REGION 5

Bicol 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.

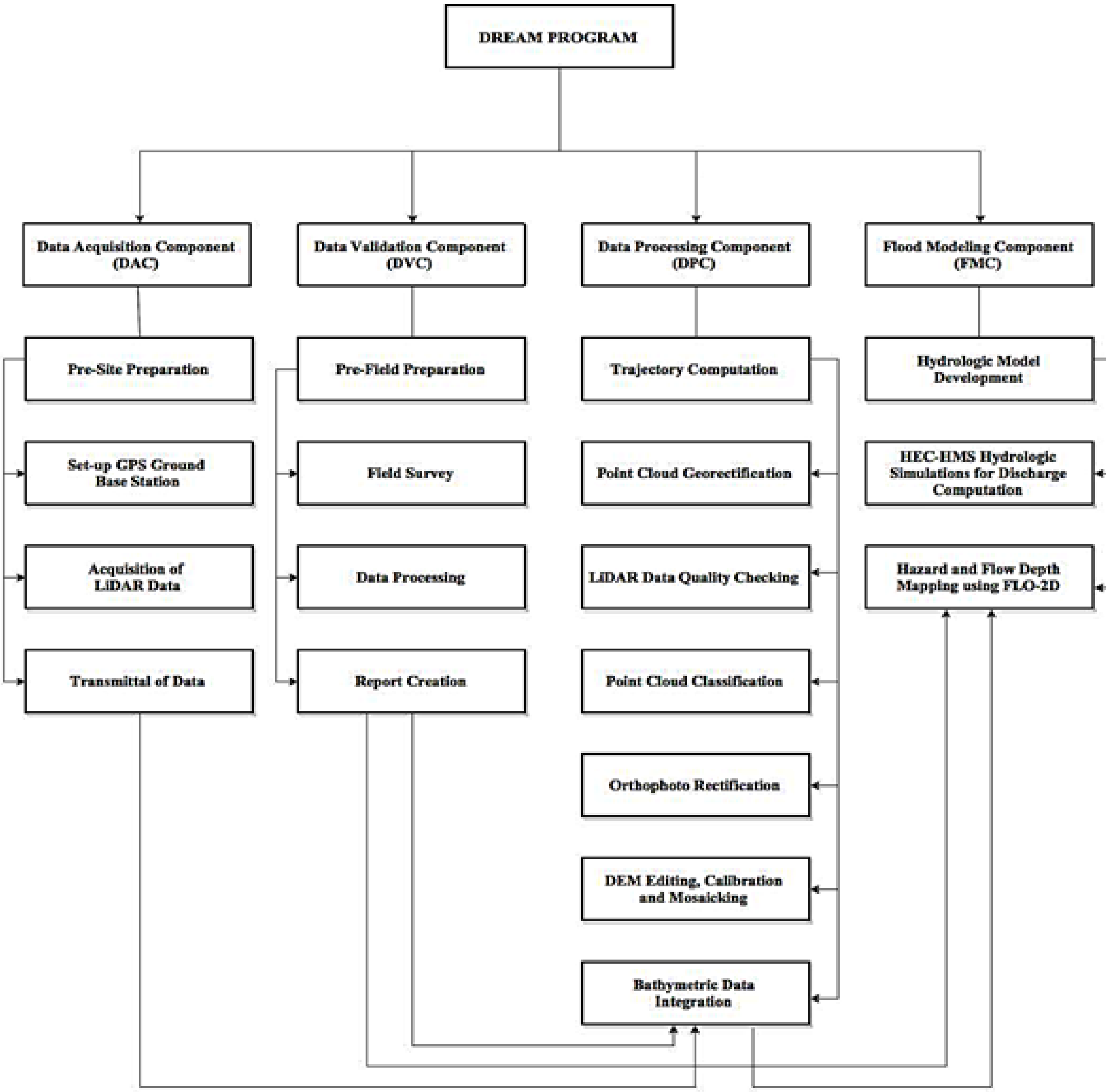


Figure 1. The general methodological framework of the program

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

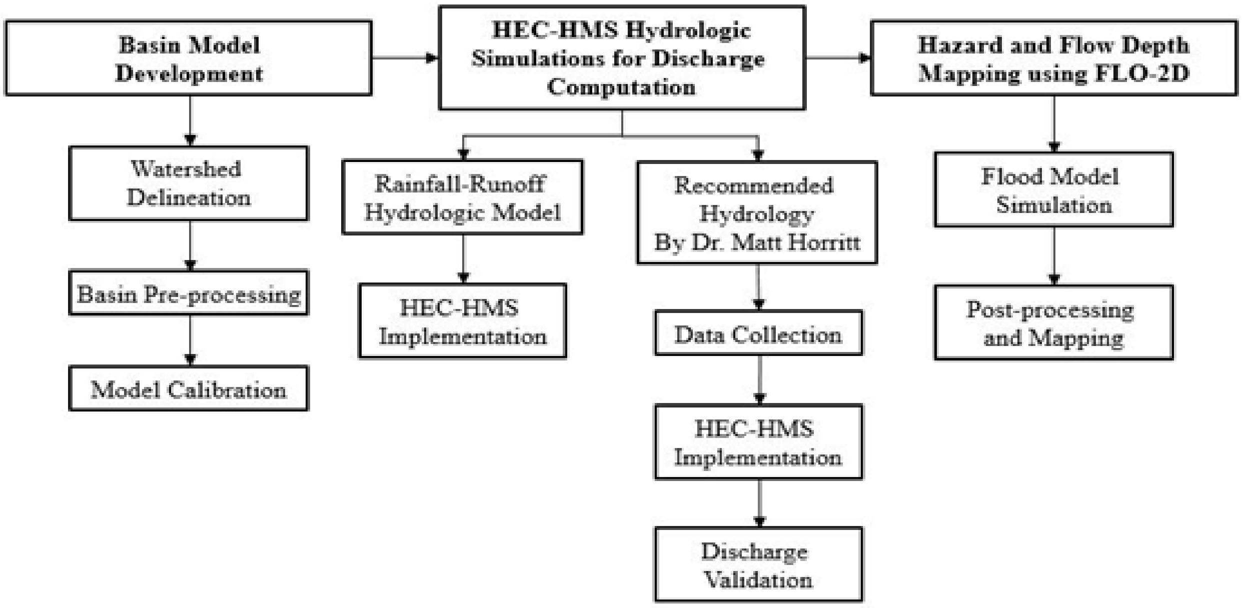


Figure 2. The operational framework and specific work flow of the Flood Modeling Component

The Bicol River Basin

The Bicol River Basin

The Bicol River Basin is the eighth largest river in the Philippines in terms of drainage basin size, having an estimated basin area of 3,770 square kilometers. The river drains the south-western part of the island of Luzon and passes through the central portion of Camarines Sur, the northern portion of Albay, and a portion of Camarines Norte in the Bicol Region. It is also bounded by a chain of volcanoes, highlands and lowhills. The location of Bicol River Basin is as shown in Figure 3.

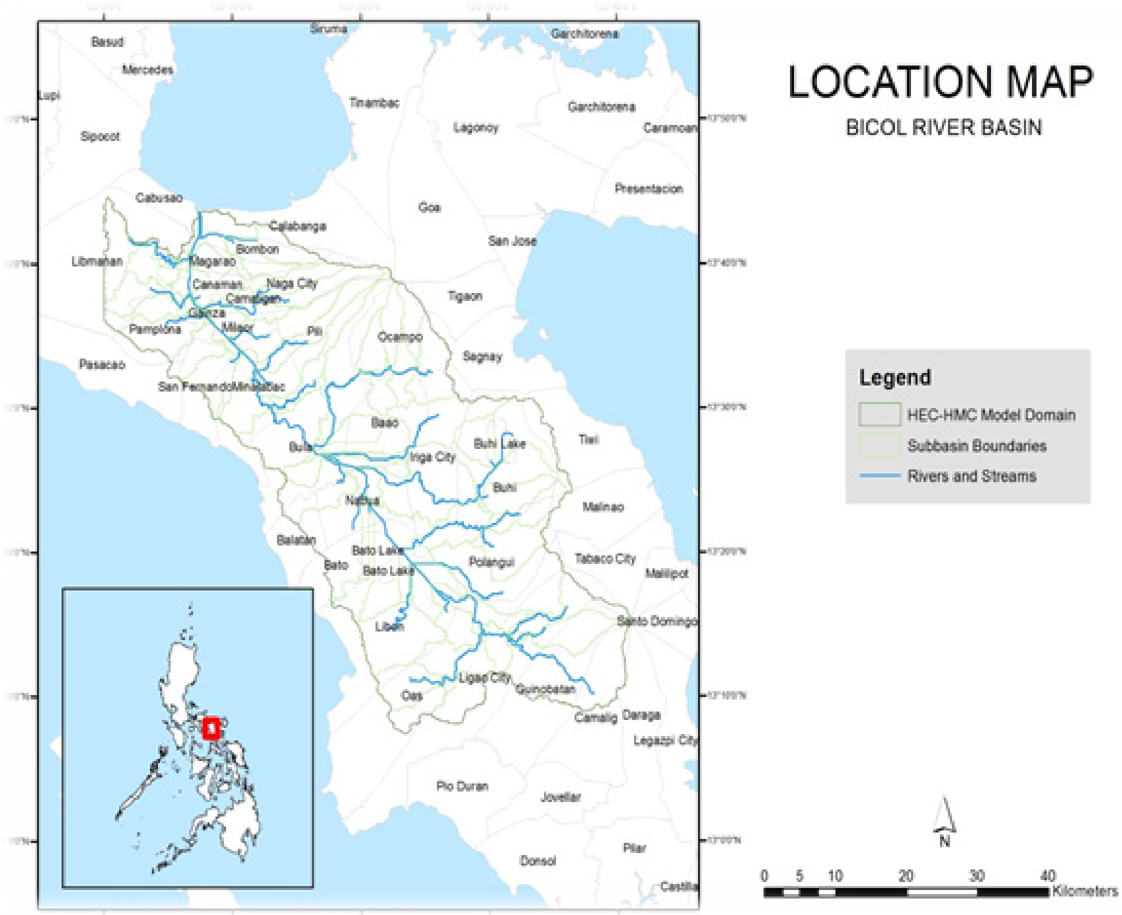


Figure 3. The Bicol River Basin Location Map

Average annual rainfall ranges between 1,850 – 2,300 millimeters in the lower basin and 2,000 – 3,600 millimeters in the southwestern section of the basin. Storm surges associated with slow-moving typhoons cause flooding in the alluvial plain near or over the San Miguel Bay. Flood target areas are the central part of the basin, extending from Baao Lake to Bato Lake and the alluvial plain, which extends from Naga City to the river mouth.

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

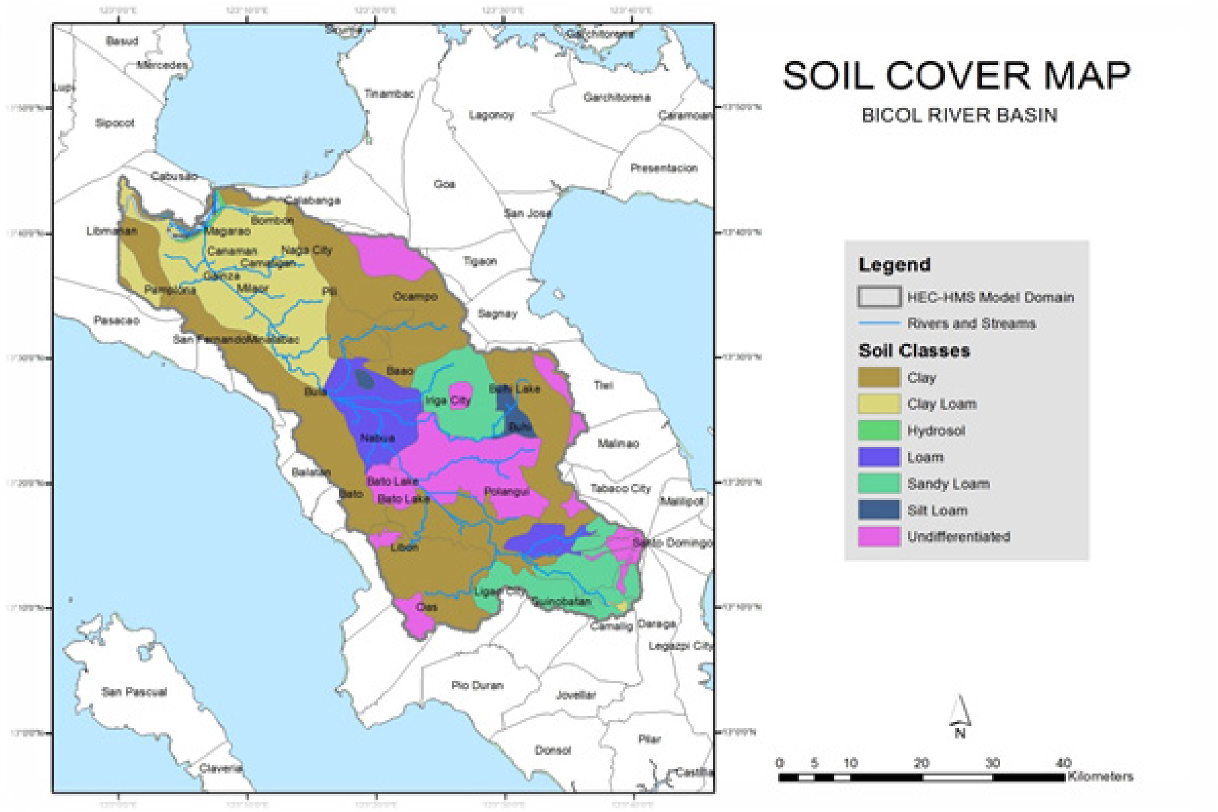


Figure 4. Bicol River Basin Soil Map

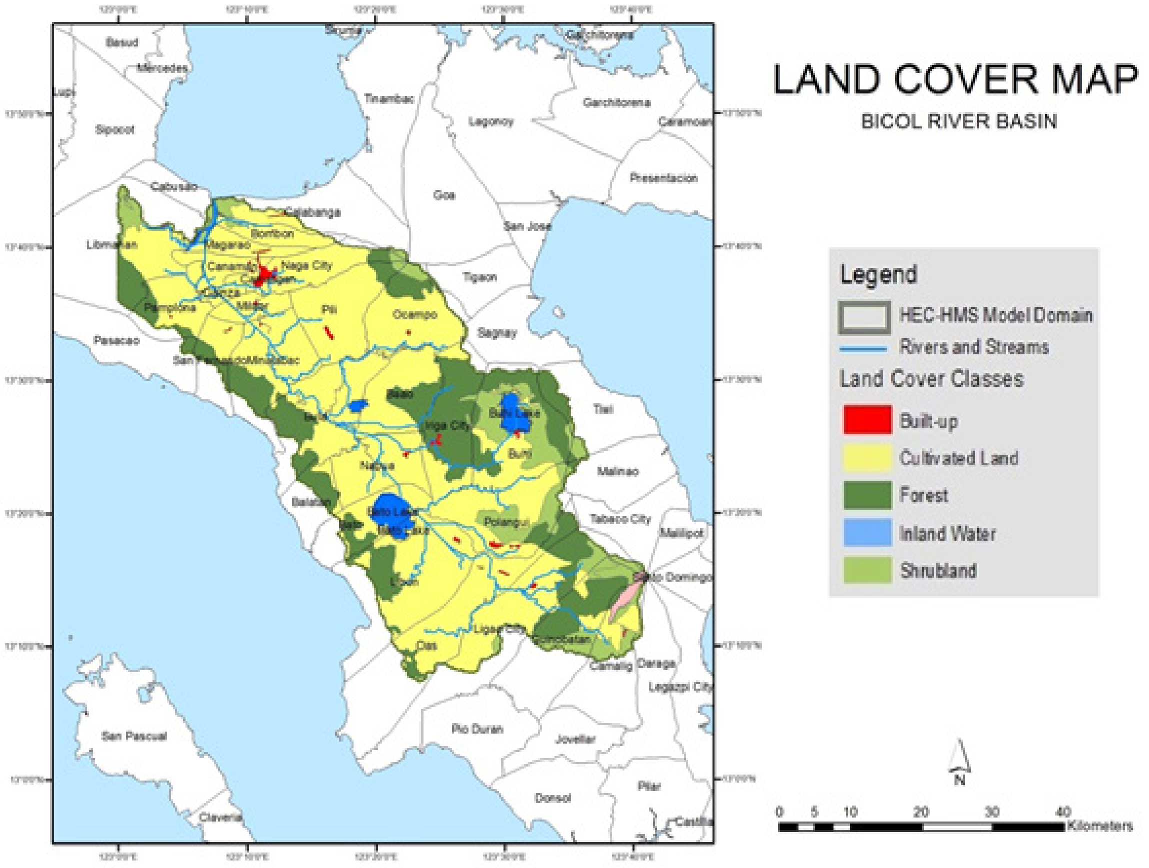


Figure 5. Bicol River Basin Land Cover Map

Methodology

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.

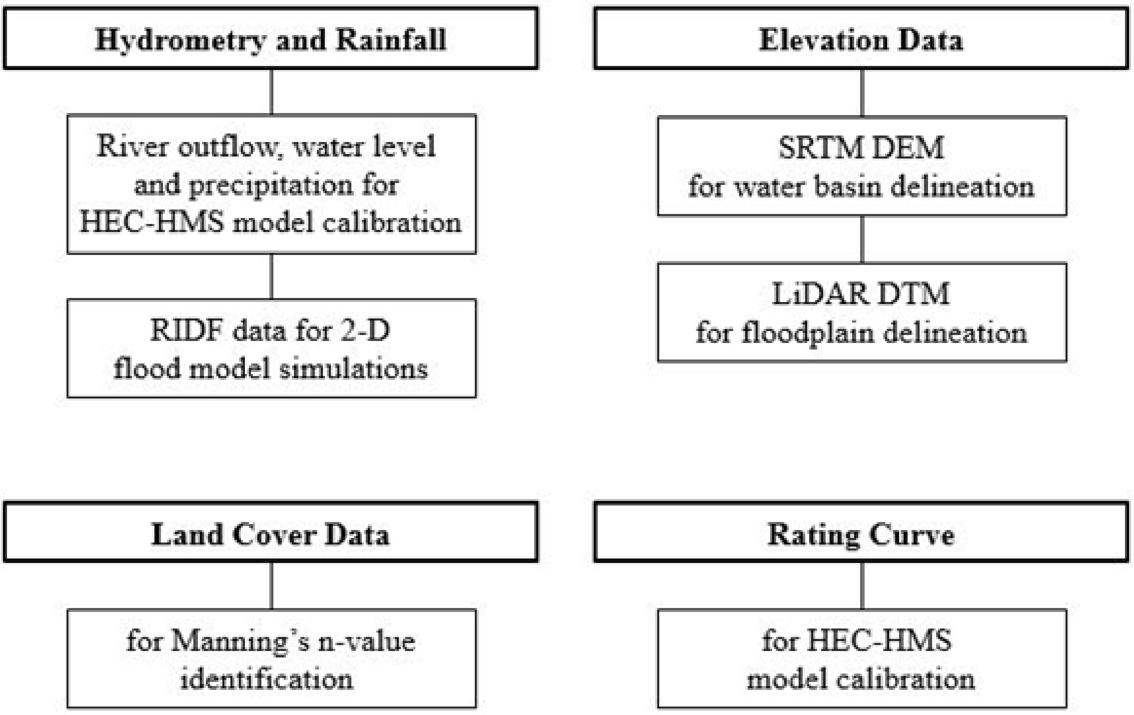


Figure 6. Summary of data needed for the purpose of flood modeling

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.

