1611.9	28.6666667	2579.6	1930.4	1187.1
21	3769.4	2766.3	1634.1	28.8333333	2514.1	1882.4	1158.9
21.1666667	3812.3	2799.1	1654.9	29	2450.3	1835.6	1131.4
21.3333333	3848.5	2826.9	1672.7	29.1666667	2387.4	1789.4	1104.2
21.5	3877.9	2849.6	1687.5	29.3333333	2325.7	1744	1077.4
21.6666667	3902.8	2869	1700.2	29.5	2264.6	1699	1050.7
21.8333333	3924	2885.5	1711.2	29.6666667	2204.9	1654.9	1024.5
22	3942.5	2900.1	1721.1	29.8333333	2148.7	1613.3	999.6
22.1666667	3958.9	2913.2	1730.1	30	2096	1574.4	976.4
22.3333333	3972.3	2924.1	1737.8	30.1666667	2045.6	1537.1	954.1
30.3333333	1996.9	1501.1	932.6	38.1666667	646.3	490	310.4
30.5	1949.3	1465.9	911.5	38.3333333	630.6	478.2	302.9
30.6666667	1902.6	1431.2	890.6	38.5	615.2	466.4	295.5
30.8333333	1857	1397.5	870.3	38.6666667	599.8	454.8	288.2
31	1813.2	1365	850.8	38.8333333	584.6	443.3	280.9
31.1666667	1770.6	1333.4	831.7	39	569.4	431.8	273.7
31.3333333	1728.8	1302.4	813.1	39.1666667	554.6	420.6	266.5
31.5	1687.6	1271.9	794.6	39.3333333	540.2	409.7	259.6
31.6666667	1647.1	1241.7	776.4	39.5	526.7	399.4	253
31.8333333	1607.4	1212.2	758.5	39.6666667	513.7	389.5	246.8
32	1569.4	1183.9	741.3	39.8333333	501.1	379.9	240.7
32.1666667	1532.6	1156.4	724.6	40	488.8	370.6	234.7
32.3333333	1496.6	1129.7	708.3	40.1666667	476.7	361.4	228.9
32.5	1461.4	1103.4	692.2	40.3333333	464.9	352.4	223.2
32.6666667	1426.9	1077.5	676.4	40.5	453.2	343.5	217.5
32.8333333	1393.2	1052.3	660.9	40.6666667	441.6	334.7	212
33	1361.2	1028.3	646.1	40.8333333	430.1	326	206.5
33.1666667	1331	1005.6	632.1	41	418.7	317.5	201.1
33.3333333	1302	983.8	618.6	41.1666667	407.6	309	195.7
33.5	1273.8	962.7	605.5	41.3333333	396.6	300.7	190.5
33.6666667	1246.3	942	592.7	41.5	386.2	292.8	185.4

