REGION 10

Iponan 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.

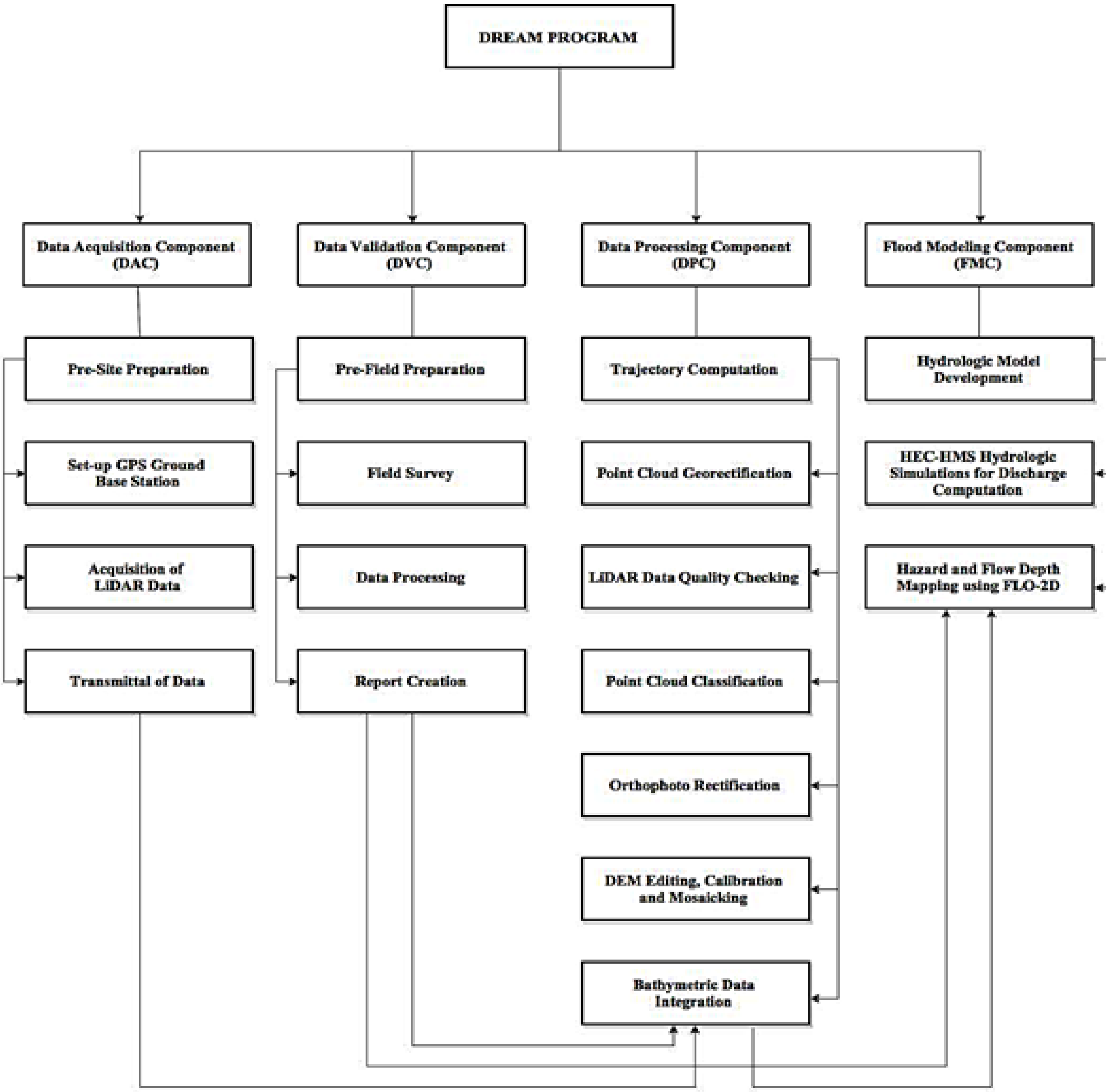


Figure 1. The general methodological framework of the program

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

1.6 Operational Framework

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

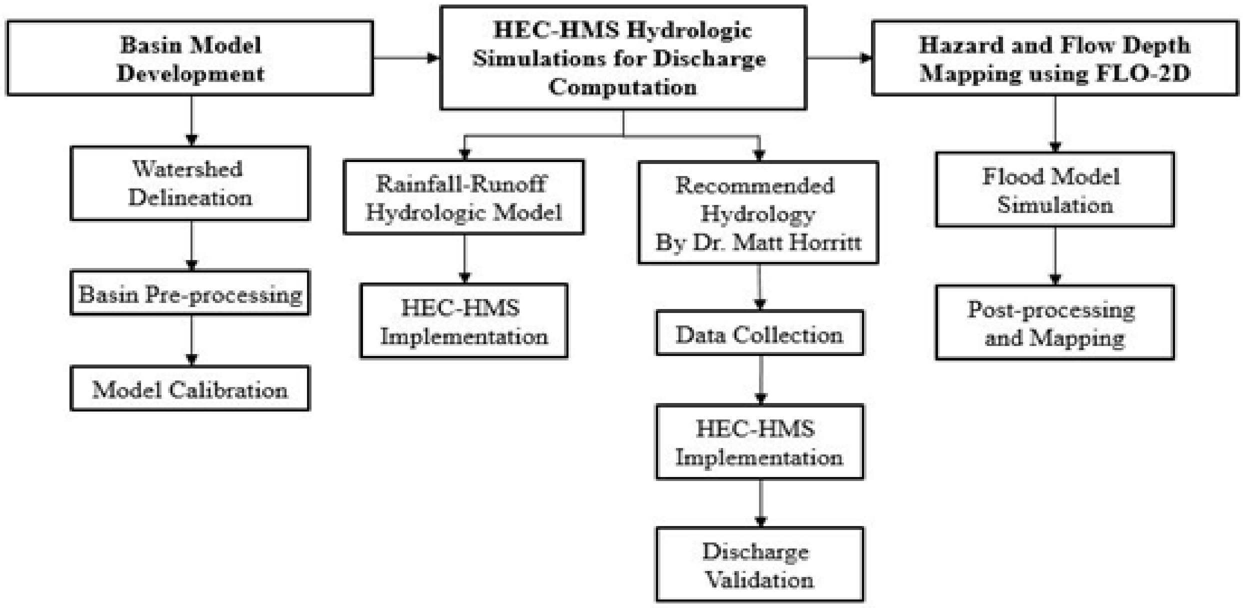


Figure 2. The operational framework and specific work flow of the Flood Modeling Component

The Iponan River Basin

Iponan River Basin is located in the northern part of Mindanao. It covers an estimated basin area of 407 square kilometers. The location of Iponan River Basin is as shown in Figure 3.

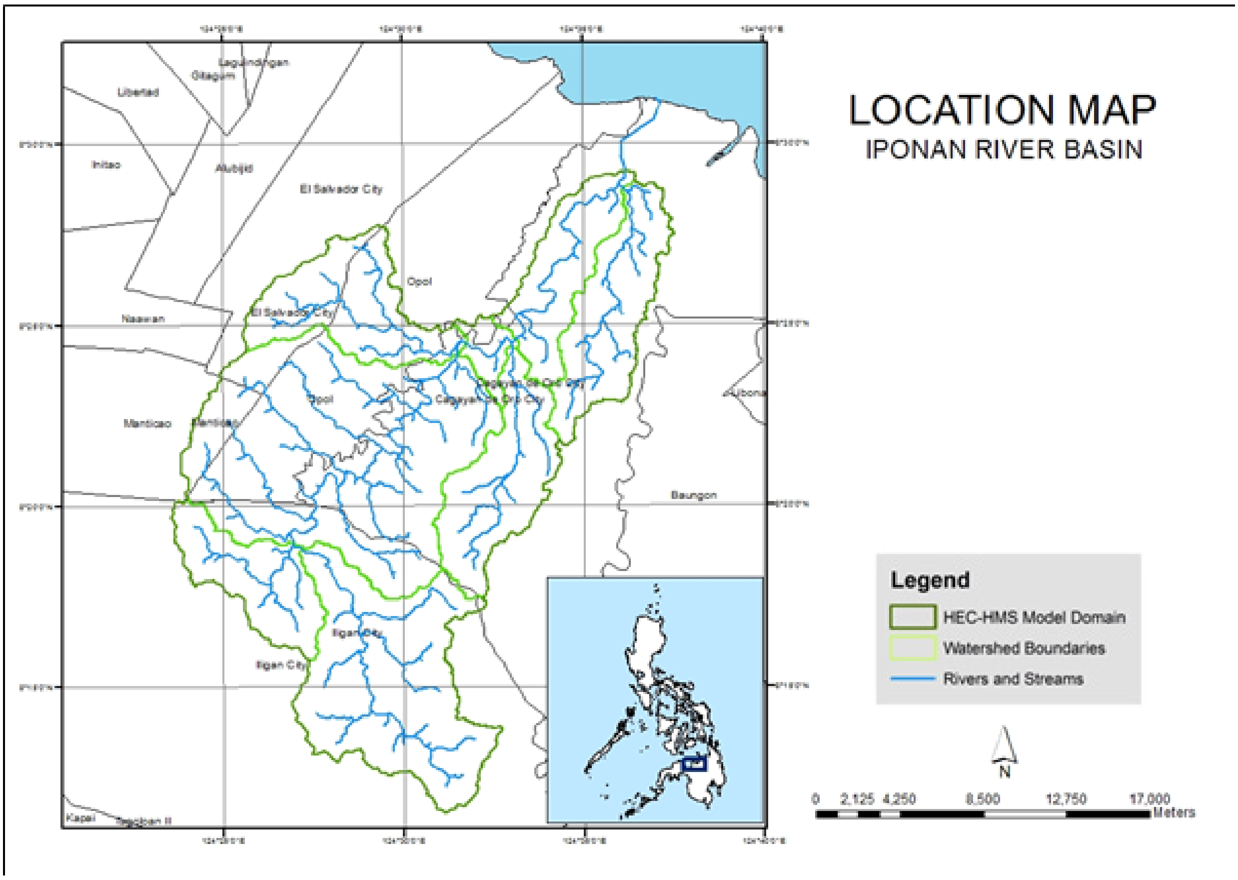


Figure 3. Iponan River Basin Location Map

It traverses through Iponan City in Misamis Oriental and the municipalities of Talakag, Baungon and Libona in Bukidnon. Iponan River, the main tributary of this river basin, has a length of 60 kilometers running from Iligan City draining towards Macajalar Bay. Its drainage area is 407 square kilometers.

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

The Iponan River Basin

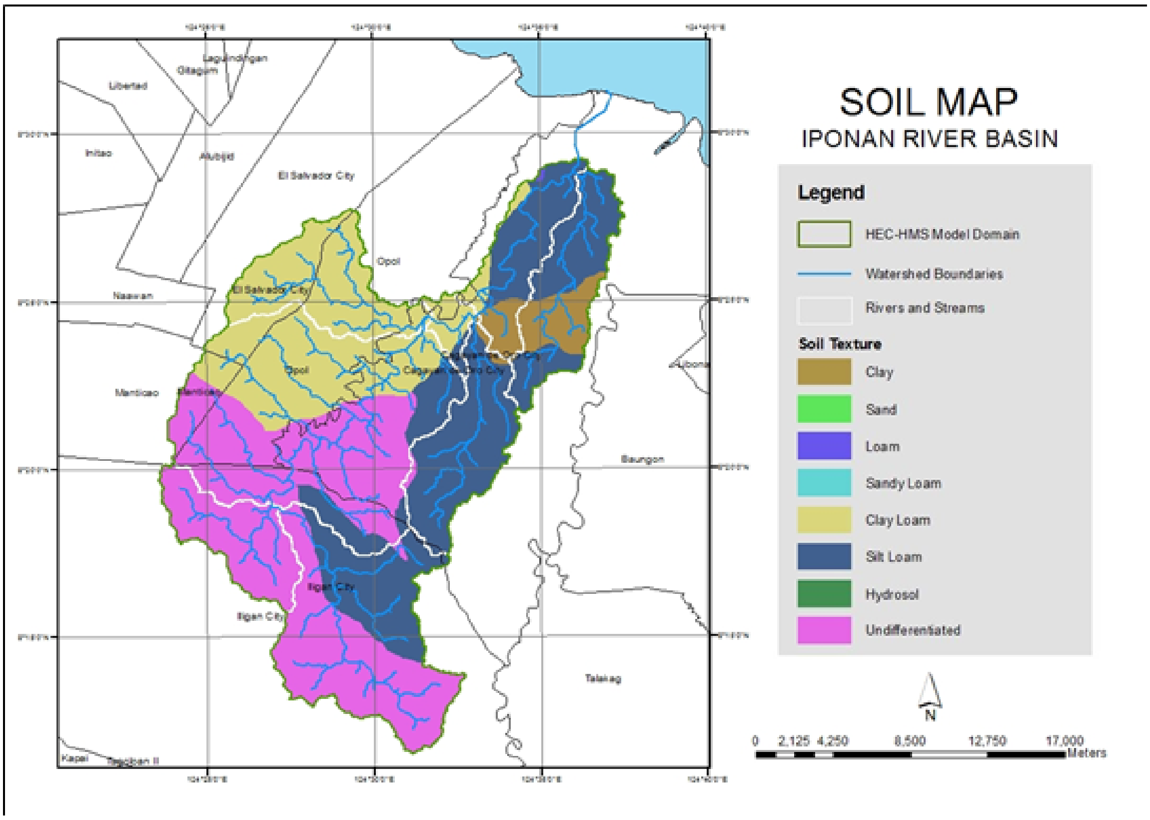


Figure 4. Iponan River Basin Soil Map

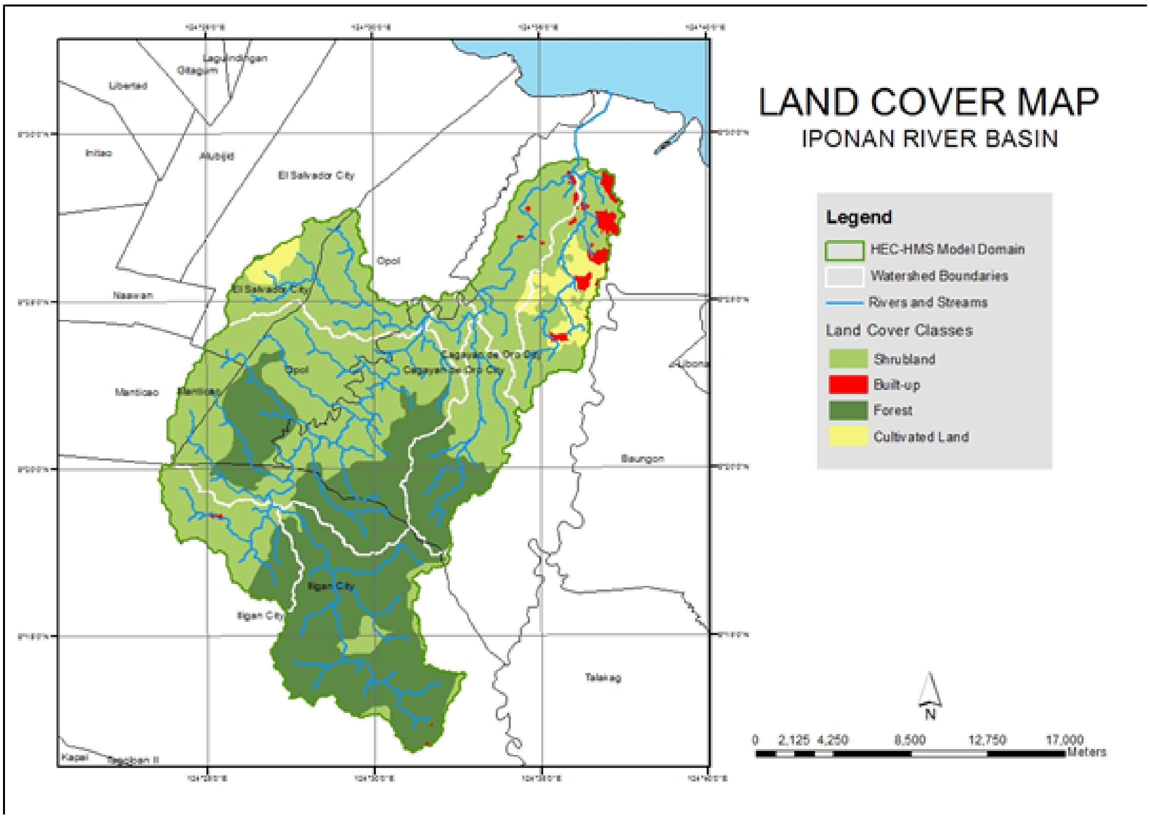


Figure 5. Iponan River Basin Land Cover Map

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.