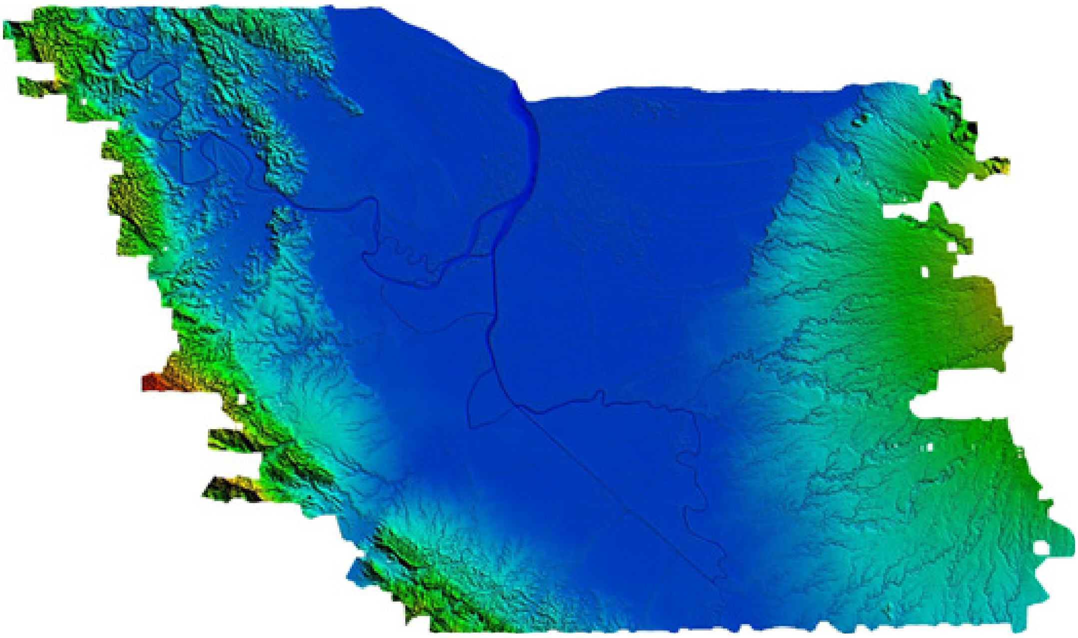


Figure 7. Digital Elevation Model (DEM) of the Bicol River Basin using Light Detection and Ranging (LiDAR) technology

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

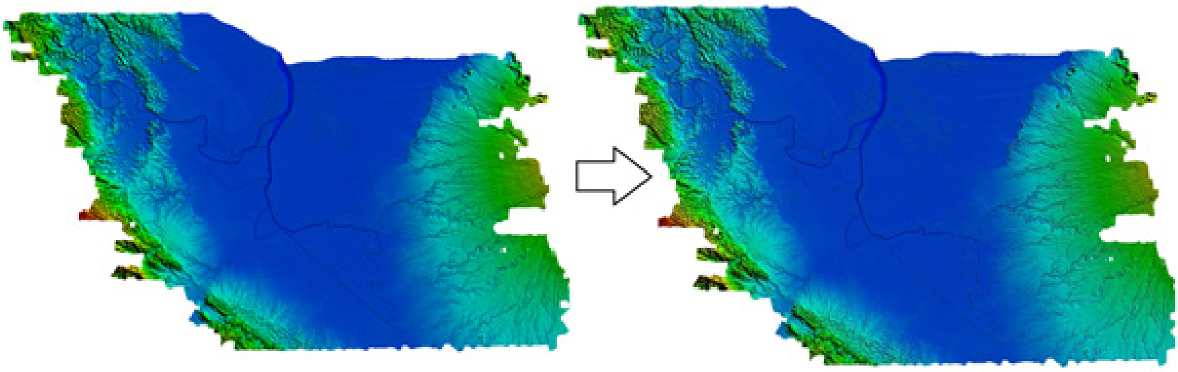


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted.

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 Bicol 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.

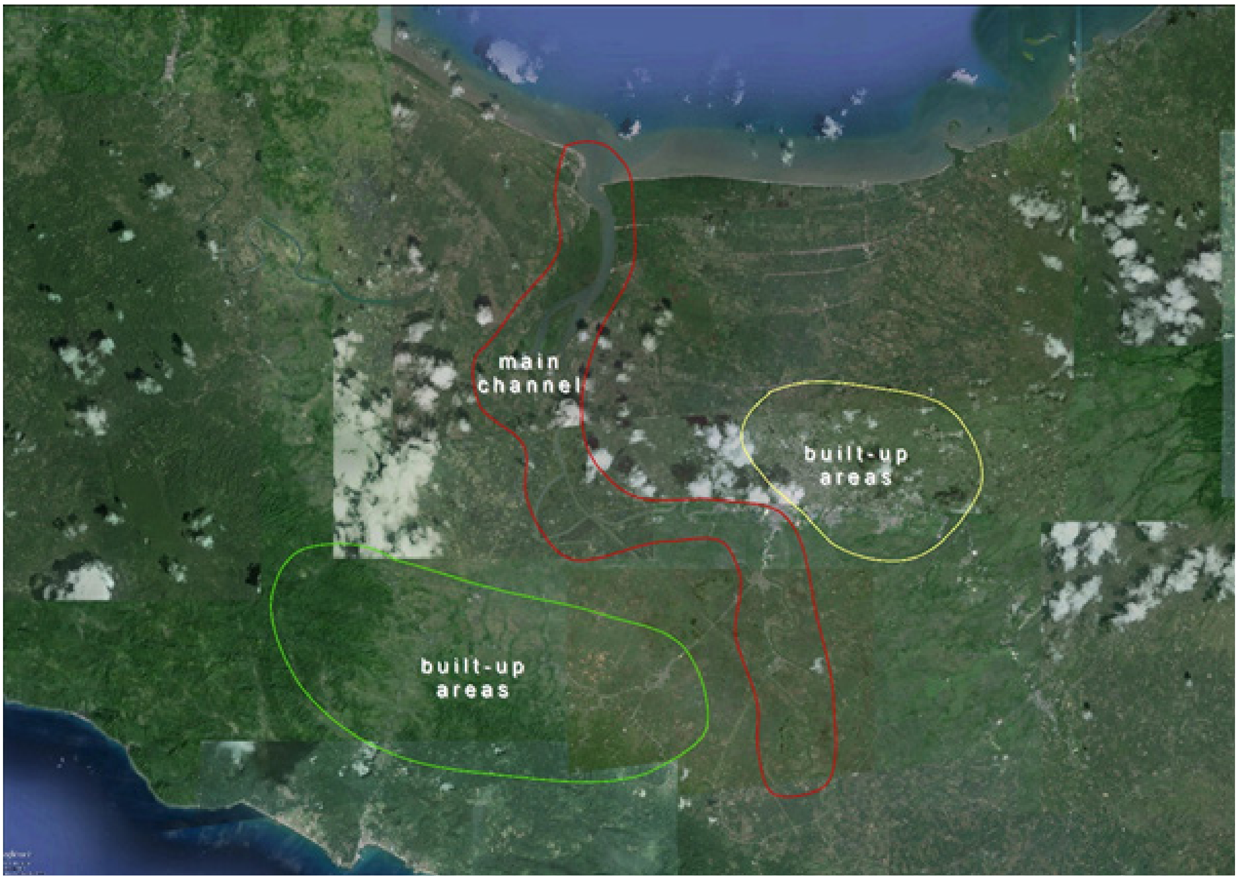


Figure 9. Stitched Quickbird images for the Bicol floodplain.

3.1.3 Hydrometry and Rainfall Data

3.1.3.1 Hydrometry for Padre Garcia, Naga City, Camarines Sur

The surveyed outflow data by the DVBC was used in the calibration of the HEC-HMS model. The rainfall data for the survey period was taken from the automated rain gauges (ARGs) installed by the DOST Advance Science and Technology Institute (ASTI).

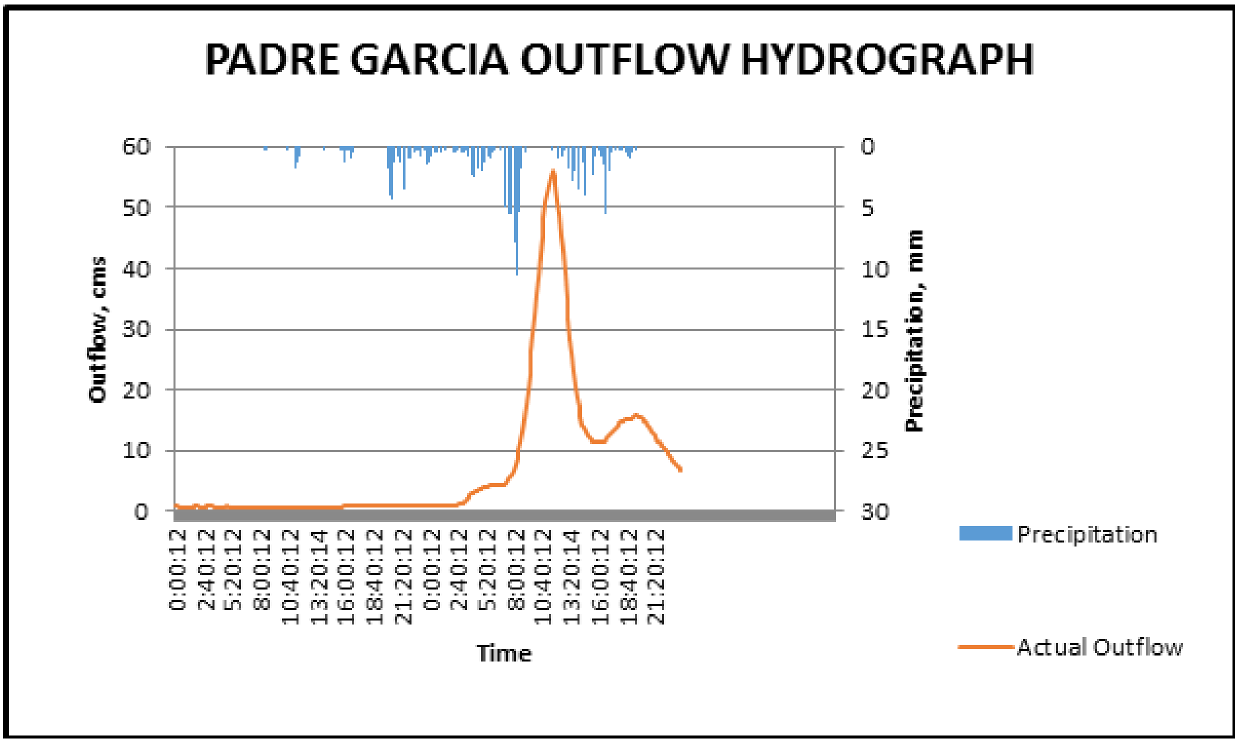


Figure 10. Rainfall and Outflow Data used for Modeling

3.1.3.2 Rainfall Intensity Duration Frequency

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values Legazpi Rain Gauge. This station was chosen based on its proximity to the Bicol 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. A map of the locations of the different PAGASA rain gauges is shown in Figure 11.

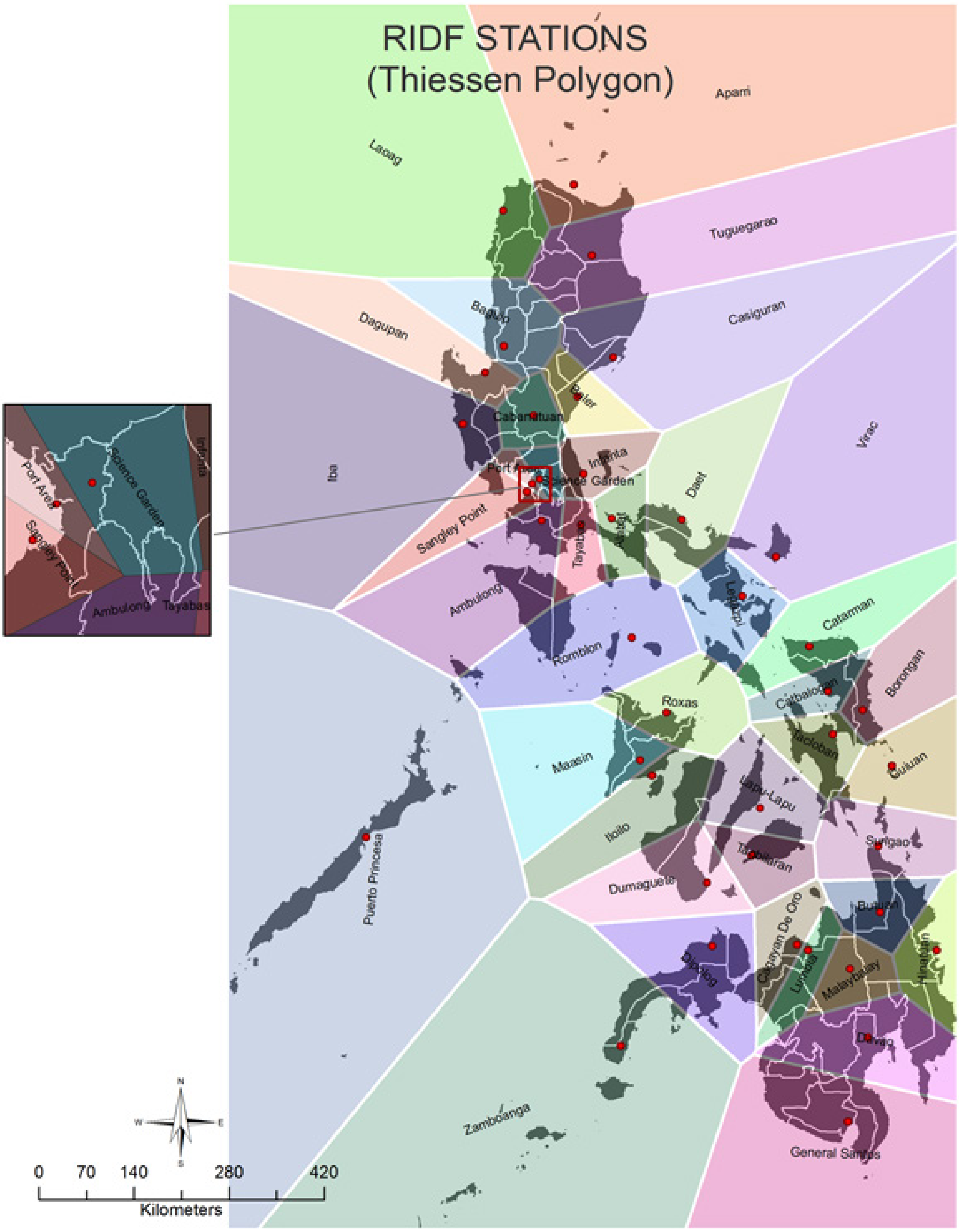


Figure 11. Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines.

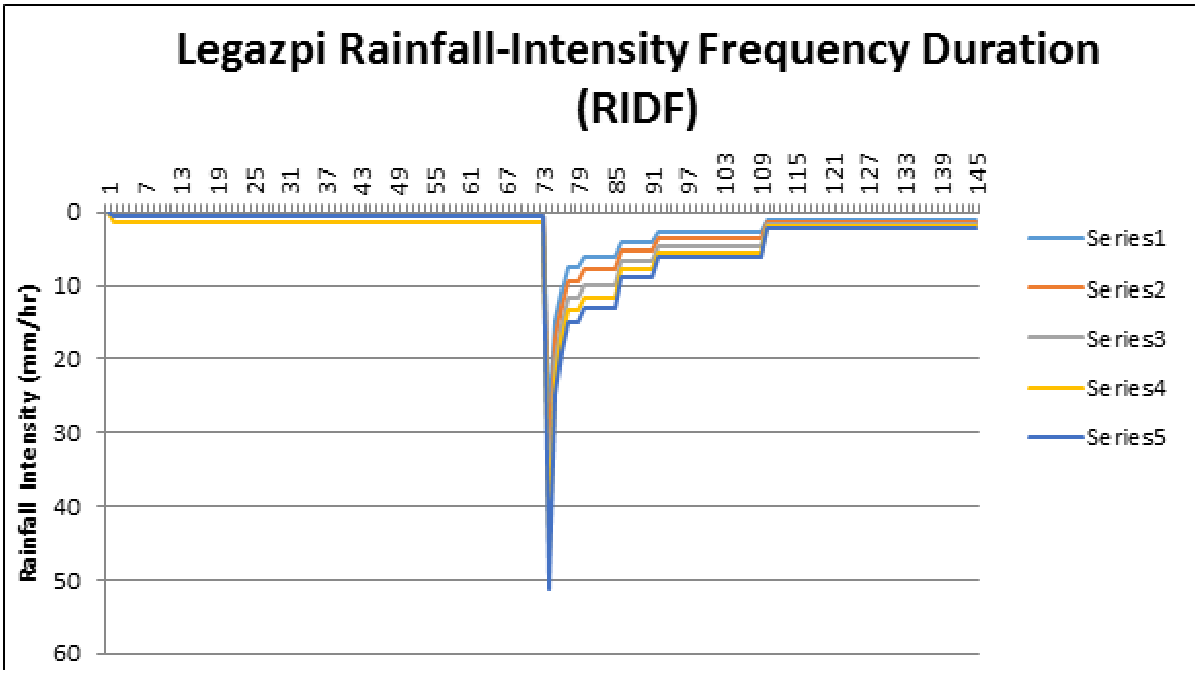


Figure 12. Legazpi Rainfall Intensity Duration Frequency Curves

The outflow for Bicol river basin 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 Padre Garcia, the rating curve is expressed as as Q= 0.0237e as shown in Figure 13.

