



REGION 10

# Iligan River Basin:

DREAM Flood Forecasting  
and Flood Hazard Mapping



TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY

2015





© University of the Philippines and the Department of Science and Technology 2015

Published by the UP Training Center for Applied Geodesy and Photogrammetry (TCAGP)  
College of Engineering  
University of the Philippines Diliman  
Quezon City  
1101 PHILIPPINES

This research work is supported by the Department of Science and Technology (DOST) Grants-in-Aid Program and is to be cited as:

UP TCAGP (2015), DREAM Flood Forecasting and Flood Hazard Mapping for Iligan River Basin, Disaster Risk and Exposure Assessment for Mitigation (DREAM) Program, DOST Grants-in-Aid Program, 54 pp.

The text of this information may be copied and distributed for research and educational purposes with proper acknowledgment. While every care is taken to ensure the accuracy of this publication, the UP TCAGP disclaims all responsibility and all liability (including without limitation, liability in negligence) and costs which might incur as a result of the materials in this publication being inaccurate or incomplete in any way and for any reason.

For questions/queries regarding this report, contact:

**Alfredo Mahar Francisco A. Lagmay, PhD.**

Project Leader, Flood Modeling Component, DREAM Program  
University of the Philippines Diliman  
Quezon City, Philippines 1101  
Email: amfal2@yahoo.com

**Enrico C. Paringit, Dr. Eng.**

Program Leader, DREAM Program  
University of the Philippines Diliman  
Quezon City, Philippines 1101  
E-mail: paringit@gmail.com

National Library of the Philippines  
ISBN: 978-971-9695-16-5



# Table of Contents

INTRODUCTION .....	1
1.1 About the DREAM Program .....	2
1.2 Objectives and Target Outputs .....	2
1.3 General Methodological Framework .....	3
1.4 Scope of Work of the Flood Modeling Component .....	4
1.5 Limitations .....	4
1.6 Operational Framework .....	4
THE ILIGAN RIVER BASIN .....	5
METHODOLOGY .....	9
3.1 Pre-processing and Data Used .....	10
3.1.1 Elevation Data .....	10
3.1.1.1 Hydro-corrected SRTM DEM .....	10
3.1.1.2 LiDAR DEM .....	10
3.1.2 Land Cover and Soil Type .....	12
3.1.3 Hydrometry and Rainfall Data .....	12
3.1.3.1 Hydrometry for Abuno Bridge, Iligan City .....	12
3.1.3.2 Rainfall Intensity Duration frequency (RIDF) .....	13
3.1.4 Rating Curves .....	15
3.2 Rainfall-Runoff Hydrologic Model Development .....	16
3.2.1 Watershed Delineation and Basin Model Pre-processing .....	16
3.2.2 Basin Model Calibration .....	18
3.3 HEC-HMS Hydrologic Simulations for Discharge Computations using PAGASA RIDF Curves .....	19
3.3.1 Discharge Computation using Rainfall-Runoff Hydrologic Model ..	19
3.3.2 Discharge Computation using Dr. Horritt’s Method .....	19
3.3.2.1 Determination of Catchment Properties .....	20
3.3.2.2 HEC-HMS Implementation .....	21
3.3.2.3 Discharge validation against other estimates .....	22
3.4 Hazard and Flow Depth Mapping using FLO-2D .....	23
3.4.1 Floodplain Delineation .....	23
3.4.2 Flood Model Generation .....	23
3.4.3 Flow Depth and Hazard Map Simulation .....	27
3.4.4 Hazard Map and Flow Depth Map Creation .....	29
RESULTS AND DISCUSSION .....	31
4.1 Efficiency of HEC-HMS Rainfall-Runoff Models calibrated based on field survey and gauge data .....	32
4.2 Calculated Outflow hydrographs and Discharge Values for different Rainfall Return Periods .....	33
4.2.1 Hydrograph using Rainfall-Runoff Model .....	33
4.2.2 Discharge Data using Dr. Horritt’s Method .....	37
4.3 Flood Hazard and Flow Depth Maps .....	38
BIBLIOGRAPHY .....	45
APPENDICES	
Appendix A. Iligan Model Basin Parameters .....	48
Appendix B. Iligan Model Reach Parameters .....	51
Appendix C. Iligan Floodplain HEC-HMS Simulation .....	52



