REGION 7

Ilog-Hilabangan River Basin:

DREAM Flood Forecasting and Flood Hazard Mapping

TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY

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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.

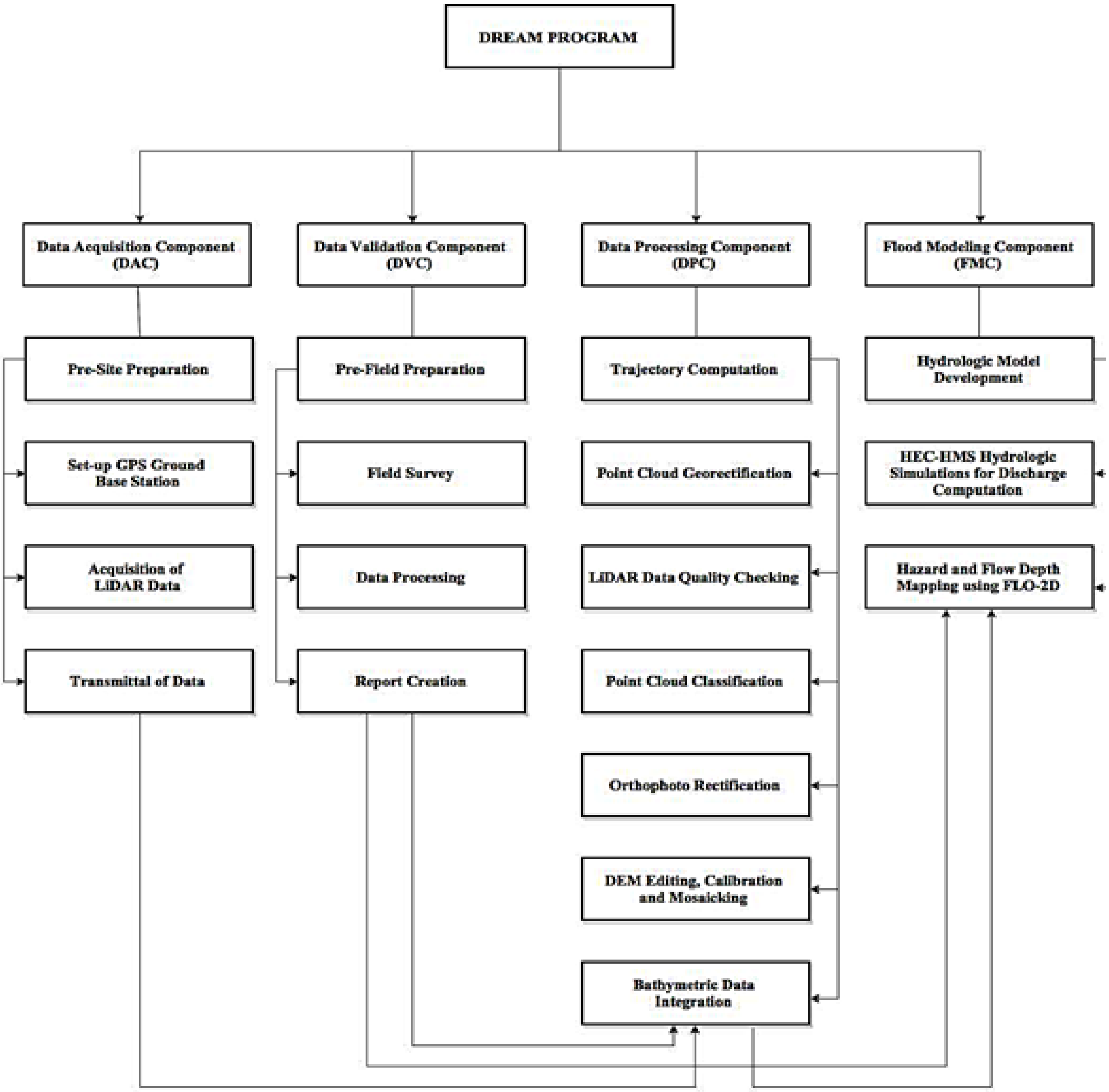


Figure 1. The general methodological framework of the program

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

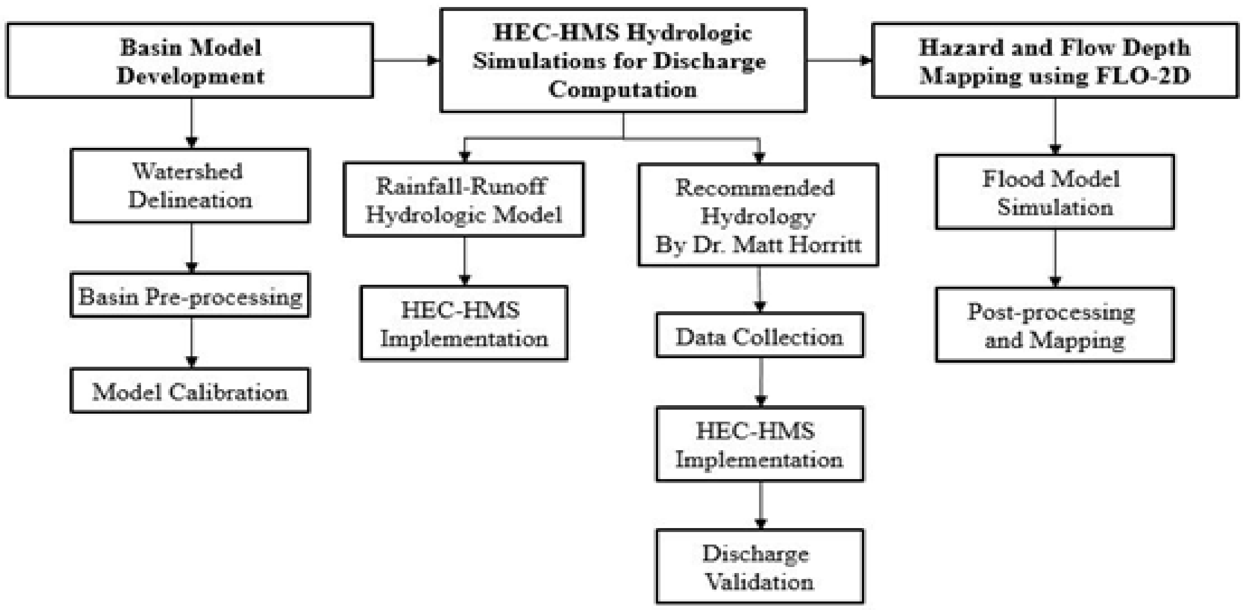


Figure 2. The operational framework and specific work flow of the Flood Modeling Component

The Hilabangan River Basin

The Hilabangan River Basin

The Hilabangan River Basin is located in Negros. The Hilabangan River Basin is the 11th largest river basin in the Philippines with an estimated basin area of 1,945 square kilometres. The location of the Hilabangan River Basin is as shown in Figure 1.

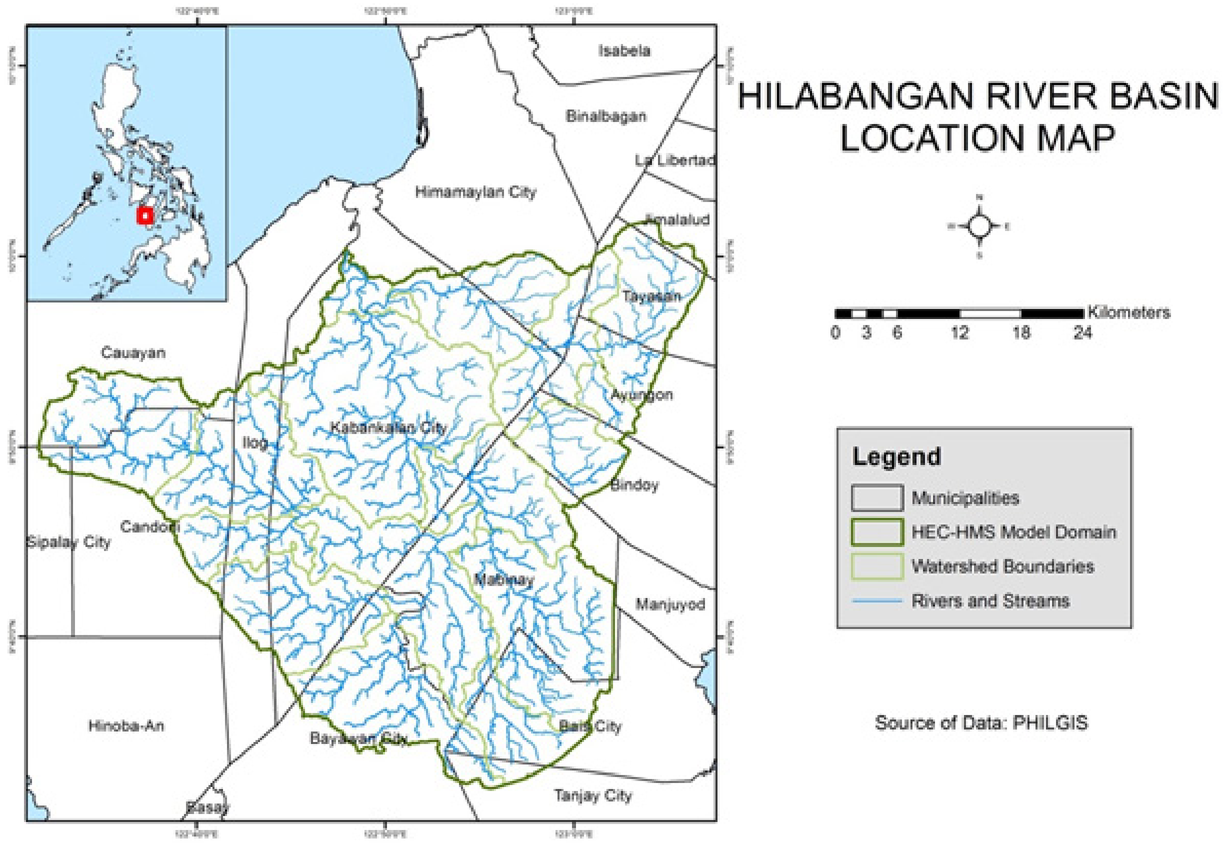


Figure 3. Hilabangan River Basin Location Map

It is composed of the provinces of Negros Occidental and Negros Oriental, covering the cities of Kabankalan, Sipalay and Himamaylan and the municipalities of Cauayan, Ilog and Candoni for Negros Occidental, and the cities of Tanjay, Bais and Bayawan and the municipalities of Jimalalud, Tayasan, Ayungon, Bindoy, Manjuyod and Mabinay in Negros Oriental.

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

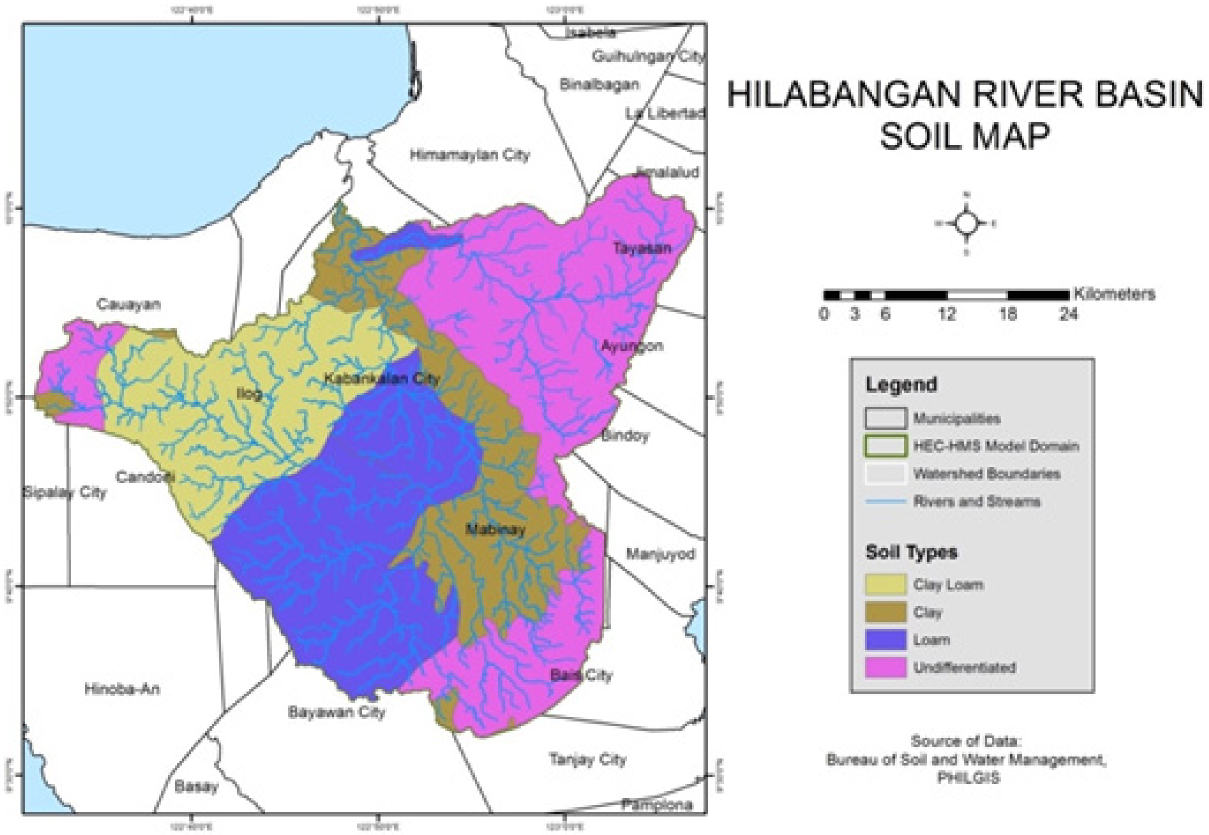


Figure 4. Hilabangan River Basin Soil Map

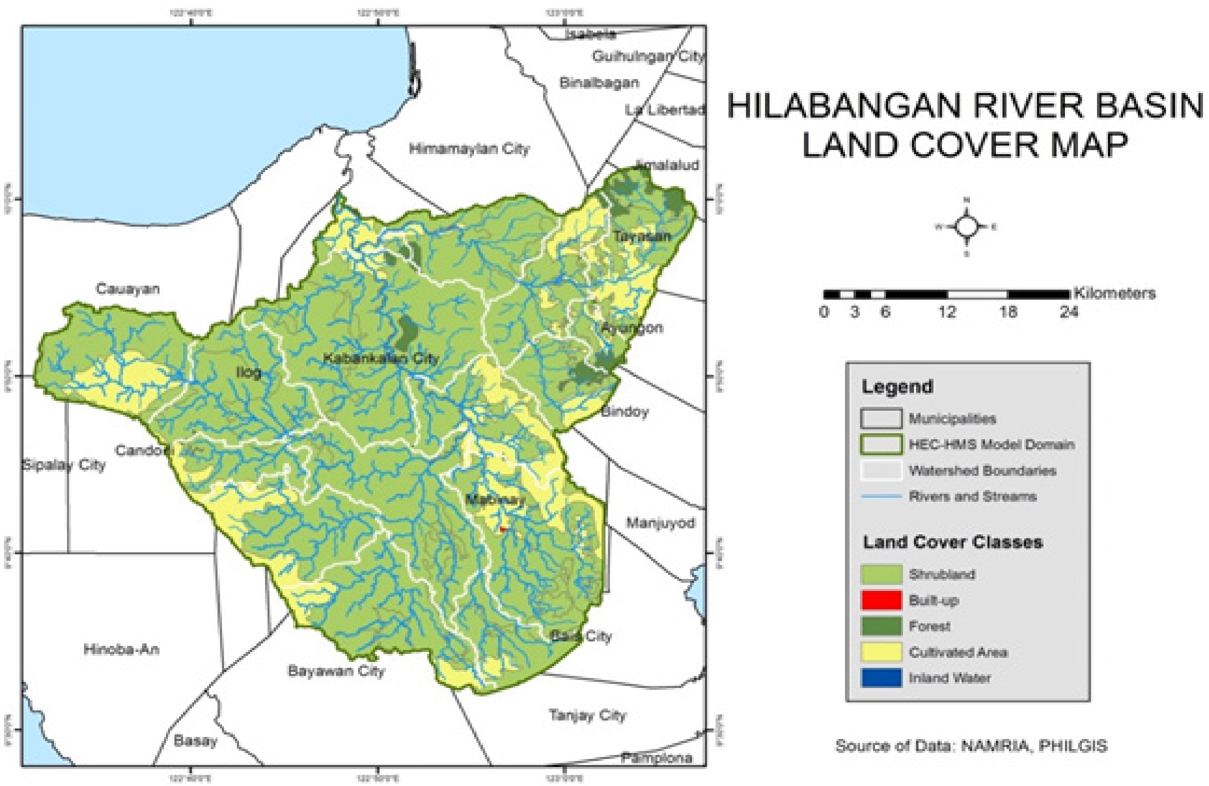


Figure 5. Hilabangan River Basin Land Cover Map

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.

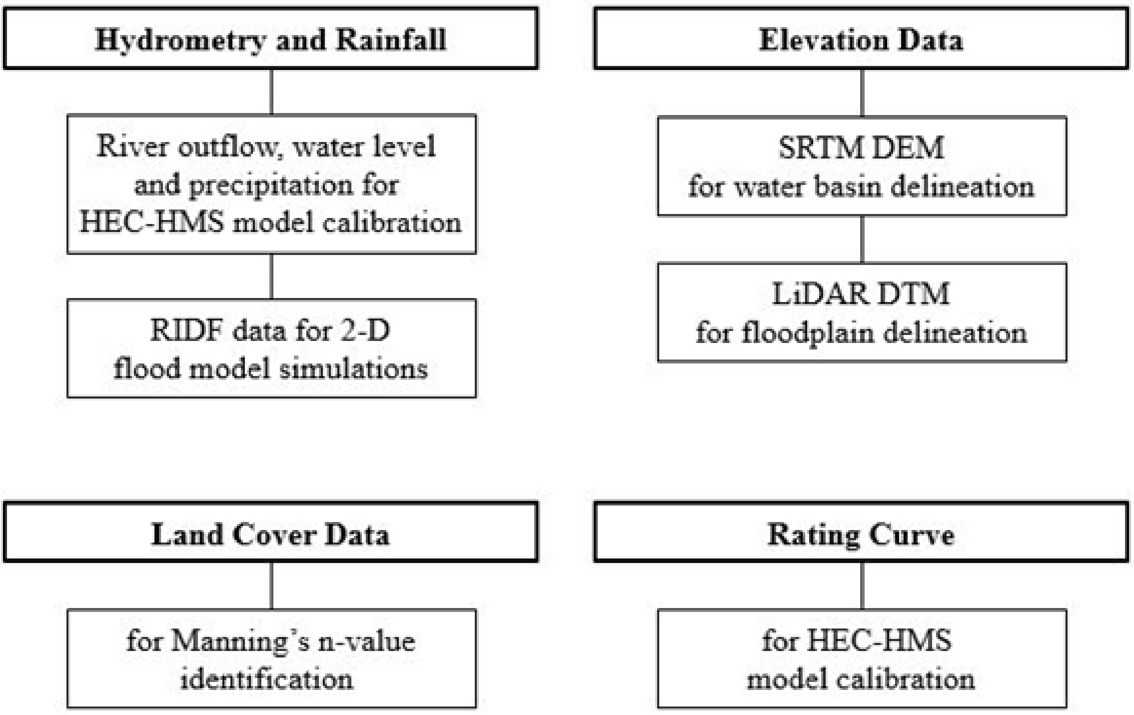


Figure 6. Summary of data needed for the purpose of flood modeling

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.