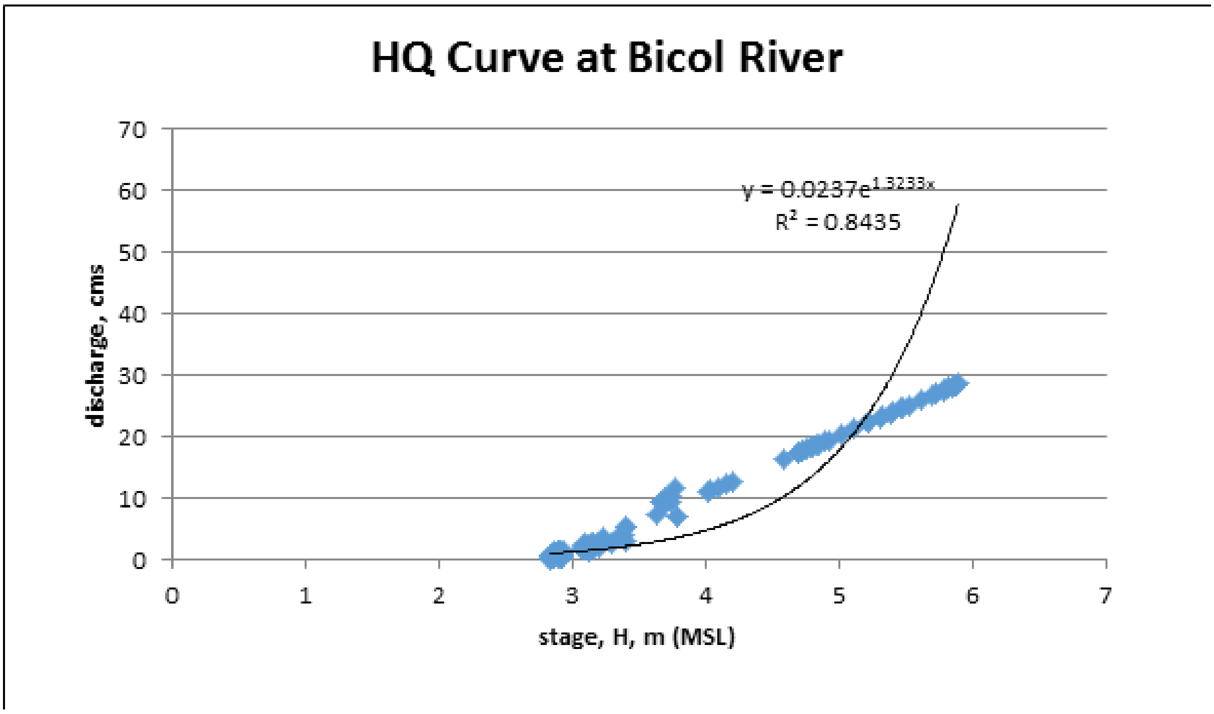


Figure 13. Water level vs. Discharge Curve for Bicol Bridge, Bicol

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Bicol 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.

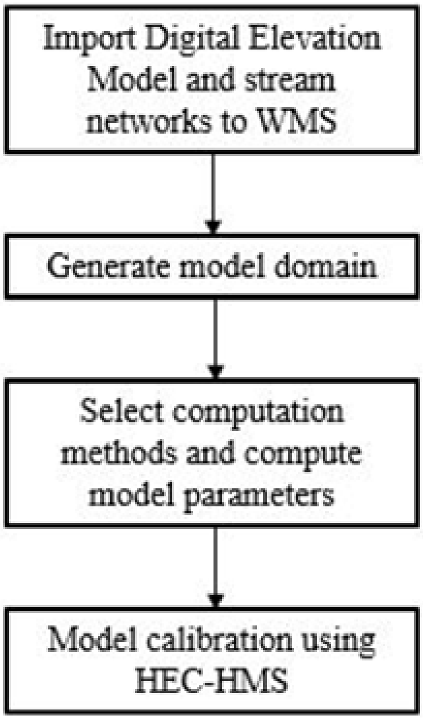


Figure 14. The Rainfall-Runoff Basin Model Development Scheme

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. An illustration of the Bicol HEC-HMS domain is shown in Figure 15.

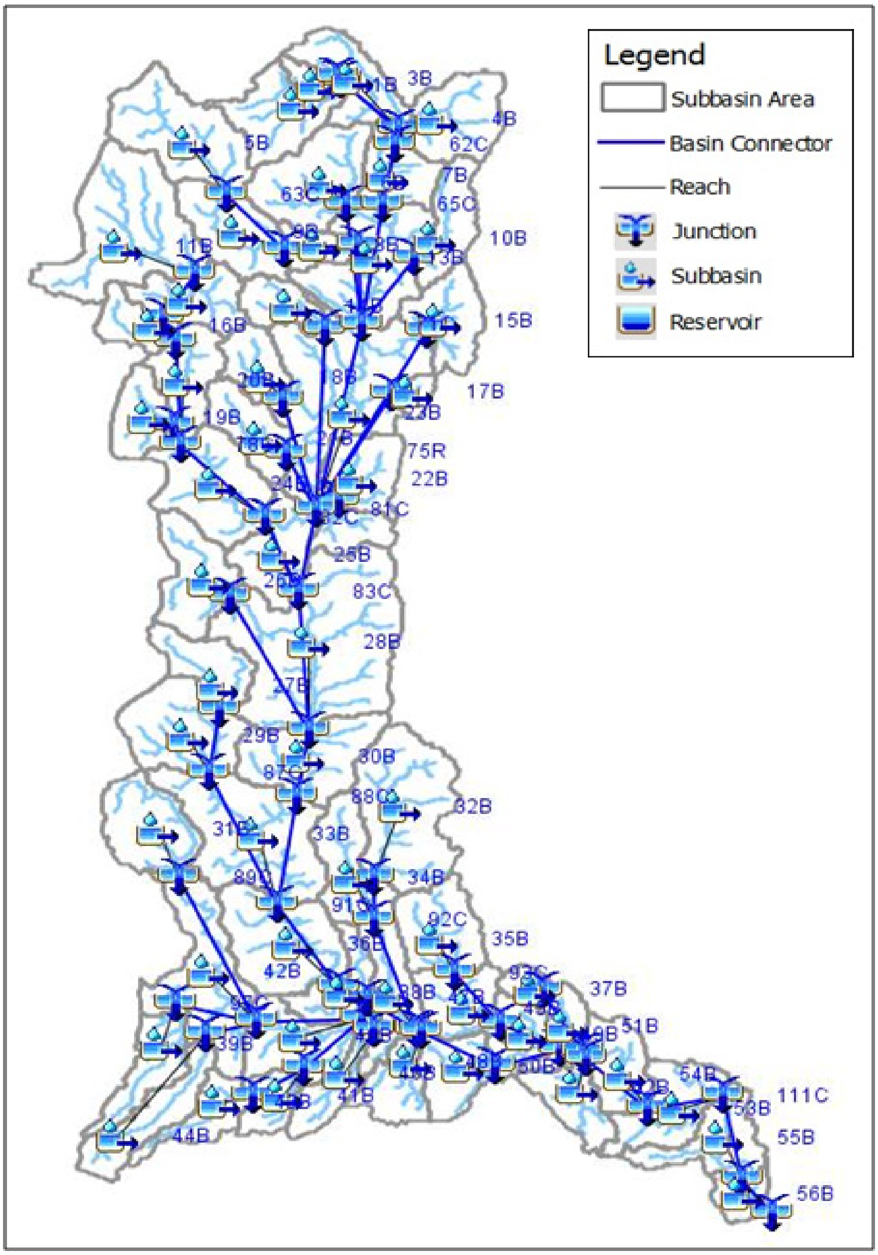


Figure 15. Bicol HEC-HMS Model domain generated by WMS

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.

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 the automatic rain gauges (ARGs) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). This is the ARG located in Brgy. Dinaga, Naga, Bicol.

Total rain from Brgy. Dinaga rain gauge is 138.64mm. It peaked to 10.668mm on 30 November 2013, 08:15 AM. A summary of the data is seen in Table 1. The lag time between the peak rainfall and discharge is 3 hours, 25 minutes.

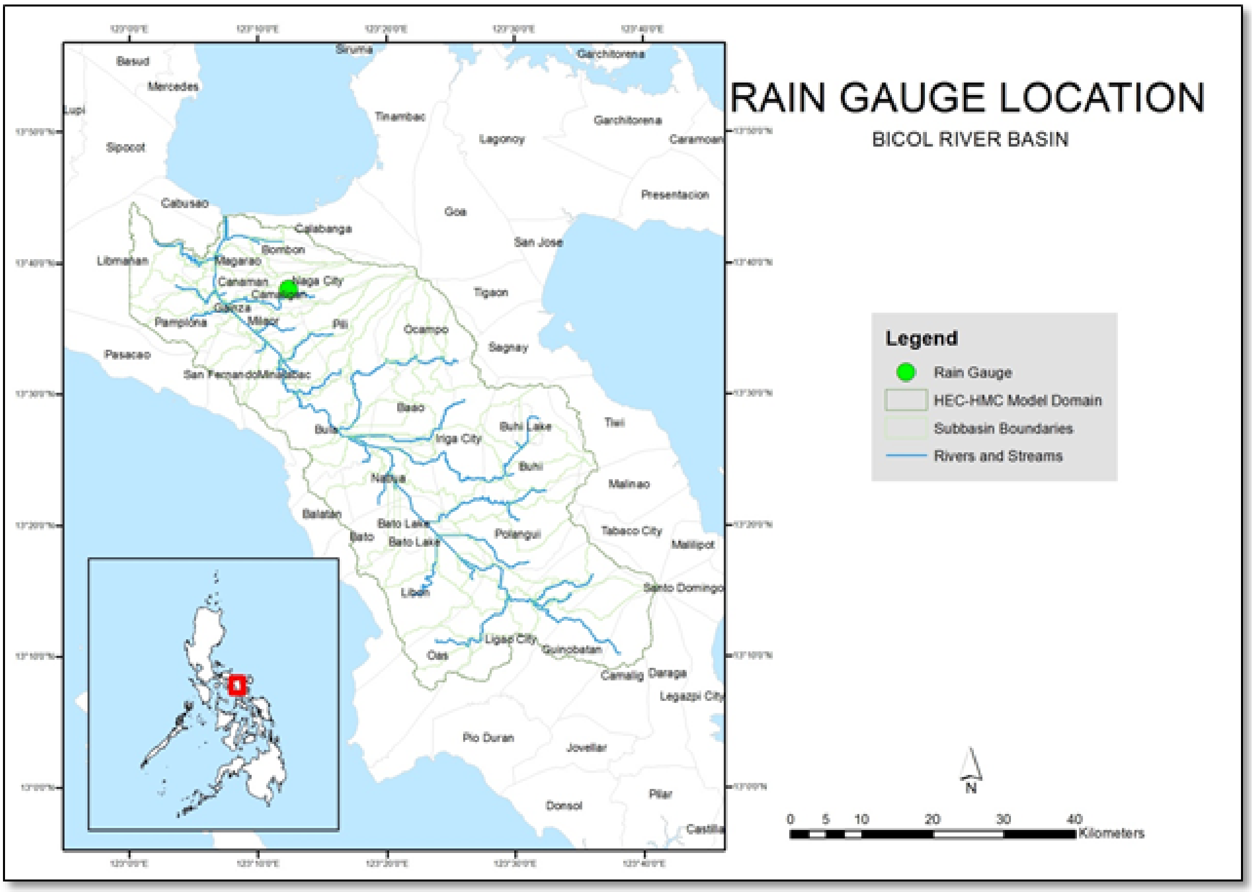


Figure 16. The location map of rain gauges used for the calibration of the Bicol HEC-HMS

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

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

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 Bicol 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 Legazpi 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 Bicol 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.

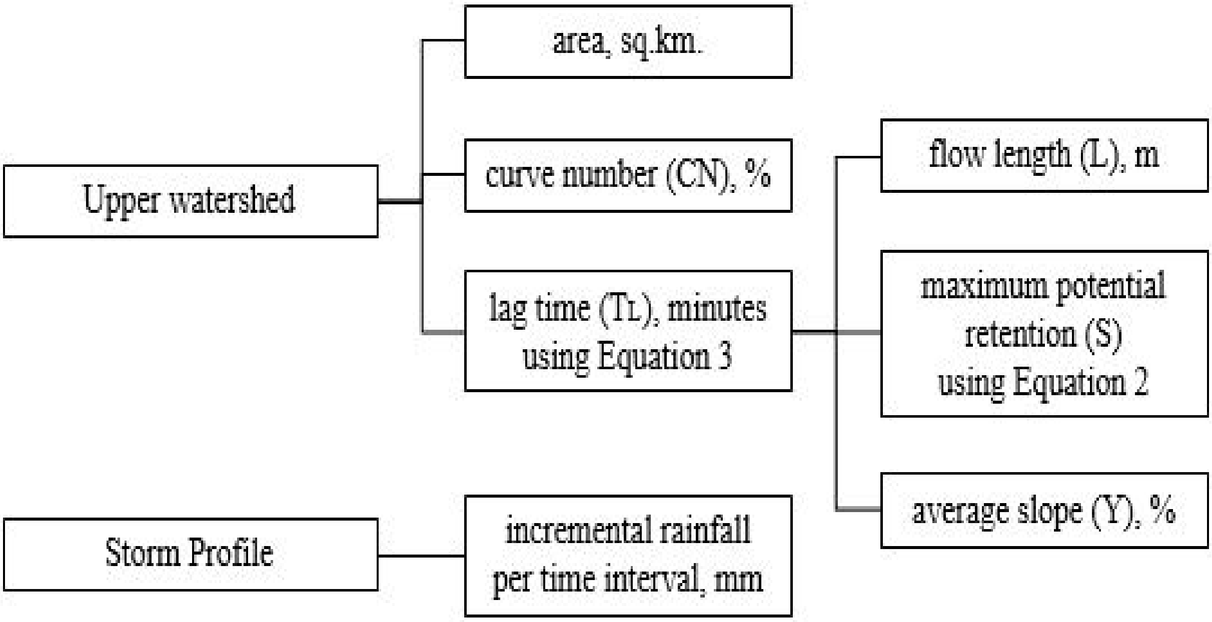


Figure 17. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method.

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 upper watershed for Bicol 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.

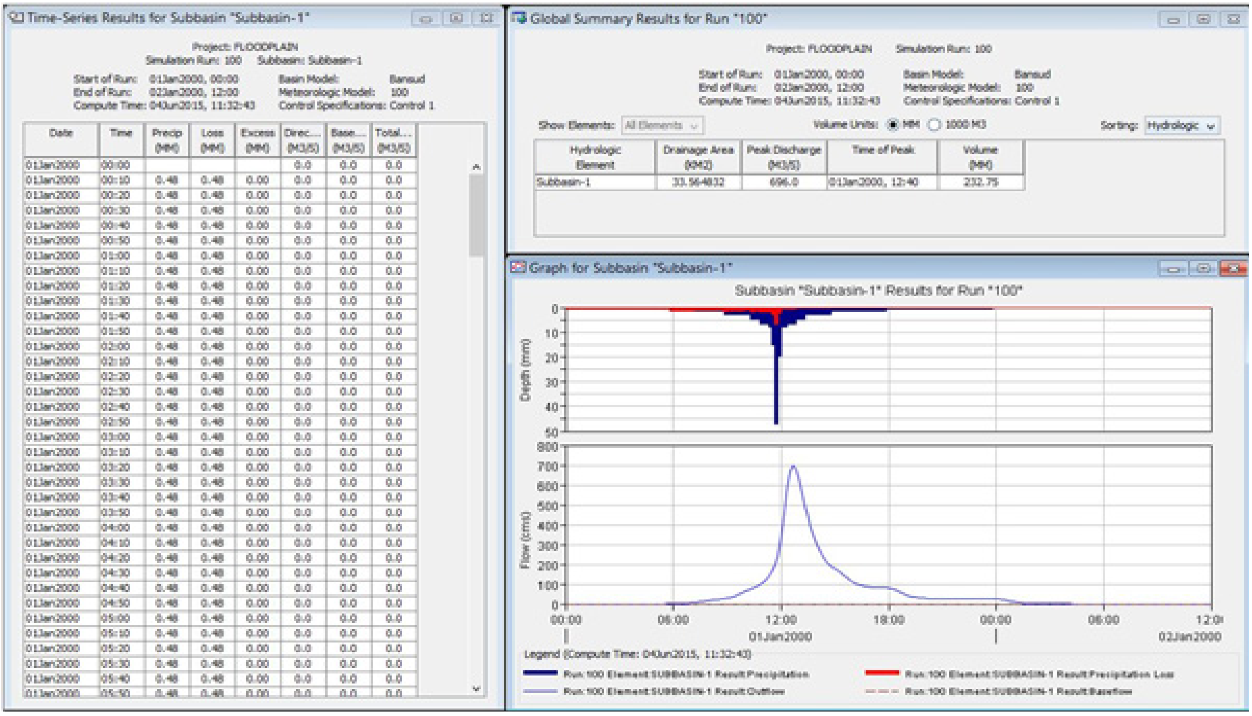
$$T_L = \frac{L^{0.8}(S+1)^{0.7}}{560Y^{0.5}}$$

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.



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

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

Project: FLOODPLAIN   Simulation Run: 100

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

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, 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.

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

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 (10,0020sqm, 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.

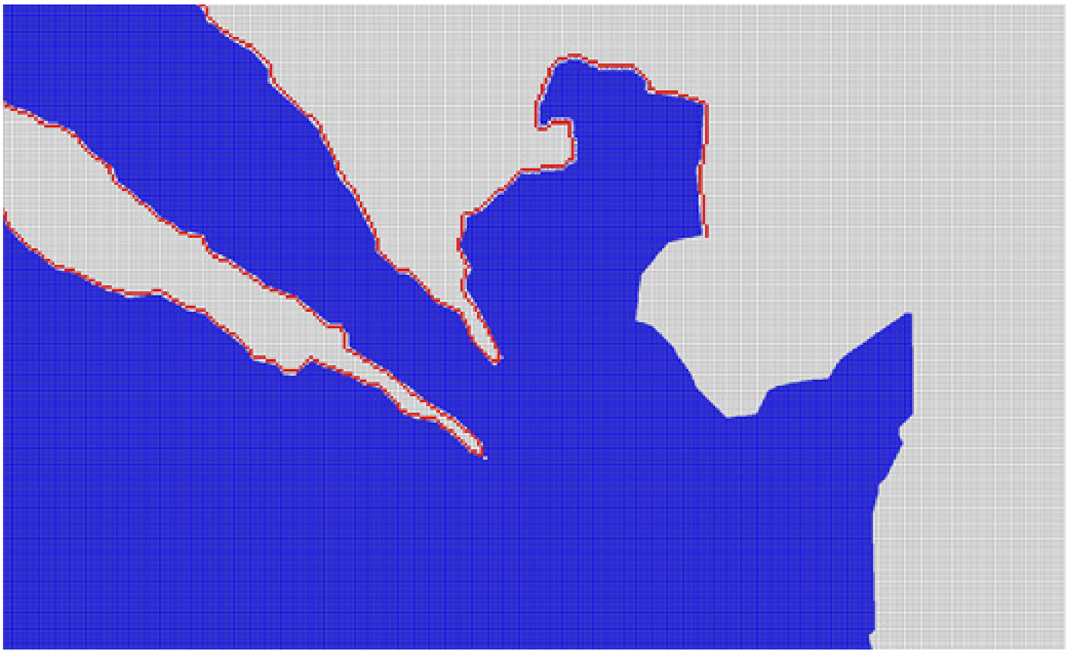


Figure 20. Screenshot showing how boundary grid elements are defined by line

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.