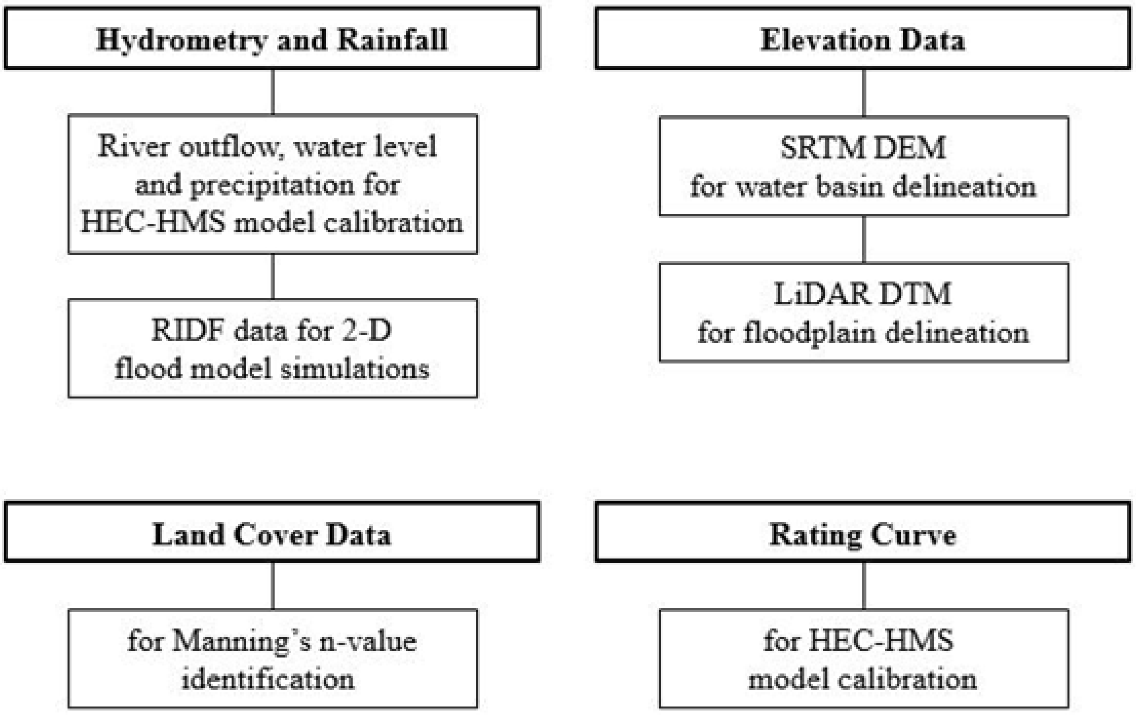


Figure 6. Summary of data needed for the purpose of flood modeling

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.

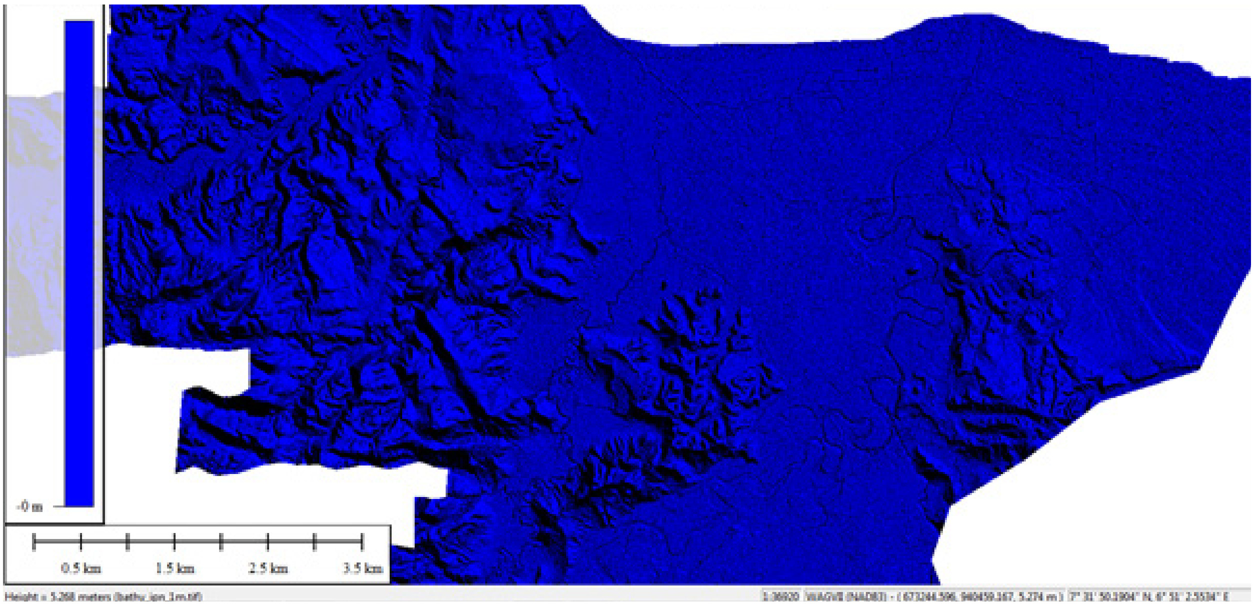


Figure 7. Digital Elevation Model (DEM) of the Iponan River Basin using Light Detection and Ranging (LiDAR) technology

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

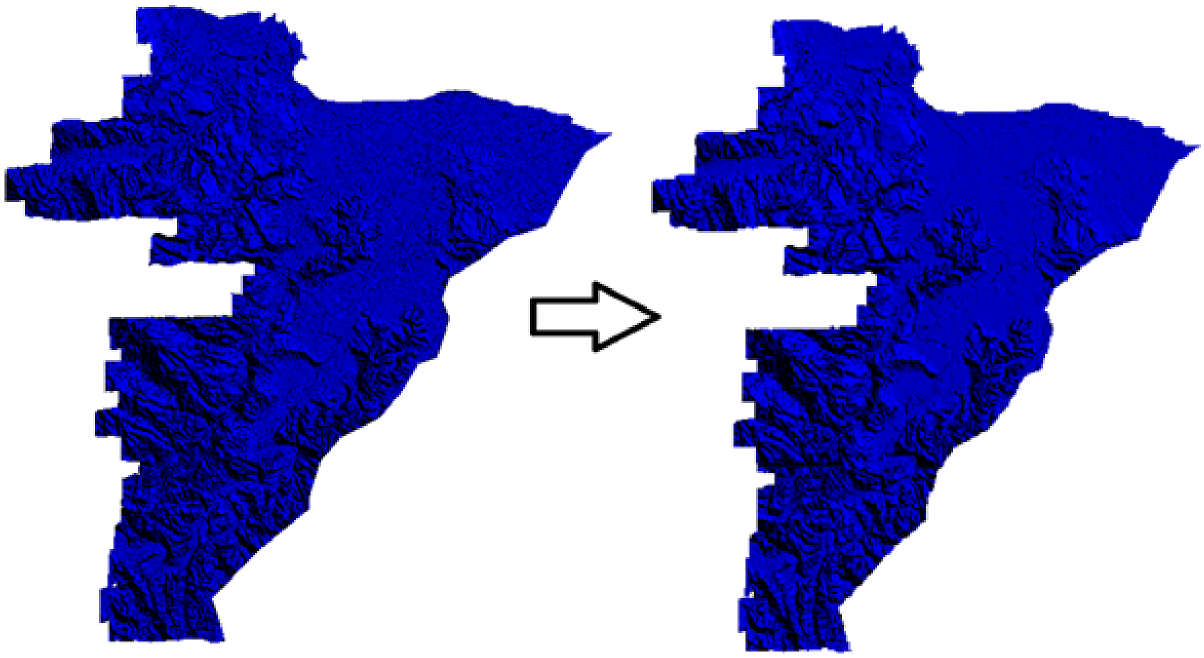


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted

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 Iponan 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.

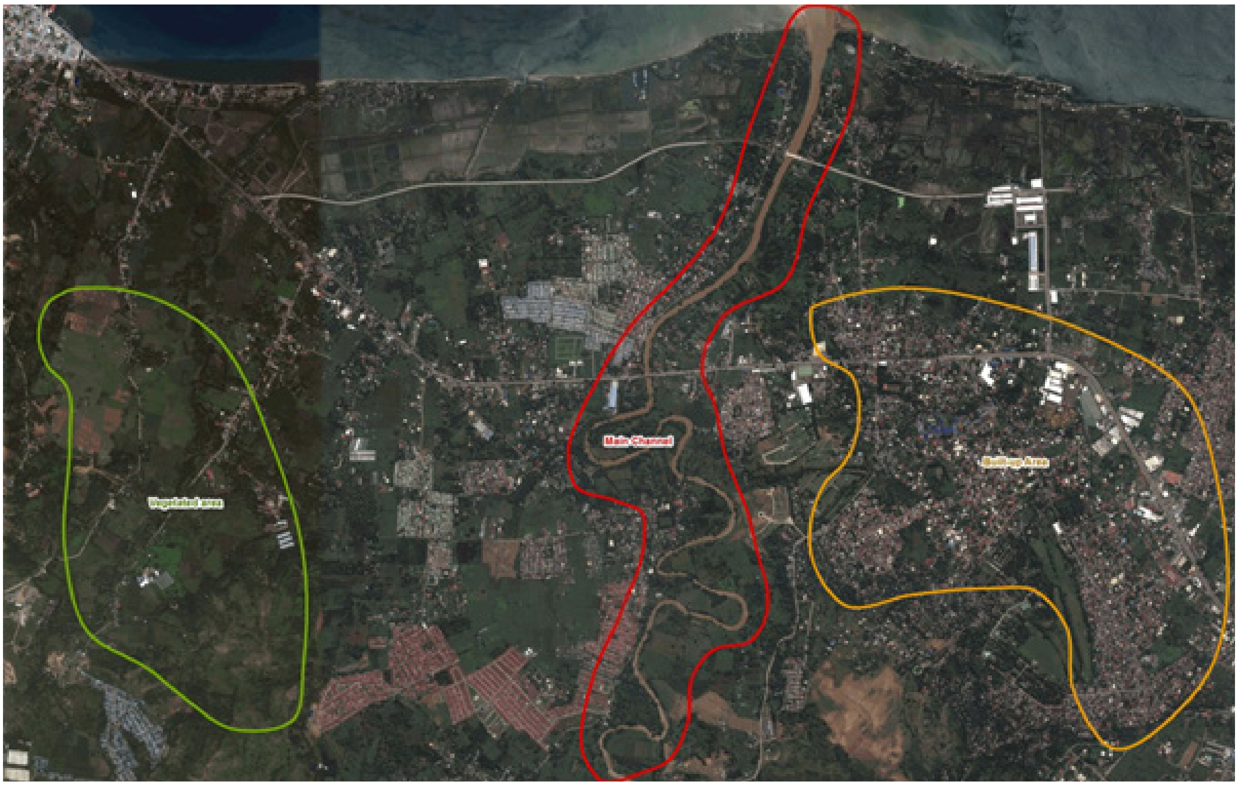


Figure 9. Stitched Quickbird images for the Iponan floodplain

3.1.3 Hydrometry and Rainfall Data

3.1.3.1 Hydrometry of San Simon Bridge, Iponan City

River outflow from the Data Validation Component was used to calibrate the HEC-HMS model. This was taken from San Simon Bridge, Barangay Macasandig, Iponan City (8°26'26.65"N, 124°34'7.70"E). Peak discharge is 18.1 at 01:00 PM, 16 June 2013.

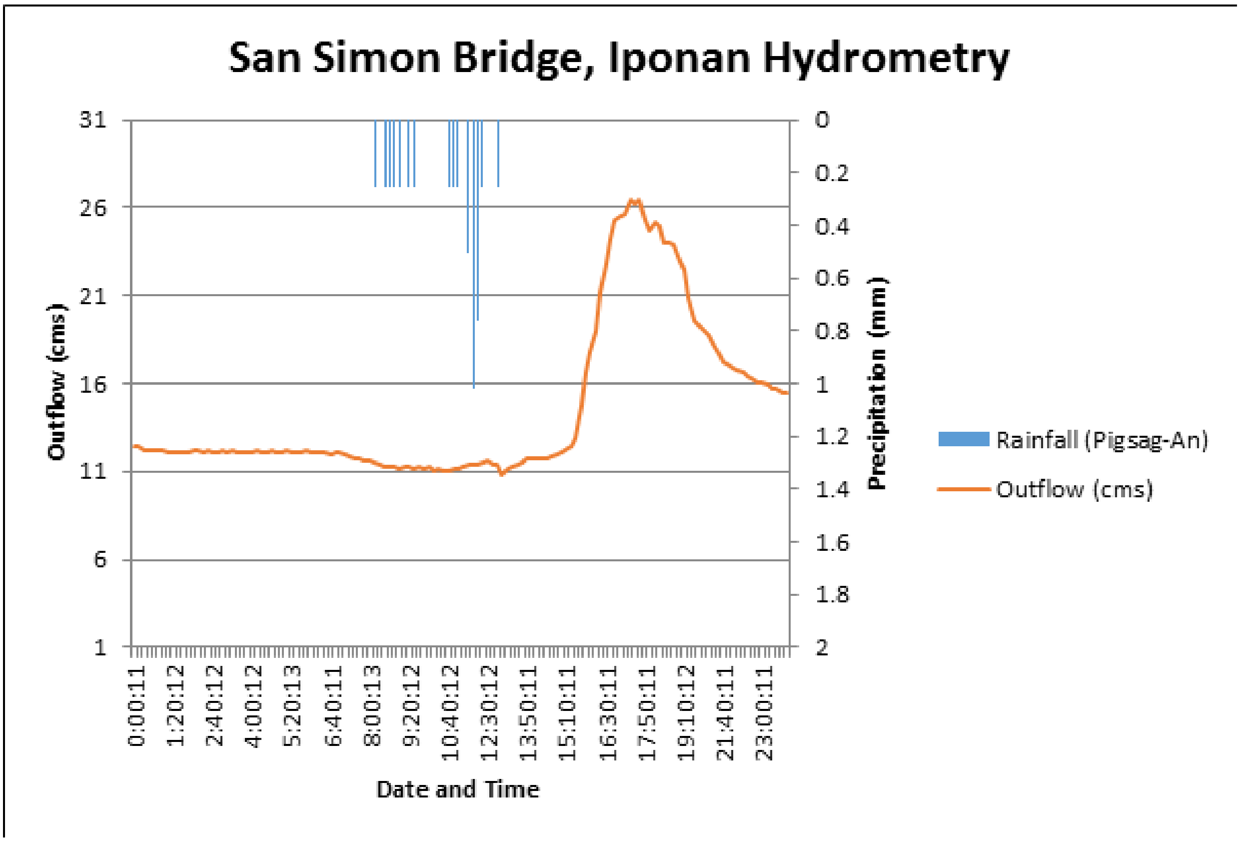


Figure 10. San Simon Bridge, Iponan Rainfall and outflow data used for modeling

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 Lumbia Rain Gauge. This station chosen based on its proximity to the Iponan watershed. The extreme values for this watershed were computed based on a 26-year record.