# List of Figures

Figure 1.	The general methodological framework of the program .....	3
Figure 2.	The operational framework and specific work flow of the Flood Modeling Component .....	4
Figure 3.	Iligan River Basin Location Map .....	6
Figure 4.	Iligan River Basin Soil Map .....	7
Figure 5.	Iligan River Basin Land Cover Map .....	7
Figure 6.	Summary of data needed for the purpose of flood modeling .....	10
Figure 7.	Digital Elevation Model (DEM) of the Iligan River Basin using Light Detection and Ranging (LiDAR) technology .....	11
Figure 8.	The 1-meter resolution LiDAR data is resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted .....	11
Figure 9.	Stitched Quickbird images for the Iligan floodplain .....	12
Figure 10.	Abuno Bridge, Iligan City rainfall and outflow data used for modeling .....	13
Figure 11.	Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines .....	14
Figure 12.	Lumbia Rainfall-Intensity Duration Frequency (RIDF) curves .....	15
Figure 13.	Water level vs. Discharge Curve for Abuno Bridge, Iligan City .....	15
Figure 14.	The Rainfall-Runoff Basin Model Development Scheme .....	16
Figure 15.	Iligan HEC-HMS Model domain generated by WMS .....	17
Figure 16.	Location of rain gauge used for the calibration of Iligan HEC-HMS Model .....	18
Figure 17.	Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method .....	19
Figure 18.	Delineation of upper watershed for Iligan floodplain discharge computation .....	20
Figure 19.	HEC-HMS simulation discharge results using Dr. Horritt's Method .....	22
Figure 20.	Screenshot showing how boundary grid elements are defined by line .....	24
Figure 21.	Screenshots of PTS files when loaded into the FLO-2D program .....	24
Figure 22.	Areal image of Iligan floodplain .....	25
Figure 23.	Screenshot of Manning's n-value rendering .....	26
Figure 24.	Flo-2D Mapper Pro General Procedure .....	27
Figure 25.	Iligan Floodplain Generated Hazard Maps using FLO-2D Mapper .....	28
Figure 26.	Iligan floodplain generated flow depth map using FLO-2D Mapper .....	28
Figure 27.	Basic Layout and Elements of the Hazard Maps .....	29
Figure 28.	Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow .....	32
Figure 29.	Sample DREAM Water Level Forecast .....	33
Figure 30.	Iligan Outflow hydrograph generated using the Lumbia 5-Year RIDF in HEC-HMS .....	34
Figure 31.	Iligan Outflow hydrograph generated using the Lumbia 10-Year RIDF in HEC-HMS .....	34
Figure 32.	Iligan Outflow hydrograph generated using the Lumbia 25-Year RIDF in HEC-HMS .....	35
Figure 33.	Iligan Outflow hydrograph generated using the Lumbia 50-Year RIDF in HEC-HMS .....	35
Figure 34.	Iligan Outflow hydrograph generated using the Lumbia 100-Year RIDF in HEC-HMS .....	36



# List of Figures

Figure 35.	Outflow hydrograph generated for Iligan using the Lumbia 5-,25-, 100-Year RIDF in HEC-HMS .....	37
Figure 36.	100-year Flood Hazard Map for Iligan River Basin .....	39
Figure 37.	100-year Flow Depth Map for Iligan River Basin .....	40
Figure 38.	25-year Flood Hazard Map for Iligan River Basin .....	41
Figure 39.	25-year Flow Depth Map for Iligan River Basin .....	42
Figure 40.	5-year Flood Hazard Map for Iligan River Basin .....	43
Figure 41.	5-year Flood Hazard Map for Iligan River Basin .....	44