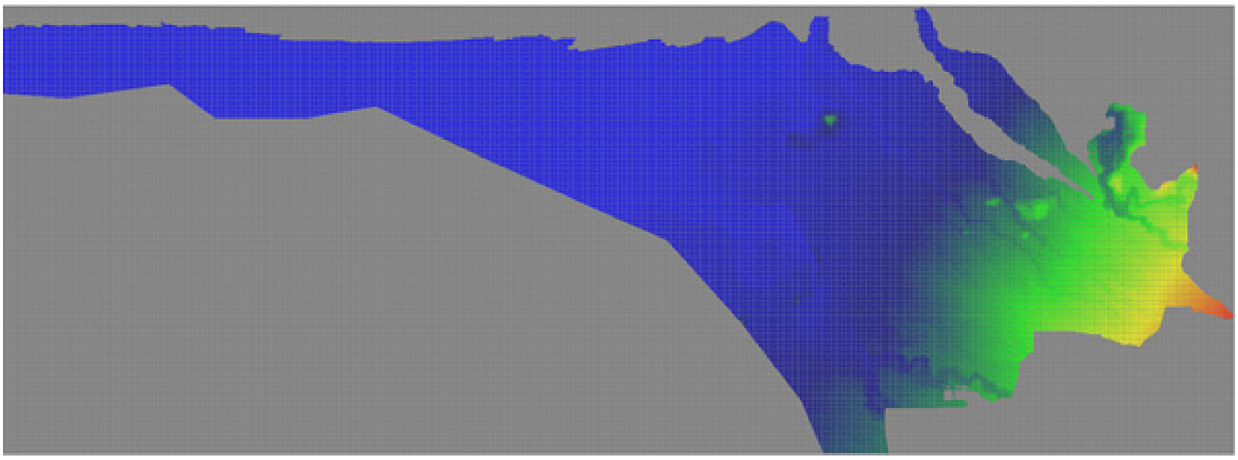


Figure 21. Screenshots of PTS files when loaded into the FLO-2D program

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 Bicol floodplain

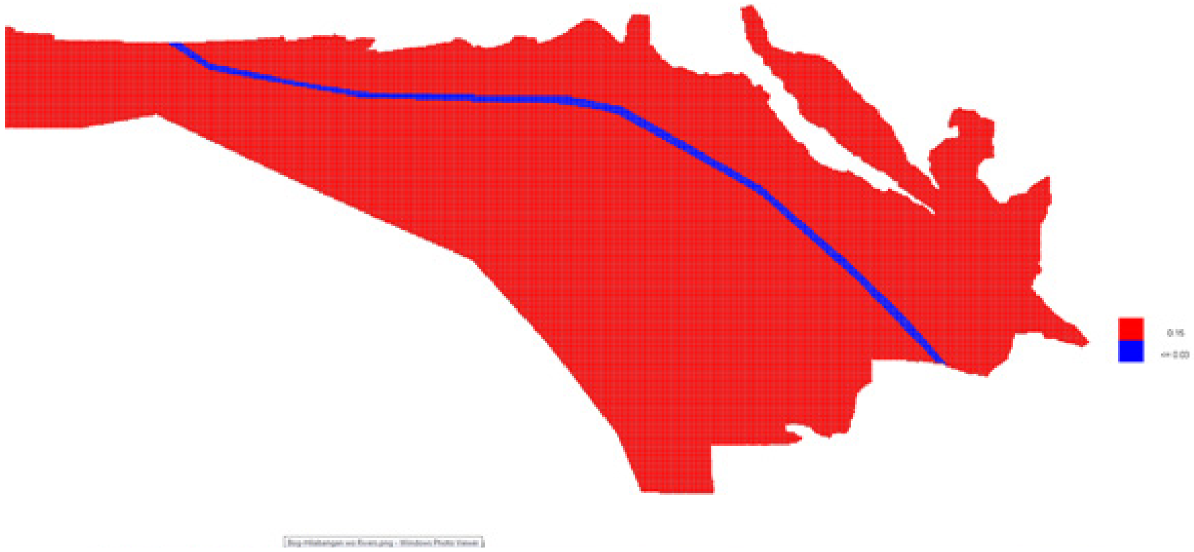


Figure 23. Screenshot of Manning's n-value rendering

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.

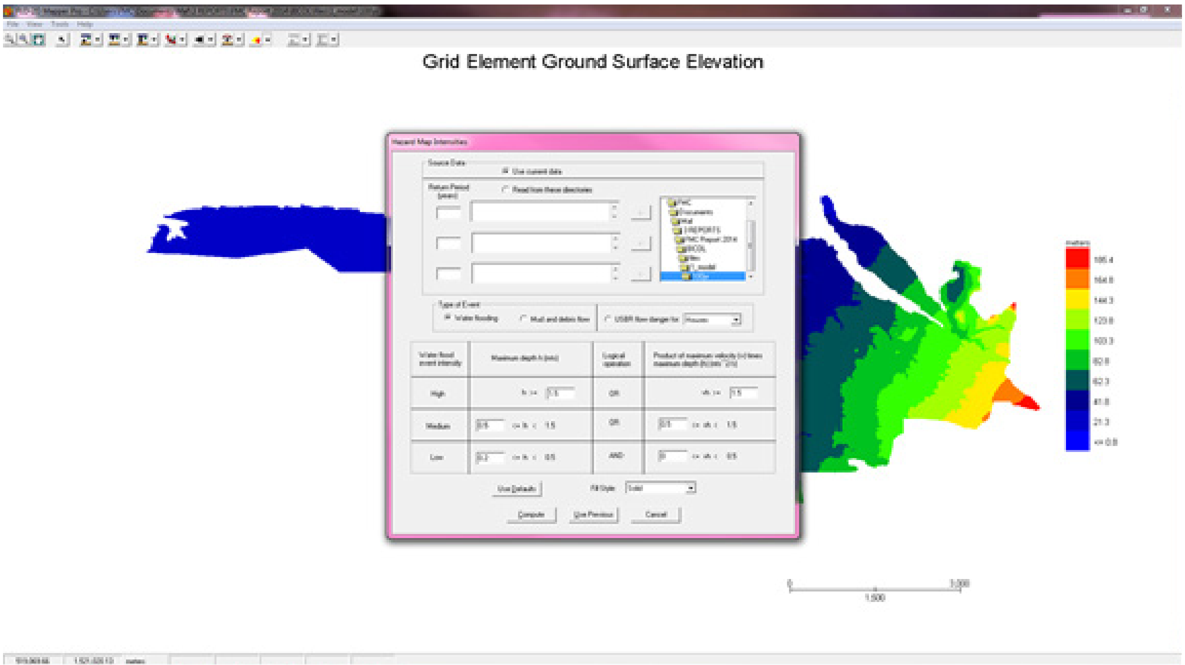


Figure 24. Flo-2D Mapper Pro General Procedure

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.

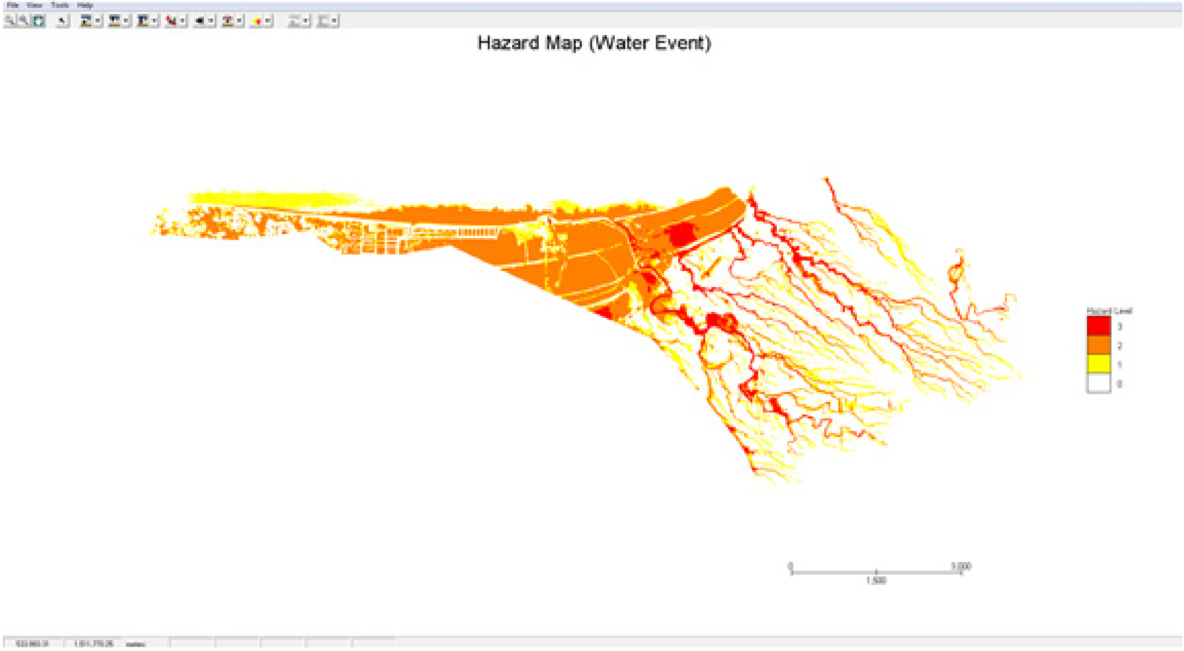


Figure 25. Bicol floodplain Generated Hazard Maps using FLO-2D Mapper

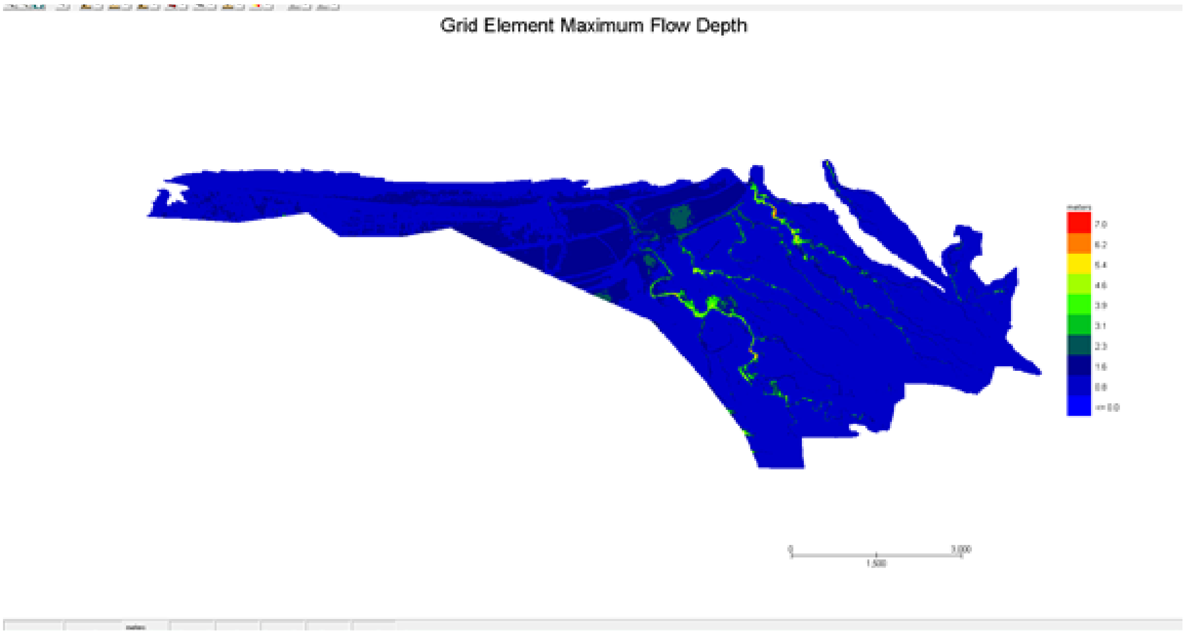
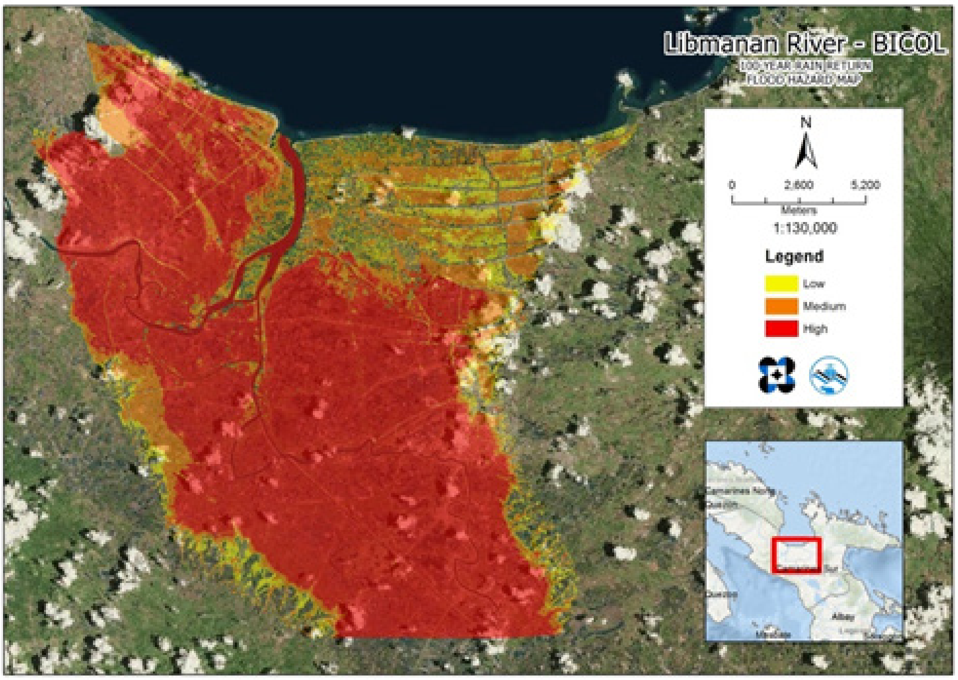


Figure 26. Bicol floodplain generated flow depth map using FLO-2D Mapper

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

After calibrating the Bicol (Padre Garcia) HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 28 shows the comparison between the two discharge data.

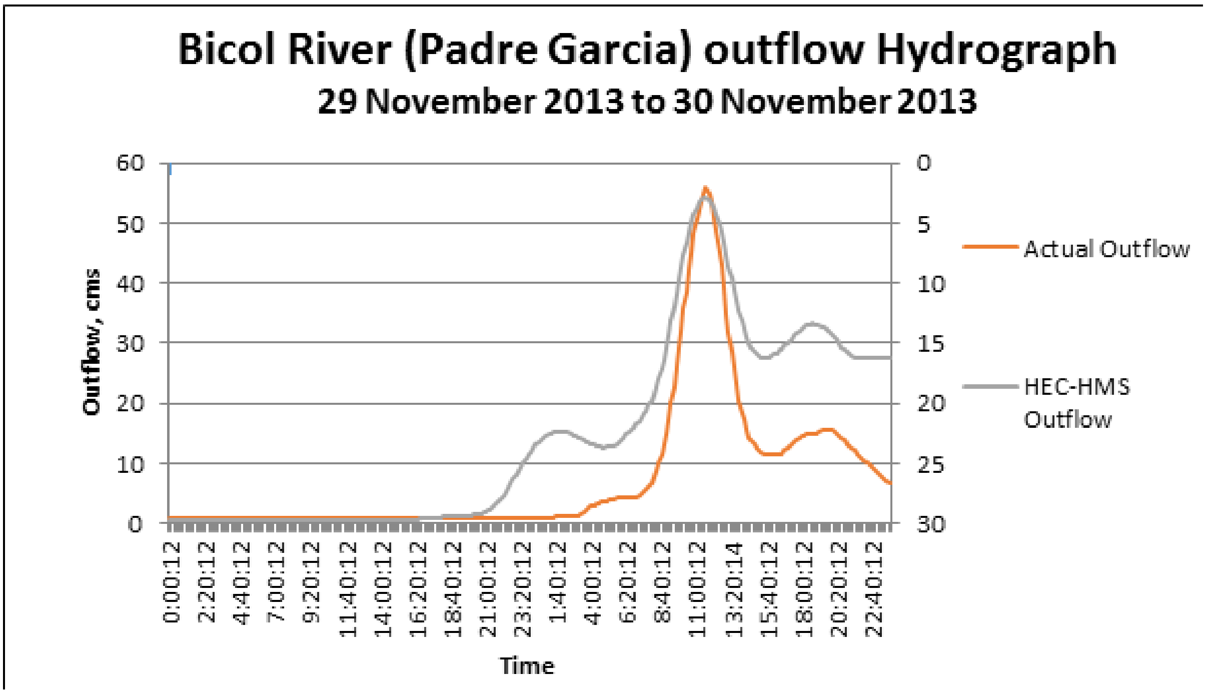


Figure 28. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow.

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 10.

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 0.33.

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 -47.45.

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 0.82.

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

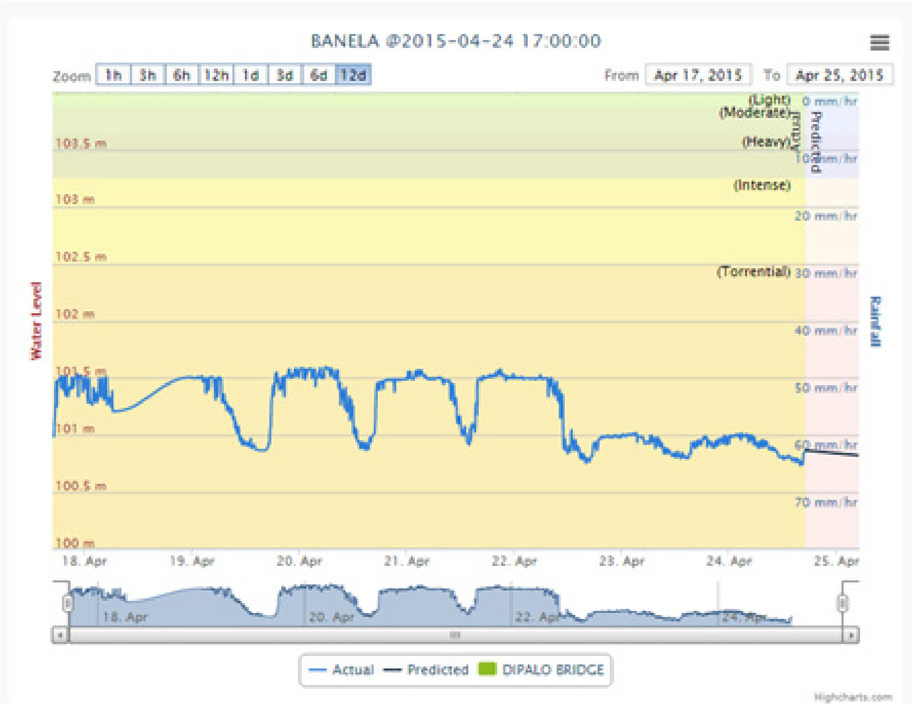


Figure 29. Sample DREAM Water Level Forecast

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 Bicol outflow was computed using the Legazpi Rainfall Intensity-Duration-Frequency curves (RIDF) in five different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. 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 (Figure 30), the peak outflow is 123.5 cms. This occurs after 4 hours and 10 minutes after the peak precipitation of 29.10 mm.