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

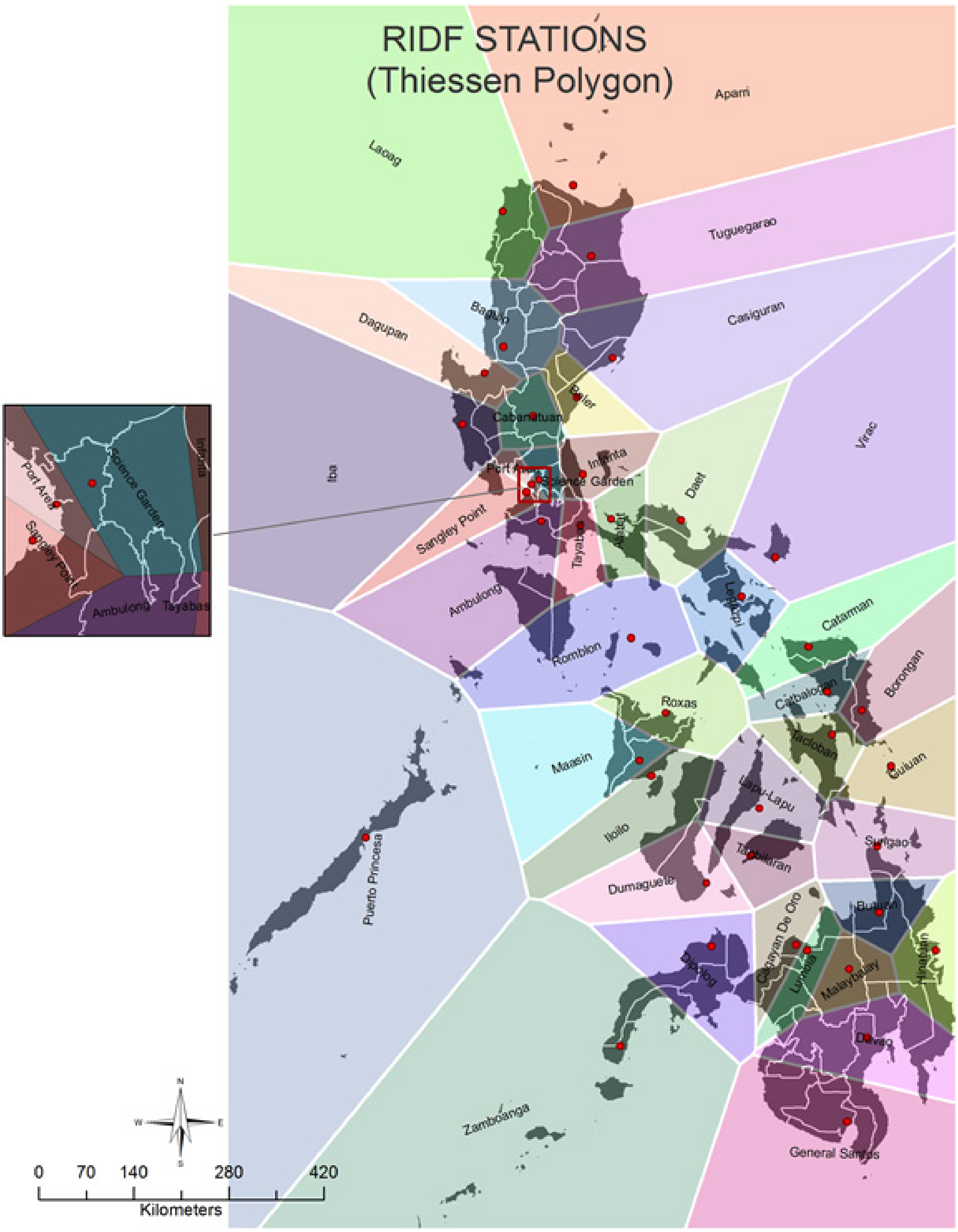


Figure 11. Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines

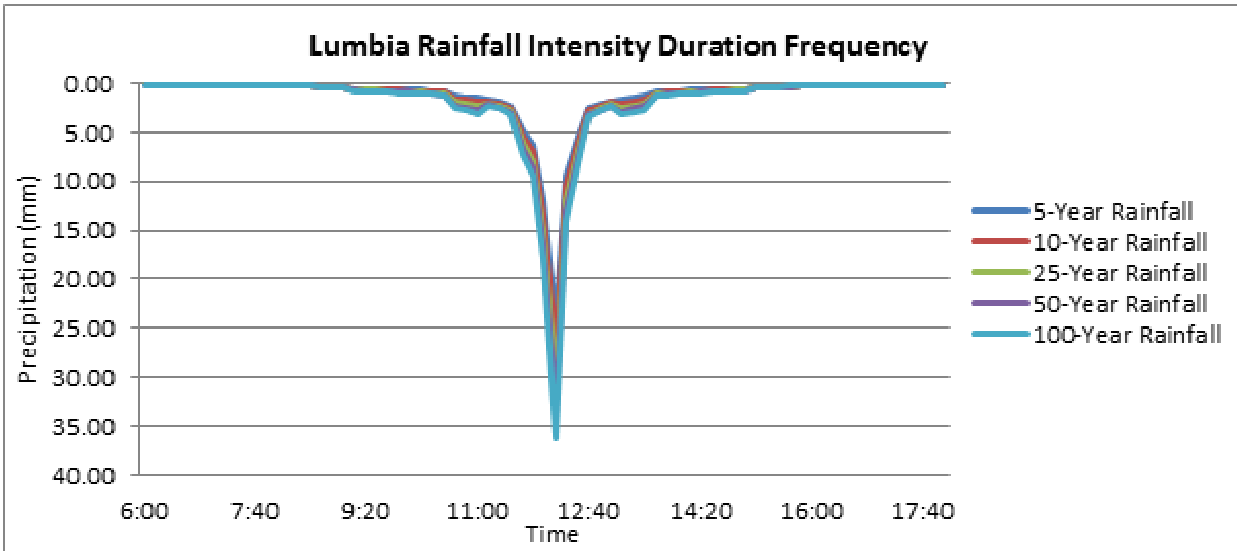


Figure 12. Lumbia Rainfall Intensity Duration Frequency Curves

The outflow for Iponan 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

The rating curve of San Simon Bridge is shown in Figure 13.

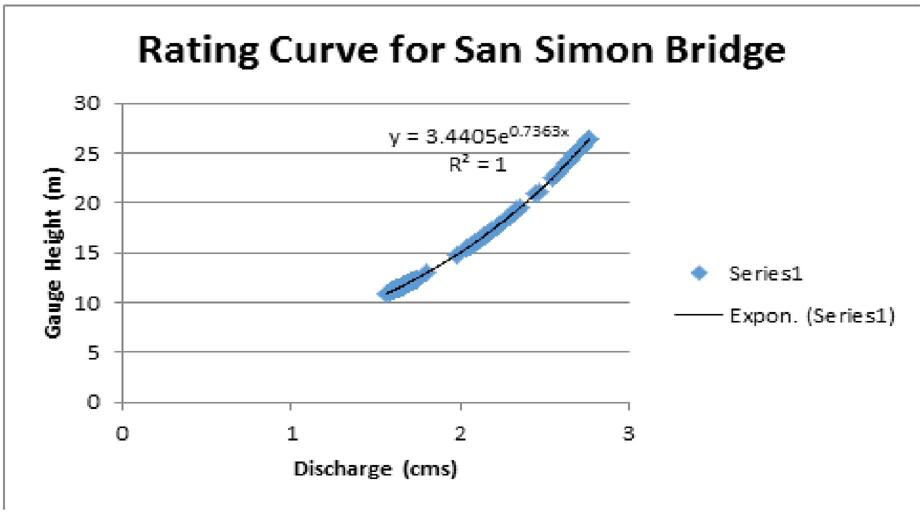


Figure 13. Water Level vs. Discharge Curve for San Simon Bridge, Iponan

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Iponan 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.

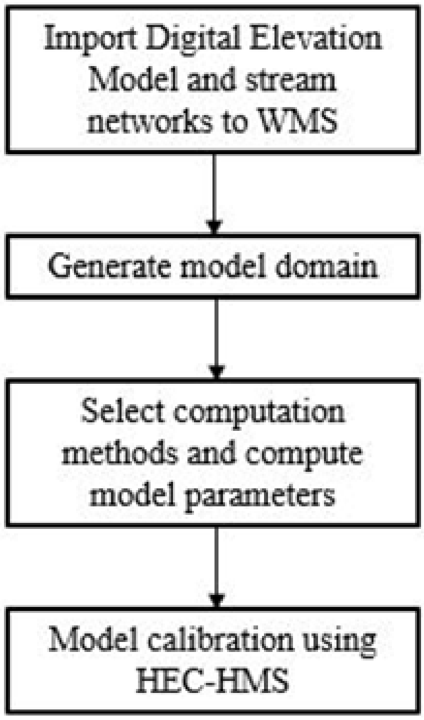


Figure 14. The Rainfall-Runoff Basin Model Development Scheme

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 Iponan HEC-HMS domain is shown in Figure 15.

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

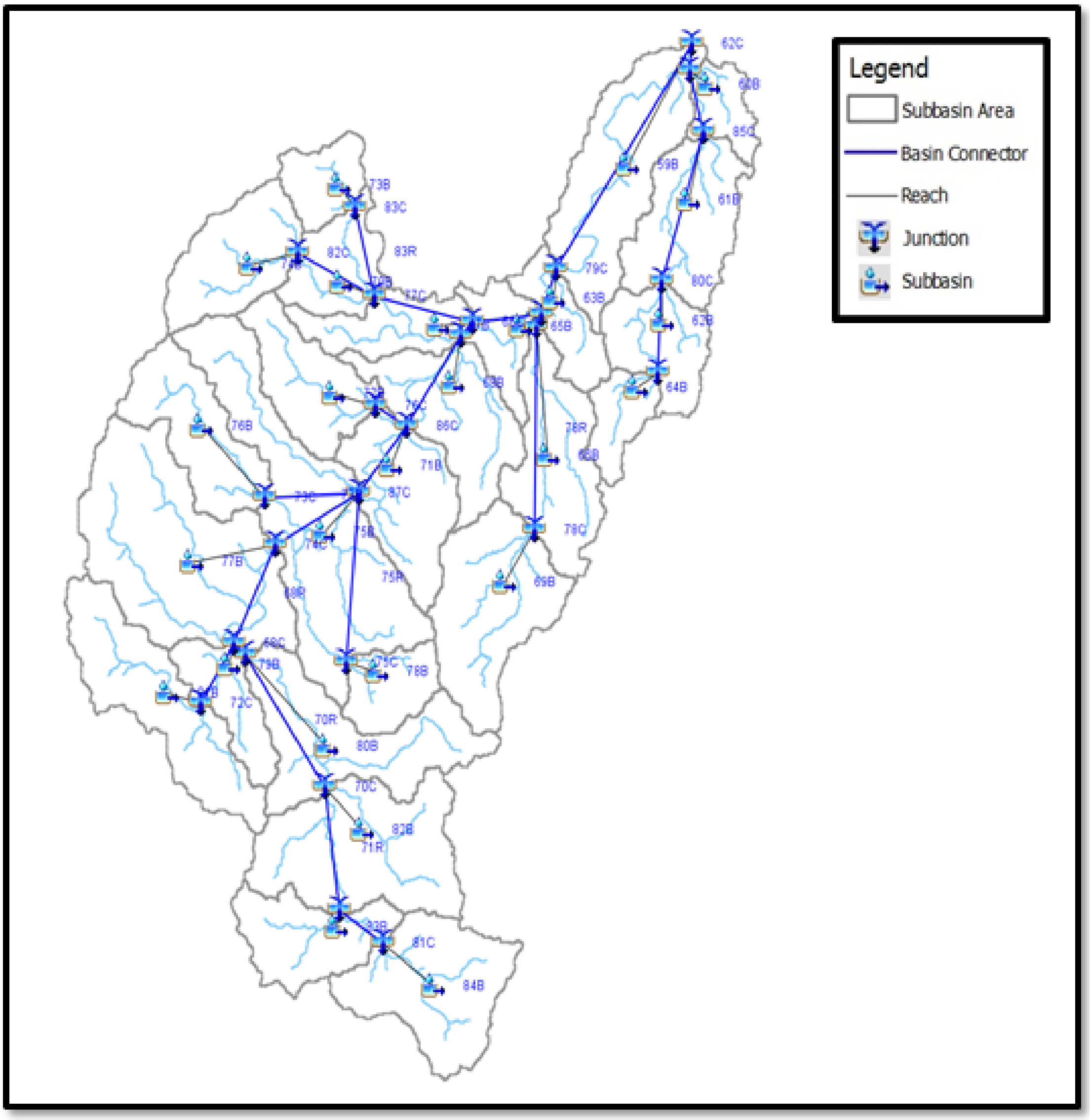


Figure 15. Iponan HEC-HMS Model domain generated by WMS

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 three automatic rain gauges (ARGs) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). This was the Rigsag-An ARG. The location of the rain gauge is seen in Figure 16.

Total rain from Pigsag-An rain gauge is 36.322mm. It peaked to 12.192mm on 15 June 2013, 20:30. The lag time between the peak rainfall and discharge is four hours and thirty minutes.

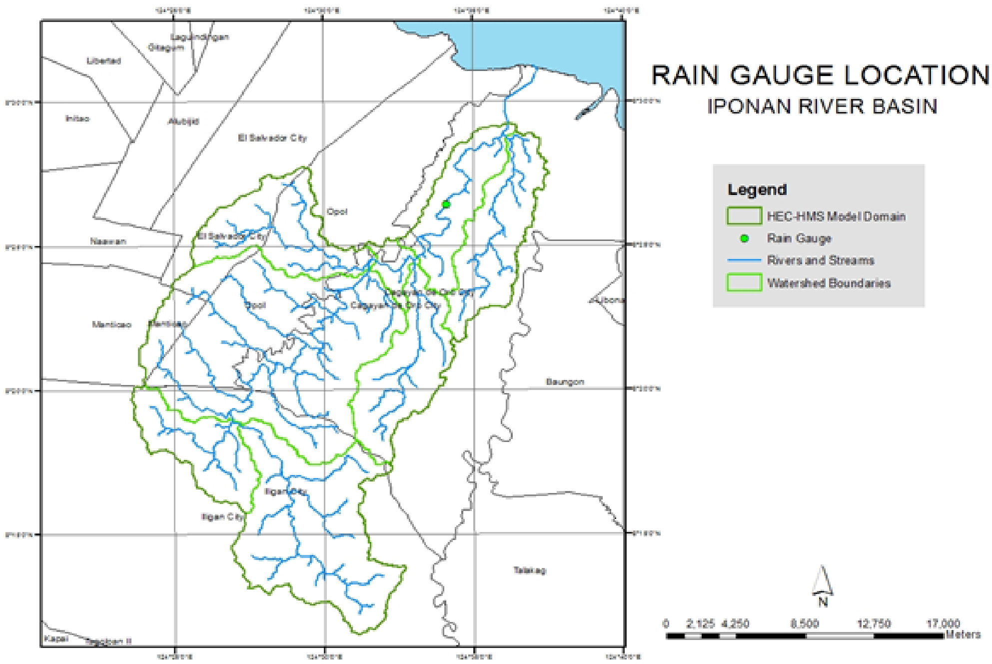


Figure 16. The location map of rain gauge used for the calibration of the Iponan HEC-HMS model

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

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

3.3.1 Discharge Computation using Rainfall-Runoff Hydrologic Model

The calibrated rainfall-Runoff Hydrologic Model for the Iponan 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 Roxas 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 Iponan Bridge. The output for each simulation was an outflow hydrograph from that result, the total inflow to the floodplain and time difference between the peak outflow and peak precipitation could be determined.

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

The required data to be accumulated for the implementation of Dr. Horrit's method is shown on Figure 17.

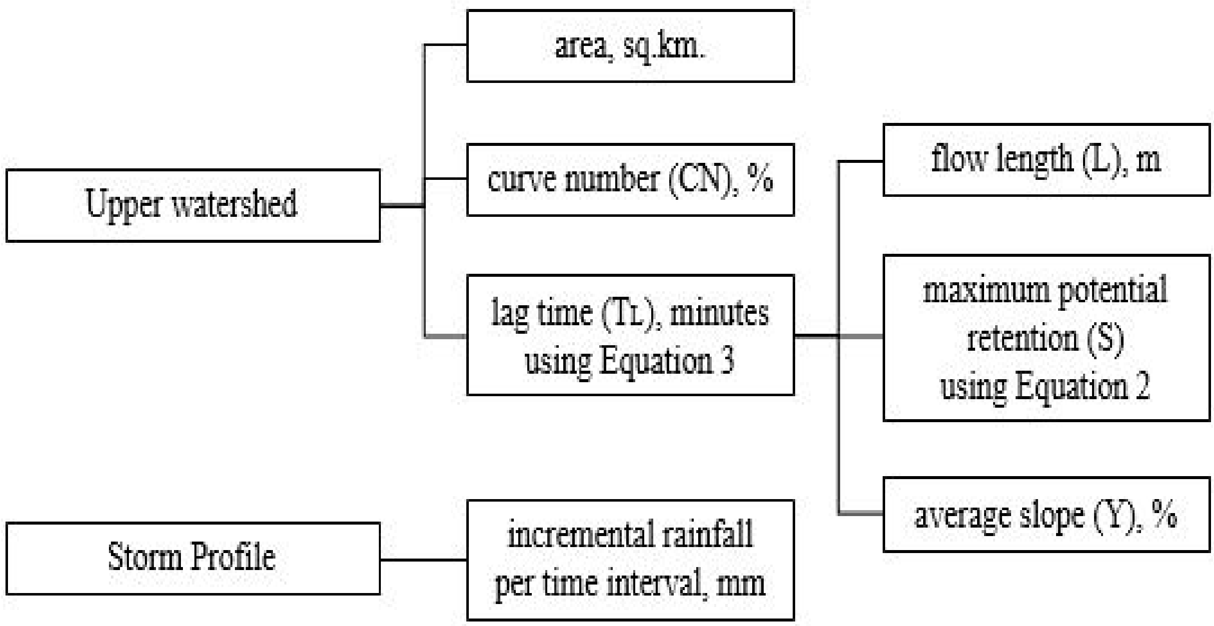


Figure 17. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method.

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

3.3.2.1 Determination of Catchment Properties

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

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

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

Figure 18. Delineation of upper watershed for Iponan 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.