# List of Tables

Table 1.	Methods used for the different calculation types for the hydrologic elements .....	17
Table 2.	Summary of Iligan discharge using Lumbia Station Rainfall Intensity Duration Frequency (RIDF) .....	36
Table 3.	Summary of Iligan river discharge using the recommended hydrological method by Dr. Horritt .....	37
Table 4.	Validation of river discharge estimate .....	38



# List of Equations

Equation 1.	Rating Curve .....	15
Equation 2.	Determination of maximum potential retention using the average curve number of the catchment .....	21
Equation 3.	Lag Time Equation Calibrated for Philippine Setting .....	21
Equation 4.	Ratio of river discharge of a 5-year rain return to a 2-year rain return scenario from measured discharge data .....	22
Equation 5.	Discharge validation equation using bankful method .....	22
Equation 6.	Bankful discharge equation using measurable channel parameters .....	23



# List of Abbreviations

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







# Introduction

# Introduction

---

## 1.1 About the DREAM Program

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

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

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

## 1.2 Objectives and Target Outputs

The program aims to achieve the following objectives:

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



# Introduction

## 1.3 General Methodological Framework

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

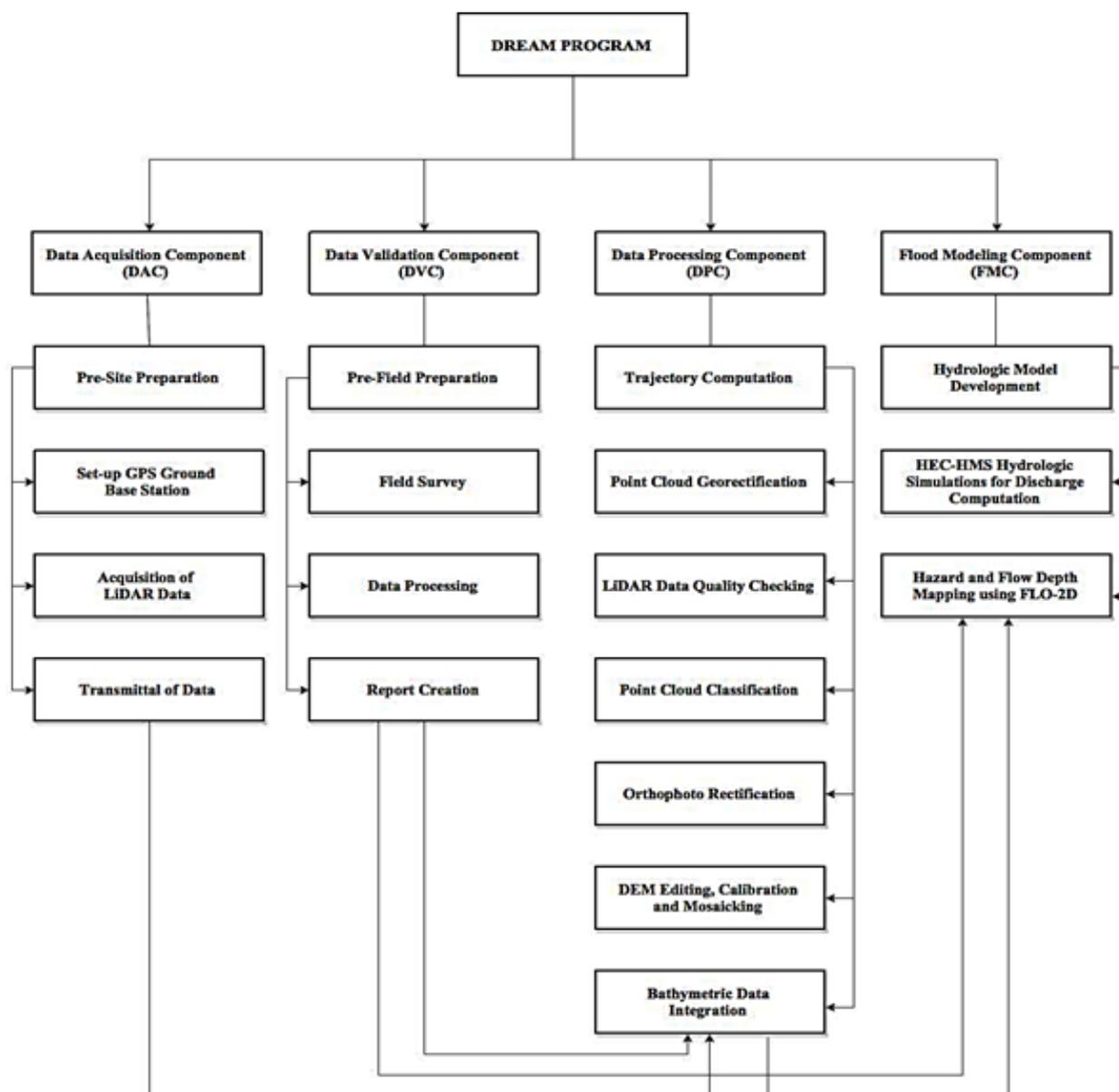


Figure 1. The general methodological framework of the program

# Introduction

## 1.4 Scope of Work of the Flood Modeling Component

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

- a) To develop the watershed hydrologic model of the Iligan 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 Iligan floodplain using FLO-2D GDS Pro; and
- d) To prepare the static flood hazard and flow depth maps for the Iligan 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.

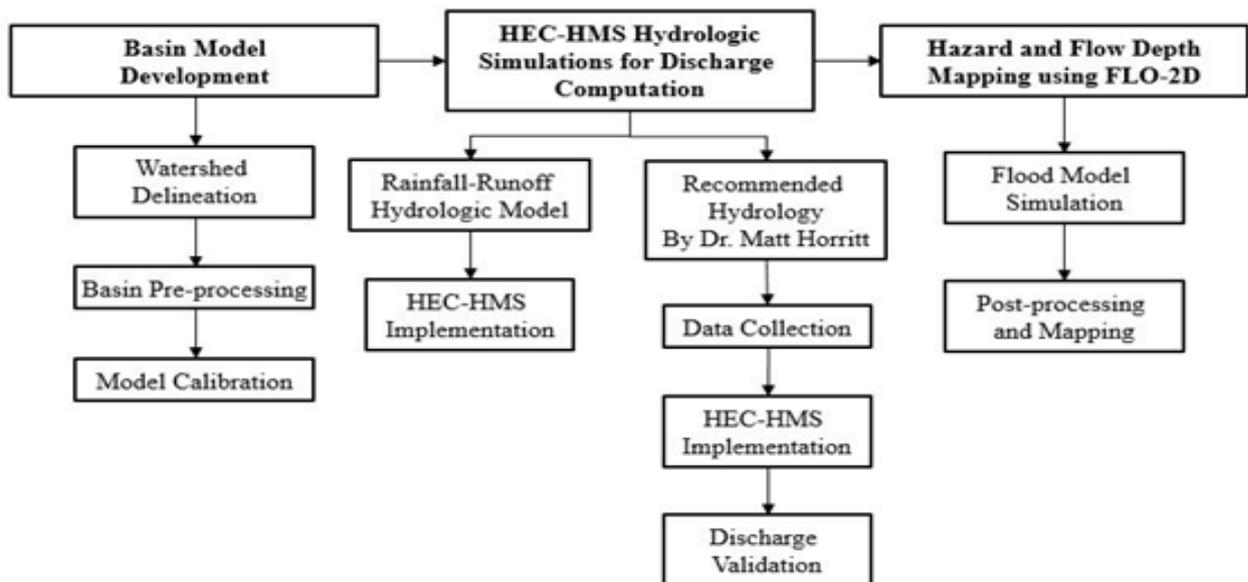
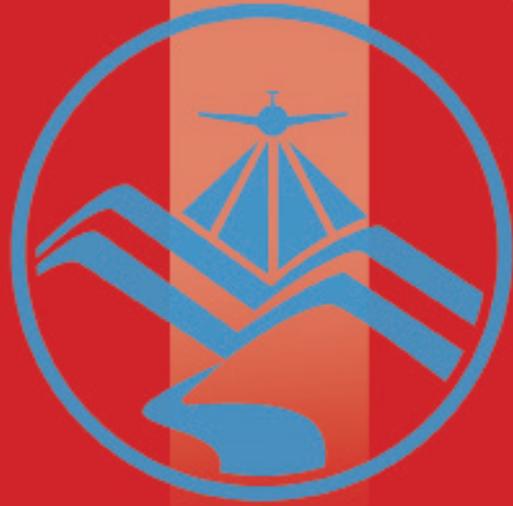