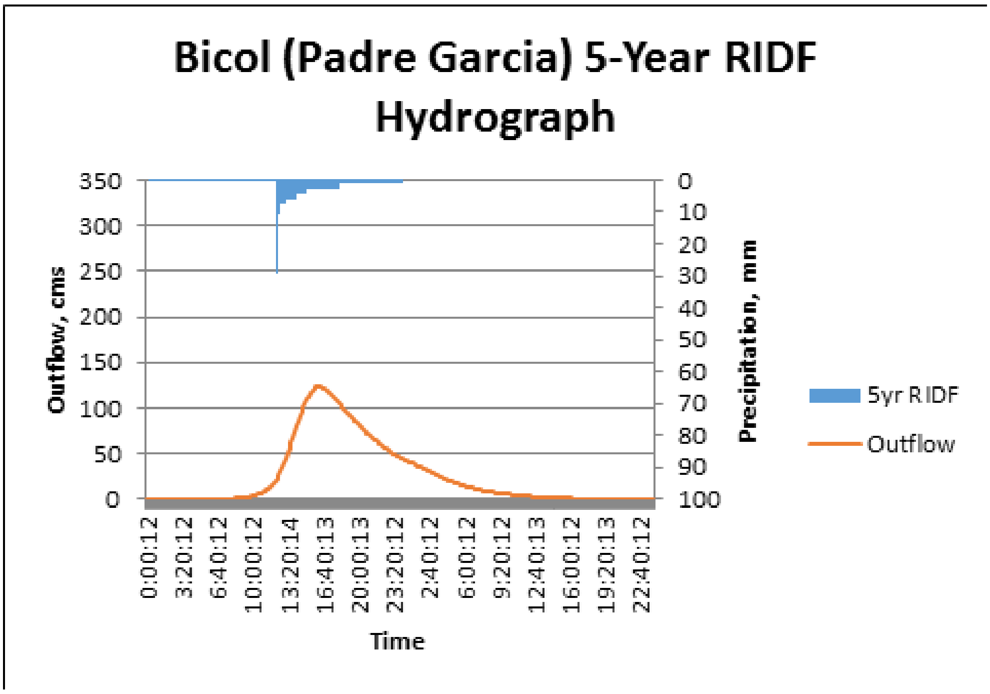


Figure 30. Outflow hydrograph generated using the Legazpi 5-Year RIDF inputted in HEC-HMS

In the 10-year return period graph (Figure 31), the peak outflow is 158.4 cms. This occurs after 4 hours and 10 minutes after the peak precipitation of 34.50 mm.

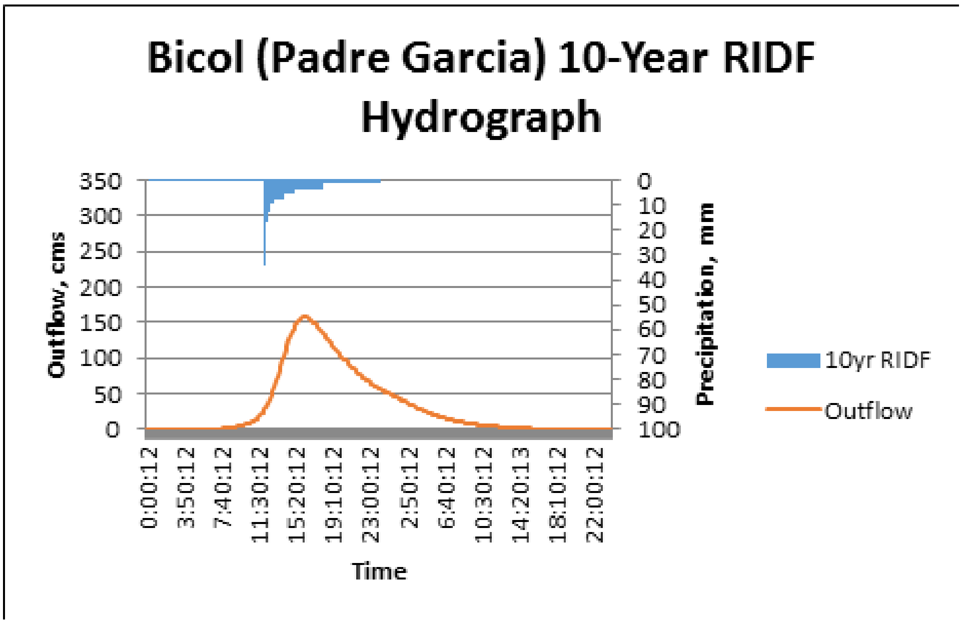


Figure 31. Outflow hydrograph generated using the Legazpi 10-Year RIDF inputted in HEC-

In the 25-year return period graph (Figure 32), the peak outflow is 202.8 cms. This occurs after 4 hours after the peak precipitation of 41.3 mm.

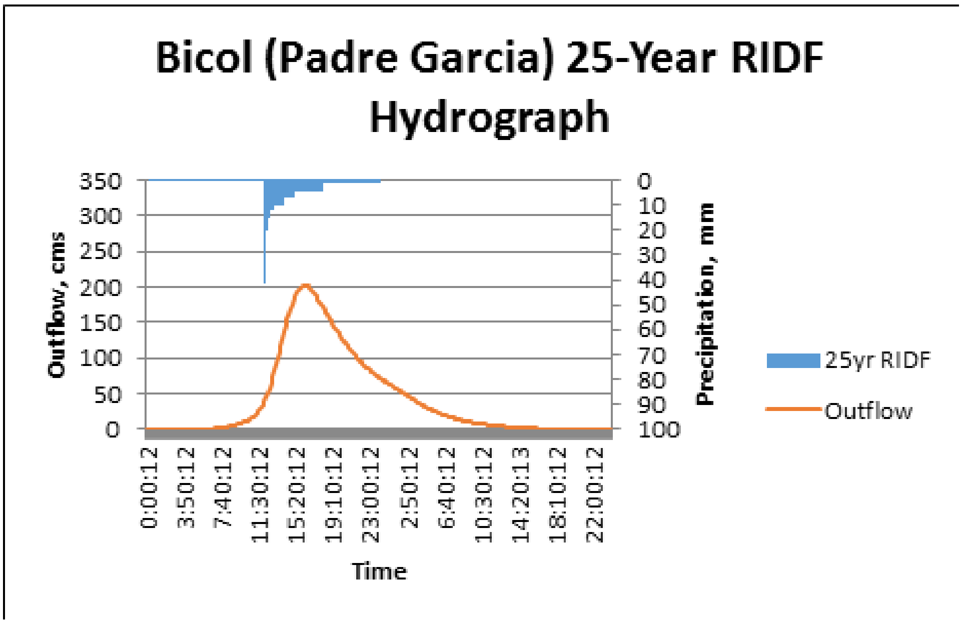


Figure 32. Outflow hydrograph generated using the Legazpi 25-Year RIDF inputted in HEC-HMS

In the 50-year return period graph (Figure 33), the peak outflow is 235.7 cms. This occurs after 4 hours after the peak precipitation of 46.3 mm.

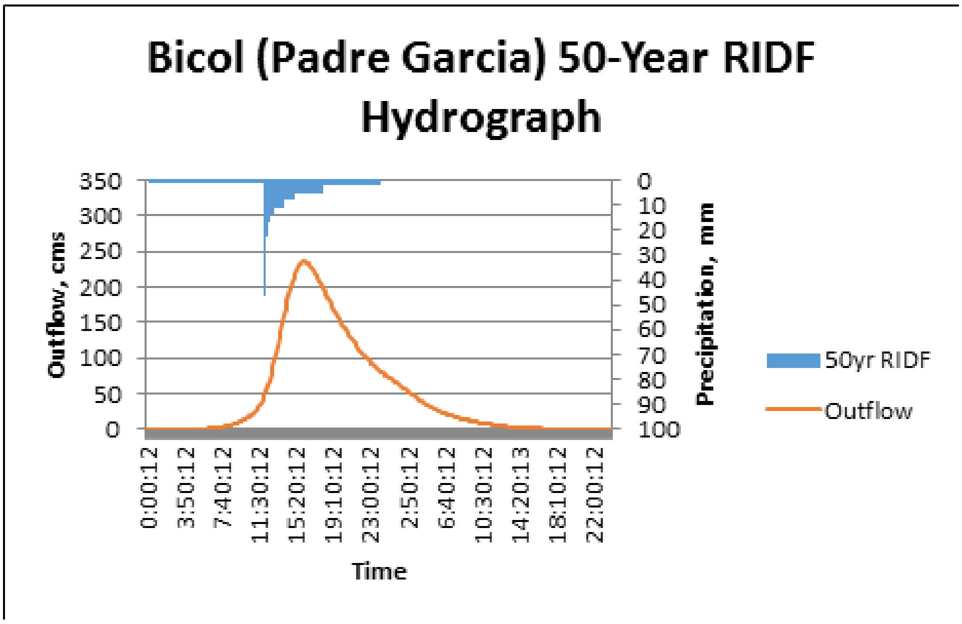


Figure 33. Outflow hydrograph generated using the Legazpi 50-Year RIDF inputted in HEC-HMS

In the 100-year return period graph (Figure 34), the peak outflow is 282.8 cms. This occurs after 5 hours and 50 minutes after the peak precipitation of 51.3 mm.

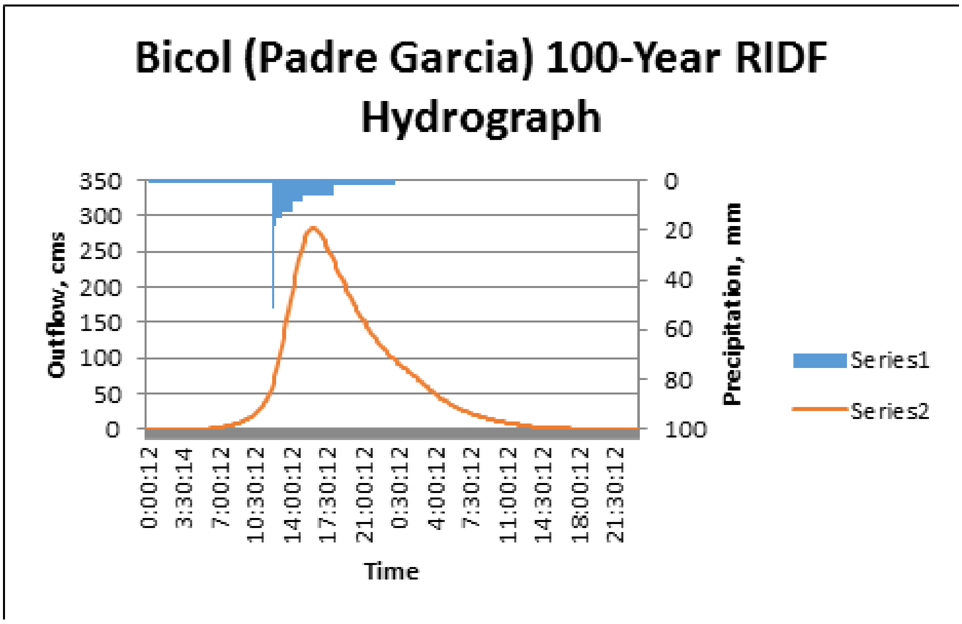


Figure 34. Outflow hydrograph generated using the Legazpi 100-Year RIDF inputted in HEC-HMS

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

Table 2. Summary of peak values of the Bicol outflow using the Legazpi RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	260.5	29.1	123.5	4 hours, 10 minutes
10-Year	316.1	34.5	158.4	4 hours, 10 minutes
25-Year	386.4	41.3	202.8	4 hours
50-Year	490.3	46.3	235.7	4 hours
100-Year	562.3	51.3	282.8	4 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 Figures 35 and 36 respectively.

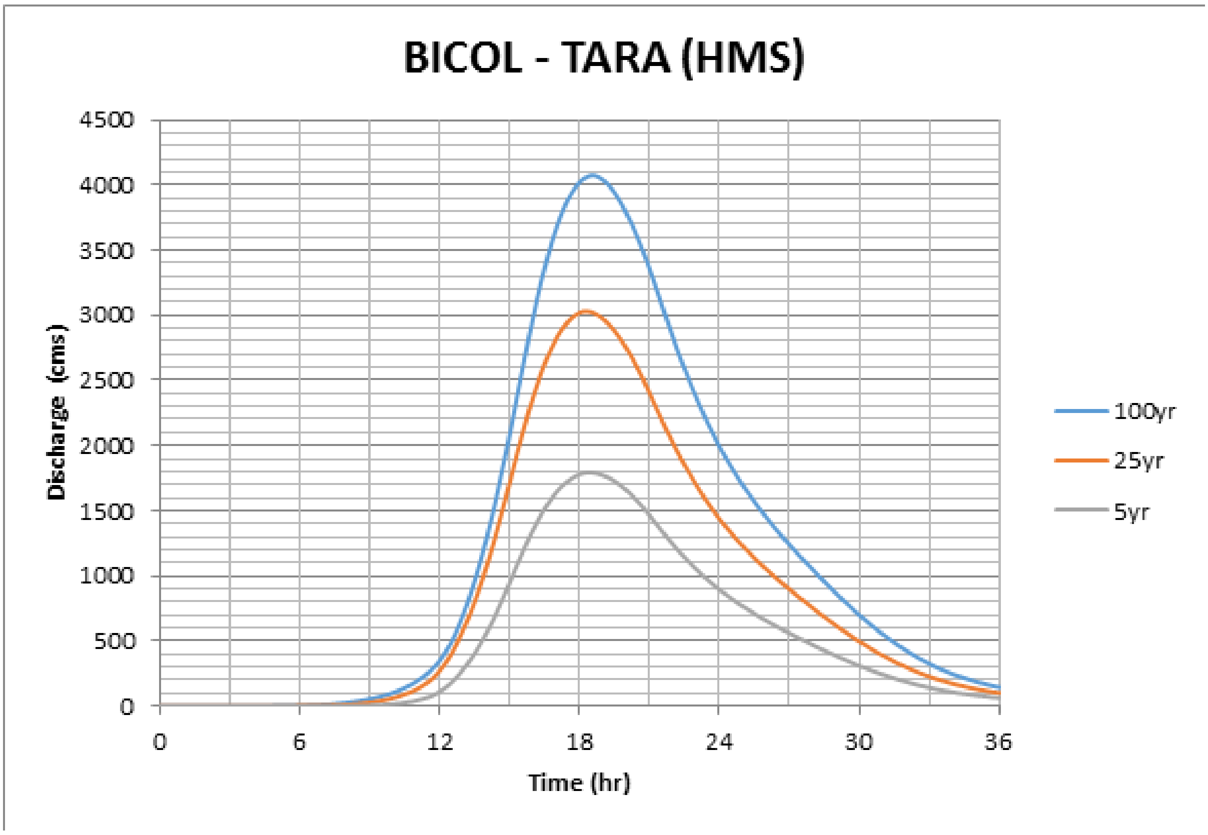


Figure 35. Outflow hydrograph generated for Tara, Bicol using the Daet 5-, 25-, and 100-year Rainfall Intensity Duration Frequency (RIDF) in HEC-HMS

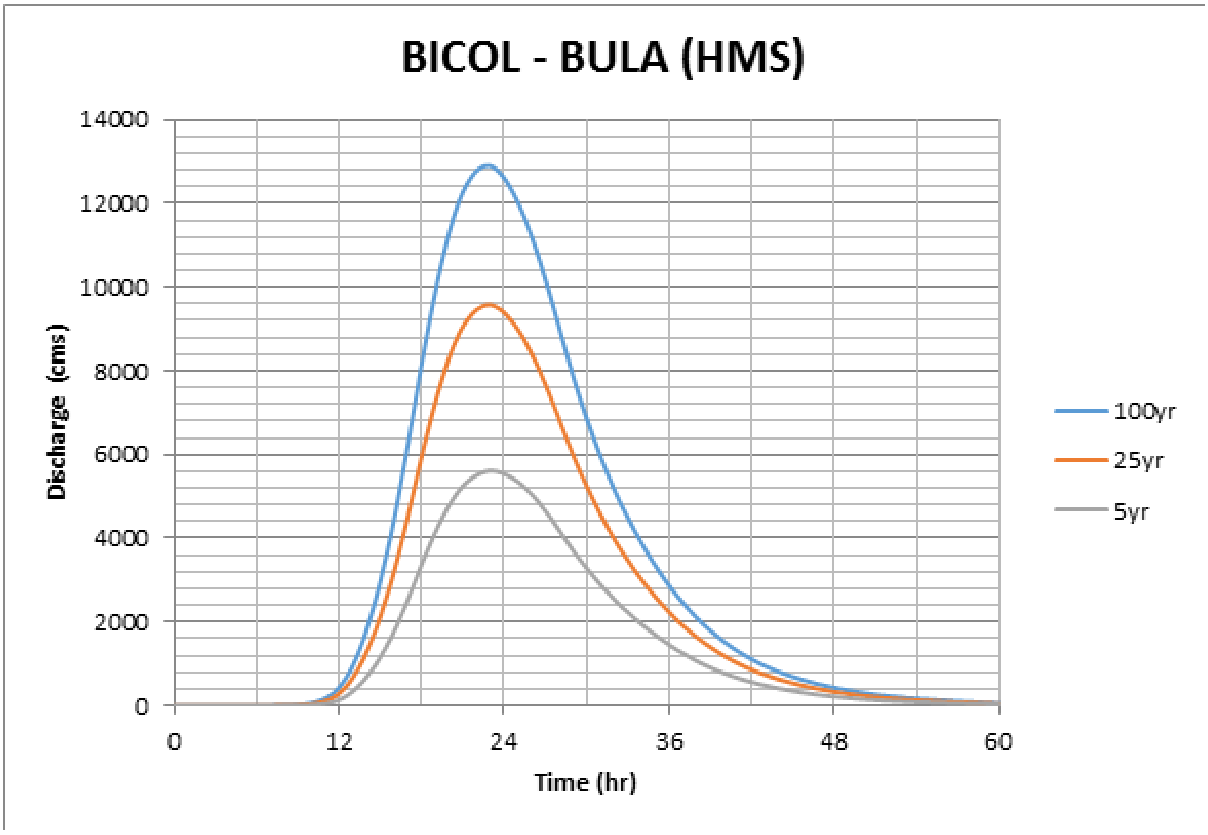


Figure 36. Outflow hydrograph generated for Bula, Bicol using the Legazpi City 5-, 25-, and 100-year Rainfall Intensity Duration Frequency (RIDF) in HEC-HMS

The peak discharge values using Dr. Horritt's recommended hydrological method are summarized in Tables 3 and 4 respectively.

Table 3. Summary of Tara River discharge using the recommended hydrological method by Dr. Horritt

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	1,792.8	18 hours, 20 minutes
25-Year	3,031.4	18 hours, 20 minutes
100-Year	4,075.4	18 hours, 30 minutes

Table 4. Summary of Bula River discharge using the recommended hydrological method by Dr. Horritt

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	5,615.7	23 hours
25-Year	9,577.1	23 hours
100-Year	12,906.9	22 hours, 50 minutes

The comparison of discharge values obtained from HEC-HMS, QMED, and from the bankful discharge method, Qbankful, is shown in Table 5. Using values from the DTM of Bicol, 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
Tara	2,794.73	1,577.66	Pass
Bula	3,934.23	4,941.82	Pass

The value from the HEC-HMS discharge estimates were able to satisfy the condition for validating the computed discharge using the bankful method. The computed values were used for the discharge points that did not have actual discharge data. The calibrated discharge data was also used for an area in the floodplain that was modeled. 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 Bicol river basin.