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
33.8333333	1219.2	921.7	580.1	41.6666667	376.3	285.3	180.7
34	1192.4	901.5	567.6	41.8333333	366.8	278.1	176.1
34.1666667	1165.8	881.6	555.3	42	357.7	271.2	171.7
34.3333333	1139.4	861.8	543	42.1666667	348.9	264.5	167.5
34.5	1113.3	842.2	530.9	42.3333333	340.2	257.9	163.3
34.6666667	1087.2	822.7	518.8	42.5	331.7	251.4	159.2
34.8333333	1061.5	803.3	506.8	42.6666667	323.2	245	155.2
35	1036.2	784.3	495	42.8333333	314.8	238.7	151.2
35.1666667	1011.8	765.9	483.5	43	306.6	232.4	147.2
35.3333333	988.3	748.2	472.5	43.1666667	298.4	226.3	143.3
35.5	965.3	730.9	461.7	43.3333333	290.3	220.2	139.5
35.6666667	942.6	713.8	451	43.5	282.5	214.2	135.8
35.8333333	920.3	697	440.5	43.6666667	275.1	208.6	132.2
36	898.2	680.4	430.1	43.8333333	268.2	203.4	128.9
36.1666667	876.3	663.9	419.8	44	261.6	198.4	125.7
36.3333333	854.6	647.5	409.6	44.1666667	255.3	193.6	122.6
36.5	832.9	631.2	399.4	44.3333333	249.2	188.9	119.7
36.6666667	811.4	615	389.3	44.5	243.1	184.3	116.8
36.8333333	790	598.9	379.3	44.6666667	237.2	179.8	113.9
37	768.9	583	369.3	44.8333333	231.4	175.4	111.1
37.1666667	748.5	567.6	359.6	45	225.6	171	108.3
37.3333333	729.6	553.2	350.5	45.1666667	219.8	166.7	105.6
37.5	711.8	539.7	342	45.3333333	214.2	162.4	102.9
37.6666667	694.7	526.8	333.8	45.5	208.7	158.2	100.3
37.8333333	678.3	514.3	325.8	45.6666667	203.3	154.1	97.7
38	662.1	502	318.1	45.8333333	198.2	150.3	95.2
46	193.3	146.6	92.9	53.1666667	64.9	49.2	31.1
46.1666667	188.7	143	90.6	53.3333333	63.3	48	30.4
46.3333333	184.1	139.6	88.4	53.5	61.7	46.8	29.6
46.5	179.7	136.2	86.3	53.6666667	60.2	45.6	28.9
46.6666667	175.3	132.9	84.2	53.8333333	58.7	44.5	28.1
46.8333333	171.1	129.7	82.1	54	57.2	43.3	27.4
47	166.8	126.4	80.1	54.1666667	55.8	42.3	26.7
47.1666667	162.6	123.3	78.1	54.3333333	54.5	41.3	26.1
47.3333333	158.4	120.1	76.1	54.5	53.2	40.3	25.5
47.5	154.3	117	74.1	54.6666667	52.1	39.5	24.9
47.6666667	150.3	113.9	72.2	54.8333333	51	38.6	24.4
47.8333333	146.4	111	70.3	55	50	37.8	23.9

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
48	142.7	108.2	68.5	55.1666667	48.9	37	23.4
48.1666667	139.2	105.5	66.8	55.3333333	47.9	36.3	22.9
48.3333333	135.8	103	65.2	55.5	46.9	35.5	22.4
48.5	132.6	100.5	63.6	55.6666667	45.9	34.8	21.9
48.6666667	129.4	98	62.1	55.8333333	45	34	21.5
48.8333333	126.2	95.6	60.5	56	44	33.3	21
49	123.1	93.3	59.1	56.1666667	43.1	32.6	20.6
49.1666667	120	90.9	57.6	56.3333333	42.2	31.9	20.1
49.3333333	116.9	88.6	56.1	56.5	41.2	31.2	19.7
49.5	113.9	86.4	54.7	56.6666667	40.3	30.5	19.2
49.6666667	111	84.1	53.3	56.8333333	39.4	29.8	18.8
49.8333333	108.1	81.9	51.9	57	38.5	29.1	18.4
50	105.3	79.8	50.5	57.1666667	37.6	28.4	17.9
50.1666667	102.6	77.8	49.3	57.3333333	36.7	27.8	17.5
50.3333333	100.1	75.9	48	57.5	35.8	27.1	17.1
50.5	97.6	74	46.9	57.6666667	34.9	26.4	16.7
50.6666667	95.2	72.2	45.7	57.8333333	34.1	25.8	16.3
50.8333333	92.8	70.4	44.6	58	33.2	25.1	15.8
51	90.5	68.6	43.4	58.1666667	32.3	24.5	15.4
51.1666667	88.2	66.9	42.3	58.3333333	31.5	23.8	15
51.3333333	85.9	65.1	41.3	58.5	30.6	23.2	14.6
51.5	83.7	63.4	40.2	58.6666667	29.8	22.5	14.2
51.6666667	81.4	61.7	39.1	58.8333333	28.9	21.9	13.8
51.8333333	79.2	60.1	38.1	59	28.1	21.3	13.4
52	77.1	58.5	37.1	59.1666667	27.2	20.6	13.1
52.1666667	75.1	57	36.1	59.3333333	26.4	20	12.7
52.3333333	73.2	55.5	35.2	59.5	25.6	19.4	12.3
52.5	71.5	54.2	34.3	59.6666667	24.8	18.8	11.9
52.6666667	69.7	52.9	33.5	59.8333333	24	18.2	11.5
52.8333333	68.1	51.6	32.7	60	23.3	17.6	11.2
53	66.5	50.4	31.9				

DREAM

Disaster RIsk and Exposure Assessment for Mitigation