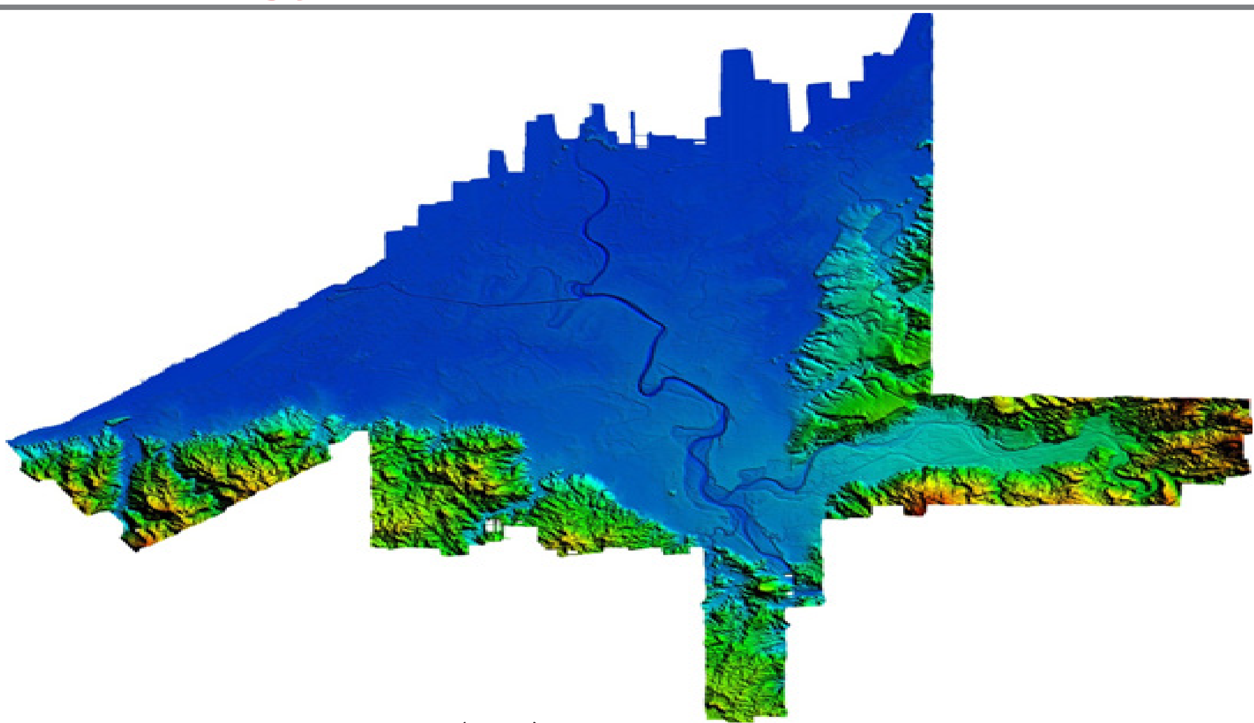


Figure 7. Digital Elevation Model (DEM) of the Hilabangan River Basin using Light Detection and Ranging (LiDAR) technology

Elevation points were created from LiDAR DTMs. Since DTMs were provided as 1-meter spatial resolution rasters (while flood models for Hilbangan 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.

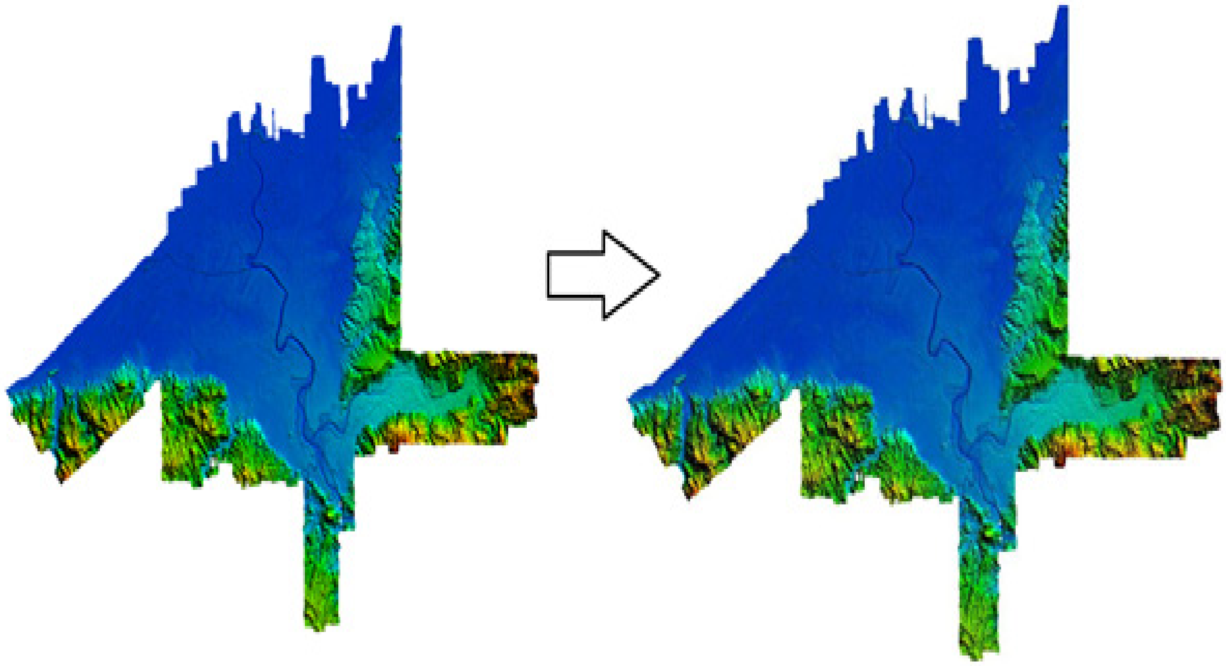


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted.

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 Hilabangan floodplain. Streams were identified against built-up 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.

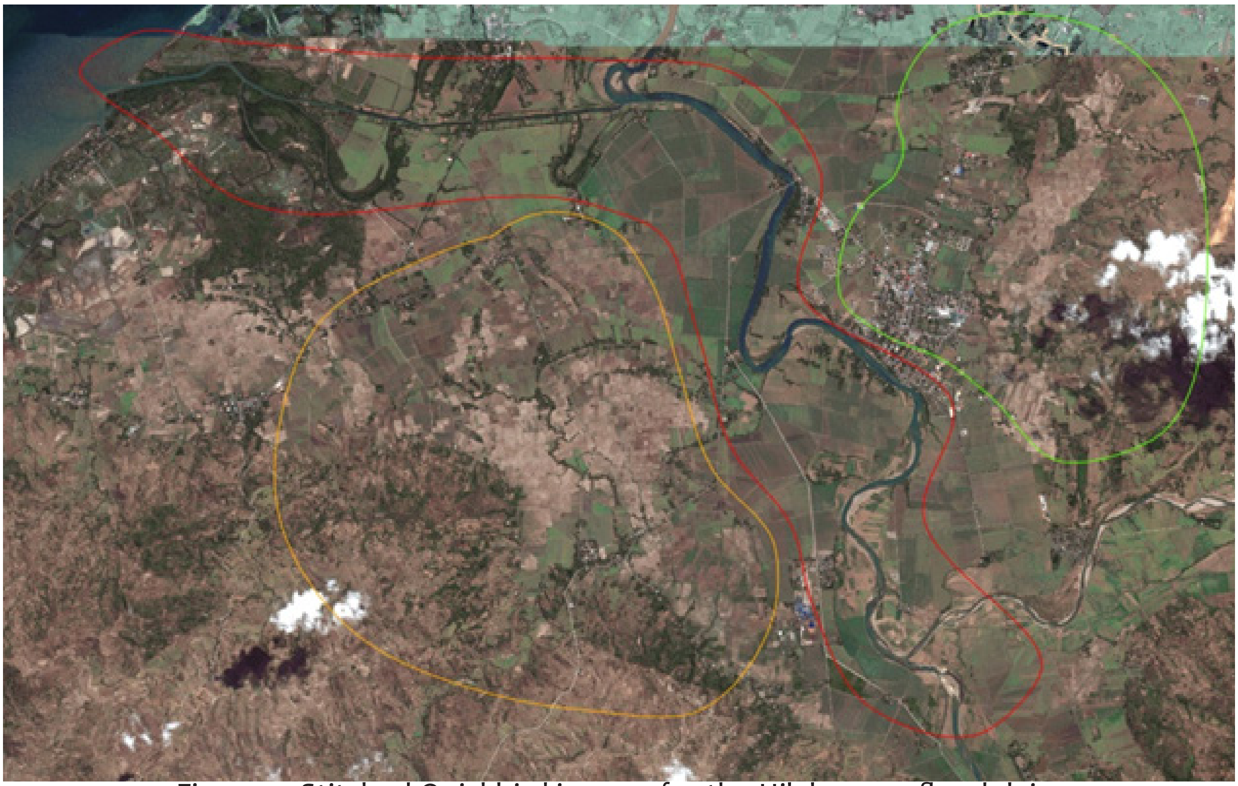


Figure 9. Stitched Quickbird images for the Hilabangan floodplain.

3.1.3 Hydrometry and Rainfall Data

3.1.3.1 Hydrometry for Hilabangan Bridge, Negros Occidental

The river outflow was computed using the derived rating curve equation. This discharge was used to calibrate the HEC-HMS model. It was taken from Hilabangan Bridge (9° 07’ 54.72233” N, 125° 34’ 58.22592” E). The recorded peak discharge is around 47.5 cms at 9:20 PM, October 12, 2013.

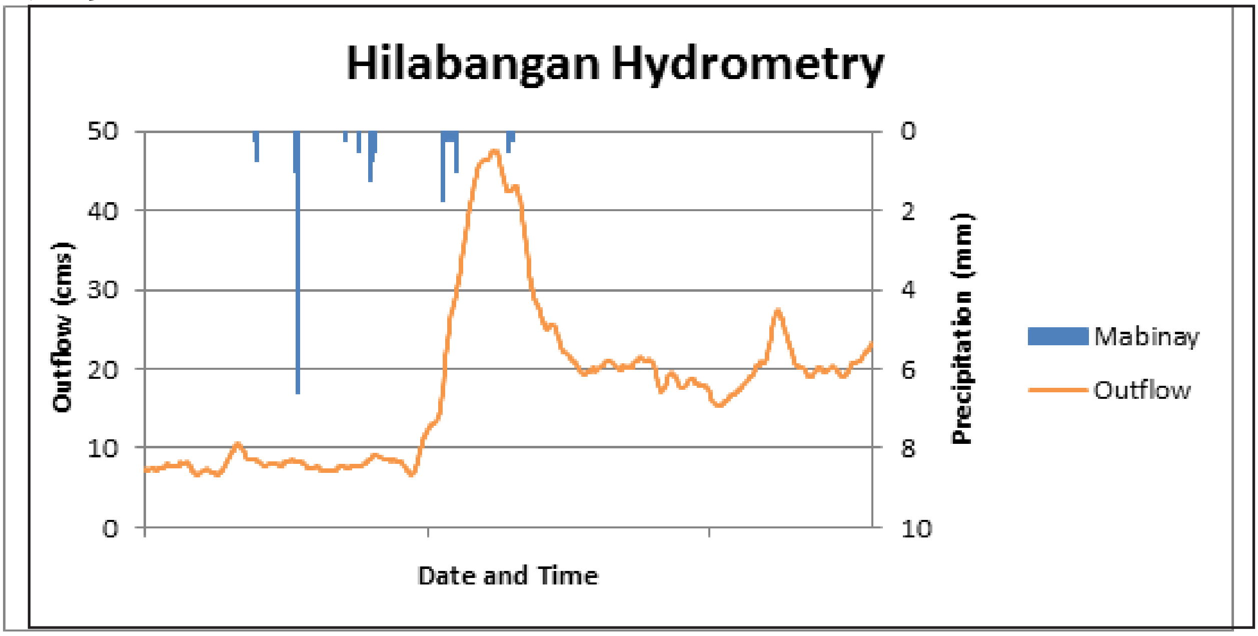


Figure 10. Hilabangan Bridge rainfall and outflow data used for modeling.

3.1.3.1.2 Hydrometry for Magballo Bridge, Negros Occidental

The river outflow was computed using the derived rating curve equation. This discharge was used to calibrate the HEC-HMS model. It was taken from Magballo Bridge, Negros Occidental (9° 47' 9.37" N, 122° 45' 3.6" E). The recorded peak discharge is 520.794 cms at 1:30 AM, April 16, 2014.

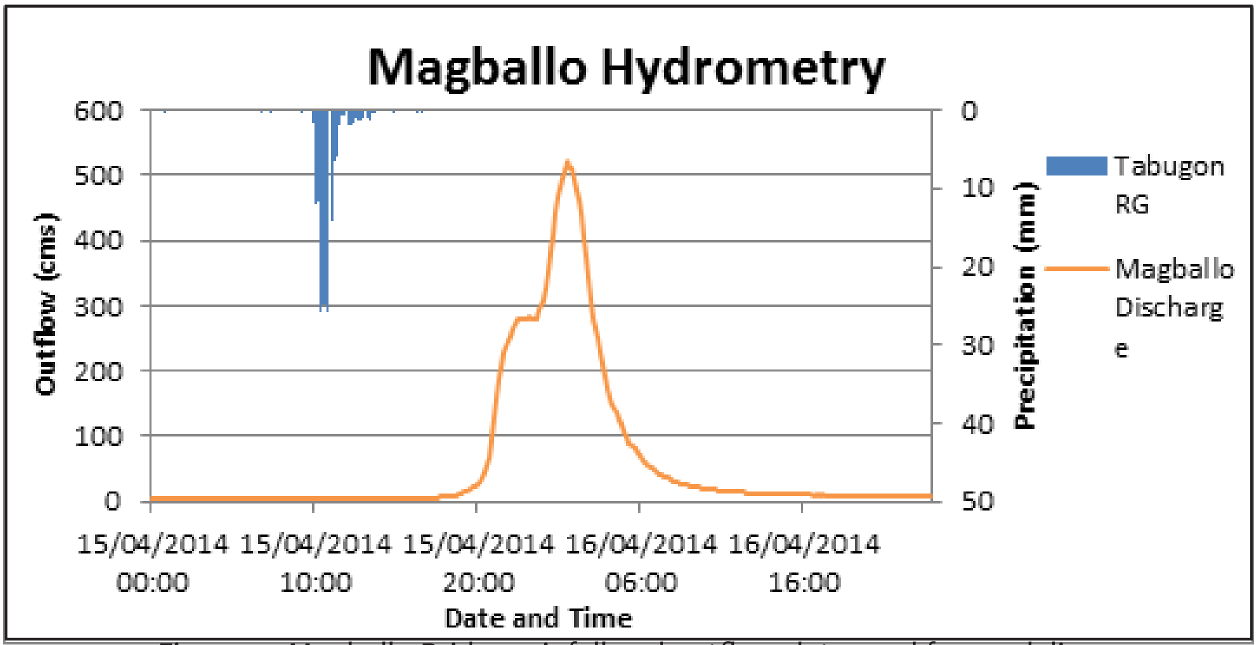


Figure 11. Magballo Bridge rainfall and outflow data used for modeling.

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 Negros and Dumaguete Rain Gauge. This station was chosen based on its proximity to the Hilabangan watershed. The extreme values for this watershed were computed based on a 57-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 12. Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines.

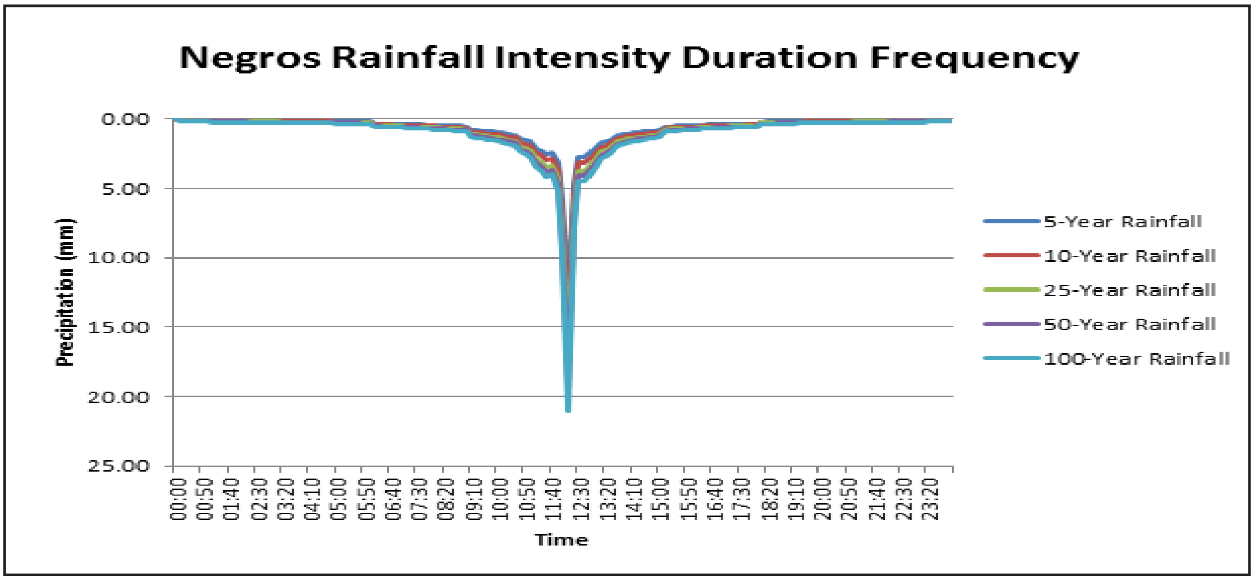


Figure 13. Negros Rainfall-Intensity Duration Frequency (RIDF) curves.