Results and Discussion

Flood Hazard Maps and Flow Depth Maps

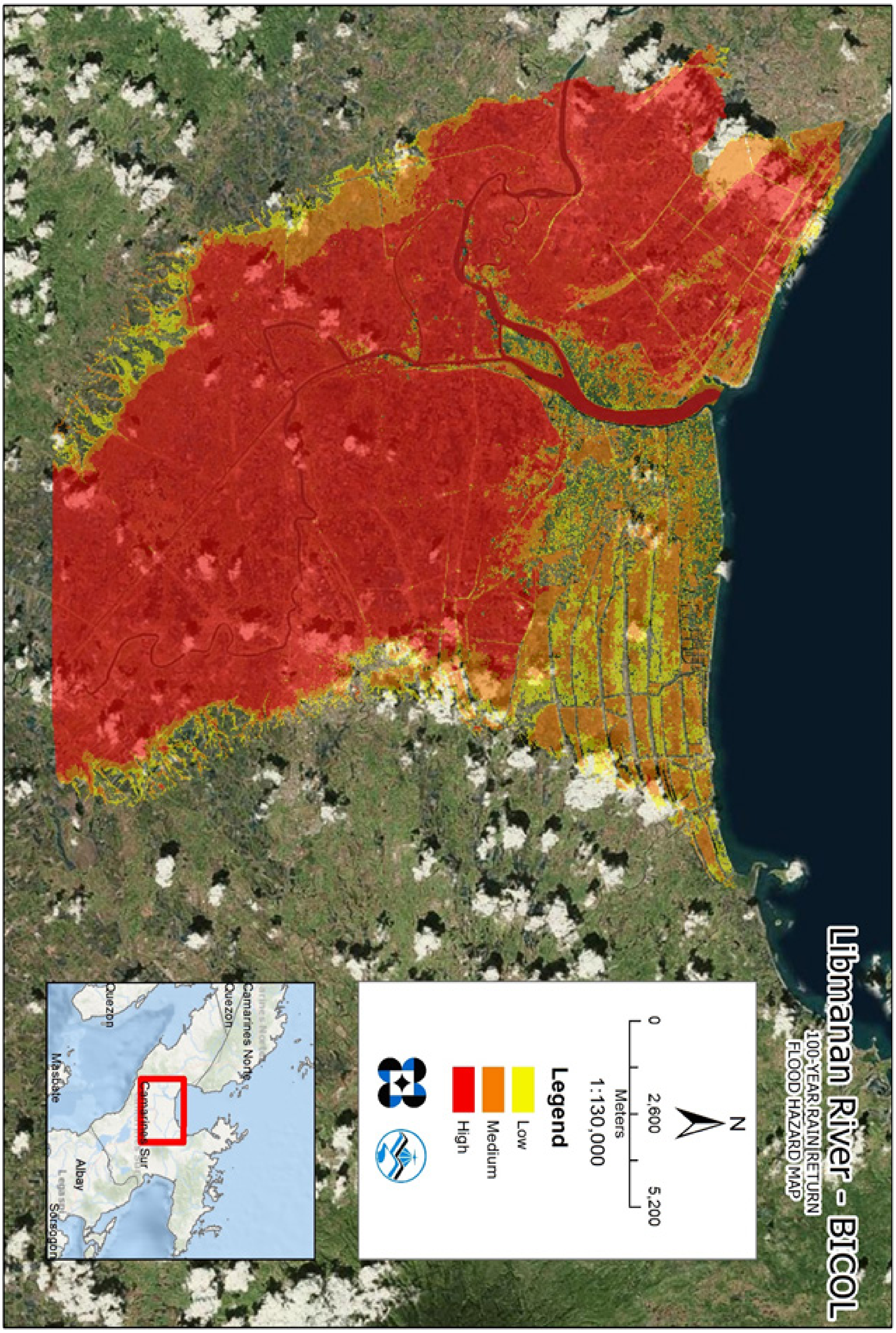


Figure 37. 100-year Flood Hazard Map for Bicol River Basin

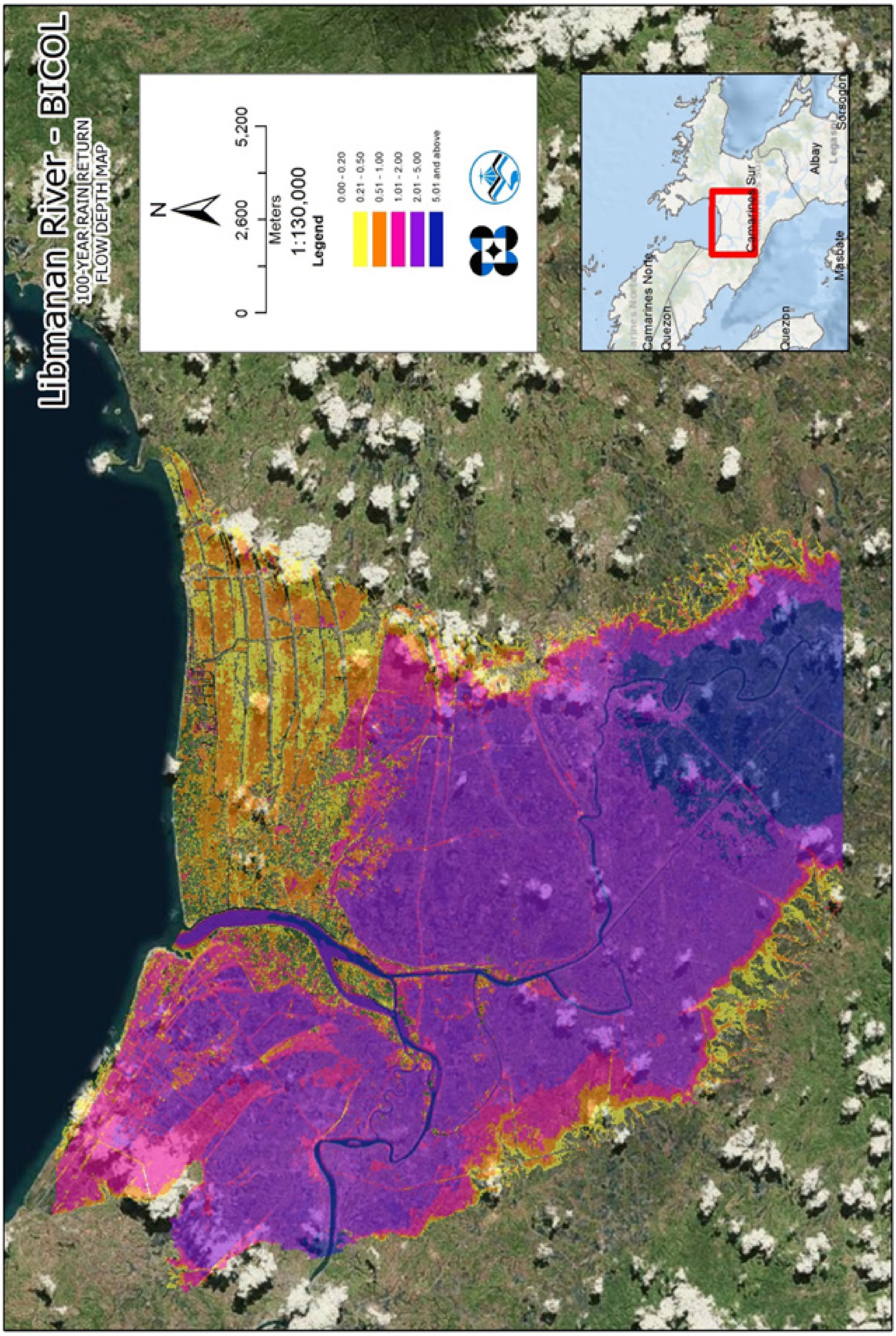


Figure 38. 100-year Flow Depth Map for Bicol River Basin

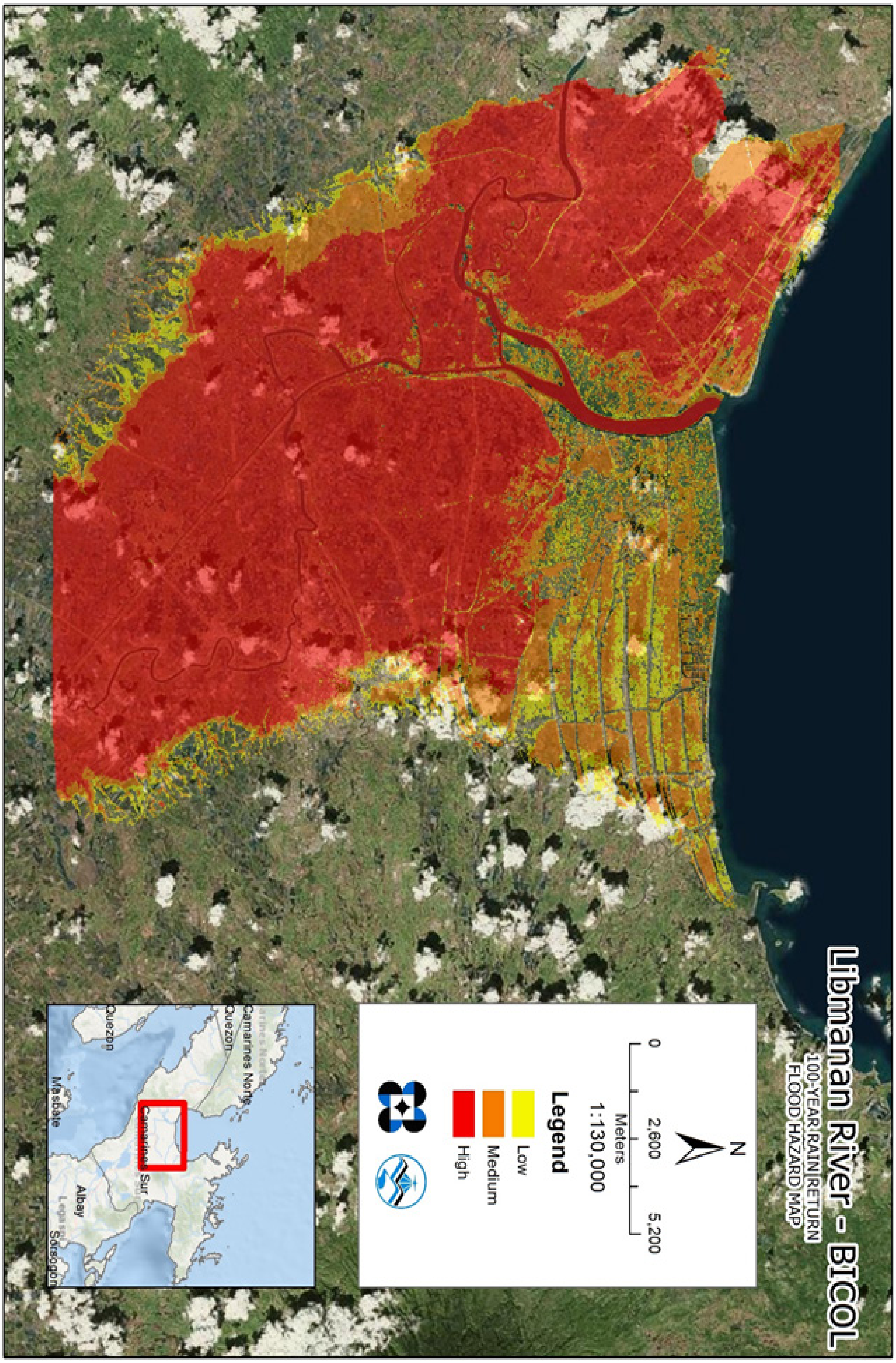


Figure 39. 25-year Flood Hazard Map for Bicol River Basin

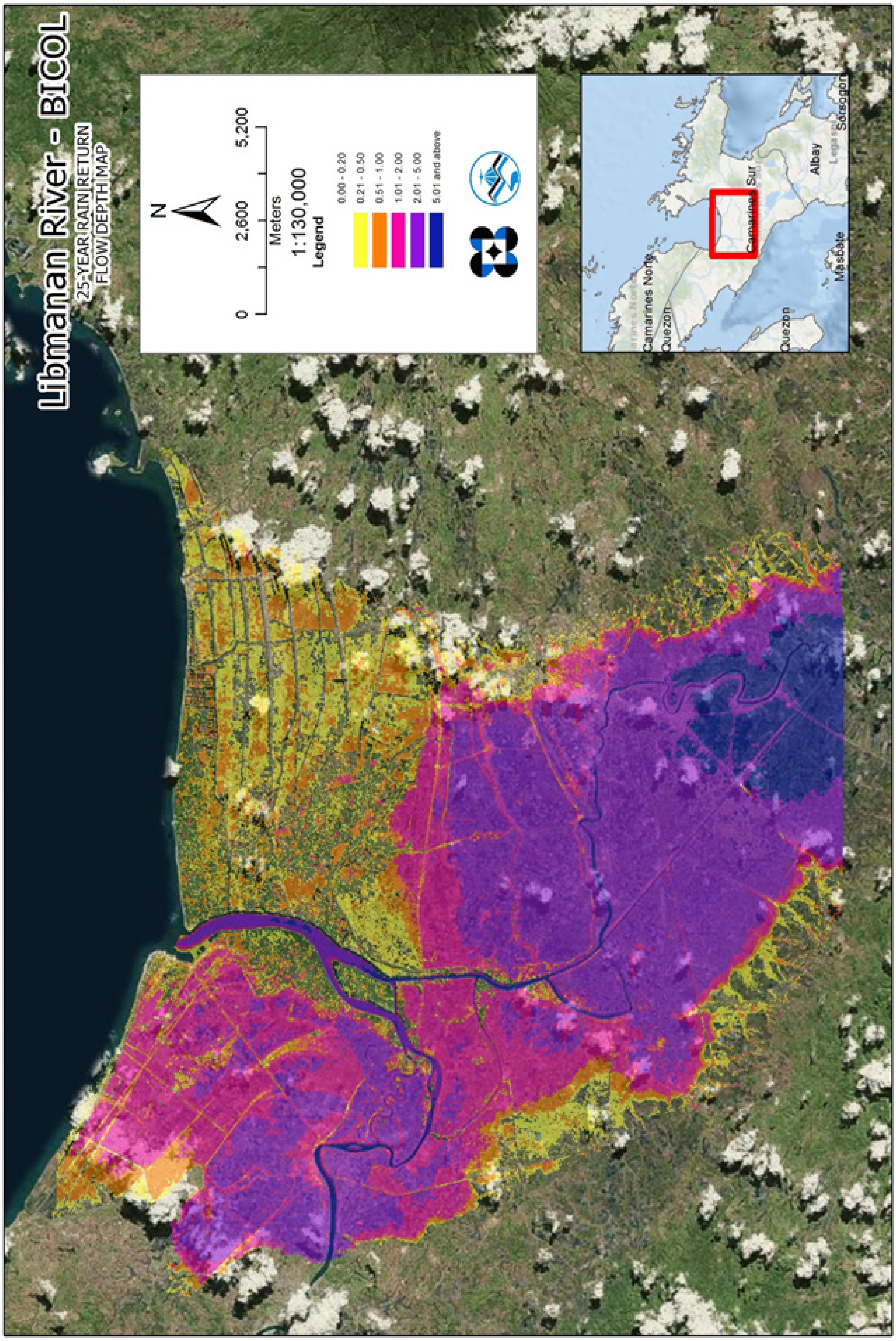


Figure 40. 25-year Flow Depth Map for Bicol River Basin

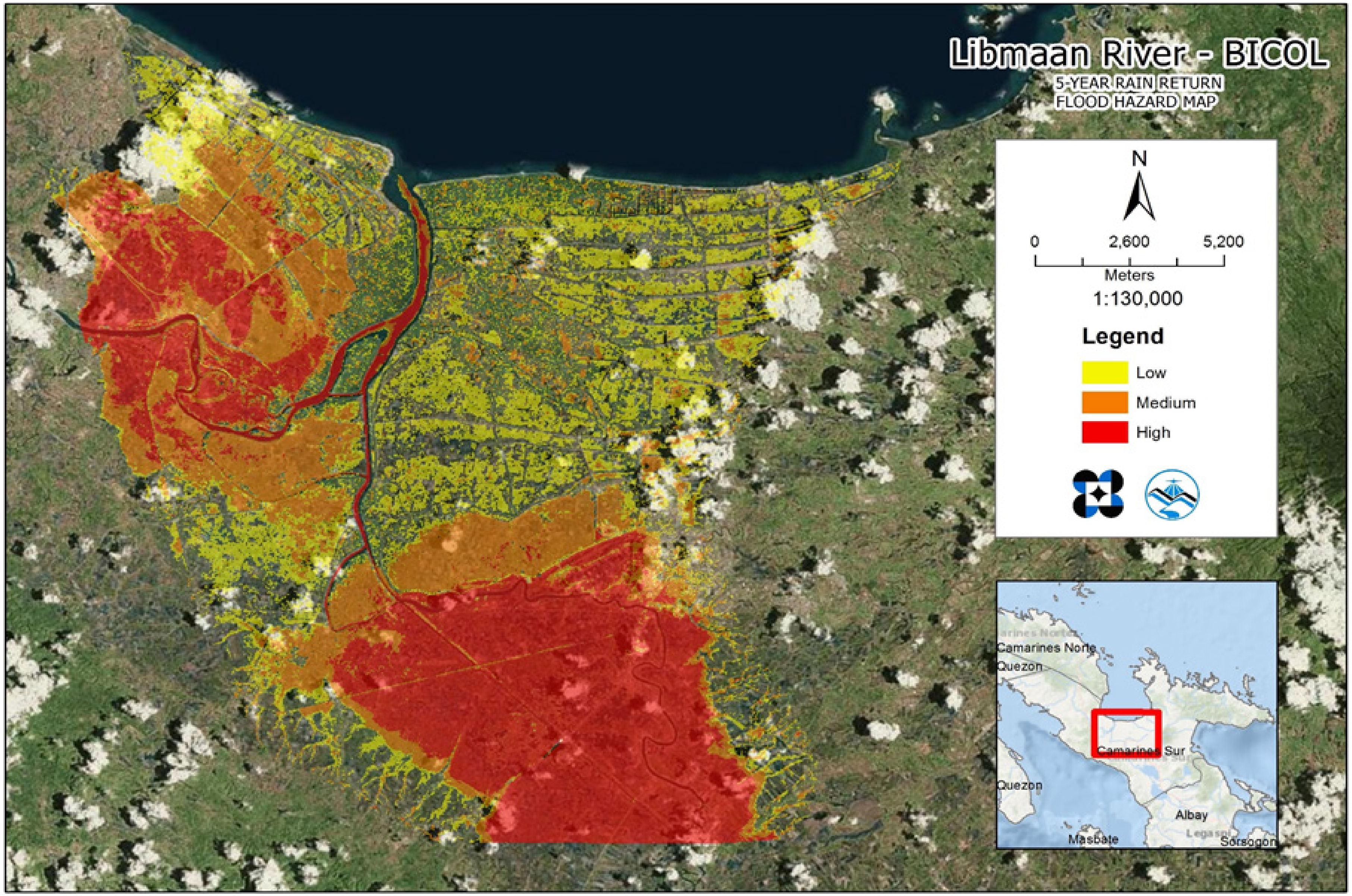


Figure 41. 5-year Flood Hazard Map for Bicol River Basin

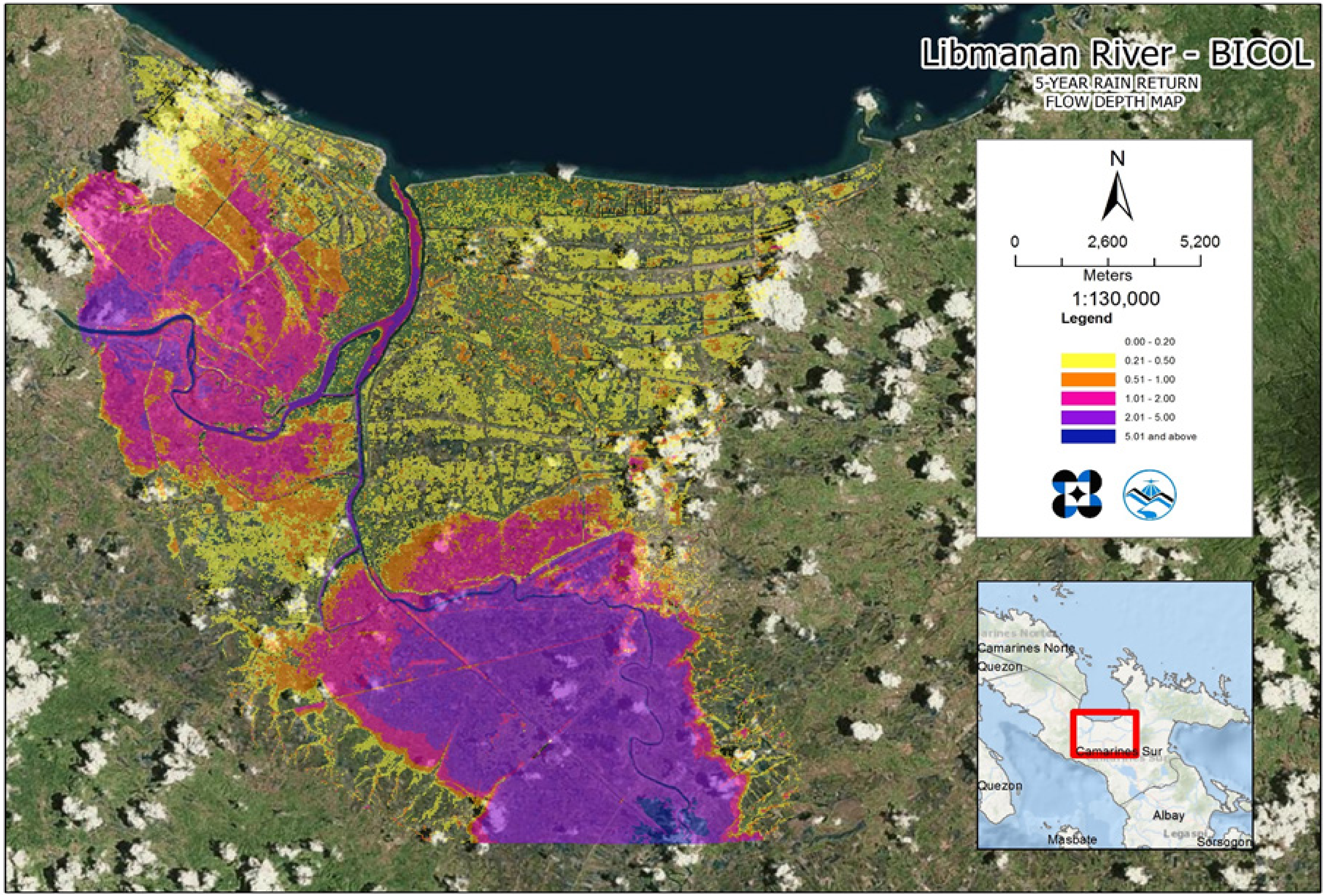


Figure 42. 5-year Flood Hazard Map for Bicol River Basin

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Appendix

Appendix A. Bicol 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
43B	2.0110	96.192	0.0	16.496	13.456	Discharge	0.00	1	Ratio to Peak	0.5
44B	7.3901	87.3	0.0	7.032	5.7364	Discharge	0.00	1	Ratio to Peak	0.5
45B	2.9430	94.524	0.0	4	3.2632	Discharge	0.00	1	Ratio to Peak	0.5
46B	3.1484	94.164	0.0	14.576	11.8904	Discharge	0.00	1	Ratio to Peak	0.5
47B	5.2261	90.672	0.0	6.144	5.0112	Discharge	0.00	1	Ratio to Peak	0.5
48B	0.51313	98	0.0	4.2	3.4268	Discharge	0.00	1	Ratio to Peak	0.5
49B	3.1484	94.164	0.0	4.872	3.9752	Discharge	0.00	1	Ratio to Peak	0.5
50B	10.006	83.544	0.0	21.808	17.7888	Discharge	0.00	1	Ratio to Peak	0.5
51B	4.4355	97.3	0.0	4.4917	2.8802	Discharge	0.29590	1	Ratio to Peak	0.5
52B	4.6900	91.548	0.0	3.296	2.6872	Discharge	0.00	1	Ratio to Peak	0.5
53B	9.3240	89.732	0.0	4.8566	2.5911	Discharge	0.40410	1	Ratio to Peak	0.5

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
54B	1.4569	97.212	0.0	4.064	3.3136	Discharge	0.00	1	Ratio to Peak	0.5
55B	6.7729	88.236	0.0	10.256	8.3664	Discharge	0.00	1	Ratio to Peak	0.5
56B	7.2147	87.564	0.0	8.432	6.8804	Discharge	0.00	1	Ratio to Peak	0.5
57B	2.6849	94.98	0.0	2.568	2.0948	Discharge	0.00	1	Ratio to Peak	0.5
58B	9.6935	83.976	0.0	4.544	3.7048	Discharge	0.00	1	Ratio to Peak	0.5
59B	7.9963	86.4	0.0	4.896	3.9944	Discharge	0.00	1	Ratio to Peak	0.5
60B	1.1746	97.74	0.0	2.544	2.074	Discharge	0.00	1	Ratio to Peak	0.5
61B	8.0535	86.316	0.0	3.744	3.0556	Discharge	0.00	1	Ratio to Peak	0.5
62B	14.348	77.976	0.0	9.376	7.6456	Discharge	0.00	1	Ratio to Peak	0.5
63B	7.3901	87.3	0.0	3.392	2.7692	Discharge	0.00	1	Ratio to Peak	0.5
64B	28.313	64.212	0.0	8.136	6.6344	Discharge	0.00	1	Ratio to Peak	0.5

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
65B	10.314	83.124	0.0	3.272	2.6696	Discharge	0.00	1	Ratio to Peak	0.5
66B	6.8356	88.14	0.0	3.608	2.9416	Discharge	0.00	1	Ratio to Peak	0.5
67B	14.489	77.808	0.0	8.624	7.0348	Discharge	0.00	1	Ratio to Peak	0.5
68B	3.7462	93.132	0.0	5.72	4.6684	Discharge	0.00	1	Ratio to Peak	0.5
69B	10.059	83.472	0.0	6.76	5.5156	Discharge	0.00	1	Ratio to Peak	0.5
70B	10.252	83.208	0.0	3.008	2.4516	Discharge	0.00	1	Ratio to Peak	0.5
71B	0.51313	99	0.0	4.152	3.3888	Discharge	0.00	1	Ratio to Peak	0.5
72B	10.901	82.332	0.0	5.2	4.2416	Discharge	0.00	1	Ratio to Peak	0.5
73B	12.140	80.712	0.0	4.616	3.7676	Discharge	0.00	1	Ratio to Peak	0.5
74B	5.5393	90.168	0.0	4.24	3.456	Discharge	0.00	1	Ratio to Peak	0.5
75B	5.3376	90.492	0.0	4.008	3.2672	Discharge	0.00	1	Ratio to Peak	0.5

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
76B	14.059	78.324	0.0	2.376	1.9412	Discharge	0.00	1	Ratio to Peak	0.5
77B	4.0075	92.688	0.0	3.648	2.9764	Discharge	0.00	1	Ratio to Peak	0.5
78B	10.508	82.86	0.0	1.992	1.6244	Discharge	0.00	1	Ratio to Peak	0.5
79B	7.0008	87.888	0.0	5.552	4.5264	Discharge	0.00	1	Ratio to Peak	0.5
80B	3.4179	93.696	0.0	2	1.6312	Discharge	0.00	1	Ratio to Peak	0.5
81B	6.3223	88.932	0.0	3.512	2.8648	Discharge	0.00	1	Ratio to Peak	0.5
82B	2.8136	94.752	0.0	4.024	3.2808	Discharge	0.00	1	Ratio to Peak	0.5
83B	1.4634	97.2	0.0	1.24	1.01	Discharge	0.00	1	Ratio to Peak	0.5

Appendix B. Bicol Bridge, Bicol 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	29501.722	0.002630	0.0400	Trapezoid	60	1.000
101R	Automatic Fixed Interval	32694.043	0.001220	0.0400	Trapezoid	60	1.000
102R	Automatic Fixed Interval	21458.998	0.014880	0.0400	Trapezoid	60	1.000
103R	Automatic Fixed Interval	44586.930	0.002880	0.0400	Trapezoid	60	1.000
104R	Automatic Fixed Interval	33427.312	0.003070	0.0400	Trapezoid	60	1.000
105R	Automatic Fixed Interval	33883.892	0.001340	0.0400	Trapezoid	60	1.000
106R	Automatic Fixed Interval	49620.812	0.002250	0.0400	Trapezoid	60	1.000
107R	Automatic Fixed Interval	28059.670	0.004590	0.0400	Trapezoid	60	1.000
108R	Automatic Fixed Interval	42578.597	0.000470	0.0400	Trapezoid	60	1.000
109R	Automatic Fixed Interval	28358.548	0.000530	0.0400	Trapezoid	60	1.000
110R	Automatic Fixed Interval	54680.442	0.000440	0.0400	Trapezoid	60	1.000
111R	Automatic Fixed Interval	40795.907	0.000470	0.0400	Trapezoid	60	1.000
112R	Automatic Fixed Interval	58145.483	0.000470	0.0400	Trapezoid	60	1.000
113R	Automatic Fixed Interval	56441.083	0.000470	0.0400	Trapezoid	60	1.000
114R	Automatic Fixed Interval	14661.033	0.002600	0.0400	Trapezoid	60	1.000
76R	Automatic Fixed Interval	42081.223	0.000470	0.0400	Trapezoid	60	1.000
77R	Automatic Fixed Interval	44868.393	0.000470	0.0400	Trapezoid	60	1.000
78R	Automatic Fixed Interval	18728.735	0.000490	0.0400	Trapezoid	60	1.000
79R	Automatic Fixed Interval	36559.311	0.000470	0.0400	Trapezoid	60	1.000