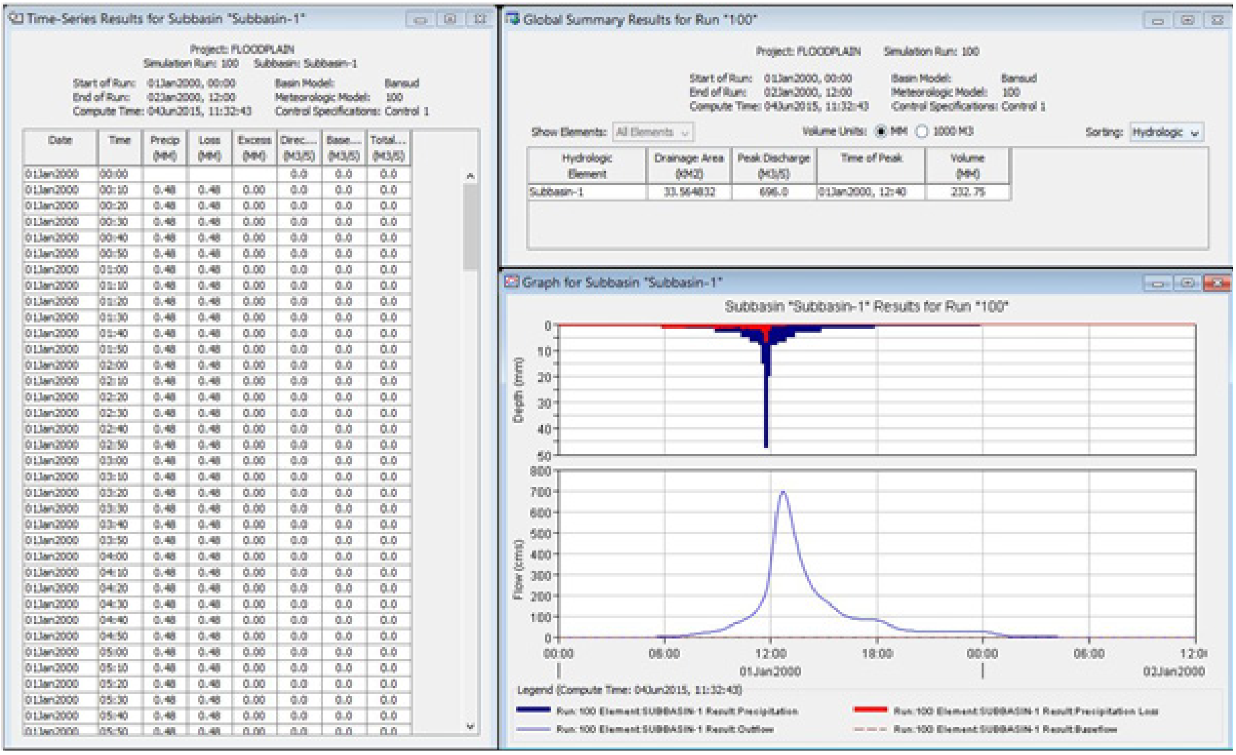


Figure 19. HEC-HMS simulation discharge results using Dr. Horritt's Method

3.3.2.3 Discharge validation against other estimates

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

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

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

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

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

Equation 5. Discharge validation equation using bankful method

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

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

Equation 6. Bankful discharge equation using measurable channel parameters

3.4 Hazard and Flow Depth Mapping using FLO-2D

3.4.1 Floodplain Delineation

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

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

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

3.4.2 Flood Model Generation

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

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

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

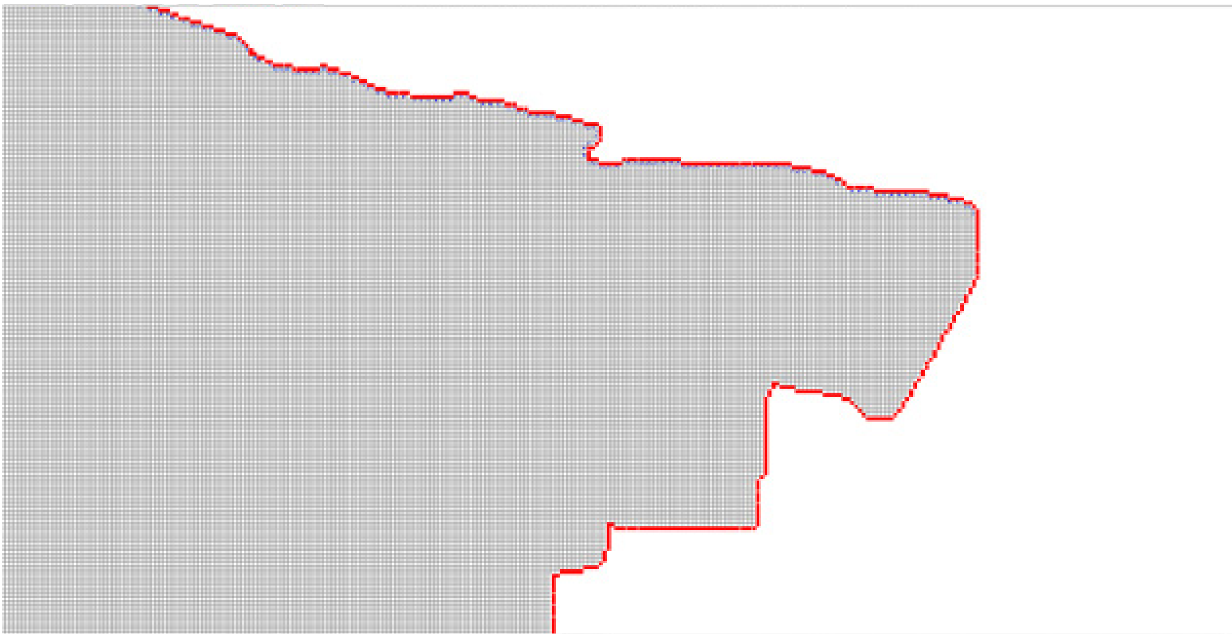


Figure 20. Screenshot showing how boundary grid elements are defined by line

Elevation data was imported in the form of the DEM gathered through LiDAR. These elevation points in PTS format were extrapolated into the model, providing an elevation value for each grid element.

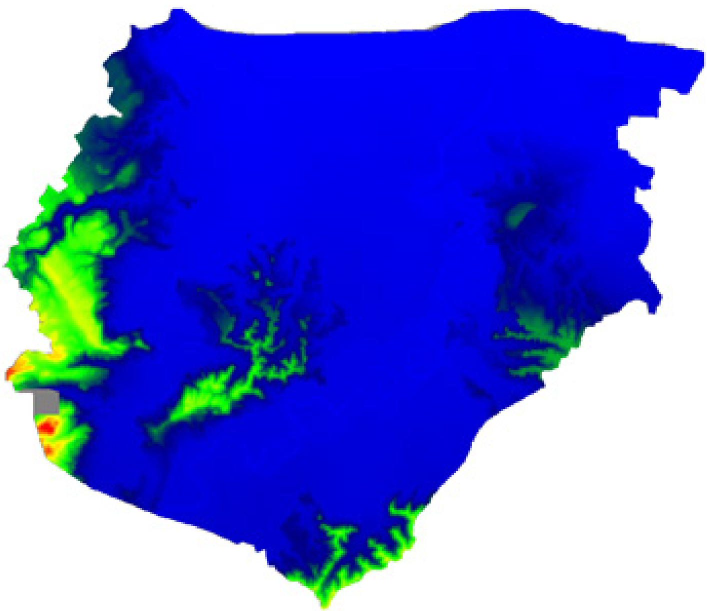


Figure 21. Screenshots of PTS files when loaded into the FLO-2D program

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

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

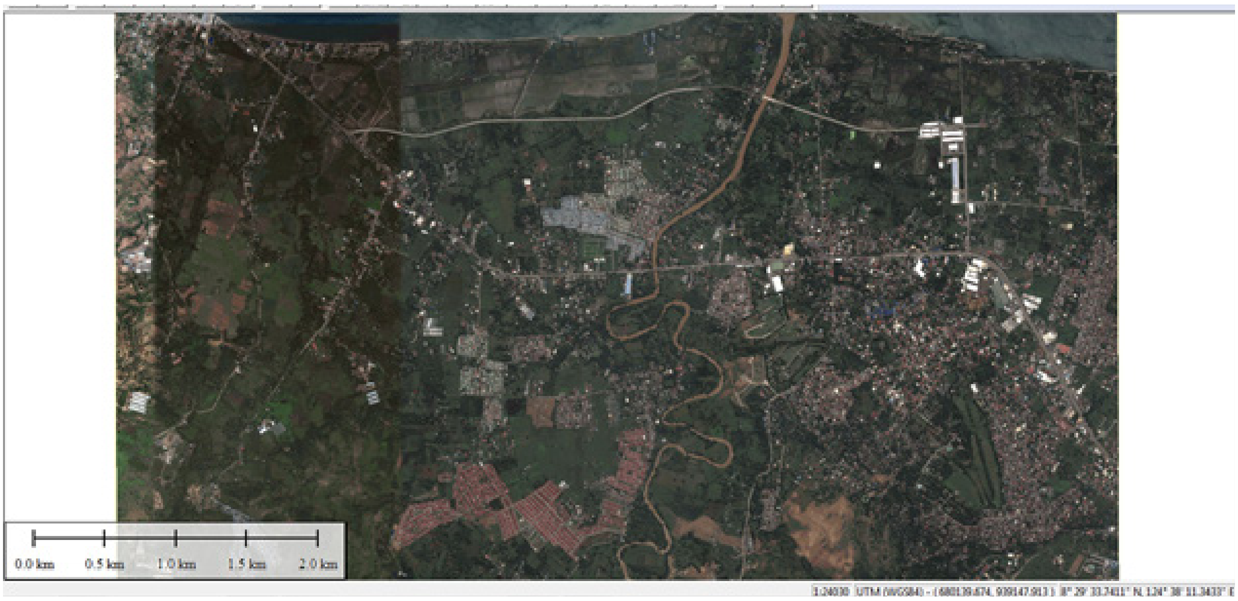


Figure 22. Areal image of Iponan floodplain

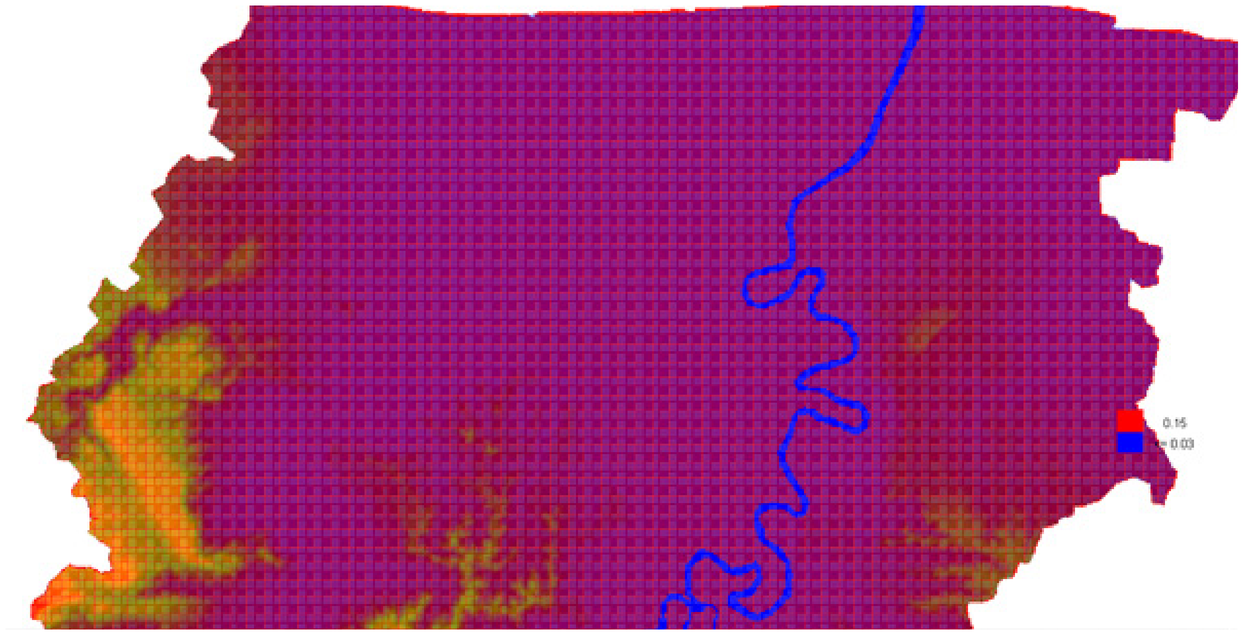


Figure 23. Screenshot of Manning's n-value rendering

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.

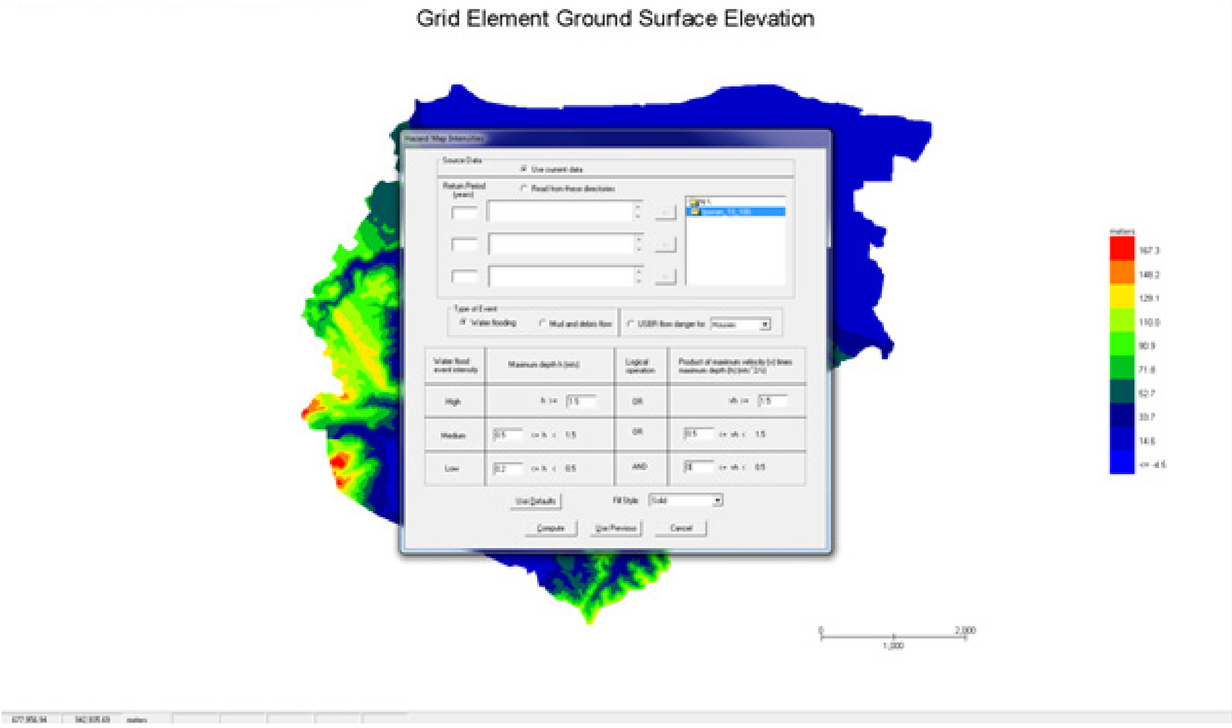


Figure 24. Flo-2D Mapper Pro General Procedure

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.