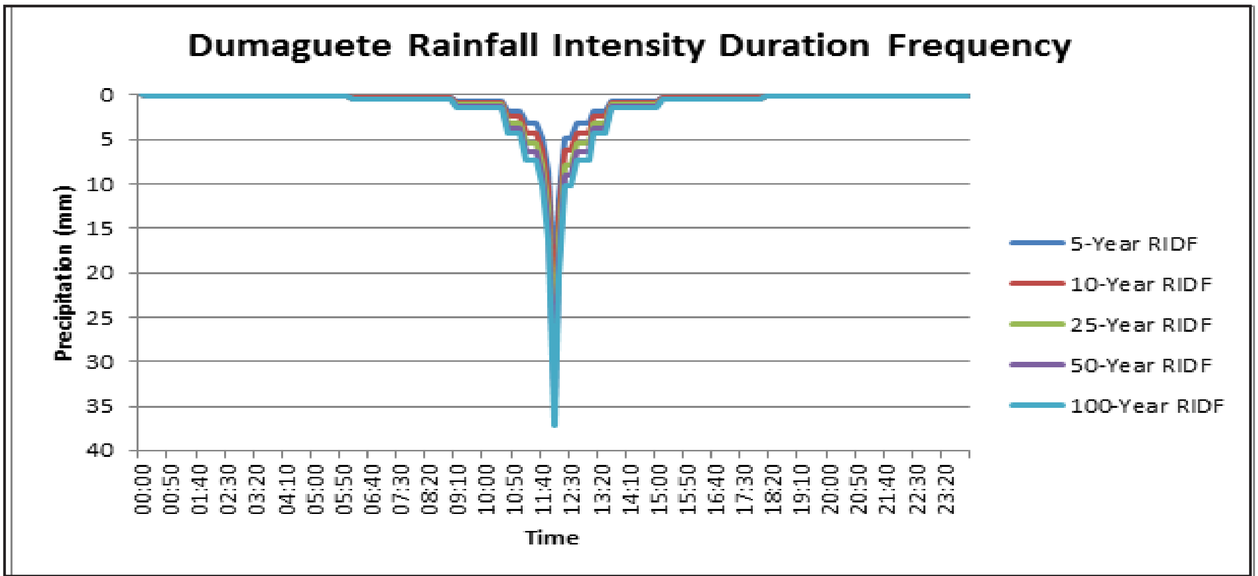


Figure 14. Dumaguete Rainfall-Intensity Duration Frequency (RIDF) curves.

The outflow values at the discharge points in the Hilabangan river basin were 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 Bridge AWLS and constants (a and n).

$$Q = a^{nh}$$

Equation 1. Rating Curve

3.1.4.1 Hilabangan Bridge, Negros Occidental Rating Curve

For Hilabangan Bridge, the rating curve is expressed as Q = 6E-13e3.9449x as shown in Figure 15.

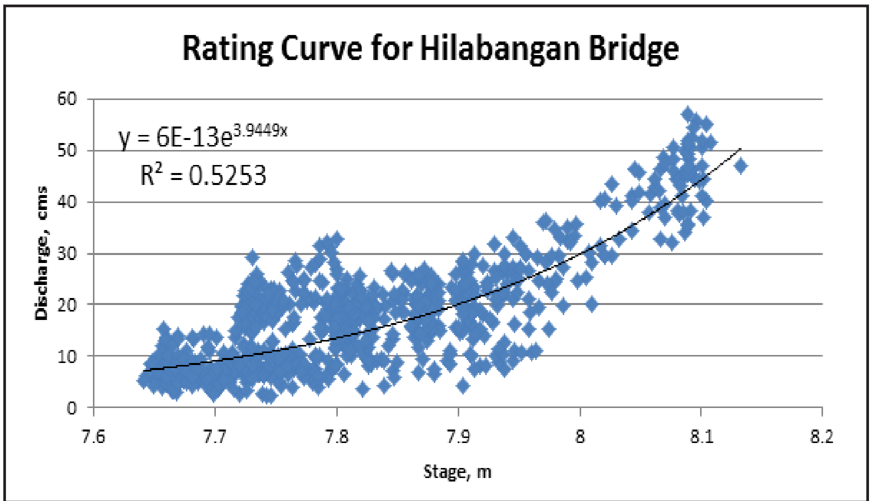


Figure 15. Water level vs. Discharge Curve for HIlabangan Bridge

v

3.1.4.2 Magballo Bridge, Negros Occidental Rating Curve

For Magballo Bridge, the rating curve is expressed as Q = 2E-50e0.9794h as shown in Figure 16.

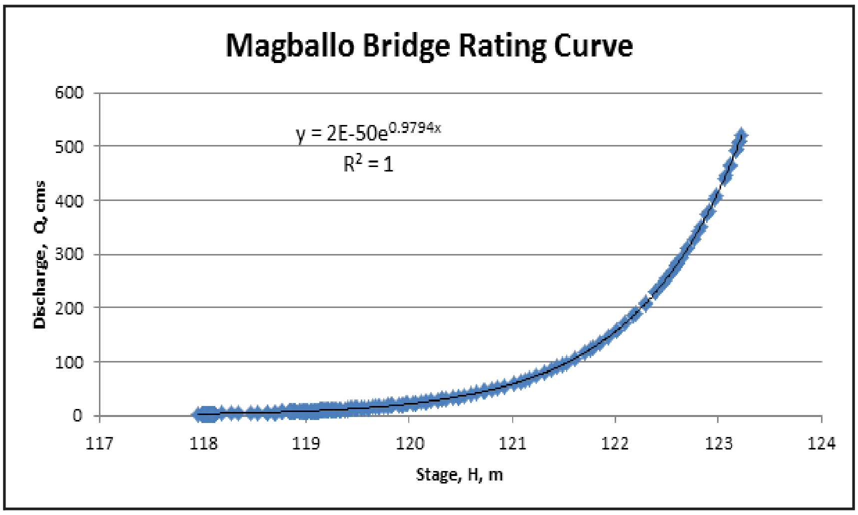


Figure 16. Water level vs. Discharge Curve for Magballo Bridge

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Hilabangan 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 Figure 17.

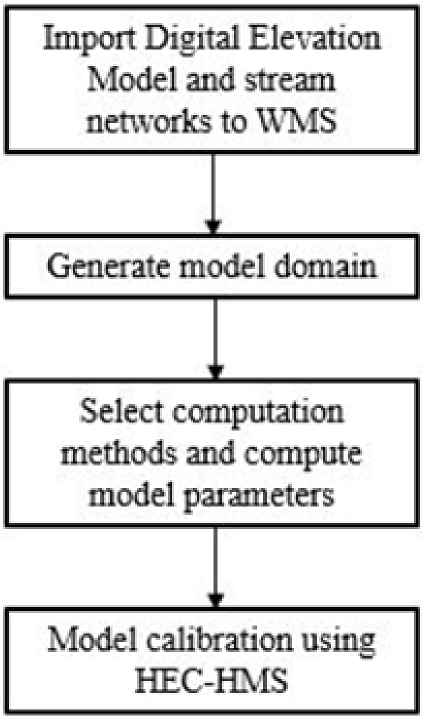


Figure 17. The Rainfall-Runoff Basin Model Development Scheme

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.

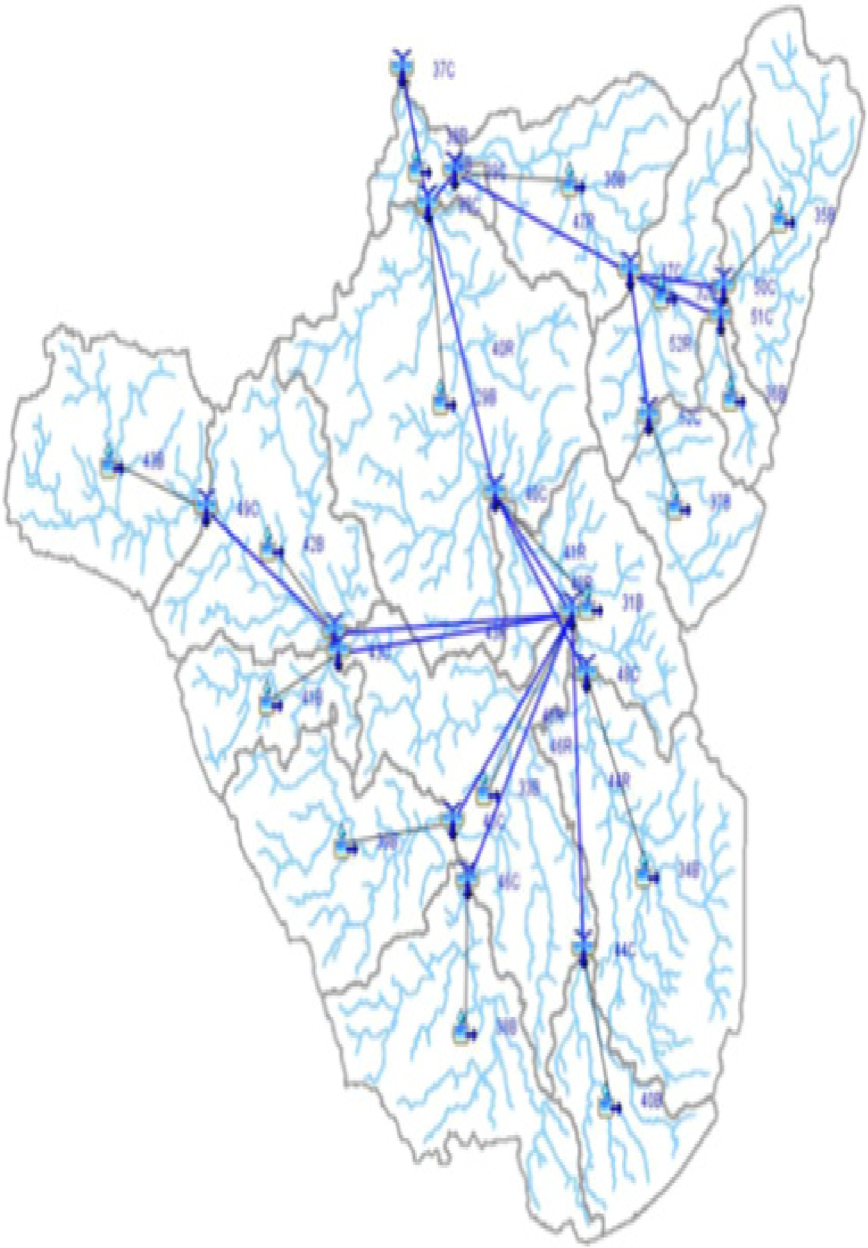


Figure 18. Hilabangan HEC-HMS Model domain generated by WMS

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 Tanawan sensor, an automatic rain gauge (ARG) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). The location of the ARG is seen in Figure 20.

Total rainfall from Tanawan rain gauge is 19.3 mm. Its peak rainfall is 6.604 mm which happened on 10 October, 2013 at 17:45. The lag time between the peak rainfall and peak discharge is 2 days, 3 hours, and 35 minutes.

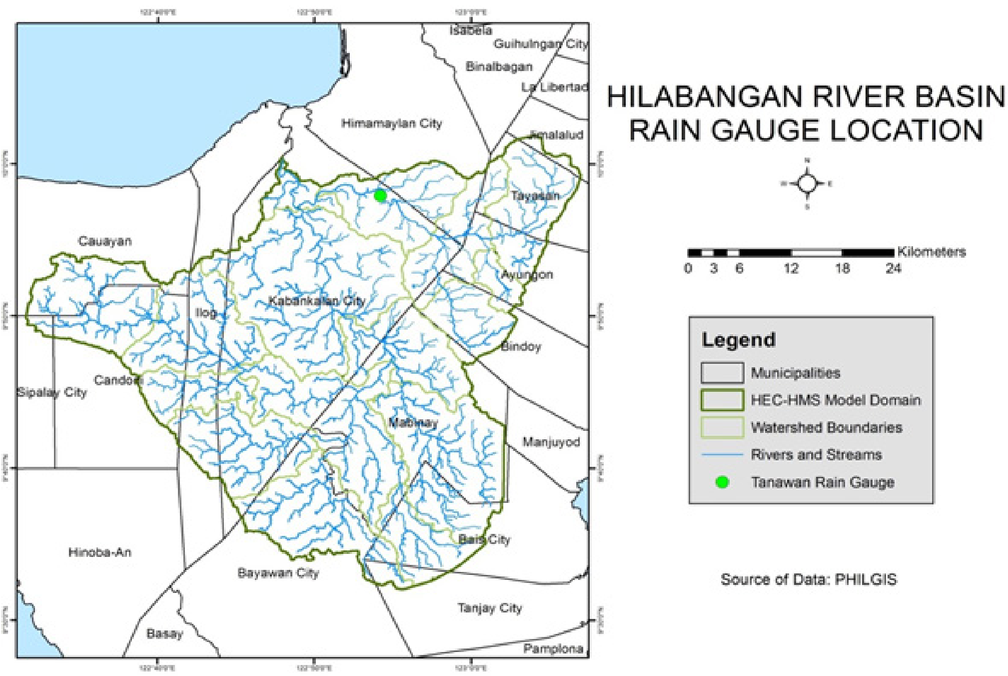


Figure 19. Location of rain gauge used for the calibration of Hilabangan HEC-HMS Model.

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.

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 Hilabangan 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 Negros and Dumaguete 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 – Hilabangan Bridge and Magballo 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 20.

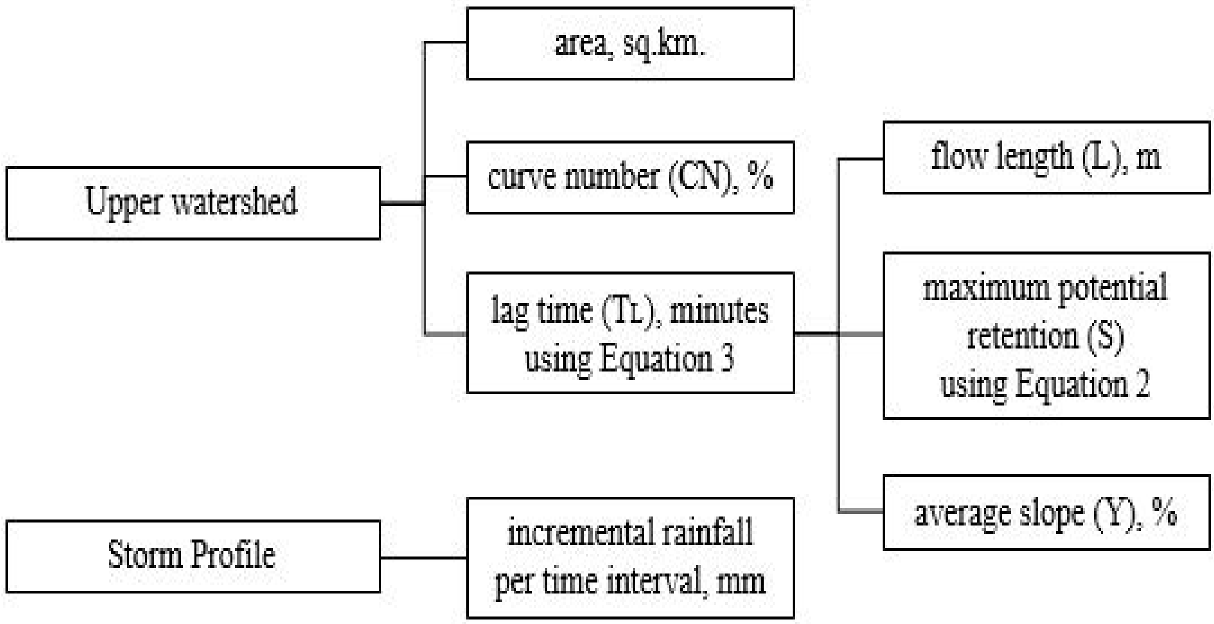


Figure 20. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method.

Flows from streams were computed using the hydrology method developed by the flood modelling component with the help of 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. The method 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.

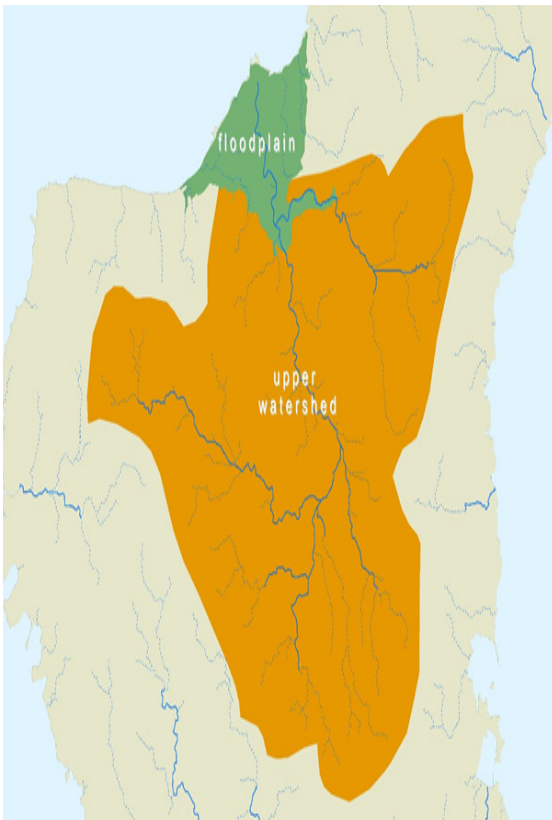


Figure 21. Delineation upper watershed for Hilabangan floodplain discharge computation

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.

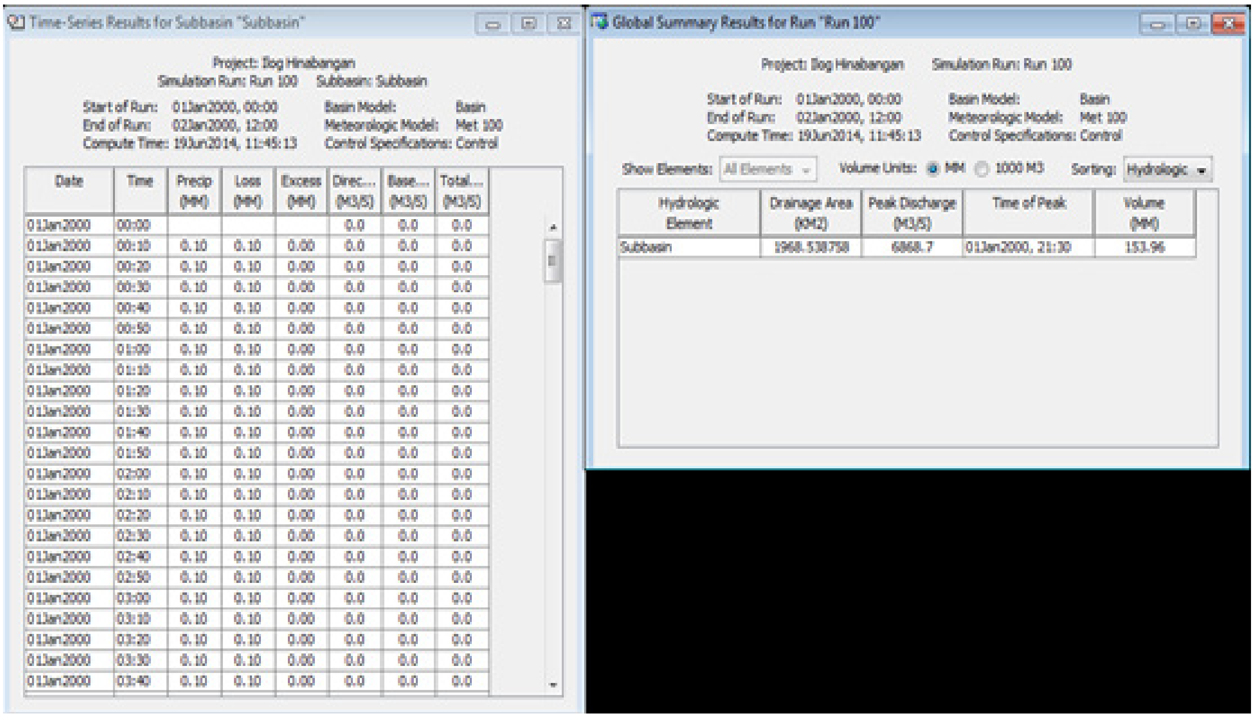


Figure 22. HEC-HMS simulation discharge results using Dr. Horritt's Method

3.3.2.3 Discharge validation against other estimates

As a general rule, the river discharge of a 2-year rain return, QMED, should approximately be equal to the bankful discharge, Qbankful, 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.