80R	Automatic Fixed Interval	41211.645	0.000650	0.0400	Trapezoid	60	1.000
81R	Automatic Fixed Interval	42777.511	0.000470	0.0400	Trapezoid	60	1.000
82R	Automatic Fixed Interval	16128.526	0.001660	0.0400	Trapezoid	60	1.000
83R	Automatic Fixed Interval	21859.679	0.002210	0.0400	Trapezoid	60	1.000
84R	Automatic Fixed Interval	13009.182	0.004420	0.0022799	Trapezoid	60	1.000
85R	Automatic Fixed Interval	26719.578	0.000470	0.0400	Trapezoid	60	1.000
86R	Automatic Fixed Interval	21571.292	0.000470	0.0400	Trapezoid	60	1.000
87R	Automatic Fixed Interval	38323.891	0.000770	0.0400	Trapezoid	60	1.000
88R	Automatic Fixed Interval	49179.276	0.000470	0.0400	Trapezoid	60	1.000
89R	Automatic Fixed Interval	49036.548	0.000470	0.0400	Trapezoid	60	1.000
90R	Automatic Fixed Interval	31076.357	0.001150	0.0400	Trapezoid	60	1.000
91R	Automatic Fixed Interval	39388.301	0.003760	0.0400	Trapezoid	60	1.000
92R	Automatic Fixed Interval	33924.344	0.001900	0.0400	Trapezoid	60	1.000
93R	Automatic Fixed Interval	35238.981	0.000640	0.0400	Trapezoid	60	1.000
94R	Automatic Fixed Interval	21518.607	0.001300	0.0400	Trapezoid	60	1.000
95R	Automatic Fixed Interval	51090.820	0.001340	0.0400	Trapezoid	60	1.000
96R	Automatic Fixed Interval	58839.627	0.000470	0.0400	Trapezoid	60	1.000

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
97R	Automatic Fixed Interval	21538.799	0.001600	0.0400	Trapezoid	60	1.000
98R	Automatic Fixed Interval	34571.429	0.001160	0.0400	Trapezoid	60	1.000
99R	Automatic Fixed Interval	33454.425	0.003120	0.0400	Trapezoid	60	1.000

Appendix C. Tara HEC-HMS Discharge Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	6	3.1	0.7	0
0.166666667	0	0	0	6.166666667	3.9	0.9	0
0.333333333	0	0	0	6.333333333	4.7	1.2	0
0.5	0	0	0	6.5	5.7	1.6	0
0.666666667	0	0	0	6.666666667	6.9	2.1	0
0.833333333	0	0	0	6.833333333	8.3	2.7	0.1
1	0	0	0	7	9.9	3.4	0.1
1.166666667	0	0	0	7.166666667	11.8	4.2	0.2
1.333333333	0	0	0	7.333333333	14	5.2	0.3
1.5	0	0	0	7.5	16.4	6.4	0.4
1.666666667	0	0	0	7.666666667	19.1	7.7	0.6
1.833333333	0	0	0	7.833333333	22.2	9.3	0.9
2	0	0	0	8	25.5	11.1	1.2
2.166666667	0	0	0	8.166666667	29.3	13.1	1.6
2.333333333	0	0	0	8.333333333	33.4	15.4	2
2.5	0	0	0	8.5	37.9	18	2.5
2.666666667	0	0	0	8.666666667	42.8	20.8	3.2
2.833333333	0	0	0	8.833333333	48.1	24	3.9
3	0	0	0	9	53.8	27.6	4.8
3.166666667	0	0	0	9.166666667	60	31.7	5.9
3.333333333	0	0	0	9.333333333	66.9	36.3	7.2
3.5	0	0	0	9.5	74.4	41.5	8.8
3.666666667	0	0	0	9.666666667	82.7	47.4	10.7
3.833333333	0	0	0	9.833333333	91.9	54.1	12.9
4	0	0	0	10	102.1	61.5	15.5
4.166666667	0.1	0	0	10.16666667	113.4	69.8	18.5
4.333333333	0.1	0	0	10.33333333	125.7	79	21.9
4.5	0.2	0	0	10.5	139.2	89.3	25.9
4.666666667	0.3	0	0	10.66666667	154	100.7	30.4
4.833333333	0.5	0	0	10.83333333	170.3	113.4	35.7
5	0.6	0.1	0	11	188.2	127.7	41.8
5.166666667	0.9	0.1	0	11.16666667	207.9	143.9	48.8
5.333333333	1.2	0.2	0	11.33333333	229.9	162.2	57
5.5	1.5	0.2	0	11.5	254.4	182.7	66.4
5.666666667	2	0.3	0	11.66666667	281.8	206.4	77.7
5.833333333	2.5	0.5	0	11.33333333	229.9	162.2	57

Appendix

DIRECT FLOW (cms)							
Time (hr)	**100-yr**	**25-yr**	**5-year**	**Time (hr)**	**100-yr**	**25-yr**	**5-year**
11.5	254.4	182.7	66.4	17.83333333	3985.6	3002.8	1764.9
11.66666667	281.8	206.4	77.7	18	4021.5	3019.3	1778.3
11.83333333	312.3	236.3	92.6	18.16666667	4047.7	3029.6	1788.1
12	347	270.2	110	18.33333333	4065.6	3031.4	1792.8
12.16666667	390.1	307.7	129.5	18.5	4075.4	3024.8	1792.5
12.33333333	438.4	351.1	152.6	18.66666667	4073.6	3012.6	1788.6
12.5	491.5	401.2	179.8	18.83333333	4060.8	2995.4	1781.8
12.66666667	552.3	455.7	209.7	19	4040.6	2972.7	1771.7
12.83333333	622	514.5	242.4	19.16666667	4013.9	2945.7	1759
13	697.4	579	278.5	19.33333333	3979.8	2914.6	1743.8
13.16666667	778.3	648.1	317.5	19.5	3940	2879.3	1726
13.33333333	866.8	721.3	359.1	19.66666667	3894.9	2839.6	1705.6
13.5	961.2	799.5	403.8	19.83333333	3844	2796.6	1683.1
13.66666667	1060.9	884	452.5	20	3787.7	2750.3	1658.4
13.83333333	1167	972.7	504	20.16666667	3726.9	2699.5	1631
14	1281.3	1065.2	558	20.33333333	3662	2645.3	1601.2
14.16666667	1400.8	1163.9	616.1	20.5	3591.1	2588.6	1569.8
14.33333333	1525.1	1267.7	677.6		3516	2529.4	1536.6
14.5	1657.3	1374.7	741.5	20.83333333	3437.9	2466.6	1500.9
14.66666667	1796	1484.3	807.3	21	3356.7	2401.7	1463.7
14.83333333	1938.3	1598.7	876.4	21.16666667	3270.8	2335.9	1425.7
15	2083.6	1715	947.1	21.33333333	3182.7	2270.7	1387.8
15.16666667	2234.9	1831.5	1018.4	21.5	3093.4	2206.5	1350.3
15.33333333	2388.3	1945.7	1088.6	21.66666667	3005.3	2142.5	1312.9
15.5	2541.6	2056.7	1157.1	21.83333333	2918.5	2079.3	1275.8
15.66666667	2691.6	2165.4	1224.5	22	2832.2	2020	1241
15.83333333	2836.8	2270.9	1290	22.16666667	2747.1	1962.6	1207.2
16	2978.9	2368	1350.9	22.33333333	2667.4	1906.2	1174
16.16666667	3116.4	2459.5	1408.4	22.5	2590	1851.6	1141.7
16.33333333	3242.5	2546.5	1463.4	22.66666667	2514.2	1798.9	1110.5
16.5	3361	2626.6	1514.3	22.83333333	2440.8	1747.7	1080
16.66666667	3473.4	2697.8	1560	23	2370.1	1697.9	1050.4
16.83333333	3576.6	2762.8	1602	23.16666667	2301.4	1650.1	1021.9
17	3667.8	2822.1	1640.5	23.33333333	2234.8	1604	994.3
17.16666667	3750.8	2872.1	1673.6	23.5	2170.8	1559.5	967.5
17.33333333	3826.1	2914.3	1702	23.66666667	2109.2	1516.6	941.7
17.5	3889.1	2950.2	1726.7	23.83333333	2049.6	1476.1	917.3
17.66666667	3941.5	2980.1	1747.9	24	1992.4	1437.1	893.7