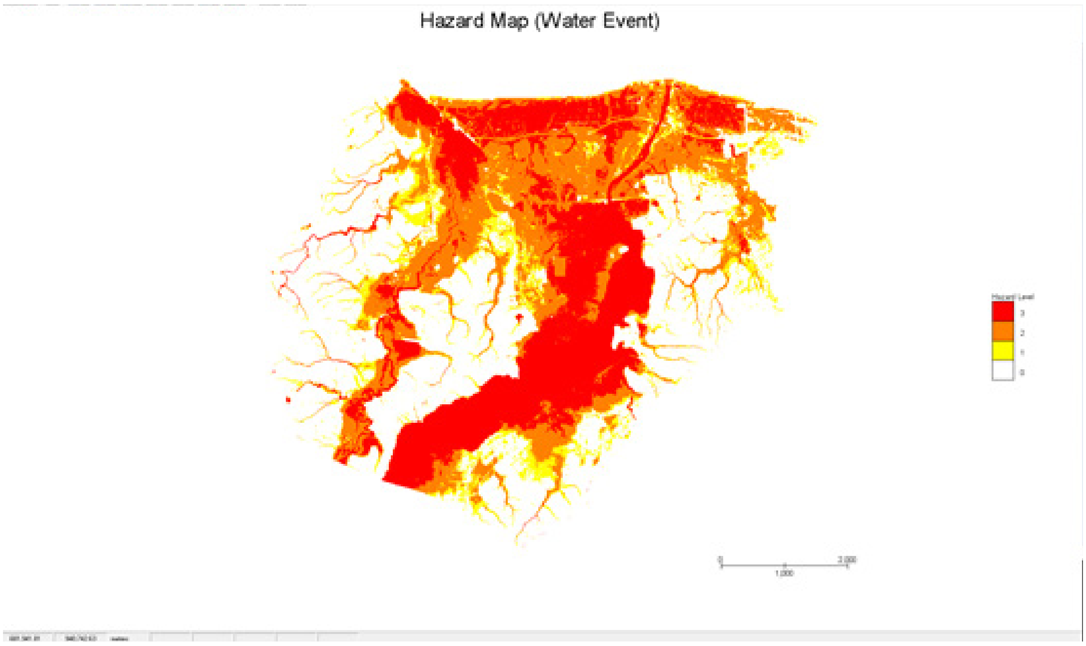


Figure 25. Iponan Floodplain Generated Hazard Maps using FLO-2D Mapper

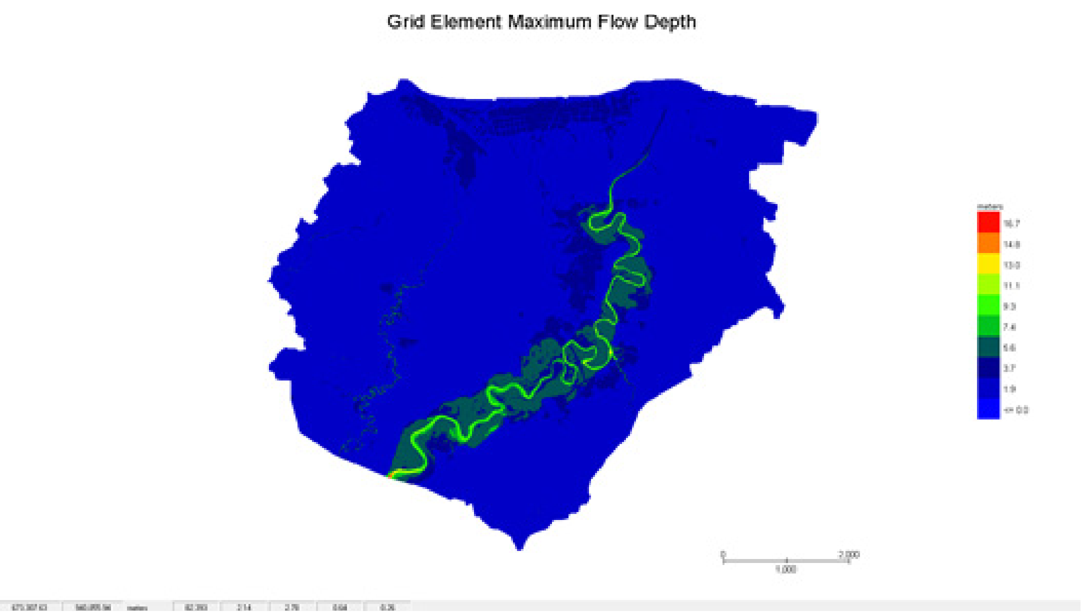
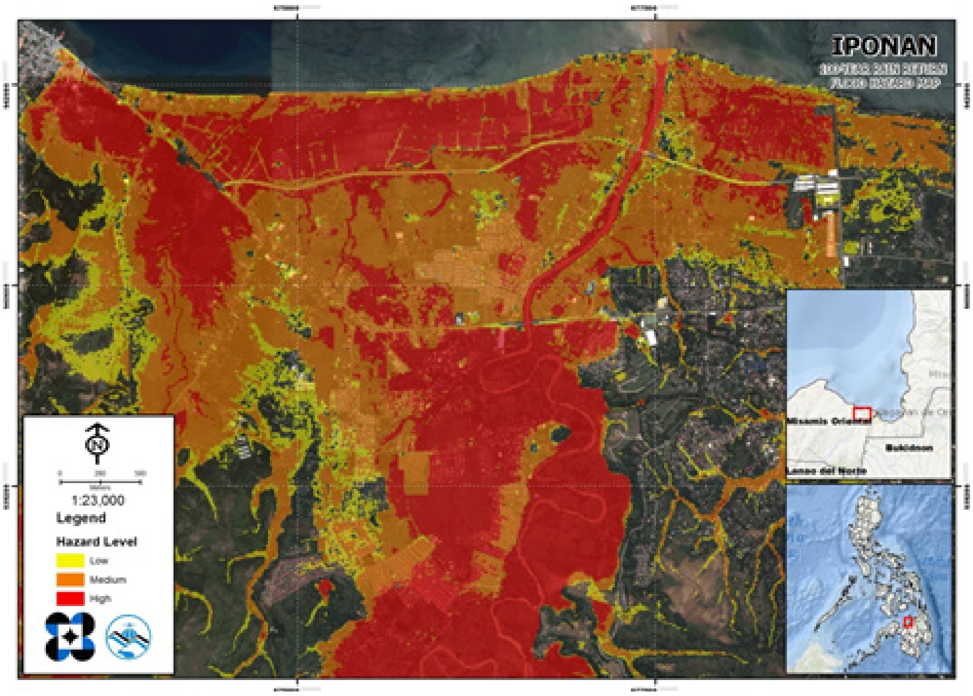


Figure 26. Iponan floodplain generated flow depth map using FLO-2D Mapper

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

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

After calibrating the Iponan HEC-HMS river basin model, its accuracy was measured against the observed values. The comparison between the two discharge data are shown in Figure 28.

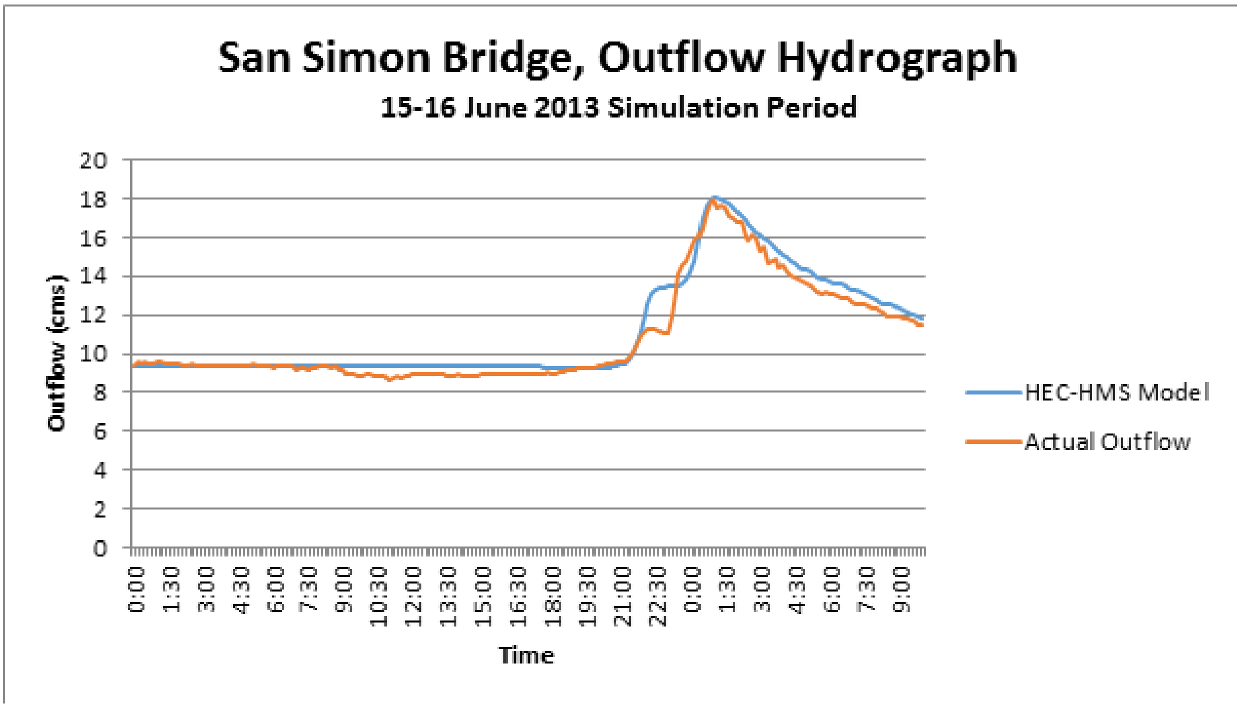


Figure 28. Iponan Bridge - Passi Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.574117.

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 0.953.

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 -4.74.

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 0.217.

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

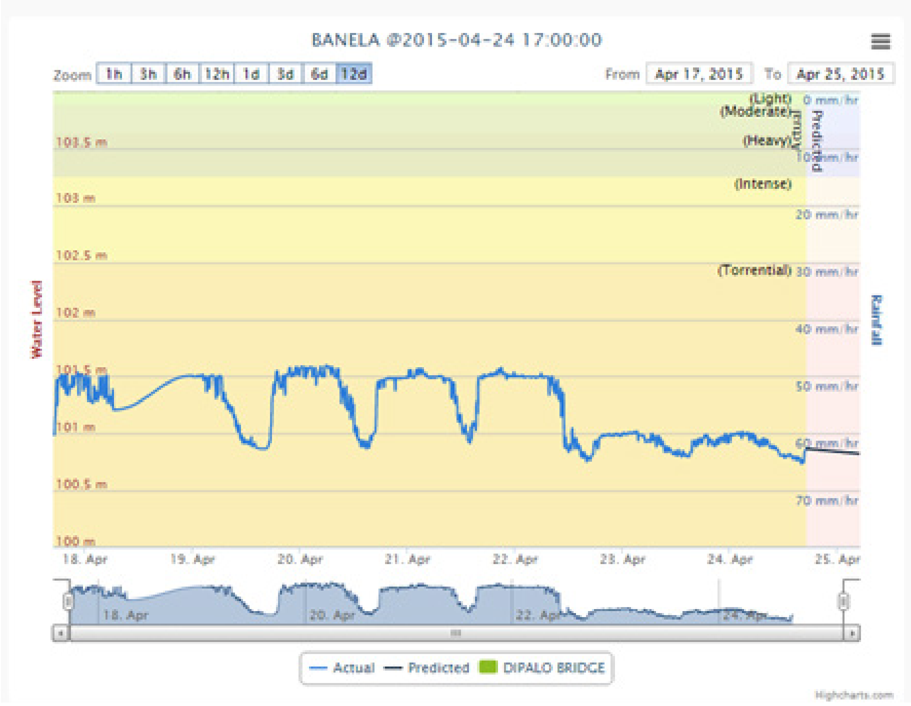


Figure 29. Sample DREAM Water Level Forecast

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

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

4.2.1 Hydrograph using the Rainfall-Runoff Model

The outflow of Iponan using the Lumbia 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 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 589.3 cms. This occurs after 4 hours and 20 minutes after the peak precipitation of 24.22 mm.

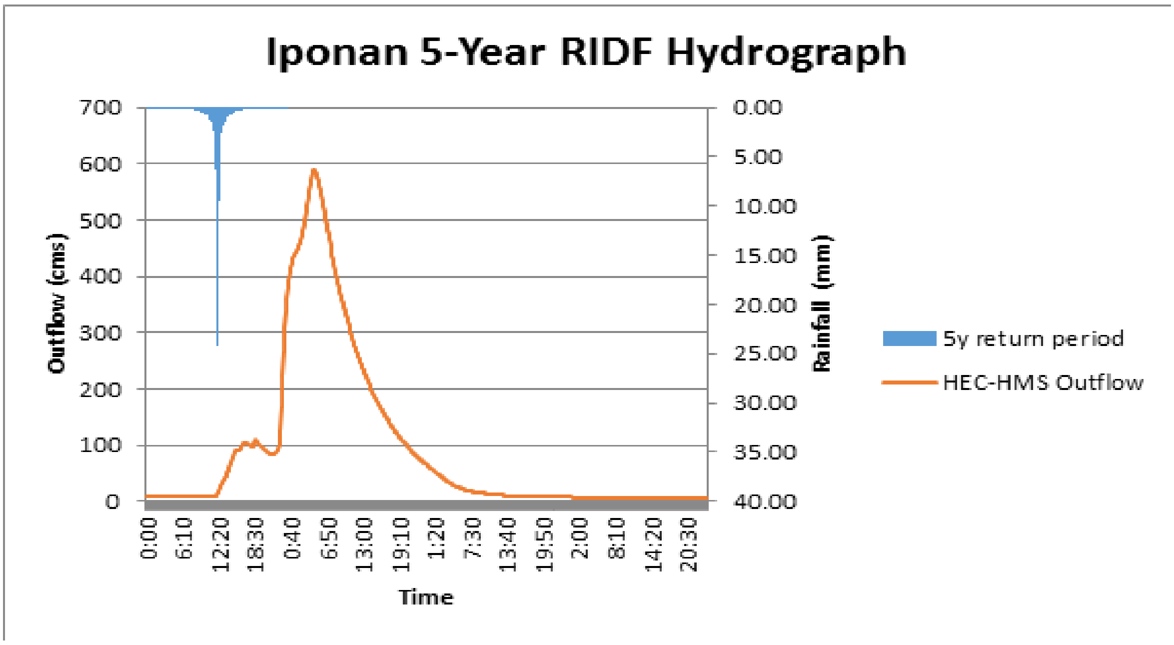


Figure 30. Outflow hydrograph generated using the Lumbia 5-Year RIDF inputted in HEC-HMS

In the 10-year return period graph (Figure 31), the peak outflow is 806.2 cms. This occurs after 3 hours and 10 minutes after the peak precipitation of 27.12 mm.

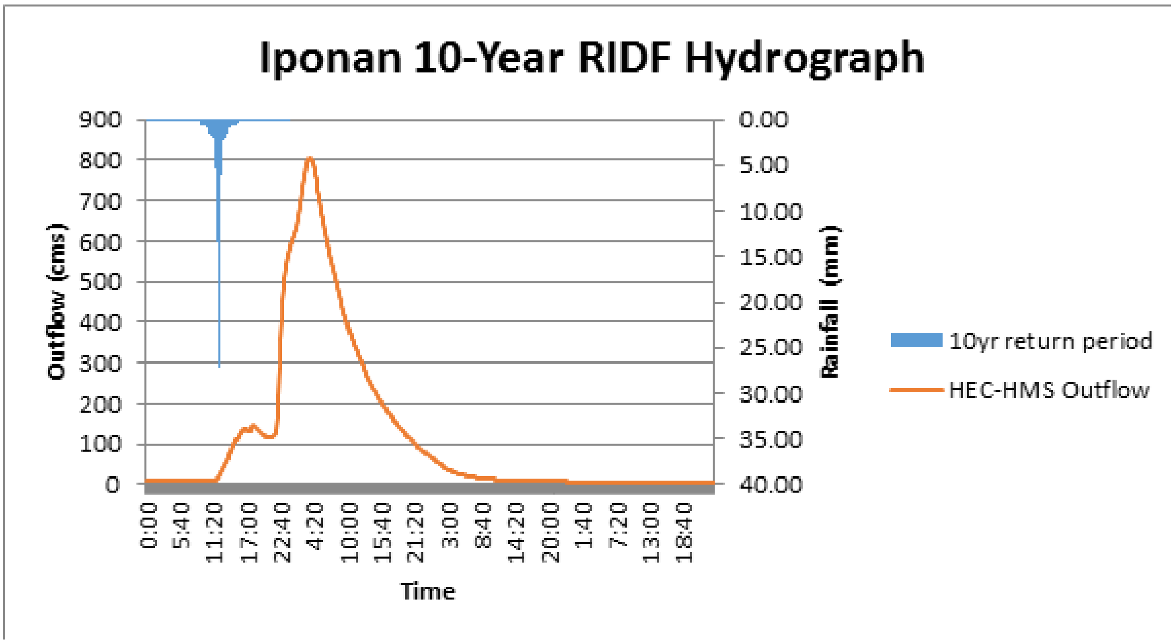


Figure 31. Outflow hydrograph generated using the Lumbia 10-Year RIDF inputted in HEC-HMS

In the 25-year return period graph (Figure 32), the peak outflow is 1100.3 cms. This occurs after 2 hours and 10 minutes after the peak precipitation of 30.79 mm.