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

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 shown below:

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

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.

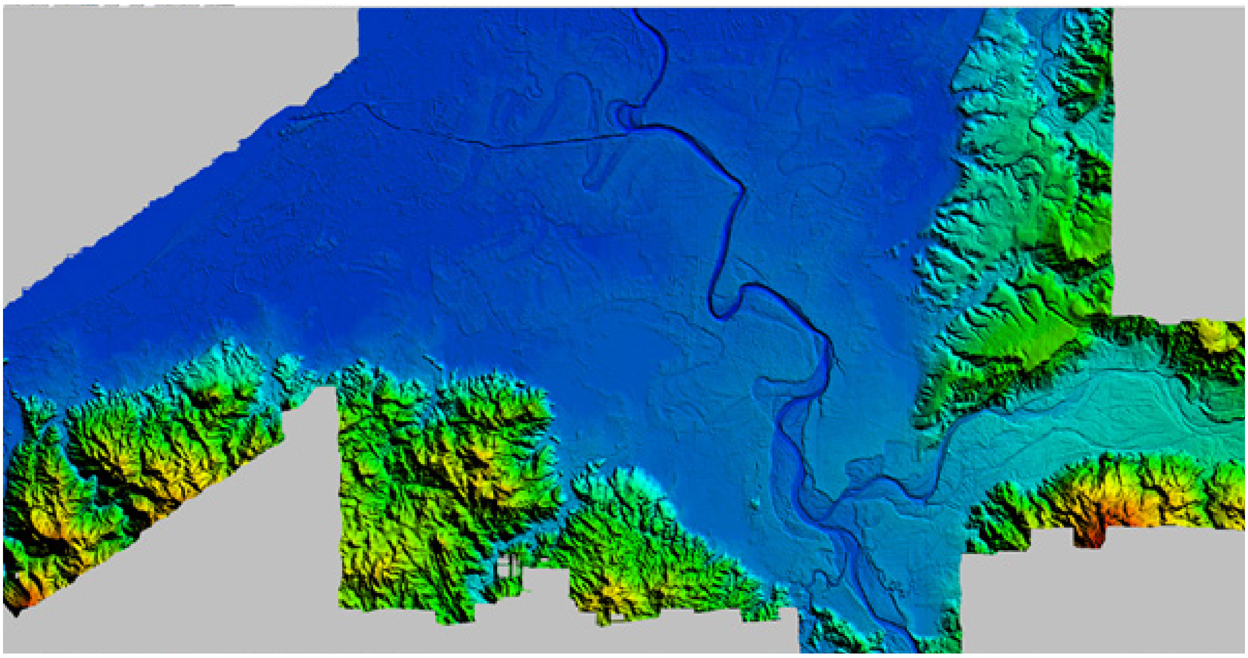


Figure 23. Screenshot showing how boundary grid elements are defined by line

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.

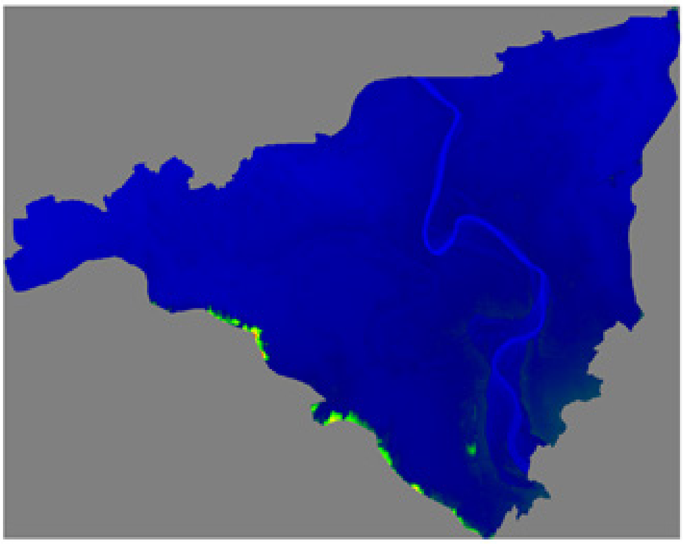


Figure 24. Screenshots of PTS files when loaded into the FLO-2D program

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 25. Areal image of Hilabangan floodplain

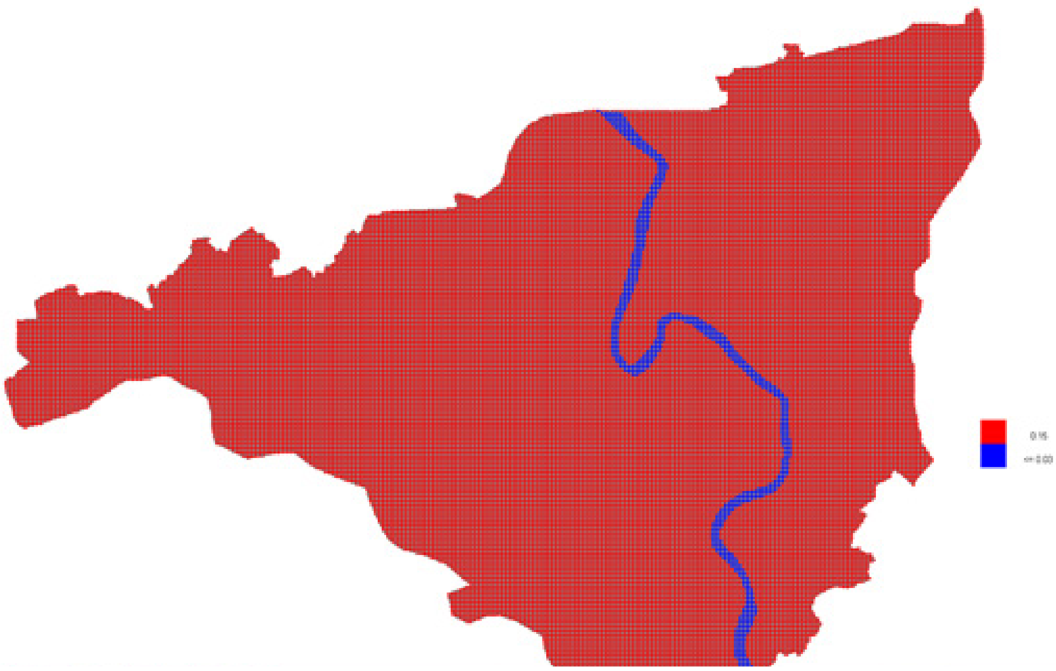


Figure 26. Screenshot of Manning's n-value rendering

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 rainreturn 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.

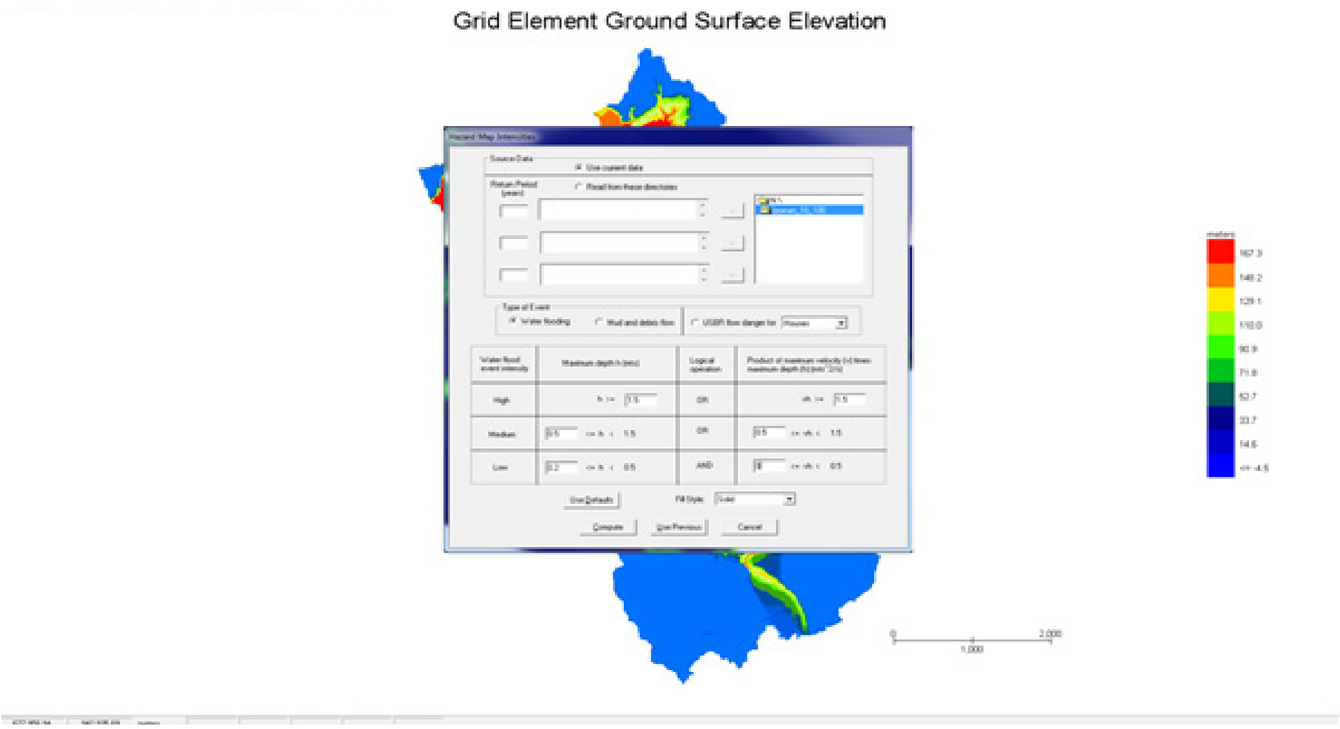


Figure 27. Flo-2D Mapper Pro General Procedure

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.

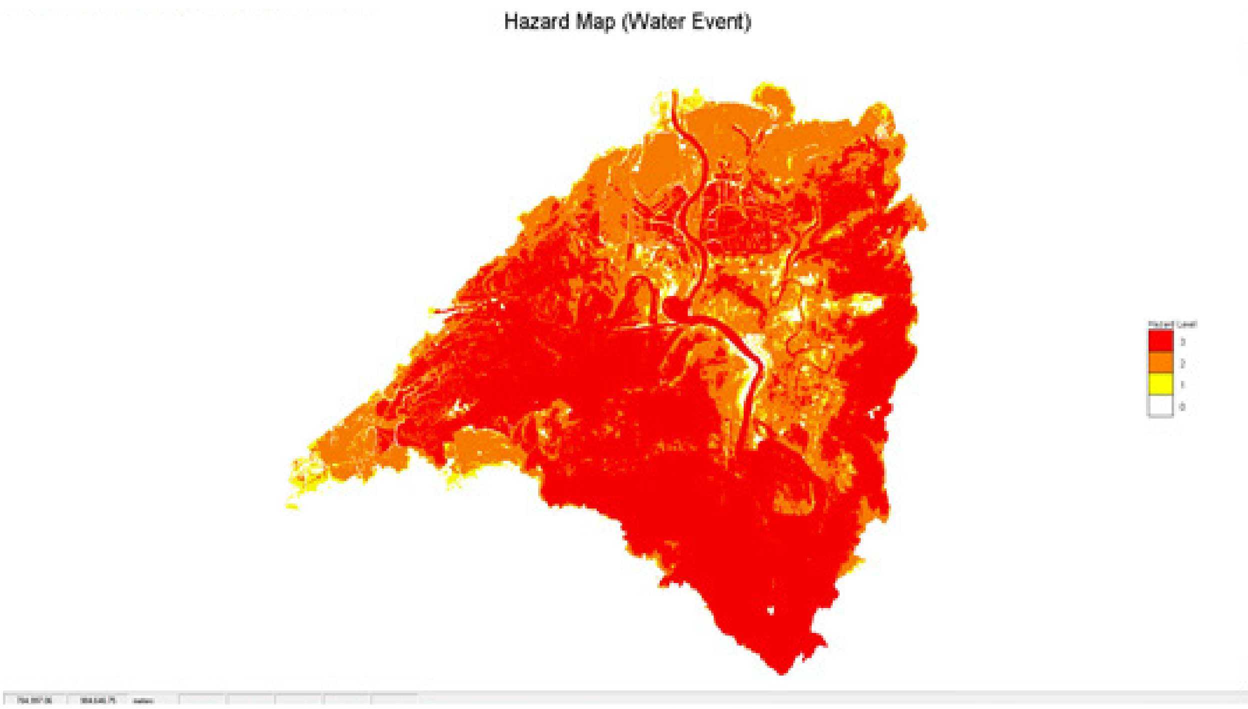


Figure 28. Hilabangan Floodplain Generated Hazard Maps using Flo-2D Mapper

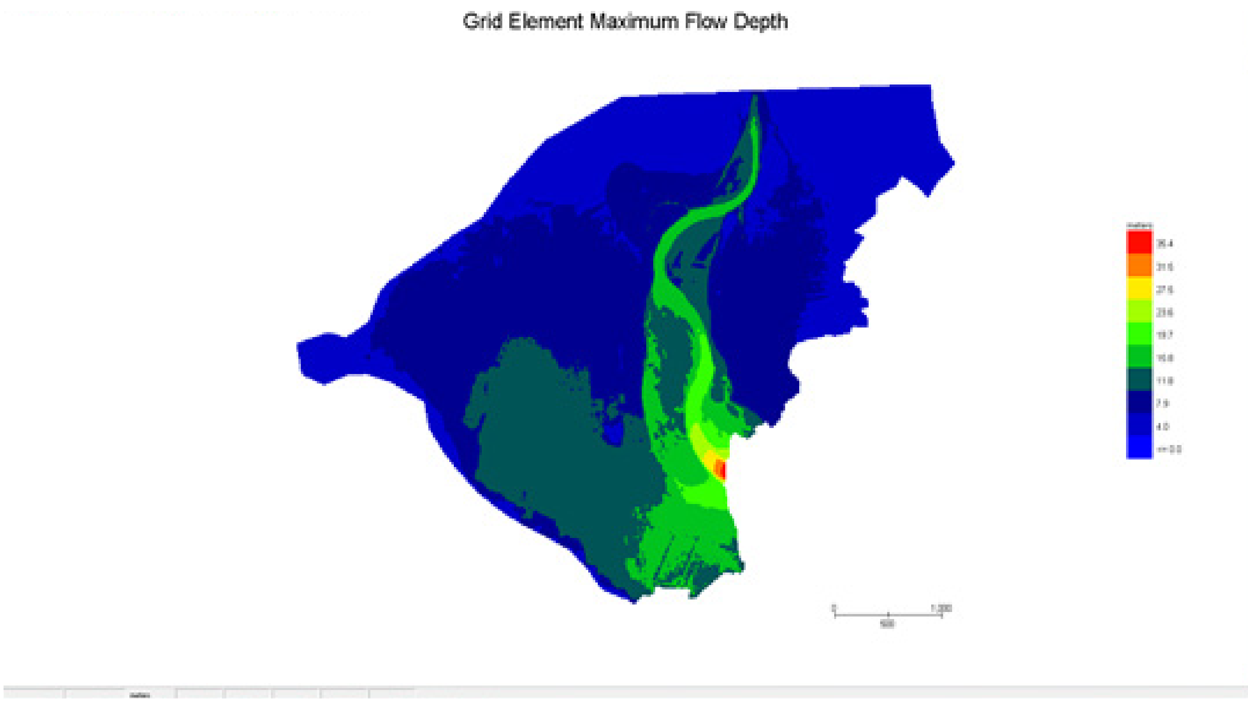
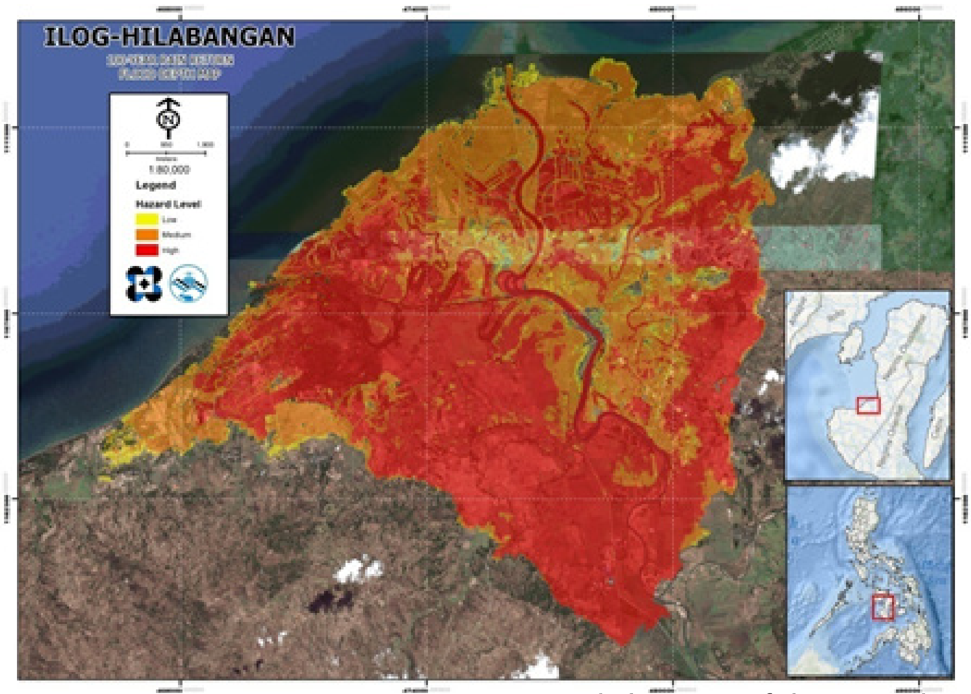


Figure 29. Hilabangan floodplain generated flow depth map using Flo-2D Mapper

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 figures below show the basic lay-out for the hazard and flood depth maps.