Appendix

DIRECT FLOW (cms)							
Time (hr)	**100-yr**	**25-yr**	**5-year**	**Time (hr)**	**100-yr**	**25-yr**	**5-year**
24.16666667	1938.4	1399.5	870.9	30.5	622.9	439.5	273.9
24.33333333	1886.5	1363.1	848.7	30.66666667	598.6	421.8	262.9
24.5	1836.5	1327.7	827	30.83333333	574.7	404.6	252.1
24.66666667	1788	1293.2	805.9	31	551.5	388	241.8
24.83333333	1741.1	1259.9	785.4	31.16666667	529	371.9	231.7
25	1695.5	1228.2	765.8	31.33333333	507.3	356.2	222
25.16666667	1651.5	1197.2	746.6	31.5	486.3	341	212.5
25.33333333	1609.5	1166.8	727.8	31.66666667	465.8	326.2	203.3
25.5	1568.6	1137	709.2	31.83333333	445.9	311.9	194.4
25.66666667	1528.6	1107.7	691	32	426.6	298	185.7
25.83333333	1489.3	1078.9	672.9	32.16666667	407.9	284.8	177.5
26	1450.8	1050.6	655.3	32.33333333	389.7	272	169.5
26.16666667	1412.8	1023.8	638.5	32.5	372.4	259.8	161.9
26.33333333	1375.7	997.8	622.2	32.66666667	355.7	247.9	154.5
26.5	1340.6	972.1	606.1	32.83333333	339.6	236.6	147.4
26.66666667	1306.4	946.7	590.2	33	324.2	225.8	140.7
26.83333333	1272.7	921.6	574.4	33.16666667	309.4	215.5	134.3
27	1239.4	896.6	558.8	33.33333333	295.2	205.7	128.2
27.16666667	1206.4	871.8	543.3	33.5	281.7	196.5	122.5
27.33333333	1173.7	847.6	528.1	33.66666667	269	187.7	117
27.5	1141.2	823.7	513.2	33.83333333	257	179.4	111.8
27.66666667	1109.3	800	498.5	34	245.5	171.4	106.8
27.83333333	1078	776.4	483.8	34.16666667	234.6	163.8	102.1
28	1047	753	469.2	34.33333333	224.2	156.5	97.5
28.16666667	1016	729.6	454.6	34.5	214.2	149.7	93.2
28.33333333	985.2	706.4	440.2	34.66666667	204.7	143.1	89.2
28.5	954.6	683.7	426	34.83333333	195.7	136.9	85.3
28.66666667	924.3	661.4	412.2	35	187.1	130.9	81.6
28.83333333	894.5	639.4	398.5	35.16666667	179	125.2	78
29	865.2	617.8	385	35.33333333	171.2	119.8	74.6
29.16666667	836.5	596.4	371.6	35.5	163.7	114.5	71.4
29.33333333	808.1	575.2	358.5	35.66666667	156.6	109.6	68.3
29.5	780	554.4	345.5	35.83333333	149.8	104.9	65.4
29.66666667	752.4	534.2	332.9	36	143.3	100.4	62.6
29.83333333	725.1	514.5	320.6				
30	698.6	495.2	308.6				
30.16666667	672.8	476.3	296.8				
30.33333333	647.6	457.7	285.3				

Appendix D. Bula HEC-HMS Discharge Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	6.333333333	0.1	0	0
0.166666667	0	0	0	6.5	0.2	0.1	0
0.333333333	0	0	0	6.666666667	0.4	0.2	0
0.5	0	0	0	6.833333333	0.6	0.3	0.1
0.666666667	0	0	0	7	0.9	0.5	0.2
0.833333333	0	0	0	7.166666667	1.4	0.8	0.3
1	0	0	0	7.333333333	2	1.2	0.4
1.166666667	0	0	0	7.5	2.8	1.6	0.6
1.333333333	0	0	0	7.666666667	3.8	2.2	0.8
1.5	0	0	0	7.833333333	5	3	1.1
1.666666667	0	0	0	8	6.4	3.9	1.4
1.833333333	0	0	0	8.166666667	8.2	4.9	1.9
2	0	0	0	8.333333333	10.2	6.2	2.4
2.166666667	0	0	0	8.5	12.7	7.7	3
2.333333333	0	0	0	8.666666667	15.4	9.5	3.8
2.5	0	0	0	8.833333333	18.6	11.5	4.7
2.666666667	0	0	0	9	22.6	14	5.8
2.833333333	0	0	0	9.166666667	27.5	17.1	7.1
3	0	0	0	9.333333333	33.3	20.9	8.8
3.166666667	0	0	0	9.5	40.1	25.3	10.7
3.333333333	0	0	0	9.666666667	48	30.4	13
3.5	0	0	0	9.833333333	57	36.3	15.7
3.666666667	0	0	0	10	67.7	43.2	18.8
3.833333333	0	0	0	10.16666667	80.1	51.3	22.5
4	0	0	0	10.33333333	94.4	60.7	26.8
4.166666667	0	0	0	10.5	111.1	71.7	31.9
4.333333333	0	0	0	10.66666667	130.2	84.4	37.8
4.5	0	0	0	10.83333333	152	98.9	44.6
4.666666667	0	0	0	11	177.2	115.7	52.5
4.833333333	0	0	0	11.16666667	206	135.1	61.7
5	0	0	0	11.33333333	238.6	157.1	72.3
5.166666667	0	0	0	11.5	275.9	182.3	84.5
5.333333333	0	0	0	11.66666667	318.6	211.6	99
5.5	0	0	0	11.83333333	372.1	248.9	118.4
5.666666667	0	0	0	12	433.1	291.9	141.1
5.833333333	0	0	0	12.16666667	500.6	339.4	166.4
6	0	0	0	12.33333333	574.6	391.7	194.2
6.166666667	0	0	0	12.5	655.6	449	224.7

Appendix

DIRECT FLOW (cms)							
Time (hr)	**100-yr**	**25-yr**	**5-year**	**Time (hr)**	**100-yr**	**25-yr**	**5-year**
12.66666667	744.3	512	258.5	19.33333333	10390.9	7627.4	4371.5
12.83333333	846.7	585.4	298.7	19.5	10631.7	7808.8	4480.6
13	959.4	666.5	343.6	19.66666667	10863.9	7984.2	4586.6
13.16666667	1080.1	753.4	391.9	19.83333333	11086.2	8152.4	4688.6
13.33333333	1208.5	846.1	443.3	20	11292.4	8308.5	4783.5
13.5	1344.3	944	497.6	20.16666667	11483.5	8453.4	4871.6
13.66666667	1488	1047.7	555.2	20.33333333	11662.7	8589.6	4954.8
13.83333333	1642.1	1159.2	617.4	20.5	11830.7	8717.8	5033.8
14	1805.5	1277.6	683.7	20.66666667	11988.1	8838.3	5108.6
14.16666667	1977.2	1402.1	753.4	20.83333333	12133.9	8950.5	5178.9
14.33333333	2156.8	1532.4	826.4	21	12263.3	9050.4	5241.9
14.5	2344.2	1668.3	902.4	21.16666667	12376.2	9137.9	5297.5
14.66666667	2539.9	1810.3	982	21.33333333	12477.4	9216.8	5348
14.83333333	2746.9	1960.9	1066.7	21.5	12568.1	9288	5394.4
15	2965.1	2119.9	1156.5	21.66666667	12648.8	9352	5436.8
15.16666667	3191.7	2285.2	1250	21.83333333	12719.2	9408.6	5475.2
15.33333333	3425.9	2456.1	1346.9	22	12777.5	9456.3	5508.6
15.5	3667.4	2632.6	1446.9	22.16666667	12823.5	9494.9	5536.7
15.66666667	3916.9	2815	1550.4	22.33333333	12859	9525.9	5560.5
15.83333333	4177.2	3005.6	1659	22.5	12884.6	9549.8	5580.5
16	4450	3206	1773.8	22.66666667	12900.7	9566.7	5596.6
16.16666667	4730.5	3412.3	1892.4	22.83333333	12906.9	9576.4	5608.8
16.33333333	5017	3623.4	2013.9	23	12901	9577.1	5615.7
16.5	5309.2	3838.7	2138.1	23.16666667	12877.2	9564.3	5614.3
16.66666667	5606.5	4058.1	2264.8	23.33333333	12842.3	9542.9	5607.6
16.83333333	5910	4282.4	2394.8	23.5	12798.2	9514.9	5597.2
17	6222.8	4514.1	2529.6	23.66666667	12745	9480.2	5583
17.16666667	6539.3	4748.9	2666.8	23.83333333	12683.3	9439.3	5565.4
17.33333333	6857.8	4985.5	2805.5	24	12612.7	9391.9	5544.1
17.5	7177.8	5223.6	2945.3	24.16666667	12532.5	9337.2	5518.6
17.66666667	7497.7	5461.9	3085.6	24.33333333	12445.1	9277.3	5490
17.83333333	7816.6	5699.6	3225.8	24.5	12351.1	9212.5	5458.6
18	8128.4	5932.1	3362.8	24.66666667	12250.3	9142.8	5424.5
18.16666667	8435.1	6160.9	3497.8	24.83333333	12143.4	9068.6	5387.8
18.33333333	8737.5	6386.9	3631.5	25	12030.1	8989.7	5348.5
18.5	9035.3	6609.8	3763.9	25.16666667	11909.3	8905.1	5305.7
18.66666667	9327.5	6828.8	3894.4	25.33333333	11782.1	8815.7	5260.2
18.83333333	9612.7	7042.9	4022.2	25.5	11649.2	8722.2	5212.1
19	9882.9	7245.7	4143.3	25.66666667	11510.8	8624.5	5161.7
19.16666667	10141.4	7439.8	4259.1	25.83333333	11366.9	8522.6	5108.8

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
26	11216.9	8416.2	5053.1	32.66666667	4710.3	3638.4	2334
26.16666667	11059	8303.7	4993.7	32.83333333	4600.2	3555.4	2283.5
26.33333333	10894.8	8186.4	4931.2	33	4492.1	3473.6	2233.6
26.5	10726.2	8065.5	4866.4	33.16666667	4385.8	3393.2	2184.3
26.66666667	10553.6	7941.6	4799.7	33.33333333	4281.6	3314.2	2135.7
26.83333333	10377.2	7814.7	4731.1	33.5	4179.2	3236.5	2087.8
27	10197.1	7684.9	4660.5	33.66666667	4078.8	3160.2	2040.6
27.16666667	10011.7	7550.9	4587.2	33.83333333	3980.4	3085.3	1994.1
27.33333333	9821.2	7412.7	4511	34	3883.9	3011.7	1948.3
27.5	9628.3	7272.5	4433.1	34.16666667	3789.4	2939.5	1903.1
27.66666667	9433.6	7130.7	4354.1	34.33333333	3697.1	2869	1858.9
27.83333333	9237.6	6987.8	4274.2	34.5	3607.5	2800.4	1815.9
28	9041.2	6844.3	4193.7	34.66666667	3519.7	2733.2	1773.6
28.16666667	8845.7	6701.4	4113.4	34.83333333	3433.5	2667.2	1731.9
28.33333333	8653.4	6560.8	4034.4	35	3349	2602.2	1690.8
28.5	8462.9	6421.5	3955.9	35.16666667	3266.1	2538.5	1650.3
28.66666667	8273.6	6282.8	3877.5	35.33333333	3184.9	2476	1610.5
28.83333333	8085.7	6144.9	3799.2	35.5	3105	2414.5	1571.2
29	7899.8	6008.3	3721.5	35.66666667	3026.6	2353.9	1532.5
29.16666667	7717.3	5874.1	3645	35.83333333	2949.5	2294.4	1494.4
29.33333333	7542.4	5745.6	3571.9	36	2873.9	2236	1456.9
29.5	7371.6	5620.2	3500.5	36.16666667	2799.8	2178.6	1419.9
29.66666667	7203.7	5496.6	3429.9	36.33333333	2727.3	2122.5	1383.8
29.83333333	7038.6	5374.9	3360.2	36.5	2658.2	2069	1349.3
30	6876	5254.9	3291	36.66666667	2591.1	2017	1315.8
30.16666667	6716.2	5136.7	3222.7	36.83333333	2525.6	1966.2	1282.9
30.33333333	6561.2	5022	3156.3	37	2461.5	1916.6	1250.8
30.5	6409.5	4909.6	3091	37.16666667	2398.9	1868	1219.3
30.66666667	6260.6	4799.2	3026.6	37.33333333	2337.7	1820.5	1188.5
30.83333333	6114.6	4690.7	2963	37.5	2278	1774	1158.2
31	5971.1	4583.8	2900.1	37.66666667	2219.4	1728.4	1128.5
31.16666667	5830.4	4478.9	2838.1	37.83333333	2162	1683.7	1099.4
31.33333333	5694	4377	2777.8	38	2105.8	1639.9	1070.8
31.5	5560.8	4277.5	2718.7	38.16666667	2050.7	1597	1042.7
31.66666667	5430.4	4179.9	2660.5	38.33333333	1996.9	1555	1015.1
31.83333333	5302.6	4084.1	2603.2	38.5	1944.7	1514.3	988.5
32	5177.4	3990.1	2546.7	38.66666667	1894.3	1475	962.7
32.16666667	5054.9	3898	2491.1	38.83333333	1845	1436.6	937.5
32.33333333	4936.9	3809.2	2437.5	39	1796.8	1399	912.9
32.5	4822.4	3723	2385.3	39.16666667	1749.8	1362.3	888.9

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
39.33333333	1703.9	1326.5	865.4	46	590.5	459.7	299.9
39.5	1659.1	1291.5	842.5	46.16666667	575.1	447.7	292.1
39.66666667	1615.3	1257.3	820.1	46.33333333	560.1	436	284.4
39.83333333	1572.4	1223.9	798.2	46.5	545.4	424.6	276.9
40	1530.6	1191.3	776.8	46.66666667	531.2	413.5	269.7
40.16666667	1489.7	1159.4	755.9	46.83333333	517.5	402.8	262.7
40.33333333	1449.8	1128.3	735.6	47	504.2	392.4	256
40.5	1411.2	1098.2	715.9	47.16666667	491.1	382.3	249.3
40.66666667	1374.1	1069.3	697	47.33333333	478.4	372.4	242.9
40.83333333	1338	1041.2	678.8	47.5	466.1	362.8	236.6
41	1302.8	1013.9	660.9	47.66666667	454	353.4	230.5
41.16666667	1268.6	987.2	643.6	47.83333333	442.2	344.2	224.5
41.33333333	1235.2	961.3	626.7	48	430.7	335.2	218.6
41.5	1202.8	936.1	610.3	48.16666667	419.4	326.5	212.9
41.66666667	1171.1	911.5	594.3	48.33333333	408.4	317.9	207.3
41.83333333	1140.2	887.4	578.6	48.5	397.7	309.6	201.9
42	1110	863.9	563.3	48.66666667	387.3	301.5	196.6
42.16666667	1080.5	841	548.4	48.83333333	377.3	293.7	191.5
42.33333333	1051.8	818.6	533.8	49	367.6	286.1	186.6
42.5	1023.9	796.9	519.6	49.16666667	358.1	278.7	181.7
42.66666667	997.3	776.2	506.1	49.33333333	348.8	271.5	177
42.83333333	971.5	756.1	493.1	49.5	339.7	264.4	172.4
43	946.4	736.6	480.4	49.66666667	330.9	257.5	167.9
43.16666667	921.9	717.6	468	49.83333333	322.2	250.8	163.5
43.33333333	898.1	699.1	456	50	313.8	244.2	159.2
43.5	874.9	681	444.2	50.16666667	305.6	237.8	155
43.66666667	852.3	663.5	432.8	50.33333333	297.5	231.5	151
43.83333333	830.3	646.3	421.6	50.5	289.7	225.4	147
44	808.7	629.5	410.7	50.66666667	282.1	219.5	143.1
44.16666667	787.7	613.2	400	50.83333333	274.8	213.8	139.4
44.33333333	767.1	597.2	389.6	51	267.8	208.3	135.8
44.5	747.1	581.6	379.4	51.16666667	261	203	132.3
44.66666667	727.8	566.6	369.6	51.33333333	254.3	197.9	128.9
44.83333333	709.1	552	360.2	51.5	247.9	192.8	125.6
45	690.9	537.9	350.9	51.66666667	241.6	187.9	122.4
45.16666667	673.1	524.1	341.9	51.83333333	235.5	183.2	119.3
45.33333333	655.8	510.6	333.1	52	229.6	178.5	116.3
45.5	638.9	497.4	324.5	52.16666667	223.8	174	113.3
45.66666667	622.4	484.6	316.2	52.33333333	218.1	169.6	110.4
45.83333333	606.3	472	308	52.5	212.7	165.4	107.6

Appendix

DIRECT FLOW (cms)							
Time (hr)	**100-yr**	**25-yr**	**5-year**	**Time (hr)**	**100-yr**	**25-yr**	**5-year**
52.66666667	207.3	161.2	104.9	59.33333333	68.5	53.7	35.4
52.83333333	202.2	157.2	102.3	59.5	65.9	51.7	34.1
53	197.4	153.4	99.8	59.66666667	63.4	49.7	32.9
53.16666667	192.6	149.7	97.4	59.83333333	60.9	47.8	31.7
53.33333333	188.1	146.2	95.1	60	58.3	45.9	30.5
53.5	183.6	142.7	92.8				
53.66666667	179.3	139.3	90.6				
53.83333333	175.1	136	88.4				
54	171	132.9	86.3				
54.16666667	167	129.7	84.3				
54.33333333	163	126.7	82.3				
54.5	159.2	123.7	80.3				
54.66666667	155.4	120.7	78.4				
54.83333333	151.7	117.8	76.5				
55	148	115	74.7				
55.16666667	144.4	112.2	72.9				
55.33333333	140.9	109.4	71.1				
55.5	137.4	106.7	69.3				
55.66666667	133.9	104.1	67.6				
55.83333333	130.6	101.4	65.9				
56	127.2	98.9	64.2				
56.16666667	123.9	96.3	62.6				
56.33333333	120.7	93.8	61				
56.5	117.4	91.3	59.3				
56.66666667	114.3	88.8	57.8				
56.83333333	111.1	86.4	56.2				
57	108	84	54.7				
57.16666667	104.9	81.6	53.2				
57.33333333	101.9	79.3	51.7				
57.5	98.9	77	50.2				
57.66666667	95.9	74.7	48.7				
57.83333333	92.9	72.4	47.3				
58	90.1	70.2	45.8				
58.16666667	87.2	68	44.5				
58.33333333	84.4	65.9	43.1				
58.5	81.7	63.8	41.8				
58.66666667	79	61.7	40.5				
58.83333333	76.3	59.7	39.2				
59	73.7	57.6	37.9				
59.16666667	71.1	55.6	36.6				

D R E A M

Disaster RIsk and Exposure Assessment for Mitigation