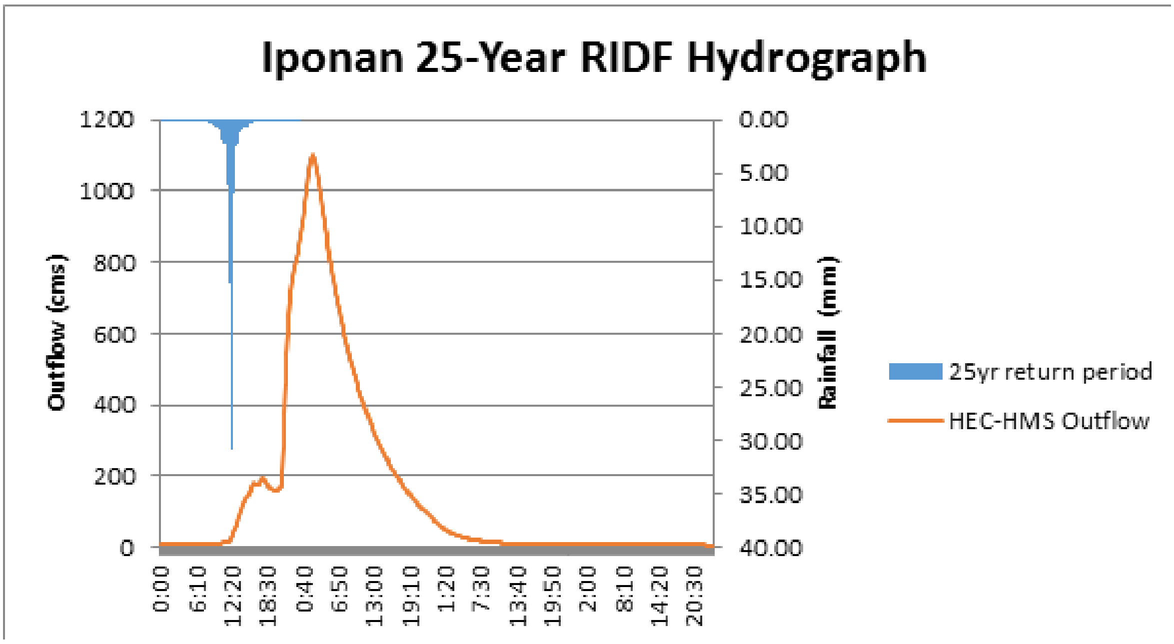


Figure 32. Outflow hydrograph generated using the Lumbia 25-Year RIDF inputted in HEC-HMS

In the 50-year return period graph (Figure 33), the peak outflow is 1336.4 cms. This occurs after 1 hours and 40 minutes after the peak precipitation of 33.54 mm.

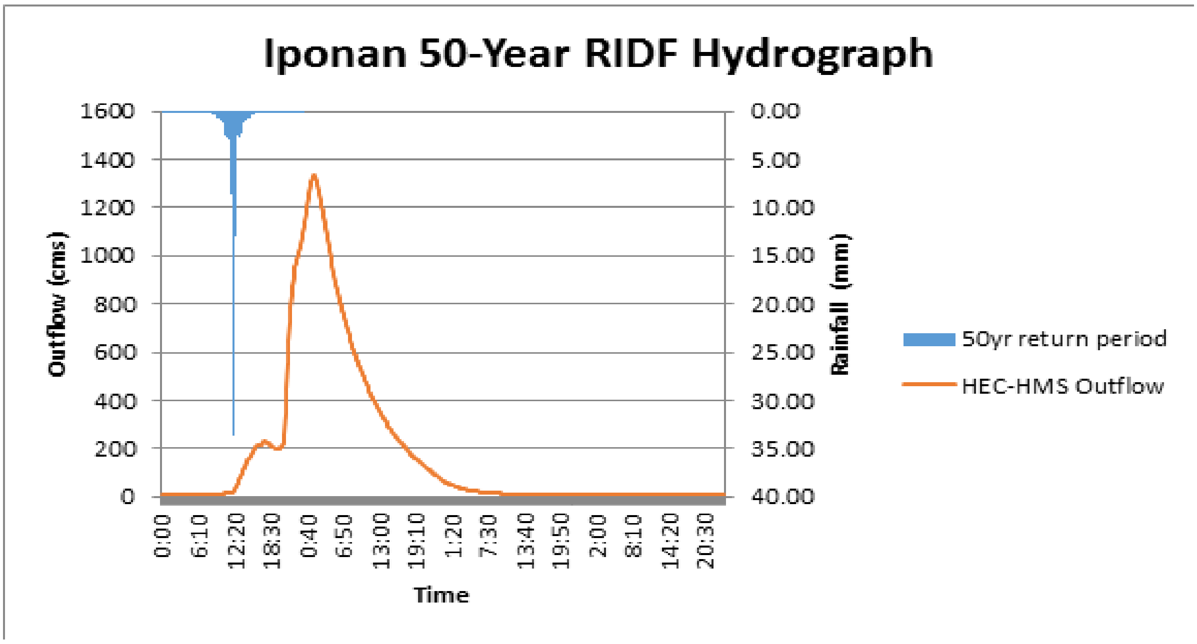


Figure 33. Outflow hydrograph generated using the Lumbia 50-Year RIDF inputted in HEC-HMS

In the 100-year return period graph (Figure 34), the peak outflow is 1473.4 cms. This occurs after 50 minutes after the peak precipitation of 36.20 mm.

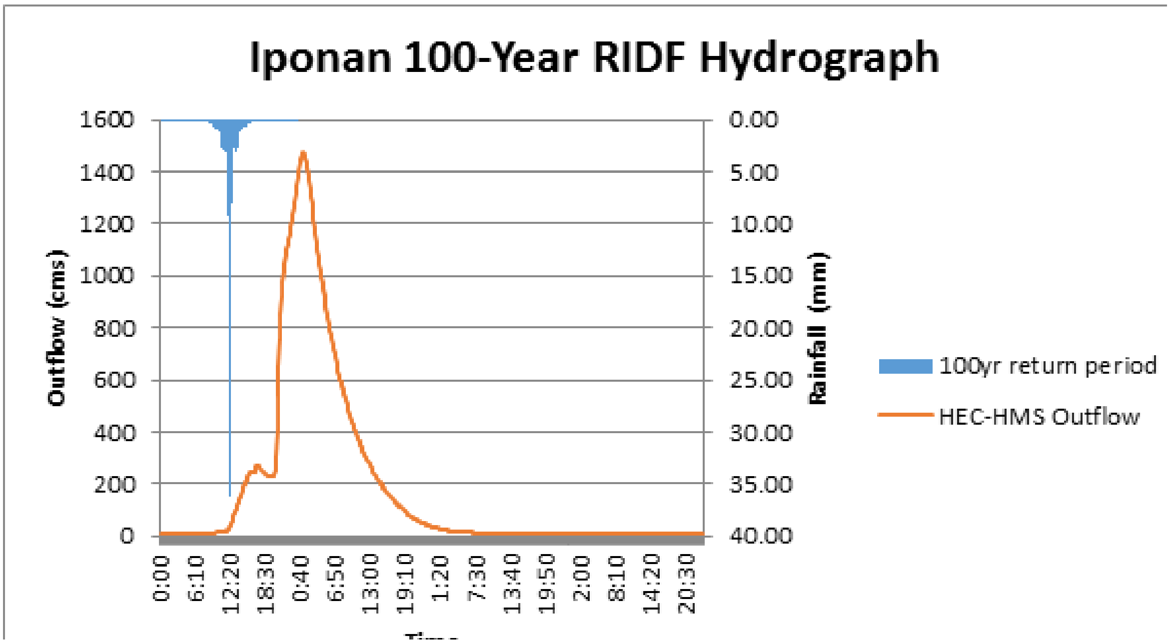


Figure 34. Outflow hydrograph generated using the Lumbia 100-Year RIDF inputted in HEC-HMS

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

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

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	104.4513851	24.22042415	589.3	4 hours, 20 minutes
10-Year	116.419773	27.12175063	806.2	3 hours, 10 minutes
25-Year	134.0261617	30.78891426	1100.3	2 hours, 10 minutes
50-Year	147.0825849	33.54046447	1336.4	1 hour, 40 minutes
100-Year	160.0400957	36.19781576	1473.4	50 minutes

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

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

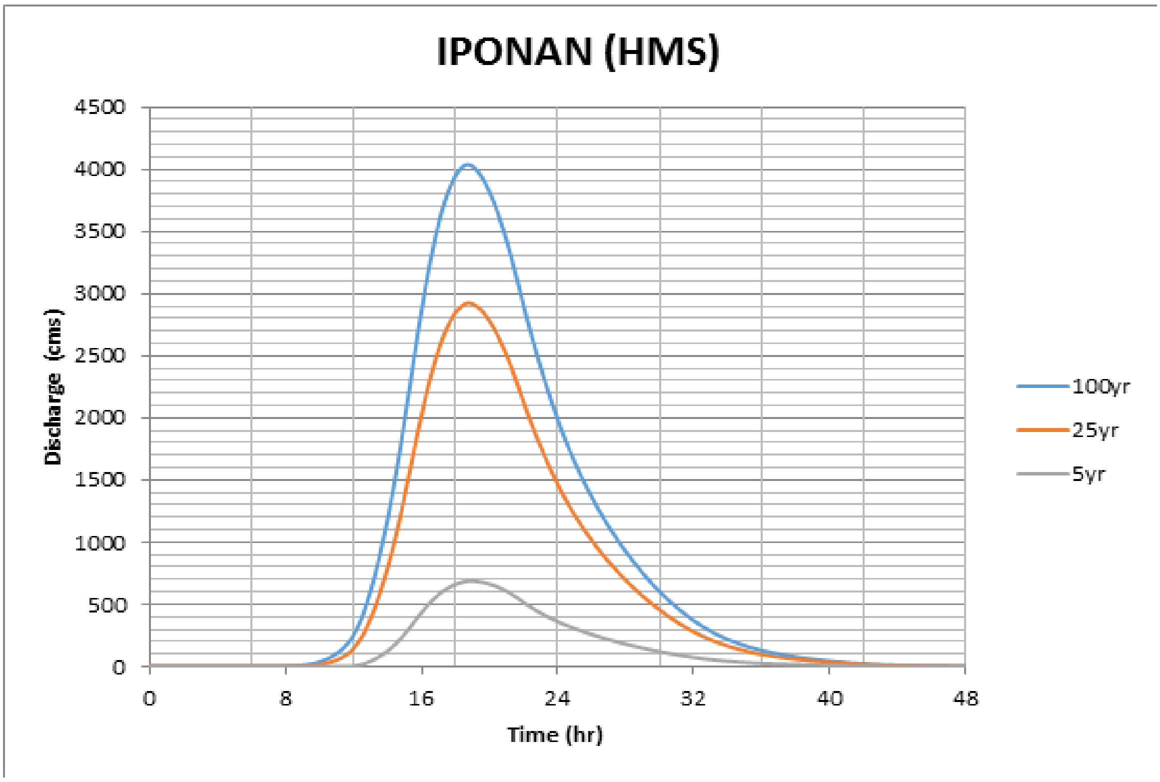


Figure 35. Outflow hydrograph generated for Iponan using the Cagayan de Oro City 5-, 25-, and 100-year Rainfall Intensity Duration Frequency (RIDF) in HEC-HMS

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

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	688.1	18 hours, 50 minutes
25-Year	2923.6	18 hours, 50 minutes
100-Year	4039.3	18 hours, 40 minutes

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

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

Discharge Point	Qbankful, cms	QMED, cms	Validation
Iponan (1)	984.99	605.53	Pass

The 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 the discharge point that did not have actual discharge data. The calibrated discharge data were also used for areas in the floodplain that were 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 Iponan river basin.