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 30. Basic Layout and Elements of the Hazard Maps

Results and Discussion

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

4.1.1 Hilabangan Bridge, Negros Occidental HMS Calibration Results

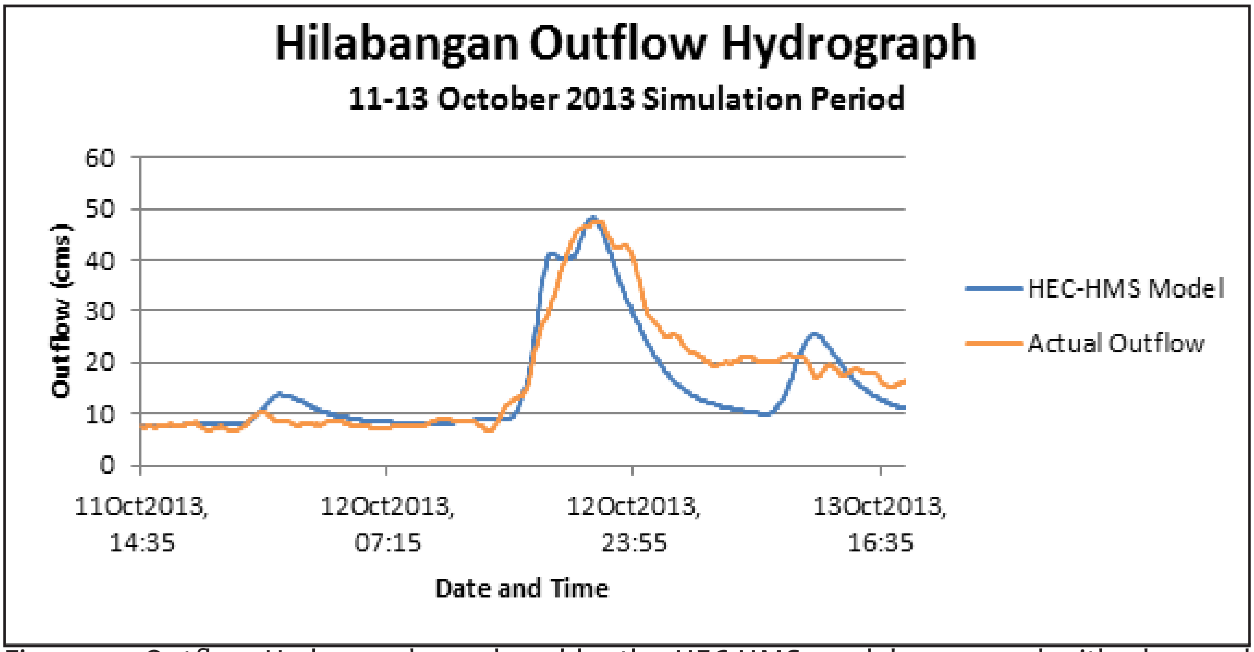


Figure 31. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow.

After calibrating the Hilabangan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 31 shows the comparison between the two discharge data.

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.004.

The Pearson correlation coefficient (r2) 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 0.491.

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 0.078.

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 -0.398.

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 0.12.

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.

4.1.2 Magballo, Negros Occidental HMS Calibration Results

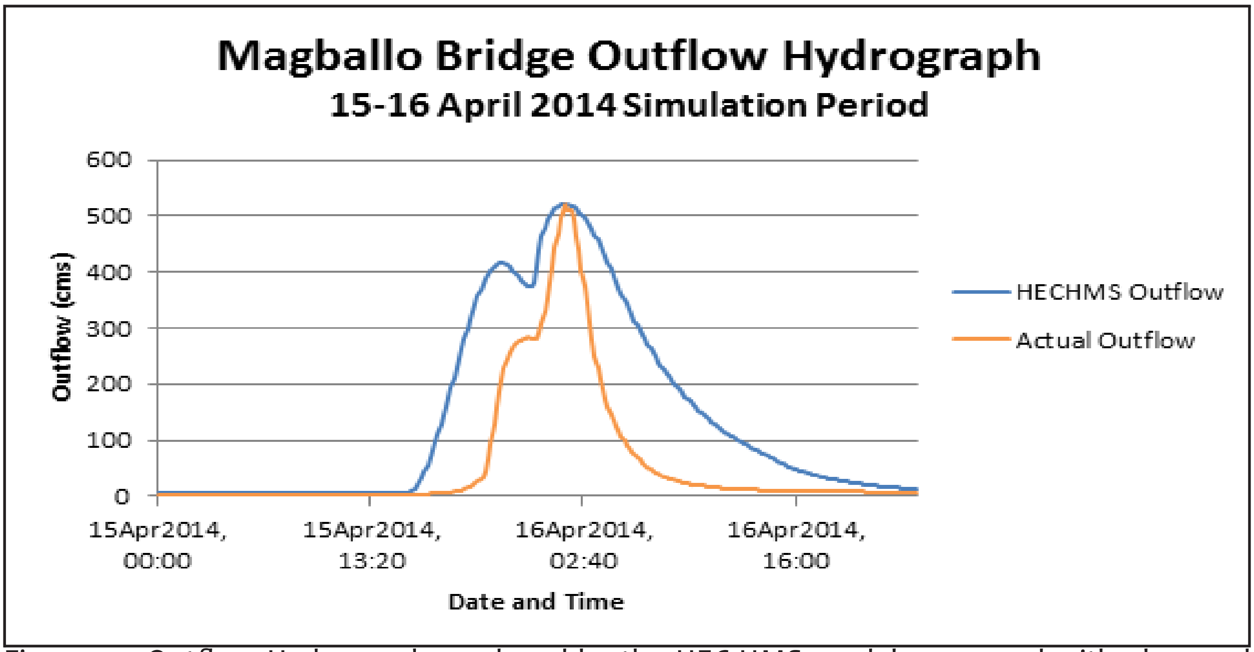


Figure 32. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow.

After calibrating the Magballo HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 32 shows the comparison between the two discharge data.

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 122.1.

The Pearson correlation coefficient (r2) 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 -1.26055E-13.

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 -0.04.

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 -55.91.

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 1.02.

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.

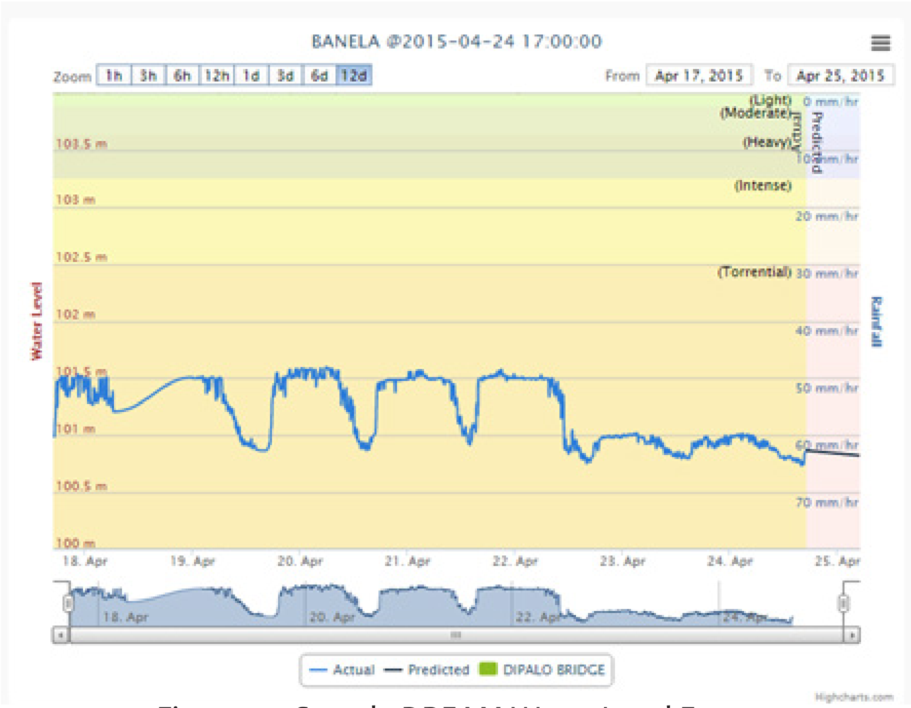


Figure 33. Sample DREAM Water Level Forecast

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

4.2.1.1 Hilabangan Bridge, Negros Occidental

The outflow of Hilabangan using the Negros 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 PAG-ASA data are shown in Figures 34-38. 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 1263.1 cms. This occurs 4 hours after the peak precipitation of 12.62 mm, as shown on Figure 34.

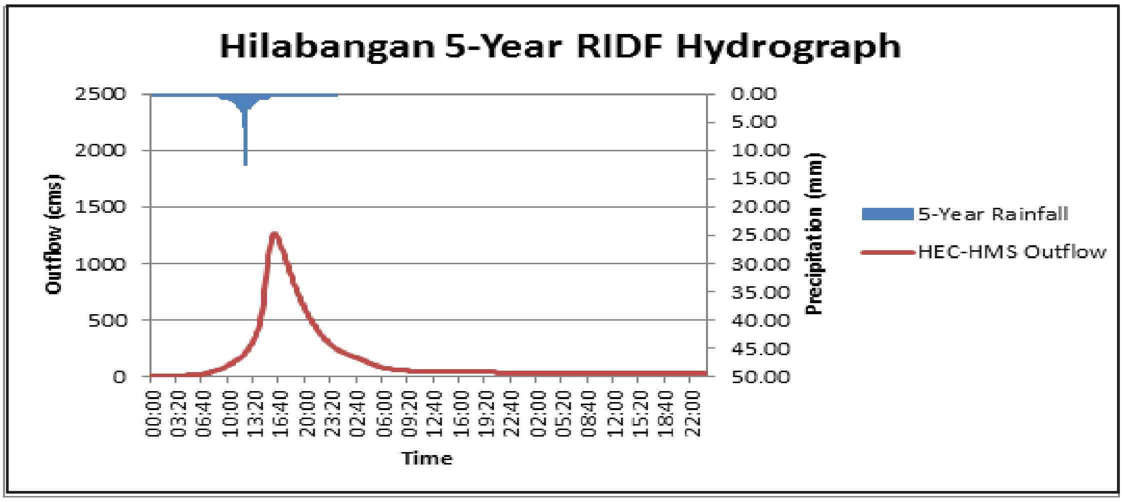


Figure 34. Hilabangan Bridge outflow hydrograph generated using the Negros 5-Year RIDF inputted in WMS and HEC-HMS Basin Model.

In the 10-year return period graph, the peak outflow is 1488 cms. This occurs 3 hours and 50 minutes after the peak precipitation of 14.89 mm, as shown in Figure 35.

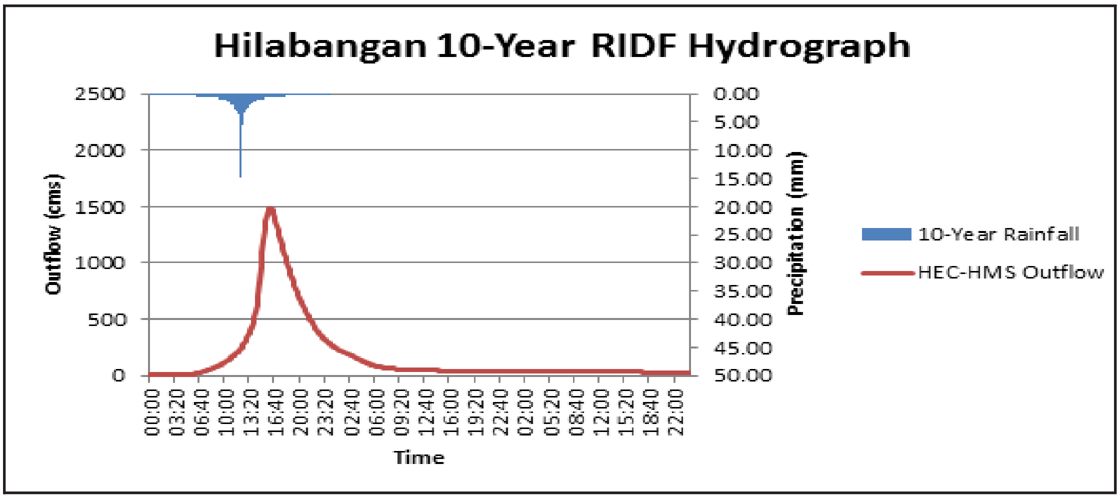


Figure 35. Hilabangan Bridge outflow hydrograph generated using the Negros 10-Year RIDF inputted in WMS and HEC-HMS Basin Model.

In the 25-year return period graph, the peak outflow is 1743.4 cms. This occurs 3 hours and 50 minutes after the peak precipitation of 17.43 mm, as shown in Figure 36.

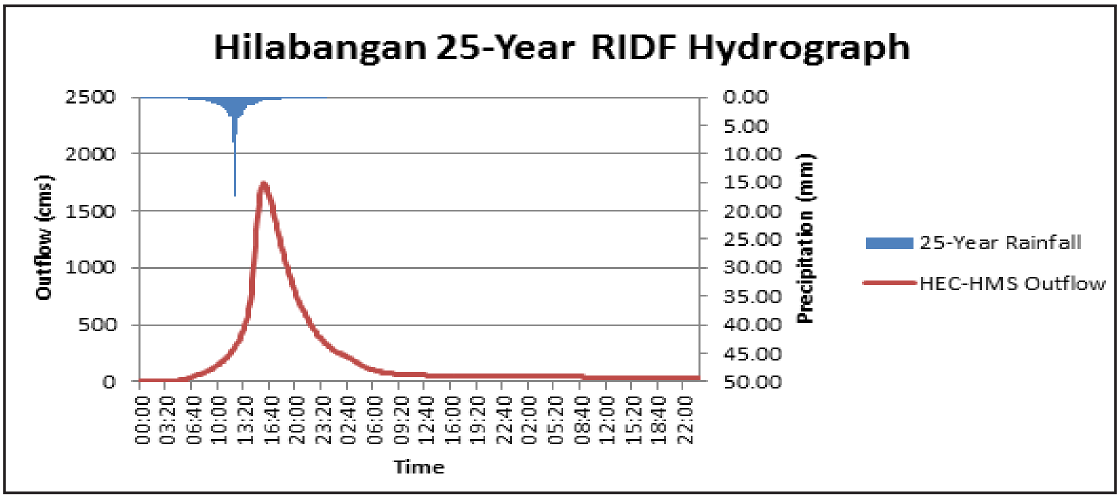


Figure 36. Hilabangan Bridge outflow hydrograph generated using the Negros 25-Year RIDF inputted in WMS and HEC-HMS Basin Model.

In the 50-year return period graph, the peak outflow is 1921.1 cms. This occurs 3 hours and 50 minutes after the peak precipitation of 19.23 mm, as shown in Figure 37.

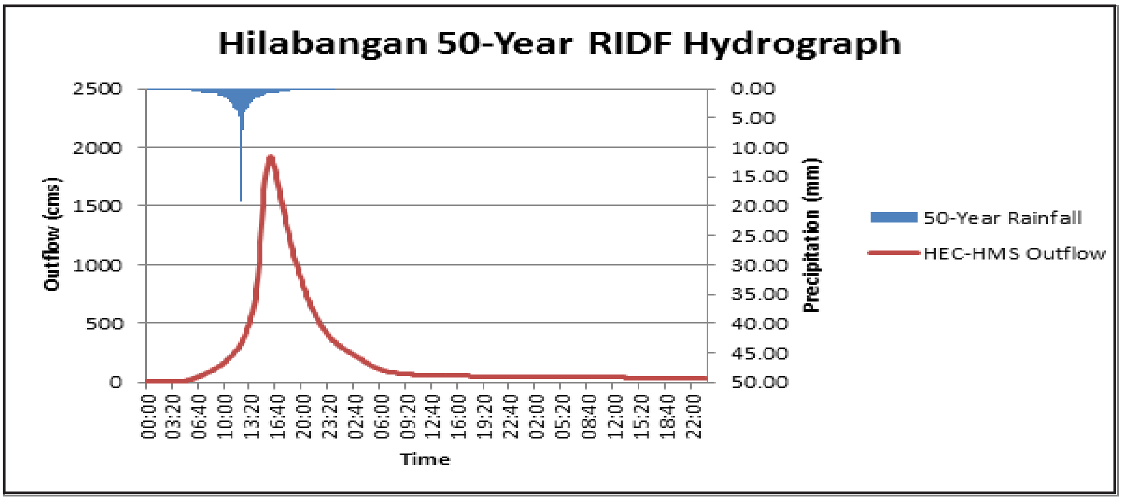


Figure 37. Hilabangan Bridge outflow hydrograph generated using the Negros 50-Year RIDF inputted in WMS and HEC-HMS Basin Model.

Results and Discussion

In the 100-year return period graph, the peak outflow is 2095.8 cms. This occurs 3 hours and 50 minutes after the peak precipitation of 21.01 mm, as shown in Figure 38.

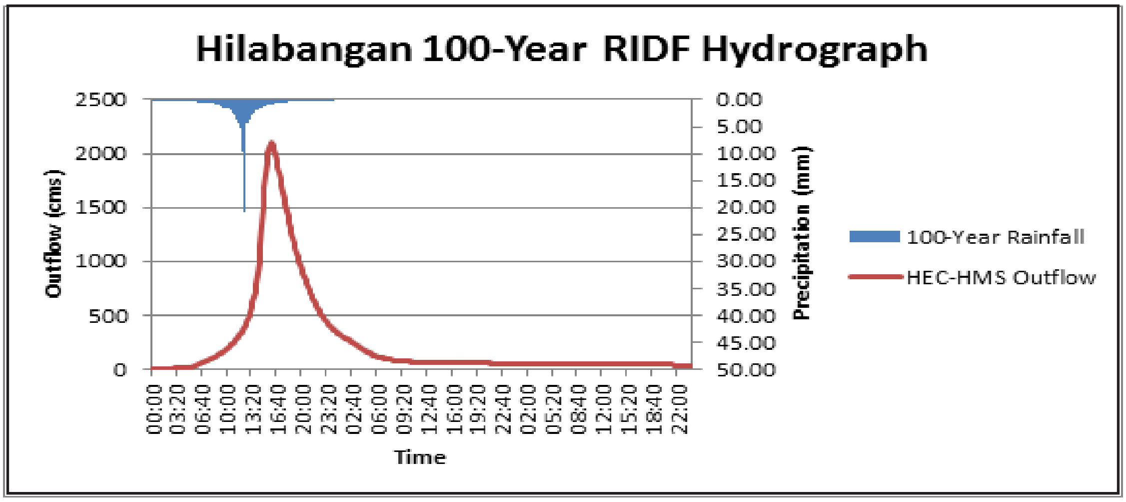


Figure 38. Hilabangan Bridge outflow hydrograph generated using the Negros 50-Year RIDF inputted in WMS and HEC-HMS Basin Model.

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

Table 2. Summary of Hilabangan discharge using Negros Station Rainfaill Intensity Duration Frequency (RIDF)

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	102.8	12.62	1263.1	4 hours
10-Year	119.76	14.89	1488	3 hours, 50 minutes
25-Year	139.86	17.43	1743.4	3 hours, 50 minutes
50-Year	153.81	19.23	1921.1	3 hours, 50 minutes
100-Year	167.66	21.01	2095.8	3 hours, 50 minutes

4.2.1.2 Magballo Bridge, Negros Occidental

The outflow of Magballo using the Dumaguete 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 PAG-ASA data are shown in Figures 39-43. 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 255.5 cms. This occurs after 10 hours and 40 minutes after the peak precipitation of 21.8 mm, as shown in Figure 39.

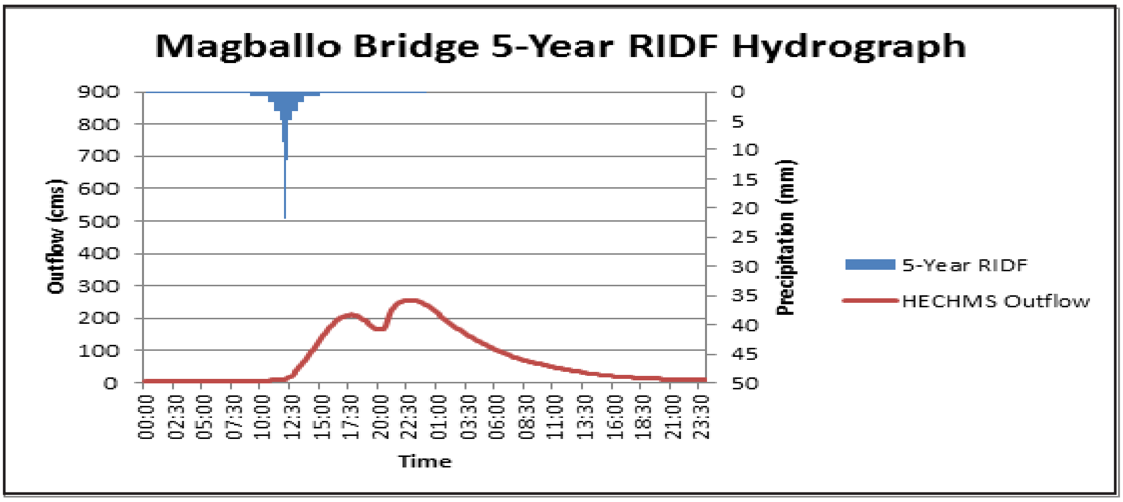


Figure 39. Magballo Bridge outflow hydrograph generated using the Dumaguete 5-Year RIDF inputted in WMS and HEC-HMS Basin Model.

In the 10-year return period graph, the peak outflow is 366.5 cms. This occurs after 10 hours and 10 minutes after the peak precipitation of 25.6 mm, as shown in Figure 40.

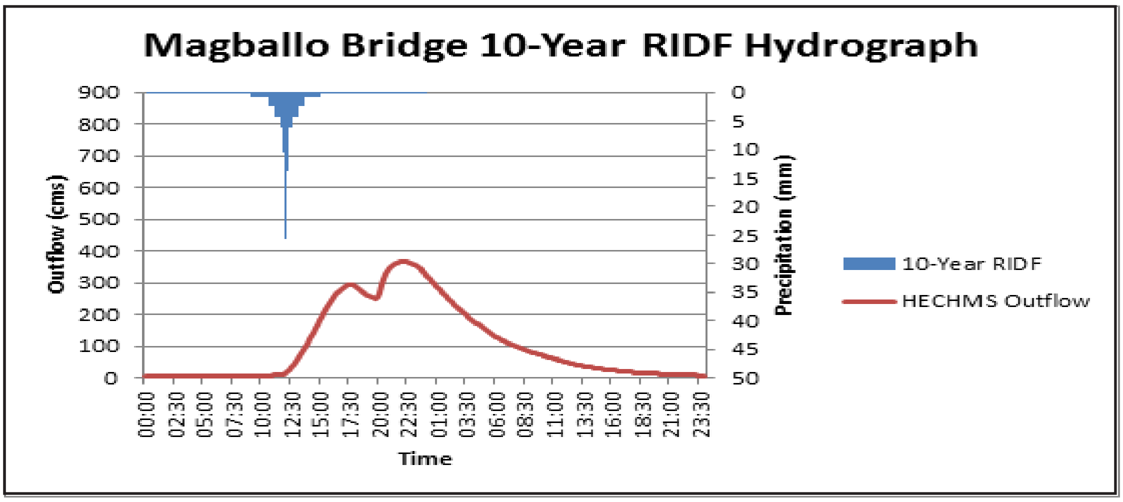


Figure 40. Magballo Bridge outflow hydrograph generated using the Dumaguete 10-Year RIDF inputted in WMS and HEC-HMS Basin Model.

In the 25-year return period graph, the peak outflow is 524.9 cms. This occurs after 9 hours and 40 minutes after the peak precipitation of 30.3 mm, as shown in Figure 41.

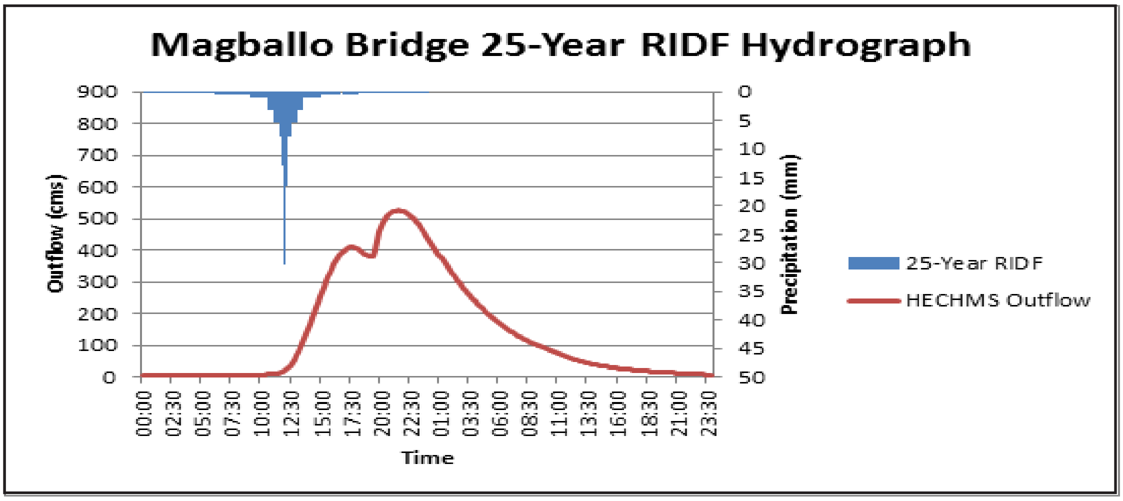


Figure 41. Magballo Bridge outflow hydrograph generated using the Dumaguete 25-Year RIDF inputted in WMS and HEC-HMS Basin Model.

In the 50-year return period graph, the peak outflow is 653.2 cms. This occurs after 9 hours and 20 minutes after the peak precipitation of 33.8 mm, as seen in Figure 42.

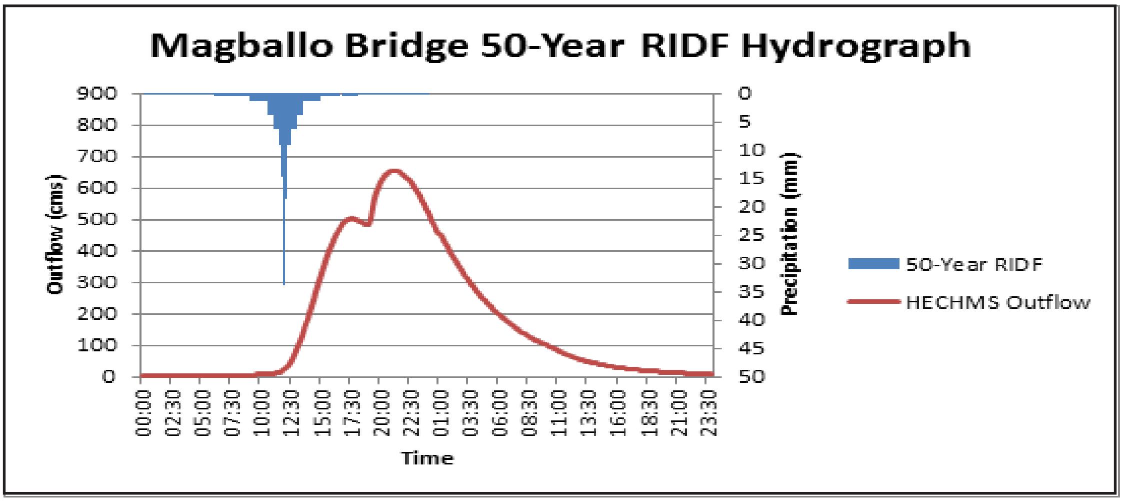


Figure 42. Magballo Bridge outflow hydrograph generated using the Dumaguete 50-Year RIDF inputted in WMS and HEC-HMS Basin Model.

In the 100-year return period graph, the peak outflow is 789.3 cms. This occurs after 9 hours after the peak precipitation of 37.2 mm, as seen in Figure 43.

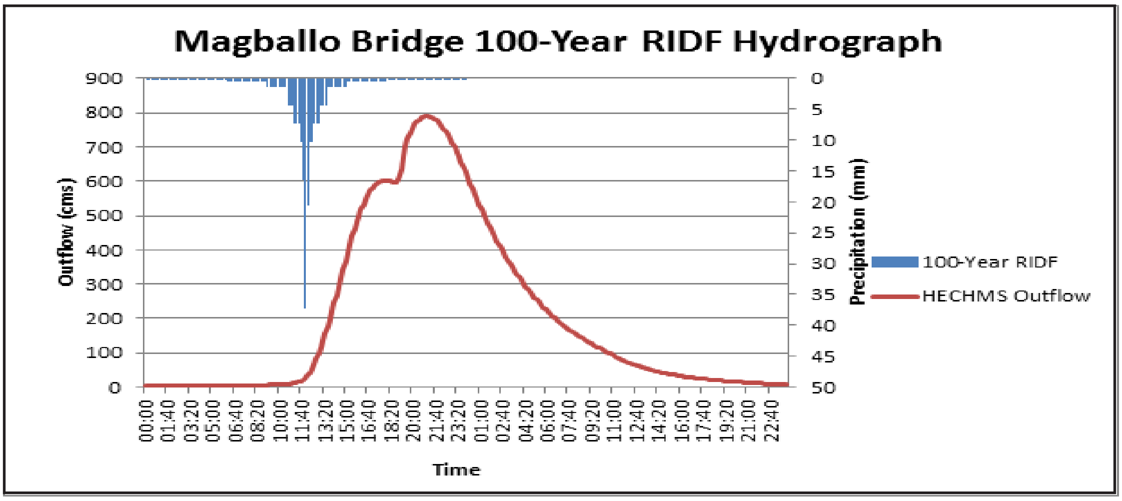


Figure 43. Magballo Bridge outflow hydrograph generated using the Dumaguete 100-Year RIDF inputted in WMS and HEC-HMS Basin Model

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

Table 3. Summary of Magballo discharge using Dumaguete Station Rainfaill Intensity Duration Frequency (RIDF)

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	116.5	21.8	255.5	10 hours, 40 minutes
10-Year	143.3	25.6	366.5	10 hours, 10 minutes
25-Year	177.2	30.3	524.9	9 hours, 40 minutes
50-Year	202.4	33.8	653.2	9 hours, 20 minutes
100-Year	227.3	37.2	789.3	9 hours

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 A.

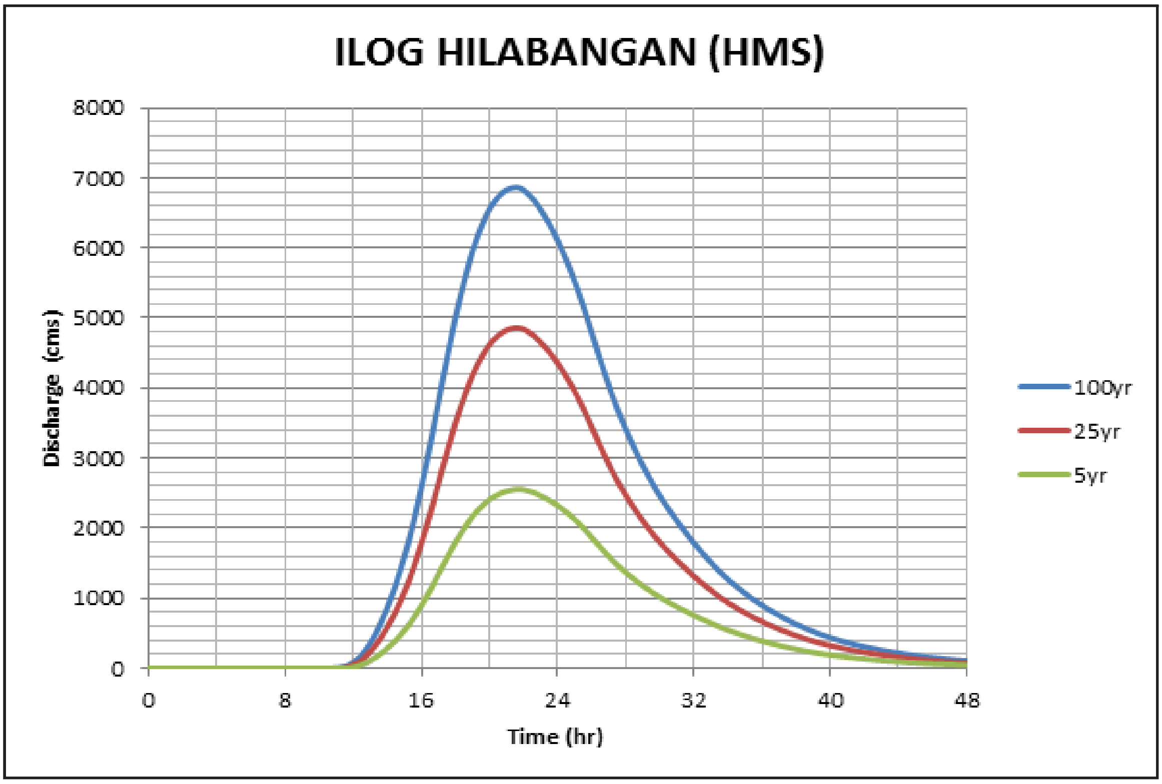


Figure 44. Outflow hydrograph generated for Ilog Hilabangan using the Iloilo Station 5-, 25-, 100-Year RIDF in HEC-HMS

The peak discharge values of the simulations are summarized in Table 4.

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

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	2558.3	21 hours, 40 minutes
25-Year	4862.3	21 hours, 40 minutes
100-Year	6863.3	21 hours, 30 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 Ilog Hilabangan, the bankful discharge for the river was computed.

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

Discharge Point	Qbankful, cms	QMED, cms	Validation
Ilog Hilabangan	3806.90	2251.3	Pass

The discharge value from the HEC-HMS discharge estimate was able to satisfy the condition for validating the computed discharge using the bankful method. The computed value was used for flood modeling for the discharge point that did not have actual data but will need further investigation for the purpose of validation. The actual calibrated value was also used. 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 Hilabangan river basin.