Flood Hazard Maps and Flow Depth Maps

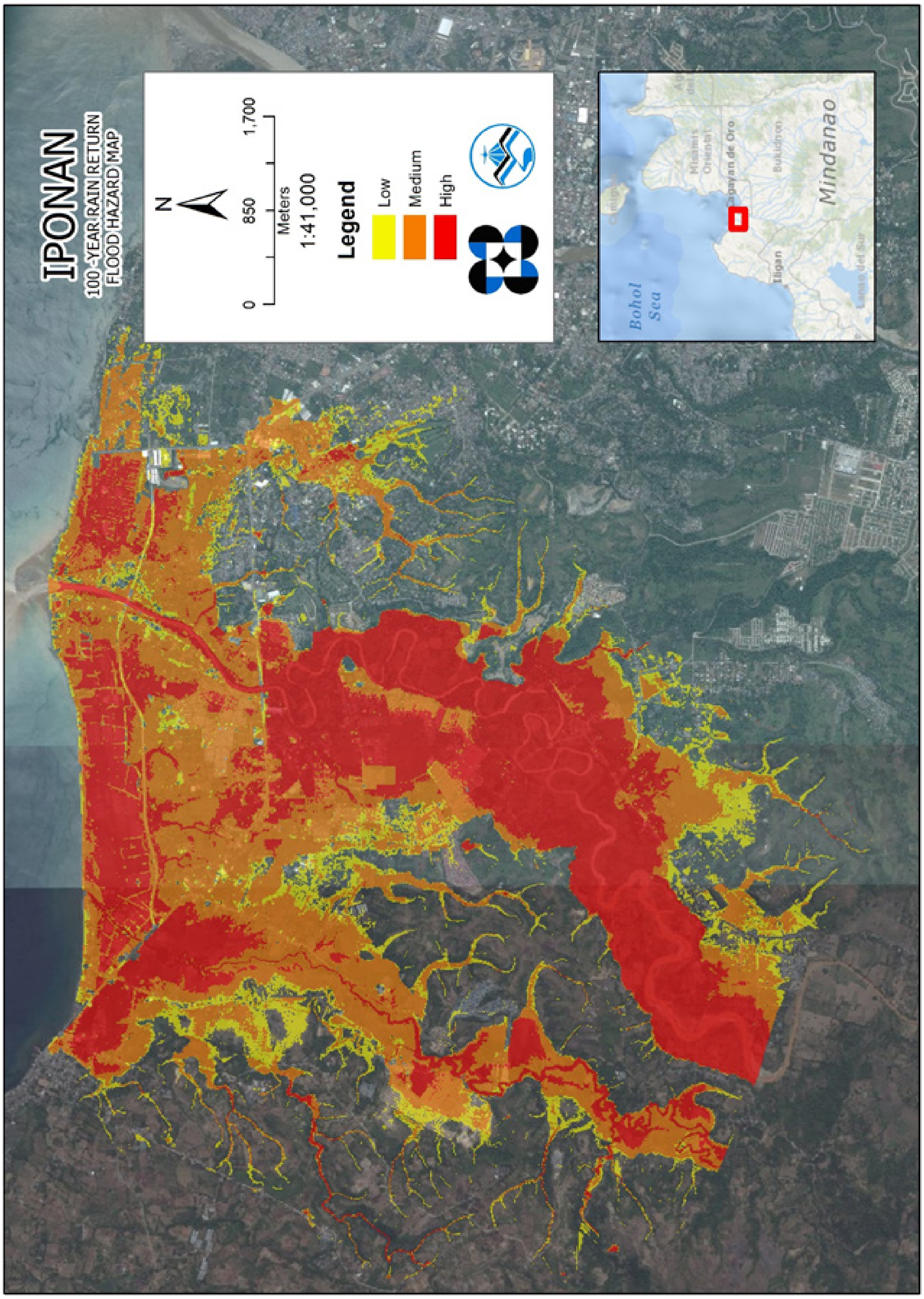


Figure 36. 100-year Flood Hazard Map for Iponan River Basin

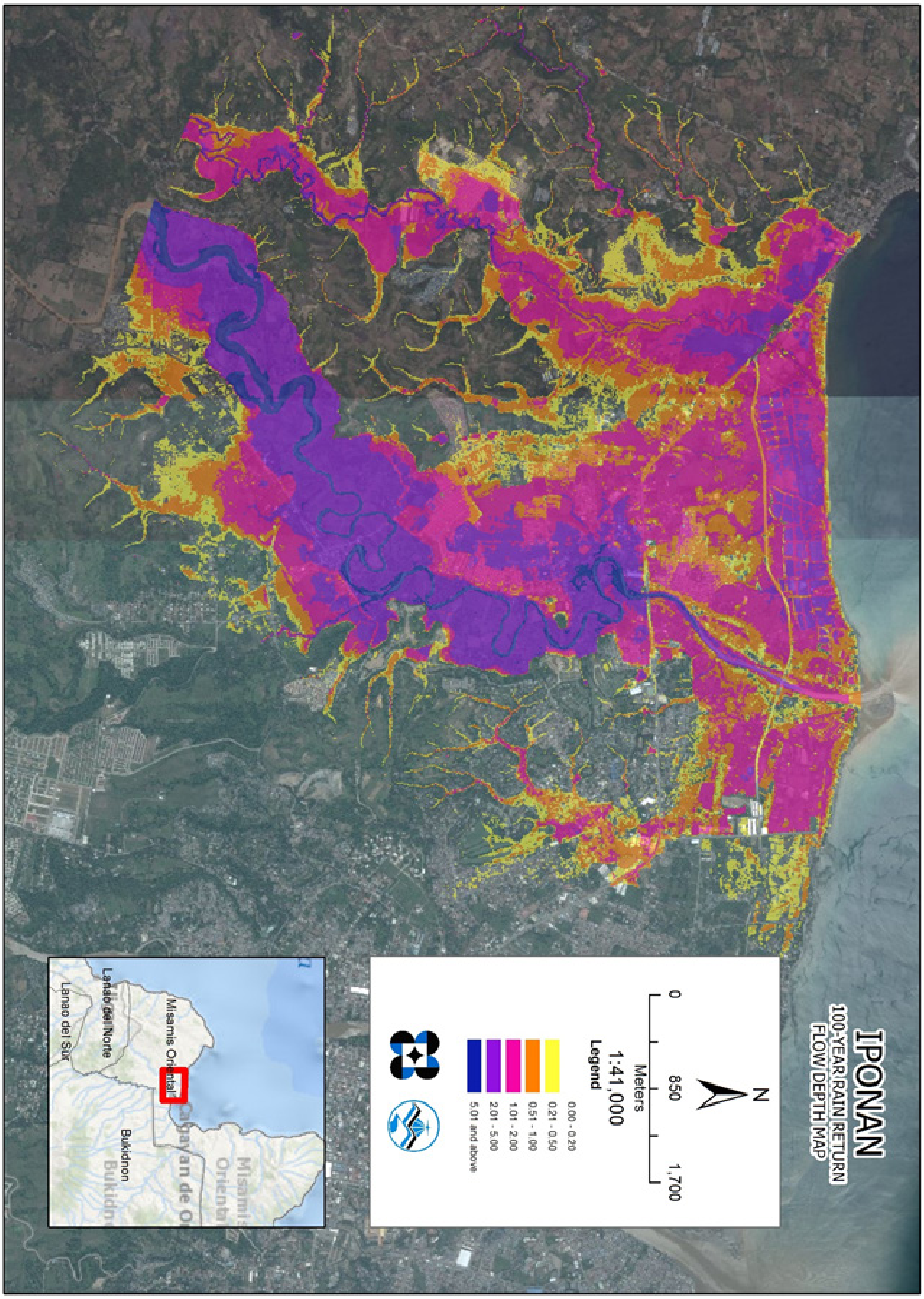


Figure 37. 100-year Flow Depth Map for Iponan River Basin

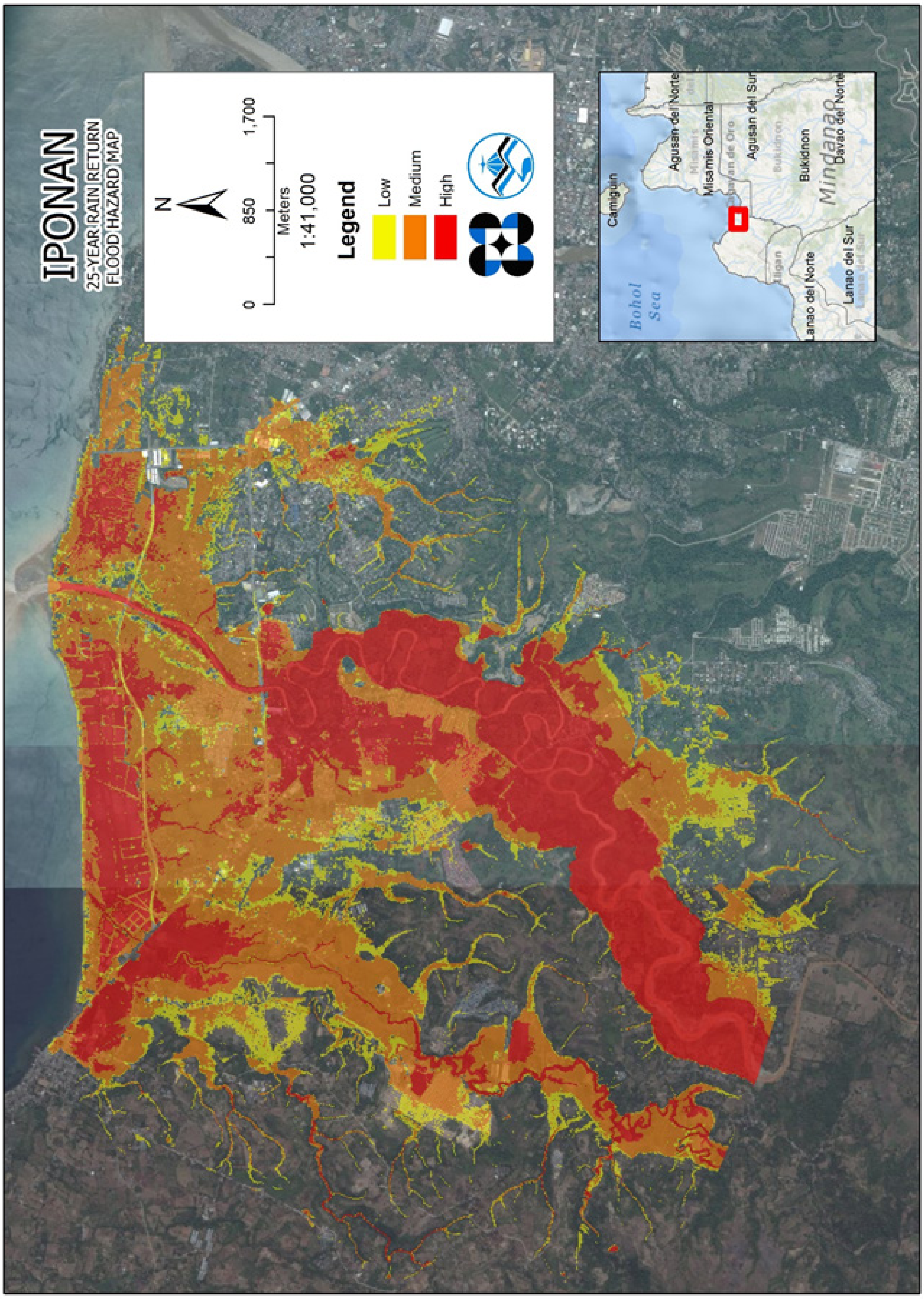


Figure 38. 25-year Flood Hazard Map for Iponan River Basin

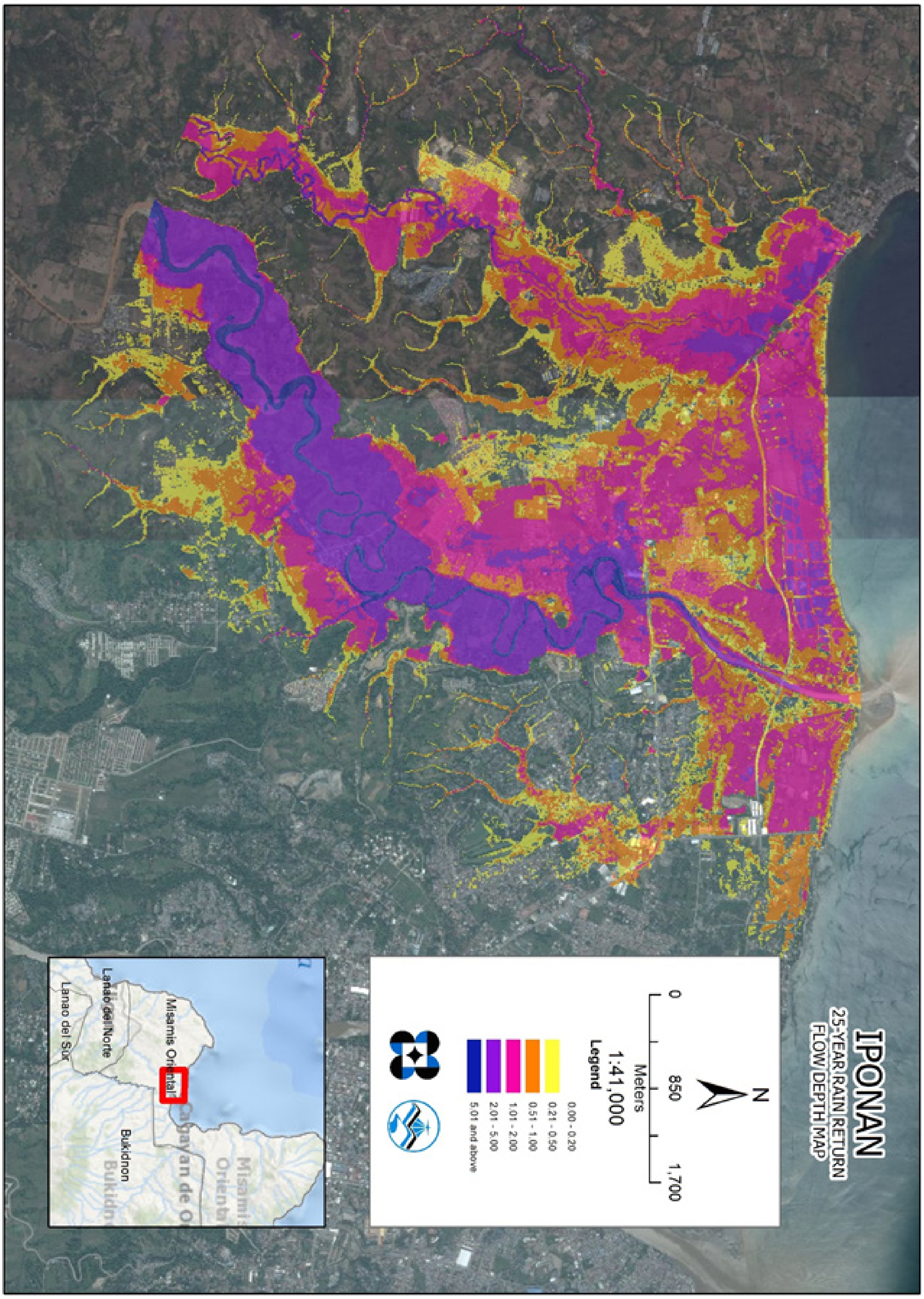


Figure 39. 25-year Flow Depth Map for Iponan River Basin

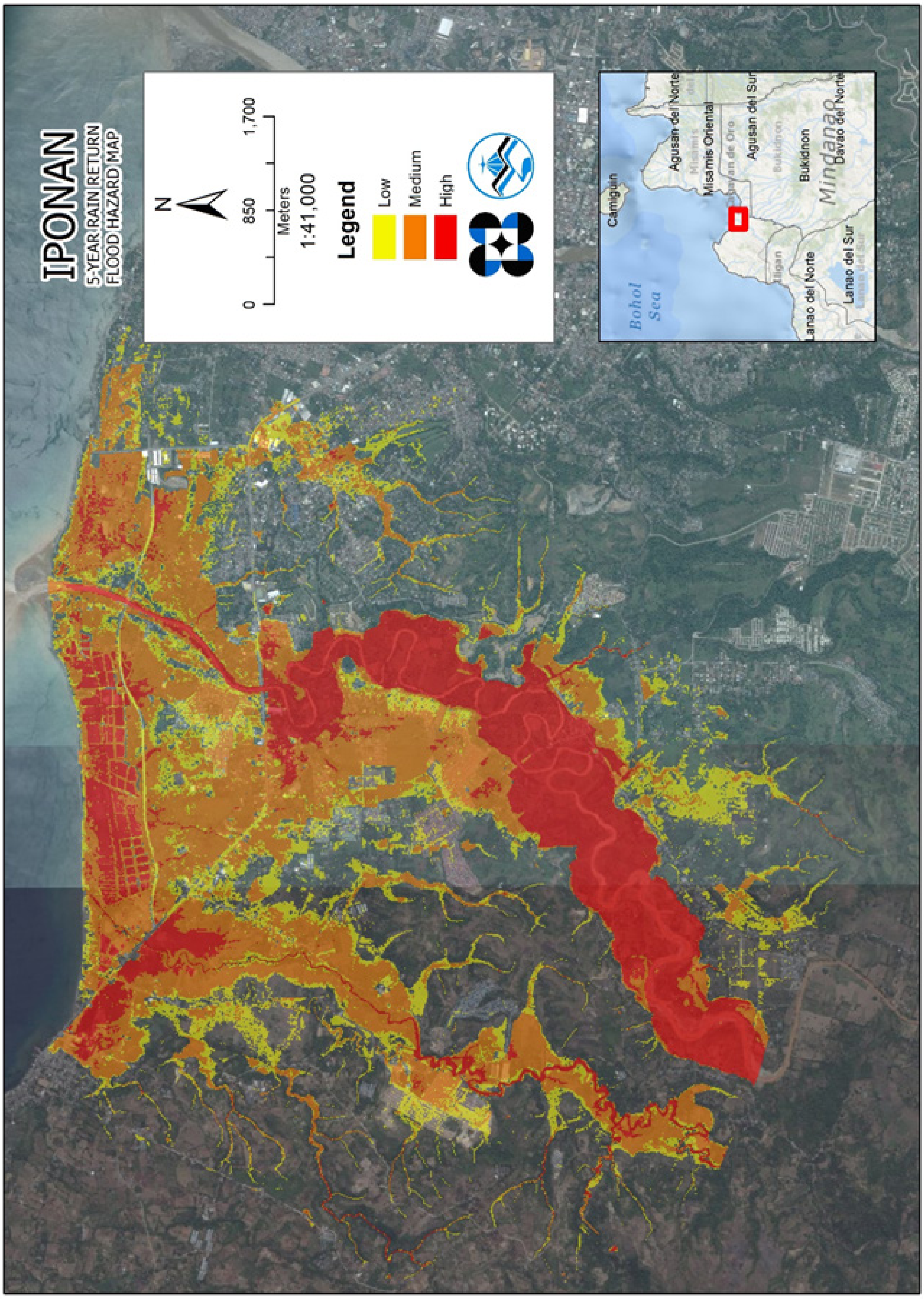


Figure 40. 5-year Flood Hazard Map for Iponan River Basin

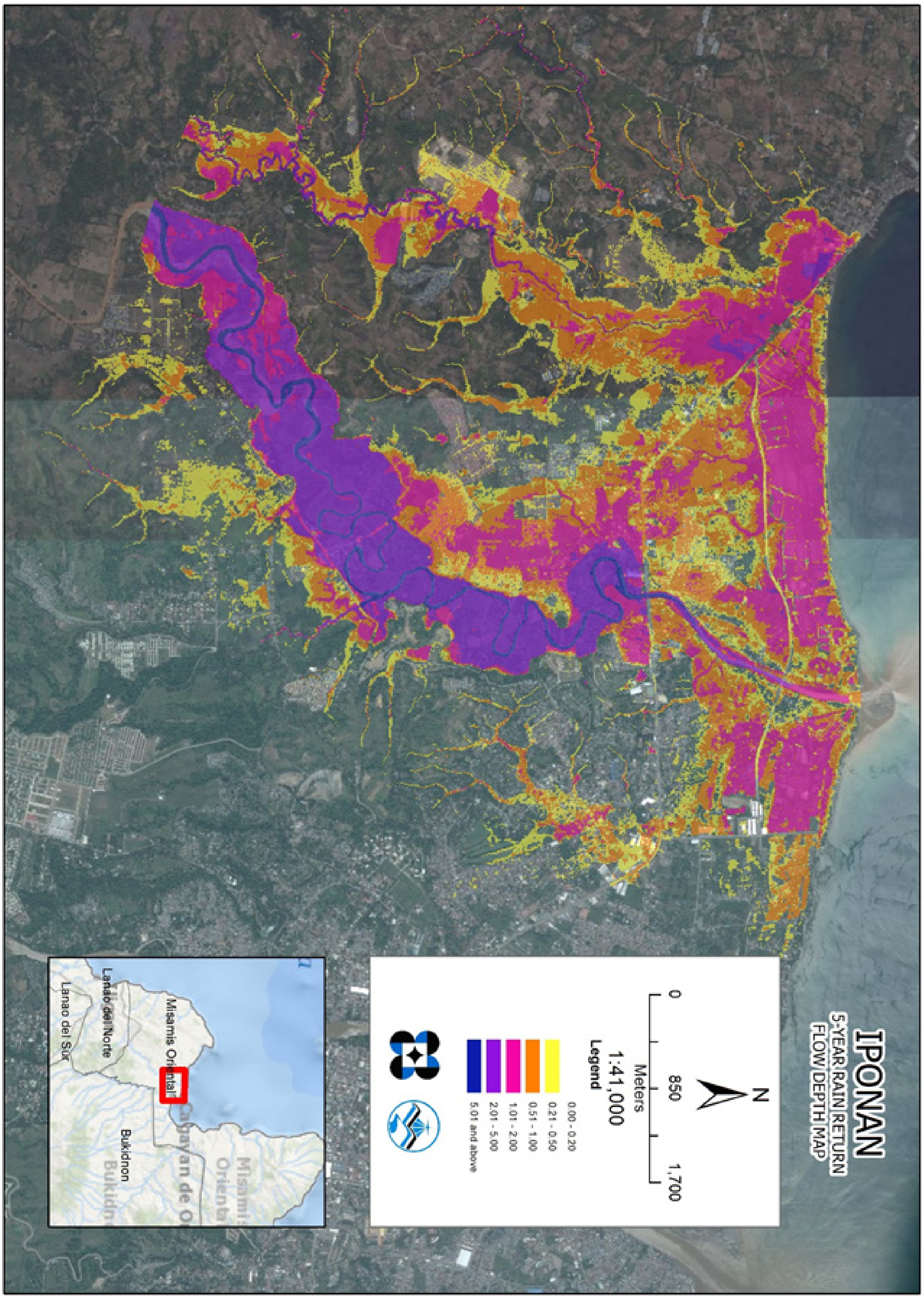


Figure 41. 5-year Flow Depth Map for Iponan River Basin

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Appendix

Appendix A. San Simon 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
59B	78.1932	0	5.27	10.319	Discharge	0.55206	0.9	Ratio to Peak	0.01	0.01
60B	83.0994	0	1.01	3.362	Discharge	0.12509	0.9	Ratio to Peak	0.01	0.01
61B	81.0186	0	2.16	5.245	Discharge	0.37993	0.9	Ratio to Peak	0.01	0.01
62B	65.6166	0	1.27	3.788	Discharge	0.25657	0.9	Ratio to Peak	0.01	0.01
63B	64.4538	0	0.79	3.01	Discharge	0.16417	0.9	Ratio to Peak	0.01	0.01
64B	77.6832	0	0.84	3.088	Discharge	0.13864	0.9	Ratio to Peak	0.01	0.01
65B	78.132	0	0.97	3.296	Discharge	0.16197	0.9	Ratio to Peak	0.01	0.01
66B	77.2446	0	2.19	5.29	Discharge	0.39633	0.9	Ratio to Peak	0.01	0.01
67B	78.54	0	1.37	3.944	Discharge	0.22199	0.9	Ratio to Peak	0.01	0.01
68B	78.54	0	0.95	3.26	Discharge	0.40537	0.9	Ratio to Peak	0.01	0.01
69B	78.54	0	0.81	3.028	Discharge	0.50534	0.9	Ratio to Peak	0.01	0.01