Results and Discussion

Flood Hazard Maps and Flow Depth Maps

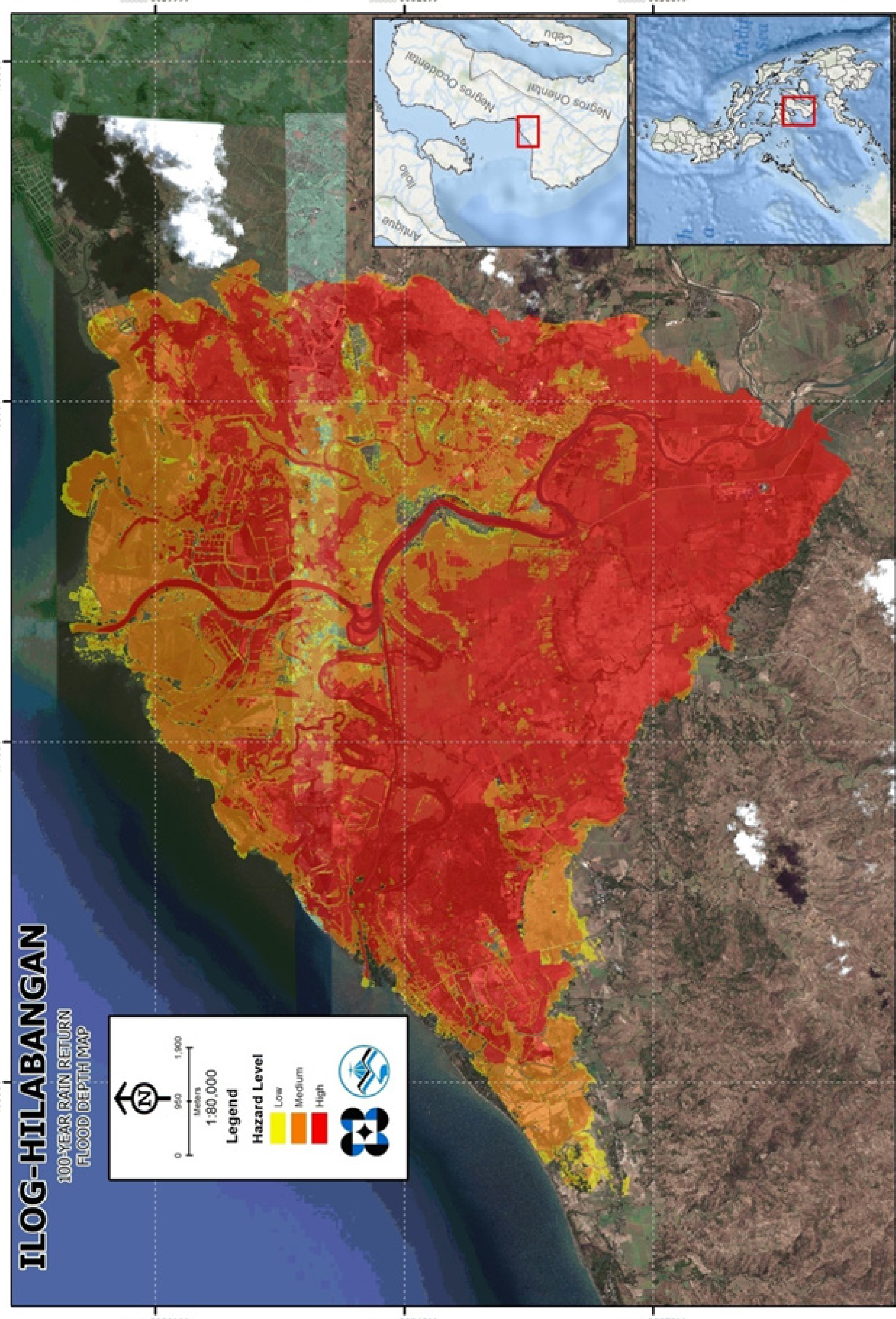


Figure 45. 100-year Flood Hazard Map for Hilabangan River Basin

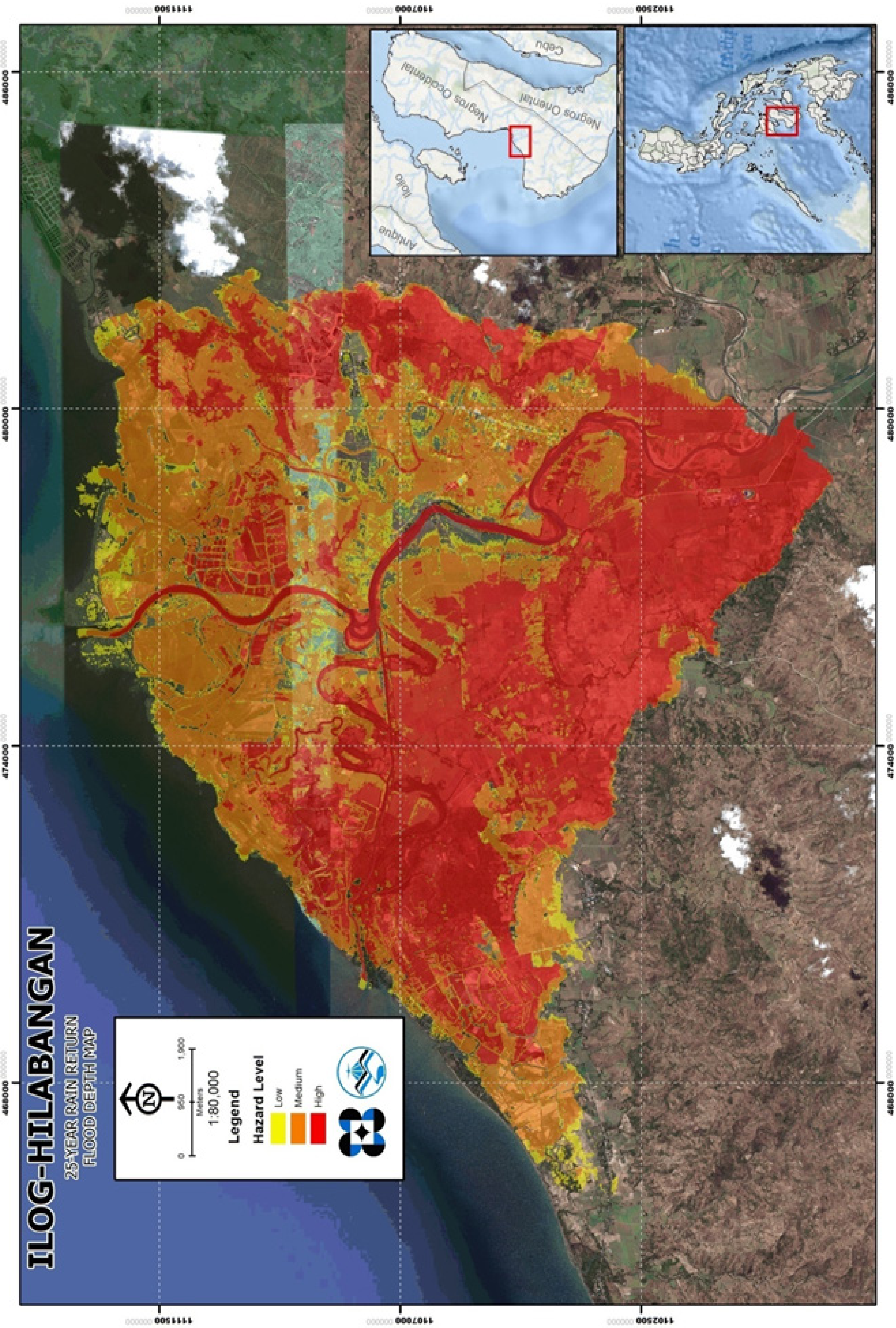


Figure 46. 100-year Flow Depth Map for Hilabangan River Basin

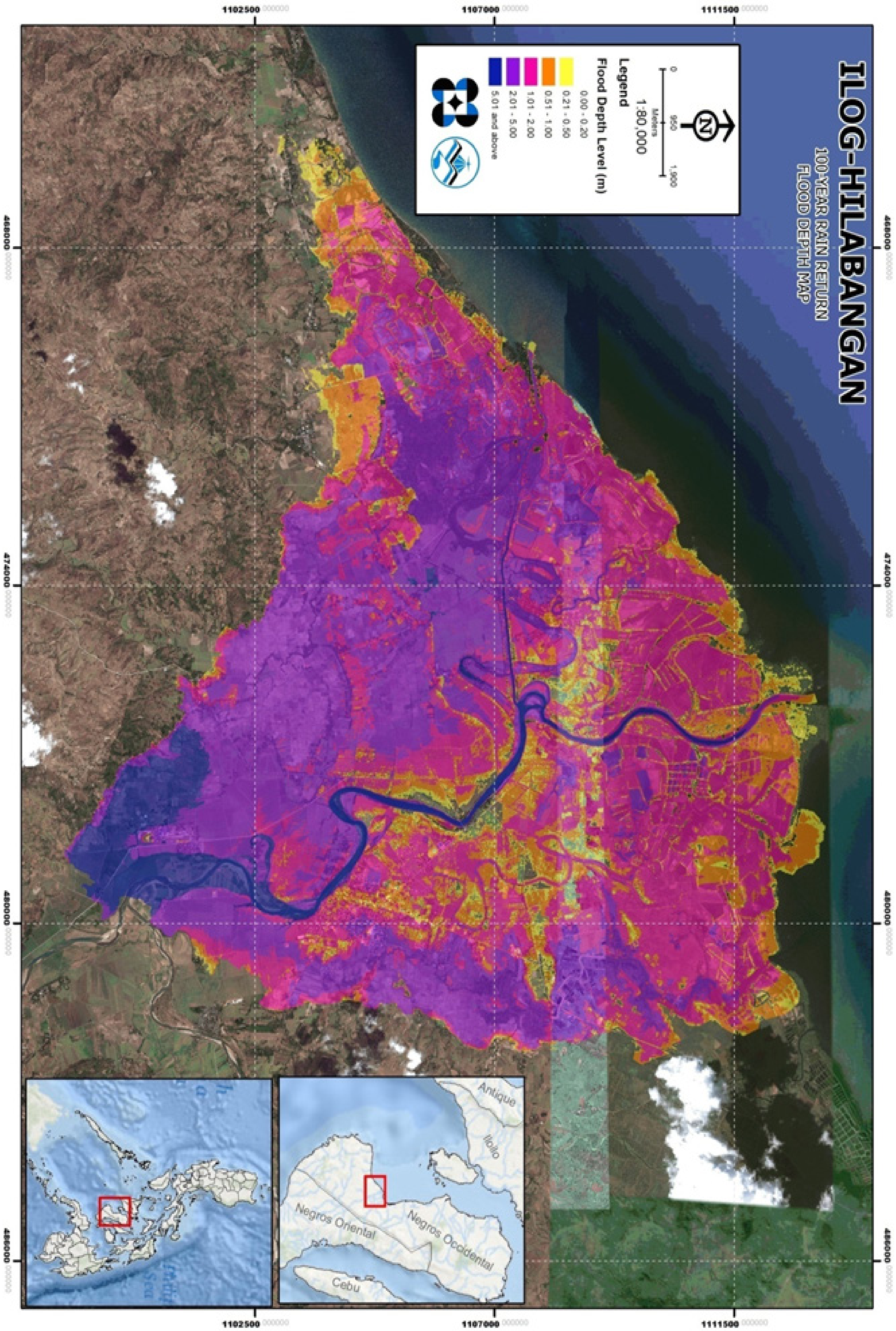


Figure 47. 25-year Flood Hazard Map for Hilabangan River Basin

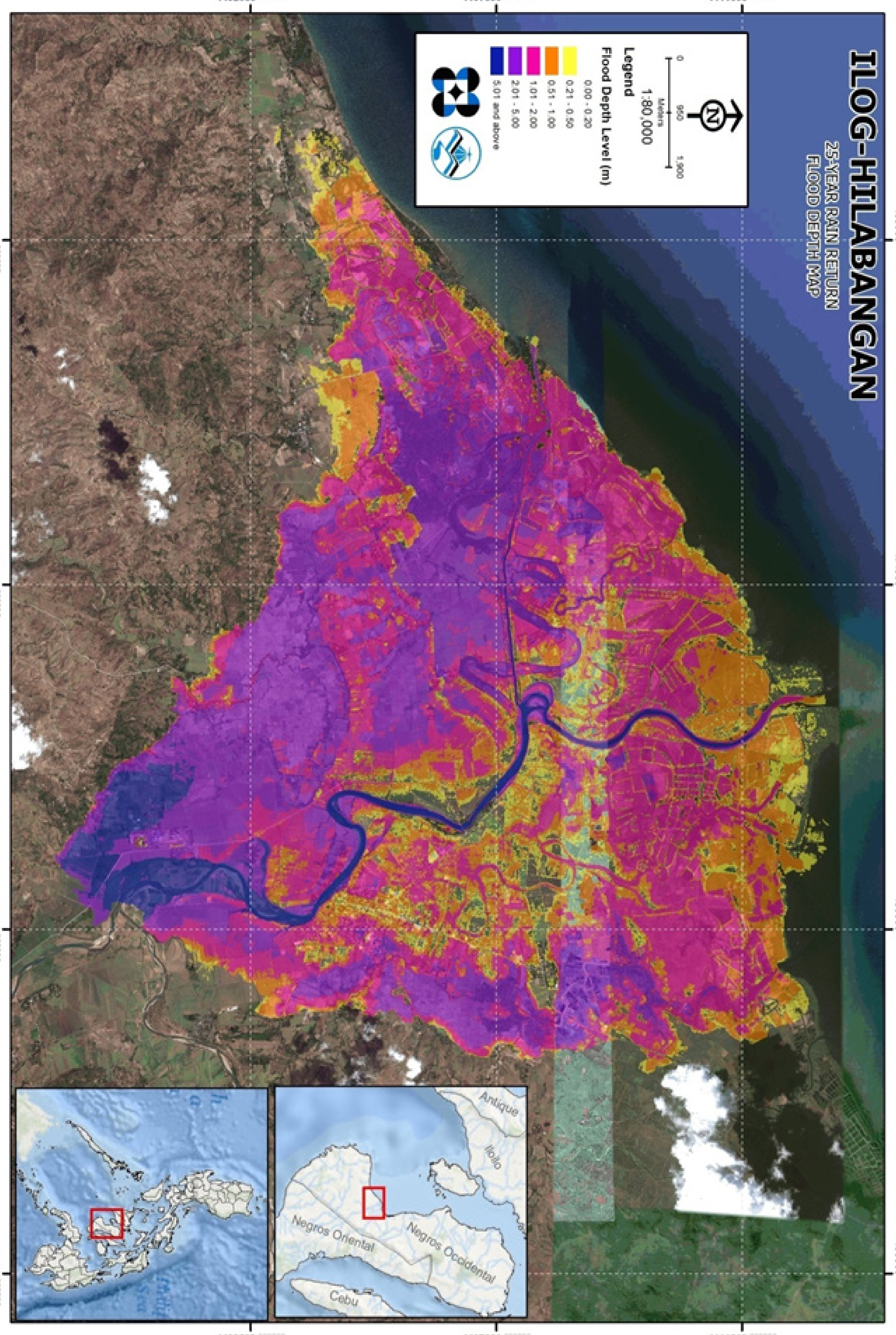


Figure 48. 25-year Flow Depth Map for Hilabangan River Basin

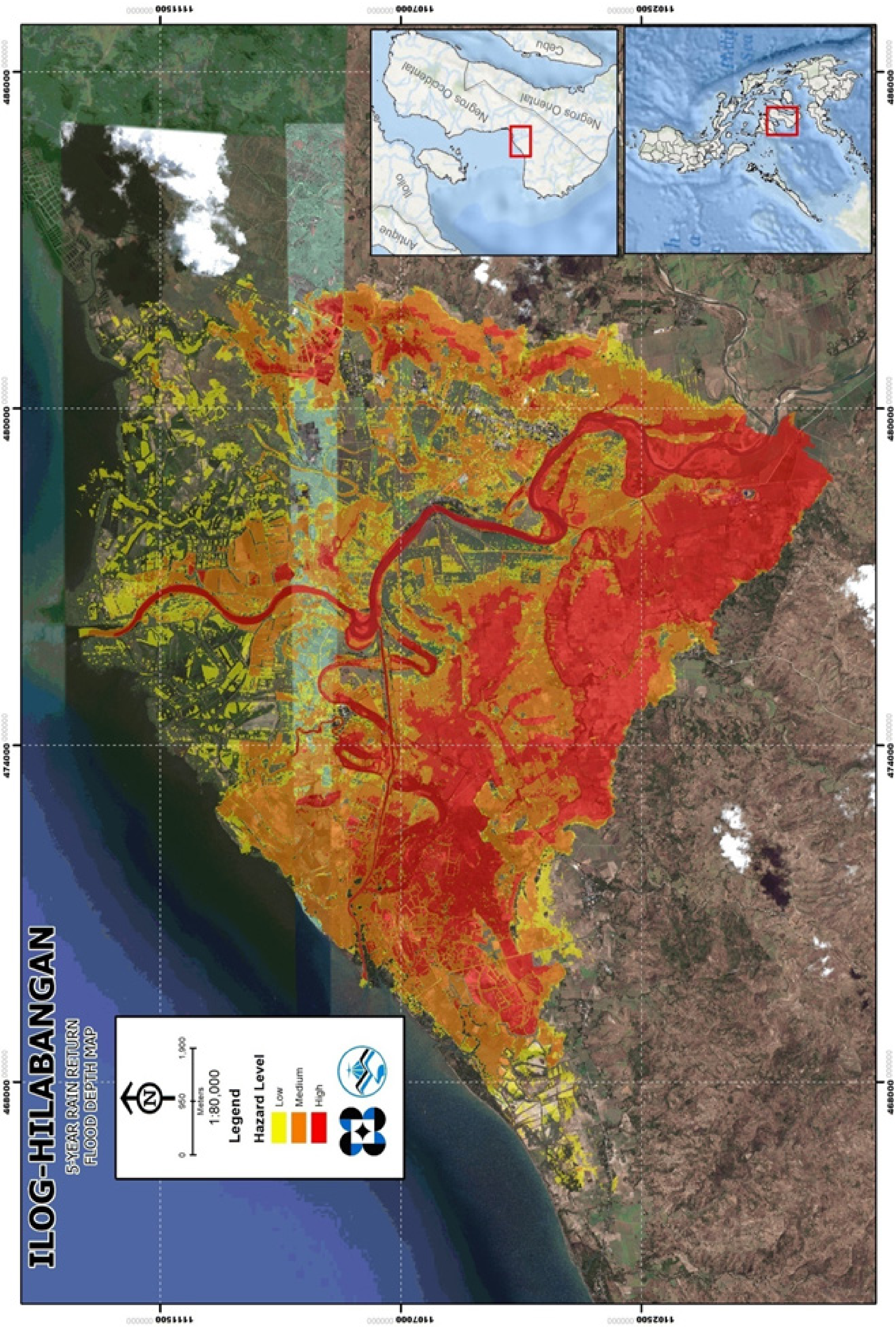


Figure 49. 5-year Flood Hazard Map for Hilabangan River Basin

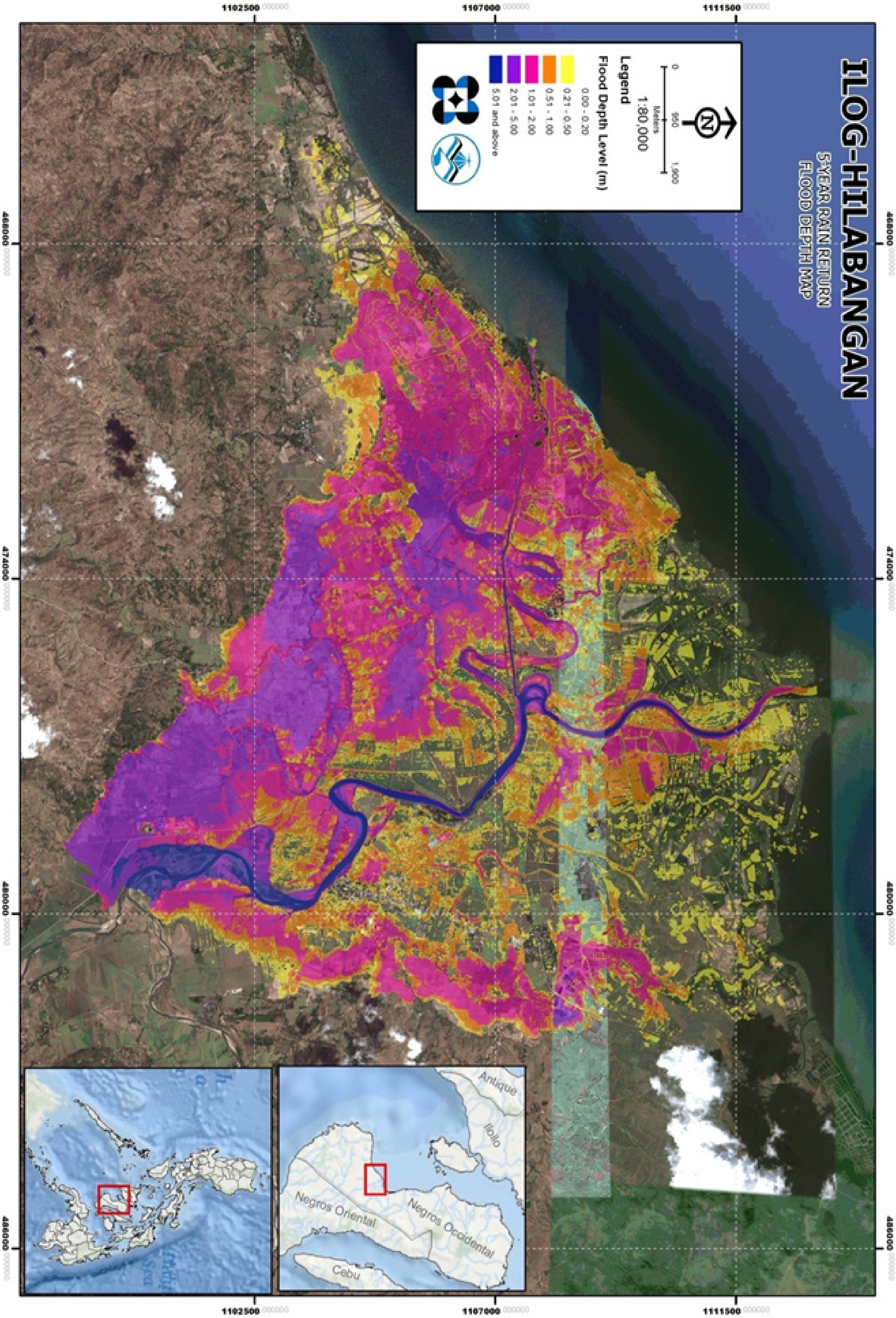


Figure 50. 5-year Flood Hazard Map for Hilabangan River Basin

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Appendix

Appendix A. Hilabangan Bridge 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
28B	0.58	98.830	0.0	1.6464	2.585625	Discharge	2.0101	1	Ratio to Peak	0.00
29B	11.78	98.830	0.0	4.4873	8.262765	Discharge	3.2782	0.90108	Ratio to Peak	0.00
30B	0.60	98.830	0.0	0.62198	62.7249	Discharge	2.5603	1	Ratio to Peak	0.00
31B	12.30	98.830	0.0	2.0144	3.321675	Discharge	2.5489	0.9	Ratio to Peak	0.00
32B	1.33	98.830	0.0	2.6389	1.733865	Discharge	1.1169	1	Ratio to Peak	0.00
33B	12.13	98.830	0.0	5.1069	9.499665	Discharge	1.2746	0.9	Ratio to Peak	0.00
34B	0.58	98.830	0.0	2.5924	4.478565	Discharge	2.3231	1	Ratio to Peak	0.00
35B	1.98	98.830	0.0	2.2765	2.38161	Discharge	2.7095	1	Ratio to Peak	0.00
36B	1.33	98.830	0.0	0.7938	2.855685	Discharge	3.5753	1	Ratio to Peak	0.00
37B	1.98	98.830	0.0	2.3629	2.609145	Discharge	2.0218	1	Ratio to Peak	0.00
38B	0.58	98.830	0.0	2.7053	4.703055	Discharge	1.8231	1	Ratio to Peak	0.00