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
70B	78.54	0	0.58	2.661	Discharge	0.22196	0.9	Ratio to Peak	0.01	0.01
71B	78.795	0	1.27	3.793	Discharge	0.3715	0.9	Ratio to Peak	0.01	0.01
72B	78.54	0	0.85	3.1	Discharge	0.29803	0.9	Ratio to Peak	0.01	0.01
73B	78.6114	0	0.13	1.922	Discharge	0.15283	0.9	Ratio to Peak	0.01	0.01
74B	80.4678	0	0.31	2.212	Discharge	0.33199	0.9	Ratio to Peak	0.01	0.01
75B	78.8664	0	1.39	3.978	Discharge	0.84372	0.9	Ratio to Peak	0.01	0.01
76B	78.54	0	0.7	2.858	Discharge	0.34625	0.9	Ratio to Peak	0.01	0.01
77B	78.6318	0	2.21	5.317	Discharge	0.84168	0.9	Ratio to Peak	0.01	0.01
78B	80.223	0	0.18	2.01	Discharge	0.1757	0.9	Ratio to Peak	0.01	0.01
79B	78.6828	0	0.23	2.095	Discharge	0.19412	0.9	Ratio to Peak	0.01	0.01
80B	79.1316	0	2.15	5.221	Discharge	0.50932	0.9	Ratio to Peak	0.01	0.01

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
81B	78.7746	0	1.15	3.584	Discharge	0.47853	0.9	Ratio to Peak	0.01	0.01
82B	78.7746	0	0.85	3.094	Discharge	0.60472	0.9	Ratio to Peak	0.01	0.01
83B	78.54	0	0.03	1.759	Discharge	0.29046	0.9	Ratio to Peak	0.01	0.01
84B	78.591	0	0.7	2.86	Discharge	0.46601	0.9	Ratio to Peak	0.01	0.01

Appendix B. San Simon Bridge Reach Parameters

Reach Num-ber	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Man-ning's n	Shape	Width	Side Slope
63R	Automatic Fixed Interval	3632.2	0.00589	0.025	Trapezoid	30	45
64R	Automatic Fixed Interval	7633.98	0.00265	0.025	Trapezoid	30	45
65R	Automatic Fixed Interval	1879.58	0.01961	0.025	Trapezoid	30	45
66R	Automatic Fixed Interval	12380.1	0.00175	0.025	Trapezoid	30	45
67R	Automatic Fixed Interval	3359.4	0.00576	0.025	Trapezoid	30	45
68R	Automatic Fixed Interval	17252	0.00877	0.025	Trapezoid	30	45
69R	Automatic Fixed Interval	2478.22	0.01447	0.025	Trapezoid	30	45
70R	Automatic Fixed Interval	21539.6	0.01748	0.025	Trapezoid	30	45
71R	Automatic Fixed Interval	17275.8	0.0198	0.025	Trapezoid	30	45
72R	Automatic Fixed Interval	9024.46	0.00679	0.025	Trapezoid	30	45
73R	Automatic Fixed Interval	18318.4	0.01343	0.025	Trapezoid	30	45
74R	Automatic Fixed Interval	18732	0.00405	0.025	Trapezoid	30	45
75R	Automatic Fixed Interval	29815.8	0.02017	0.025	Trapezoid	30	45
76R	Automatic Fixed Interval	5240.13	0.00616	0.025	Trapezoid	30	45
77R	Automatic Fixed Interval	17513.2	0.00646	0.025	Trapezoid	30	45
78R	Automatic Fixed Interval	25036.1	0.01469	0.025	Trapezoid	30	45
79R	Automatic Fixed Interval	45325.4	0.00121	0.025	Trapezoid	30	45
80R	Automatic Fixed Interval	21482.8	0.01379	0.025	Trapezoid	30	45
81R	Automatic Fixed Interval	7982.28	0.0343	0.025	Trapezoid	30	45
82R	Automatic Fixed Interval	13554	0.02196	0.025	Trapezoid	30	45
83R	Automatic Fixed Interval	12015.6	0.02198	0.025	Trapezoid	30	45
84R	Automatic Fixed Interval	14770.5	0.00656	0.025	Trapezoid	30	45
85R	Automatic Fixed Interval	8192.28	0.00722	0.025	Trapezoid	30	45
86R	Automatic Fixed Interval	16947.8	0.00252	0.025	Trapezoid	30	45
87R	Automatic Fixed Interval	17156.7	0.00593	0.025	Trapezoid	30	45

Appendix C. Iponan HEC-HMS Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	6	0	0	0
0.166667	0	0	0	6.166667	0	0	0
0.333333	0	0	0	6.333333	0	0	0
0.5	0	0	0	6.5	0.1	0	0
0.666667	0	0	0	6.666667	0.1	0	0
0.833333	0	0	0	6.833333	0.3	0	0
1	0	0	0	7	0.4	0	0
1.166667	0	0	0	7.166667	0.7	0.1	0
1.333333	0	0	0	7.333333	1	0.2	0
1.5	0	0	0	7.5	1.4	0.3	0
1.666667	0	0	0	7.666667	1.9	0.4	0
1.833333	0	0	0	7.833333	2.5	0.6	0
2	0	0	0	8	3.3	0.9	0
2.166667	0	0	0	8.166667	4.3	1.2	0
2.333333	0	0	0	8.333333	5.4	1.6	0
2.5	0	0	0	8.5	6.7	2.1	0
2.666667	0	0	0	8.666667	8.2	2.6	0
2.833333	0	0	0	8.833333	10	3.3	0
3	0	0	0	9	12.1	4.2	0
3.166667	0	0	0	9.166667	14.6	5.2	0
3.333333	0	0	0	9.333333	17.7	6.6	0
3.5	0	0	0	9.5	21.4	8.3	0
3.666667	0	0	0	9.666667	25.8	10.4	0
3.833333	0	0	0	9.833333	31.2	13	0
4	0	0	0	10	37.7	16.3	0
4.166667	0	0	0	10.16667	45.2	20.2	0
4.333333	0	0	0	10.33333	53.9	24.8	0
4.5	0	0	0	10.5	64	30.2	0
4.666667	0	0	0	10.66667	75.7	36.6	0
4.833333	0	0	0	10.83333	88.9	44.1	0.1
5	0	0	0	11	103.9	52.6	0.1
5.166667	0	0	0	11.16667	121	62.6	0.2
5.333333	0	0	0	11.33333	140.4	74.1	0.4
5.5	0	0	0	11.5	162.1	87.3	0.7
5.666667	0	0	0	11.66667	187.3	102.7	1.2
5.833333	0	0	0	11.83333	216.9	121.2	2.1

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
12	253.9	145.2	4.5	18.33333	4010.4	2896.7	676.2
12.16667	295.9	172.9	7.9	18.5	4029.2	2913.1	681.9
12.33333	343.4	204.5	11.9	18.66667	4039.3	2923.2	686.3
12.5	398.3	241.3	17.3	18.83333	4036.3	2923.6	688.1
12.66667	461.9	284.7	24.5	19	4024.9	2917.6	687.9
12.83333	531.4	332.5	33.1	19.16667	4006.2	2906.3	686.6
13	606.6	384.5	42.7	19.33333	3980.1	2889.6	684.1
13.16667	688.5	441.4	53.4	19.5	3947.8	2868.3	680.5
13.33333	776.3	502.9	65.5	19.66667	3910.1	2843	675.9
13.5	869.3	568.3	78.6	19.83333	3867.1	2813.8	670.4
13.66667	967.7	637.7	92.7	20	3818.6	2780.4	664
13.83333	1073.7	713.1	108.4	20.16667	3765.3	2743.4	656.8
14	1185.4	792.8	125.7	20.33333	3707.6	2703.2	648.8
14.16667	1302.2	876.6	144	20.5	3645.3	2659.5	640
14.33333	1424.9	964.8	163.7	20.66667	3577.2	2611.4	629.9
14.5	1556	1059.7	185.6	20.83333	3505	2560.1	618.8
14.66667	1692	1158.5	209.2	21	3429	2506	606.8
14.83333	1832.1	1260.6	234.1	21.16667	3349.1	2449	594
15	1977.1	1366.7	260.4	21.33333	3264.1	2388	579.8
15.16667	2126.6	1476.6	288.4	21.5	3176.2	2324.7	564.5
15.33333	2277.8	1588.1	317.5	21.66667	3086.5	2259.9	548.7
15.5	2429.1	1700	347.3	21.83333	2996.3	2194.7	532.7
15.66667	2577.3	1809.8	376.8	22	2907.8	2130.7	517
15.83333	2721.9	1917.2	405.6	22.16667	2819.9	2067.1	501.5
16	2862.9	2022.3	434.2	22.33333	2733.1	2004.3	486
16.16667	2998.9	2124.1	462.2	22.5	2649.8	1944	471.3
16.33333	3125.2	2218.7	488.3	22.66667	2569.4	1885.9	457.6
16.5	3245	2308.6	512.7	22.83333	2490.7	1829	444.3
16.66667	3358.6	2394.3	536.3	23	2413.7	1773.4	431.4
16.83333	3464.2	2474.1	558.4	23.16667	2339.1	1719.5	419
17	3558.7	2545.8	578.1	23.33333	2266.2	1666.9	407
17.16667	3645.9	2612.1	596.1	23.5	2194.7	1615.3	395.3
17.33333	3725.6	2673	612.9	23.66667	2125	1565	383.8
17.5	3795.2	2726.6	627.8	23.83333	2057.9	1516.6	372.9
17.66667	3854.2	2772.3	640.3	24	1992.6	1469.5	362.4
17.83333	3905.3	2812.2	651.3	24.16667	1929.3	1423.8	352
18	3948.8	2846.6	661	24.33333	1868.5	1380	342.1
18.16667	3983.5	2874.5	669.3	24.5	1810.7	1338.4	332.8

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
24.66667	1755	1298.2	323.9	31	477.5	361.5	95.1
24.83333	1701.1	1259.4	315.2	31.16667	458.6	347.2	91.4
25	1649.1	1221.9	306.7	31.33333	440.1	333.3	87.7
25.16667	1598.3	1185.3	298.3	31.5	422.1	319.7	84.2
25.33333	1549.1	1149.8	290.1	31.66667	404.7	306.5	80.7
25.5	1501.5	1115.3	282.1	31.83333	388	293.9	77.4
25.66667	1455.9	1082.3	274.3	32	371.9	281.7	74.2
25.83333	1411.5	1050.2	266.8	32.16667	356.4	270	71.1
26	1368.2	1018.8	259.3	32.33333	341.4	258.6	68.2
26.16667	1325.8	988.2	252	32.5	326.9	247.6	65.3
26.33333	1284.3	958	244.7	32.66667	312.8	236.9	62.5
26.5	1243.7	928.5	237.5	32.83333	299.2	226.6	59.7
26.66667	1204	899.6	230.4	33	286.2	216.8	57.1
26.83333	1166	871.9	223.5	33.16667	273.8	207.4	54.6
27	1129.7	845.4	217.1	33.33333	261.9	198.4	52.3
27.16667	1094.4	819.6	210.8	33.5	250.6	189.8	50
27.33333	1059.9	794.4	204.6	33.66667	239.8	181.6	47.8
27.5	1026.2	769.7	198.5	33.83333	229.4	173.7	45.8
27.66667	992.9	745.3	192.5	34	219.5	166.2	43.8
27.83333	960.4	721.4	186.6	34.16667	210	159	41.9
28	928.6	697.9	180.8	34.33333	201	152.2	40.1
28.16667	898	675.4	175.2	34.5	192.5	145.7	38.4
28.33333	868.2	653.4	169.7	34.66667	184.3	139.6	36.7
28.5	839.1	631.8	164.4	34.83333	176.5	133.6	35.2
28.66667	810.6	610.7	159.1	35	169	127.9	33.7
28.83333	782.6	589.9	153.8	35.16667	161.8	122.5	32.2
29	754.9	569.4	148.6	35.33333	154.9	117.2	30.8
29.16667	728	549.3	143.5	35.5	148.3	112.2	29.5
29.33333	701.9	529.8	138.6	35.66667	142	107.5	28.3
29.5	676.7	511	133.8	35.83333	136.1	103	27.1
29.66667	652.1	492.7	129.1	36	130.4	98.7	25.9
29.83333	628.3	474.8	124.5	36.16667	125	94.6	24.9
30	605	457.3	120	36.33333	119.8	90.7	23.8
30.16667	582.1	440.2	115.5	36.5	114.8	86.9	22.8
30.33333	559.8	423.4	111.2	36.66667	110	83.3	21.9
30.5	538.1	407.1	106.9	36.83333	105.5	79.8	21
30.66667	517.3	391.5	102.9	37	101.1	76.6	20.1
30.83333	497.1	376.2	98.9	37.16667	97	73.4	19.3

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
37.33333	93	70.4	18.5	43.66667	11.3	8.8	2.4
37.5	89.2	67.6	17.8	43.83333	10.6	8.2	2.2
37.66667	85.6	64.8	17.1	44	9.9	7.7	2.1
37.83333	82	62.1	16.4	44.16667	9.3	7.2	2
38	78.6	59.5	15.7	44.33333	8.7	6.8	1.9
38.16667	75.3	57.1	15.1	44.5	8.2	6.4	1.8
38.33333	72.1	54.7	14.5	44.66667	7.6	6	1.7
38.5	69.1	52.4	13.9	44.83333	7.2	5.6	1.6
38.66667	66.1	50.1	13.3	45	6.7	5.2	1.5
38.83333	63.3	48	12.7	45.16667	6.3	4.9	1.4
39	60.5	45.9	12.2	45.33333	5.9	4.6	1.3
39.16667	57.8	43.9	11.7	45.5	5.5	4.3	1.3
39.33333	55.2	41.9	11.1	45.66667	5.2	4.1	1.2
39.5	52.7	40	10.7	45.83333	4.9	3.8	1.1
39.66667	50.2	38.2	10.2	46	4.6	3.6	1.1
39.83333	47.9	36.4	9.7	46.16667	4.3	3.4	1
40	45.6	34.7	9.3	46.33333	4.1	3.2	0.9
40.16667	43.4	33	8.8	46.5	3.9	3	0.9
40.33333	41.2	31.4	8.4	46.66667	3.6	2.9	0.8
40.5	39.2	29.8	8	46.83333	3.4	2.7	0.8
40.66667	37.1	28.3	7.6	47	3.2	2.5	0.7
40.83333	35.2	26.8	7.2	47.16667	3	2.4	0.7
41	33.3	25.4	6.9	47.33333	2.8	2.3	0.7
41.16667	31.4	24	6.5	47.5	2.7	2.1	0.6
41.33333	29.6	22.7	6.1	47.66667	2.5	2	0.6
41.5	27.9	21.3	5.8	47.83333	2.4	1.9	0.5
41.66667	26.2	20.1	5.5	48	2.2	1.8	0.5
41.83333	24.6	18.8	5.1				
42	23	17.6	4.8				
42.16667	21.4	16.5	4.5				
42.33333	20	15.3	4.2				
42.5	18.5	14.3	3.9				
42.66667	17.2	13.2	3.6				
42.83333	15.9	12.3	3.3				
43	14.8	11.4	3.1				
43.16667	13.8	10.7	2.9				
43.33333	12.9	10	2.7				
43.5	12.1	9.4	2.5				

DREAM

Disaster RIsk and Exposure Assessment for Mitigation