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
39B	0.58	98.830	0.0	2.8507	4.992225	Discharge	1.2214	0.90192	Ratio to Peak	0.00
40B	0.58	98.830	0.0	1.6593	2.614395	Discharge	0.47149	0.99876	Ratio to Peak	0.00
41B	0.58	98.830	0.0	1.8916	3.078915	Discharge	2.0716	1	Ratio to Peak	0.00
42B	0.58	98.830	0.0	2.2018	3.699675	Discharge	5.4283	1	Ratio to Peak	0.00
43B	0.58	98.830	0.0	2.6149	4.523715	Discharge	0.56628	1	Ratio to Peak	0

Appendix B. Hilabangan Bridge Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Man-ning's n	Shape	Width	Side Slope
38R	Automatic Fixed Interval	32757.9	0.00	0.0027	Trapezoid	30	45
39R	Automatic Fixed Interval	43965.7	0.00	0.0027	Trapezoid	30	45
40R	Automatic Fixed Interval	64087.3	0.00	0.0026	Trapezoid	30	45
41R	Automatic Fixed Interval	34552.2	0.01	0.0027	Trapezoid	30	45
42R	Automatic Fixed Interval	98720.2	0.00	0.0027	Trapezoid	30	45
43R	Automatic Fixed Interval	97311.3	0.00	0.0027	Trapezoid	30	45
44R	Automatic Fixed Interval	76911.5	0.01	0.0027	Trapezoid	30	45
45R	Automatic Fixed Interval	60839.7	0.00	0.0027	Trapezoid	30	45
46R	Automatic Fixed Interval	60243.7	0.00	0.0027	Trapezoid	30	45
47R	Automatic Fixed Interval	69490.6	0.01	0.0092	Trapezoid	30	45
48R	Automatic Fixed Interval	46294.6	0.00	0.0027	Trapezoid	30	45
49R	Automatic Fixed Interval	43032.2	0.00	0.0027	Trapezoid	30	45
50R	Automatic Fixed Interval	26184.5	0.00	0.0027	Trapezoid	30	45
51R	Automatic Fixed Interval	28152.0	0.01	0.0027	Trapezoid	30	45
52R	Automatic Fixed Interval	30445.3	0.02	0.0027	Trapezoid	30	45

Appendix C. Magballo Bridge 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
28B	0.584375	58.643	0.0	4.8904	2.585625	Discharge	0.56628	0.5	Ratio to Peak	0.00
29B	11.775203	58.643	0.0	12.466	8.262765	Discharge	5.4283	0.5	Ratio to Peak	0.00
30B	0.5991293	58.643	0.0	2.1586	62.7249	Discharge	2.0218	0.5	Ratio to Peak	0.00
31B		58.643	0.0	5.8717	3.321675	Discharge	2.0101	0.5	Ratio to Peak	0.00
32B	1.3280	58.643	0.0	7.5371	1.733865	Discharge	1.8231	0.5	Ratio to Peak	0.00
33B	12.131064	58.643	0.0	14.1184	9.499665	Discharge	3.2782	0.45054	Ratio to Peak	0.00
34B	0.584375	58.643	0.0	7.4131	4.478565	Discharge	3.5753	0.5	Ratio to Peak	0.00
35B	1.9821252	58.643	0.0	6.5707	2.38161	Discharge	2.0716	0.5	Ratio to Peak	0.00
36B	1.3280	58.643	0.0	2.6168	2.855685	Discharge	0.47149	0.49938	Ratio to Peak	0.00
37B	1.9821252	58.643	0.0	6.8011	2.609145	Discharge	1.2214	0.45096	Ratio to Peak	0.00

Appendix D. Magballo Bridge Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
38R	Automatic Fixed Interval	32757.9	0.00	0.0201	Trapezoid	30	45
39R	Automatic Fixed Interval	43965.7	0.00	0.0201	Trapezoid	30	45
40R	Automatic Fixed Interval	64087.3	0.00	0.0196	Trapezoid	30	45
41R	Automatic Fixed Interval	34552.2	0.01	0.0201	Trapezoid	30	45
42R	Automatic Fixed Interval	98720.2	0.00	0.0201	Trapezoid	30	45
43R	Automatic Fixed Interval	97311.3	0.00	0.0201	Trapezoid	30	45
44R	Automatic Fixed Interval	76911.5	0.01	0.0201	Trapezoid	30	45
45R	Automatic Fixed Interval	60839.7	0.00	0.0201	Trapezoid	30	45
46R	Automatic Fixed Interval	60243.7	0.00	0.0201	Trapezoid	30	45
47R	Automatic Fixed Interval	69490.6	0.01	0.0688	Trapezoid	30	45
48R	Automatic Fixed Interval	46294.6	0.00	0.0200	Trapezoid	30	45
49R	Automatic Fixed Interval	43032.2	0.00	0.0201	Trapezoid	30	45
50R	Automatic Fixed Interval	26184.5	0.00	0.0201	Trapezoid	30	45
51R	Automatic Fixed Interval	28152.0	0.01	0.0201	Trapezoid	30	45
52R	Automatic Fixed Interval	30445.3	0.02	0.0201	Trapezoid	30	45

Appendix E. Hilabangan River Discharge from HEC-HMS Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0.3333	0	0	0	6.3333	0	0	0
0.5000	0	0	0	6.5000	0	0	0
0.6667	0	0	0	6.6667	0	0	0
0.8333	0	0	0	6.8333	0	0	0
1.0000	0	0	0	7.0000	0	0	0
1.1667	0	0	0	7.1667	0	0	0
1.3333	0	0	0	7.3333	0	0	0
1.5000	0	0	0	7.5000	0	0	0
1.6667	0	0	0	7.6667	0	0	0
1.8333	0	0	0	7.8333	0	0	0
2.0000	0	0	0	8.0000	0	0	0
2.1667	0	0	0	8.1667	0	0	0
2.3333	0	0	0	8.3333	0	0	0
2.5000	0	0	0	8.5000	0	0	0
2.6667	0	0	0	8.6667	0	0	0
2.8333	0	0	0	8.8333	0	0	0
3.0000	0	0	0	9.0000	0	0	0
3.1667	0	0	0	9.1667	0	0	0
3.3333	0	0	0	9.3333	0.1	0	0
3.5000	0	0	0	9.5000	0.1	0	0
3.6667	0	0	0	9.6667	0.3	0	0
3.8333	0	0	0	9.8333	0.5	0.1	0
4.0000	0	0	0	10.0000	0.8	0.2	0
4.1667	0	0	0	10.1667	1.2	0.3	0
4.3333	0	0	0	10.3333	1.7	0.4	0
4.5000	0	0	0	10.5000	2.6	0.8	0
4.6667	0	0	0	10.6667	4	1.3	0.1
4.8333	0	0	0	10.8333	6	2.2	0.2
5.0000	0	0	0	11.0000	9	3.6	0.5
5.1667	0	0	0	11.1667	13.1	5.8	0.9
5.3333	0	0	0	11.3333	18.7	8.7	1.7
5.5000	0	0	0	11.5000	26.5	13	2.9
5.6667	0	0	0	11.6667	37.9	19.7	5.2
5.8333	0	0	0	11.8333	57.8	32.6	10.9
6.0000	0	0	0	12.0000	83.5	49.6	18.8

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
12.3333	146.9	91.6	38.5	18.6667	5662.8	3972.6	2052.7
12.5000	186	117.6	50.7	18.8333	5810.5	4079.4	2110.7
12.6667	234.1	150.2	66.4	19.0000	5949.2	4179.9	2165.6
12.8333	292.5	190.2	86.3	19.1667	6072.5	4269.1	2214.4
13.0000	357.1	234.7	108.7	19.3333	6185.4	4351	2259.1
13.1667	426.8	282.7	132.8	19.5000	6291.2	4428.1	2301.5
13.3333	501.7	334.2	158.6	19.6667	6389.2	4499.8	2341.3
13.5000	581.7	389.3	186.2	19.8333	6479.1	4565.9	2378.4
13.6667	670	450.3	217	20.0000	6555.6	4622.3	2410.2
13.8333	764.3	515.7	250.1	20.1667	6619.1	4669.3	2436.7
14.0000	863.1	584	284.7	20.3333	6674.7	4710.6	2460.1
14.1667	967	655.8	320.8	20.5000	6723.4	4747.1	2481.2
14.3333	1076.2	731.1	358.7	20.6667	6765.3	4778.9	2500
14.5000	1193.4	812.3	399.6	20.8333	6800.5	4806.1	2516.5
14.6667	1319.5	899.8	444	21.0000	6826	4826.4	2529.3
14.8333	1451.8	991.7	490.8	21.1667	6844.3	4841.6	2539.5
15.0000	1589.2	1087.2	539.2	21.3333	6857	4853	2547.9
15.1667	1732.5	1186.7	589.6	21.5000	6863.3	4860.1	2554.3
15.3333	1883	1291.2	642.5	21.6667	6862.6	4862.3	2558.3
15.5000	2046.3	1405.1	700.7	21.8333	6849.3	4855.3	2557.3
15.6667	2218.2	1525.4	762.6	22.0000	6824.5	4839.8	2551.3
15.8333	2395.7	1649.7	826.5	22.1667	6792.5	4819.1	2542.4
16.0000	2578.7	1778	892.5	22.3333	6754.7	4794.2	2531.4
16.1667	2767	1910.1	960.6	22.5000	6711.5	4765.6	2518.3
16.3333	2963.3	2048.2	1032	22.6667	6662.9	4733.1	2503.4
16.5000	3167.2	2192.1	1107.1	22.8333	6607.7	4695.9	2485.9
16.6667	3375.3	2339.3	1184.1	23.0000	6547.6	4655.2	2466.5
16.8333	3585.9	2488.7	1262.6	23.1667	6483.6	4611.8	2445.8
17.0000	3798	2639.3	1342	23.3333	6415.7	4565.7	2423.8
17.1667	4008.6	2789.1	1421.3	23.5000	6344.4	4517.3	2400.6
17.3333	4213.4	2934.9	1498.4	23.6667	6268.7	4465.7	2375.9
17.5000	4414.7	3078.2	1574.2	23.8333	6188.9	4411.2	2349.5
17.6667	4613.6	3220.1	1649.5	24.0000	6105.9	4354.5	2322.1
17.8333	4809.2	3360	1724	24.1667	6019.6	4295.5	2293.5
18.0000	4999.6	3496.5	1797.1	24.3333	5929.8	4234.1	2263.8
18.1667	5179.1	3625.2	1866.2	24.5000	5835.5	4169.5	2232.4
18.3333	5347	3745.6	1930.6	24.6667	5734.5	4100	2198.3
18.5000	5508	3861.2	1992.7	24.8333	5628.9	4027.1	2162.3

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
25.0000	5520.1	3951.9	2125.2	31.3333	1994.4	1463	836.4
25.1667	5407.9	3874.3	2086.7	31.5000	1940.8	1424.4	815.4
25.3333	5292.5	3794.3	2047	31.6667	1888.2	1386.5	794.6
25.5000	5171.4	3710.1	2004.8	31.8333	1837	1349.5	774.4
25.6667	5045.9	3622.4	1960.5	32.0000	1787.6	1313.9	754.8
25.8333	4917.9	3532.9	1915	32.1667	1739.2	1279	735.7
26.0000	4788.2	3441.9	1868.5	32.3333	1691.7	1244.6	716.8
26.1667	4657.9	3350.3	1821.6	32.5000	1645.1	1210.9	698.2
26.3333	4529	3259.5	1774.9	32.6667	1599.2	1177.7	679.8
26.5000	4403.5	3171.2	1729.6	32.8333	1554.2	1145	661.6
26.6667	4280.3	3084.5	1685	33.0000	1510	1112.9	643.7
26.8333	4158.4	2998.6	1640.8	33.1667	1466.6	1081.3	626
27.0000	4038.3	2913.7	1597	33.3333	1424.1	1050.3	608.5
27.1667	3921.2	2830.9	1554	33.5000	1382.7	1020	591.4
27.3333	3810.9	2753.1	1513.7	33.6667	1342.9	990.9	574.8
27.5000	3706.4	2679.4	1475.9	33.8333	1305.4	963.5	559.3
27.6667	3605	2608	1439.1	34.0000	1269.2	937	544.3
27.8333	3506.4	2538.4	1403.3	34.1667	1233.9	911.2	529.6
28.0000	3410.4	2470.6	1368.3	34.3333	1199.5	886	515.3
28.1667	3317.3	2404.8	1334.2	34.5000	1165.9	861.4	501.3
28.3333	3228	2341.7	1301.5	34.6667	1133.2	837.4	487.5
28.5000	3141.2	2280.3	1269.7	34.8333	1101.2	813.9	474.1
28.6667	3056.5	2220.3	1238.5	35.0000	1069.9	790.9	460.8
28.8333	2973.9	2161.8	1207.9	35.1667	1039.3	768.3	447.8
29.0000	2893.2	2104.5	1177.8	35.3333	1009.4	746.3	435
29.1667	2815.7	2049.4	1148.9	35.5000	980.5	725	422.7
29.3333	2740.9	1996.2	1121	35.6667	952.9	704.6	410.9
29.5000	2667.7	1944.2	1093.5	35.8333	926.1	684.8	399.4
29.6667	2596.3	1893.3	1066.6	36.0000	899.8	665.5	388.2
29.8333	2526.8	1843.7	1040.2	36.1667	874.2	646.6	377.2
30.0000	2460	1795.9	1014.7	36.3333	849.1	628.1	366.5
30.1667	2396.8	1750.8	990.8	36.5000	824.5	609.9	355.9
30.3333	2335.7	1707.3	967.6	36.6667	800.4	592.1	345.6
30.5000	2276	1664.7	944.9	36.8333	776.7	574.6	335.3
30.6667	2217.7	1623	922.7	37.0000	753.5	557.4	325.3
30.8333	2160.4	1582	900.7	37.1667	730.8	540.5	315.4
31.0000	2104.2	1541.8	879	37.3333	708.9	524.4	305.9
31.1667	2049	1502.2	857.7	37.5000	688.1	508.9	296.9

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
31.3333	1994.4	1463	836.4	37.6667	667.9	493.9	288.1
31.5000	1940.8	1424.4	815.4	37.8333	648.1	479.3	279.6
31.6667	1888.2	1386.5	794.6	38.0000	628.8	465.1	271.2
31.8333	1837	1349.5	774.4	38.1667	610	451.1	263.1
32.0000	1787.6	1313.9	754.8	38.3333	591.6	437.5	255.2
32.1667	1739.2	1279	735.7	38.5000	573.7	424.3	247.4
32.3333	1691.7	1244.6	716.8	38.6667	556.3	411.4	239.9
32.5000	1645.1	1210.9	698.2	38.8333	539.3	398.8	232.5
32.6667	1599.2	1177.7	679.8	39.0000	522.8	386.6	225.4
32.8333	1554.2	1145	661.6	39.1667	507.1	374.9	218.5
33.0000	1510	1112.9	643.7	39.3333	492.2	363.9	212.1
33.1667	1466.6	1081.3	626	39.5000	478	353.4	206
33.3333	1424.1	1050.3	608.5	39.6667	464.2	343.2	200
33.5000	1382.7	1020	591.4	39.8333	450.8	333.3	194.3
33.6667	1342.9	990.9	574.8	40.0000	437.8	323.7	188.7
33.8333	1305.4	963.5	559.3	40.1667	425.1	314.3	183.2
34.0000	1269.2	937	544.3	40.3333	412.7	305.2	177.9
34.1667	1233.9	911.2	529.6	40.5000	400.7	296.2	172.7
34.3333	1199.5	886	515.3	40.6667	388.9	287.5	167.6
34.5000	1165.9	861.4	501.3	40.8333	377.4	279	162.6
34.6667	1133.2	837.4	487.5	41.0000	366.4	270.9	157.9
34.8333	1101.2	813.9	474.1	41.1667	355.9	263.1	153.3
35.0000	1069.9	790.9	460.8	41.3333	345.8	255.6	149
35.1667	1039.3	768.3	447.8	41.5000	335.9	248.4	144.8
35.3333	1009.4	746.3	435	41.6667	326.3	241.3	140.6
35.5000	980.5	725	422.7	41.8333	316.9	234.3	136.6
35.6667	952.9	704.6	410.9	42.0000	307.7	227.5	132.7
35.8333	926.1	684.8	399.4	42.1667	298.8	220.9	128.8
36.0000	899.8	665.5	388.2	42.3333	290.1	214.5	125.1
36.1667	874.2	646.6	377.2	42.5000	281.6	208.2	121.4
36.3333	849.1	628.1	366.5	42.6667	273.3	202.1	117.8
36.5000	824.5	609.9	355.9	42.8333	265.3	196.2	114.4
36.6667	800.4	592.1	345.6	43.0000	257.7	190.6	111.1
36.8333	776.7	574.6	335.3	43.1667	250.4	185.1	107.9
37.0000	753.5	557.4	325.3	43.3333	243.2	179.8	104.8
37.1667	730.8	540.5	315.4	43.5000	236.2	174.7	101.8
37.3333	708.9	524.4	305.9	43.6667	229.4	169.6	98.9
37.5000	688.1	508.9	296.9	43.8333	222.7	164.7	96

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
44.0000	216.2	159.9	93.2				
44.1667	209.8	155.2	90.5				
44.3333	203.6	150.6	87.8				
44.5000	197.5	146.1	85.2				
44.6667	191.7	141.8	82.6				
44.8333	186.1	137.6	80.2				
45.0000	180.7	133.6	77.9				
45.1667	175.5	129.7	75.6				
45.3333	170.3	125.9	73.4				
45.5000	165.3	122.2	71.3				
45.6667	160.4	118.6	69.1				
45.8333	155.6	115	67.1				
46.0000	150.9	111.6	65.1				
46.1667	146.4	108.2	63.1				
46.3333	142	105	61.2				
46.5000	137.8	101.9	59.4				
46.6667	133.8	98.9	57.7				
46.8333	130	96.1	56				
47.0000	126.3	93.4	54.4				
47.1667	122.7	90.7	52.9				
47.3333	119.2	88.1	51.4				
47.5000	115.8	85.6	49.9				
47.6667	112.6	83.2	48.5				
47.8333	109.4	80.8	47.1				
48.0000	106.3	78.5	45.7				

D R E A M

Disaster RIsk and Exposure Assessment for Mitigation