Figure 2. The operational framework and specific work flow of the Flood Modeling Component





# The Iligan River Basin

# The Iligan River Basin

The Iligan River Basin is located in Mindanao and covers the provinces of Lanao del Norte. It has an estimated drainage area of 242.53 square kilometres. The location of the Iligan River Basin is as shown in Figure 3.

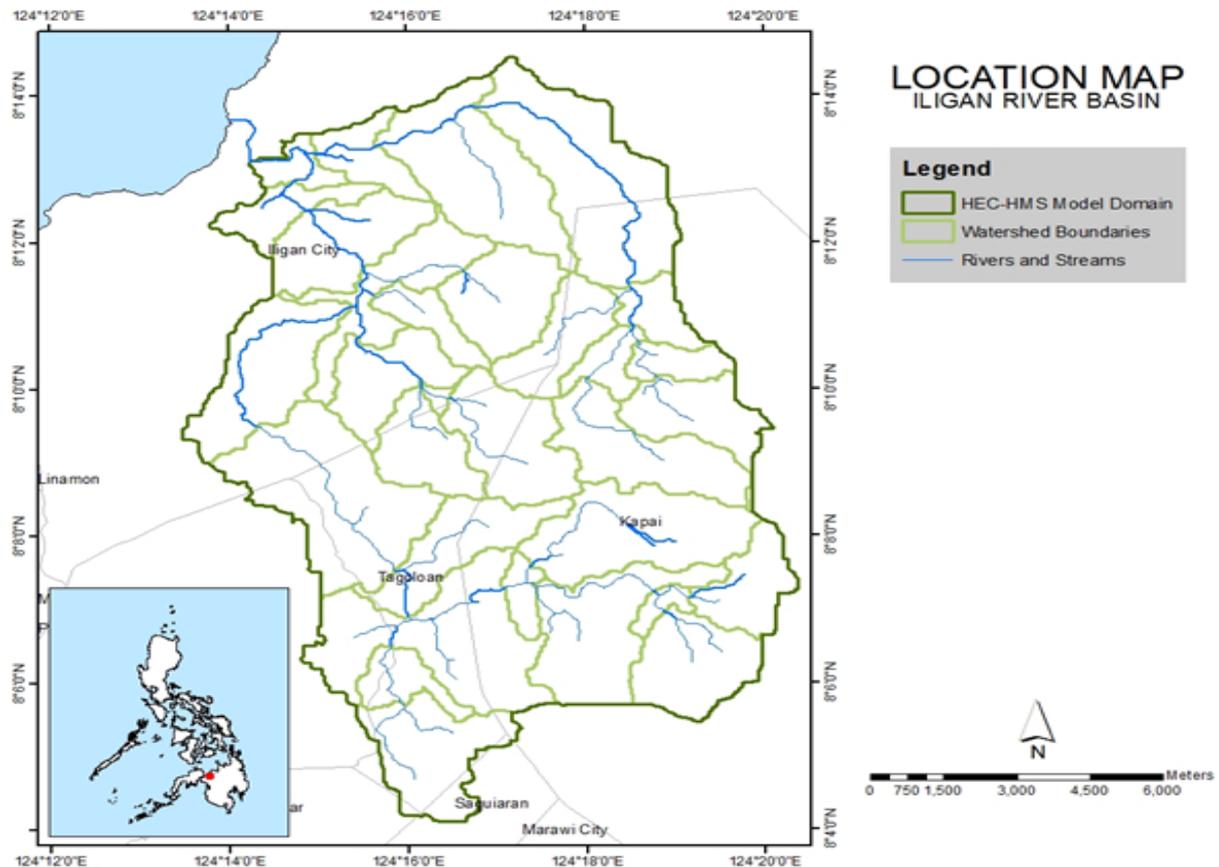


Figure 3. Iligan River Basin Location Map

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

# The Iligan River Basin

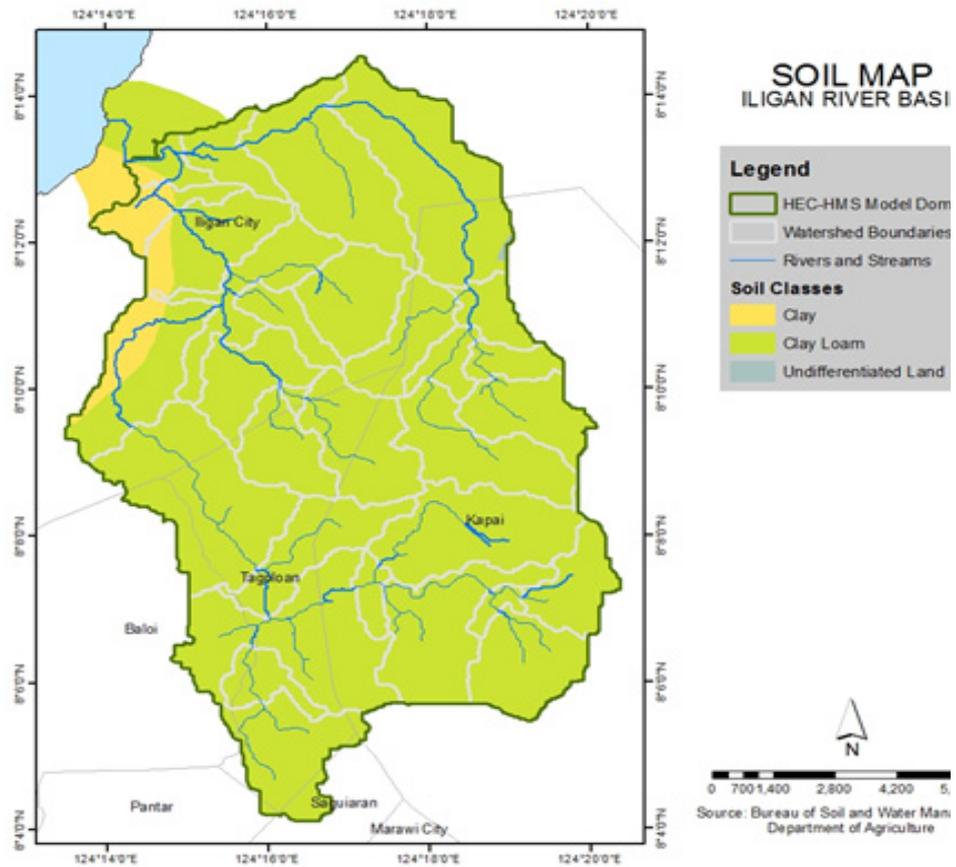


Figure 4. Iligan River Basin Soil Map

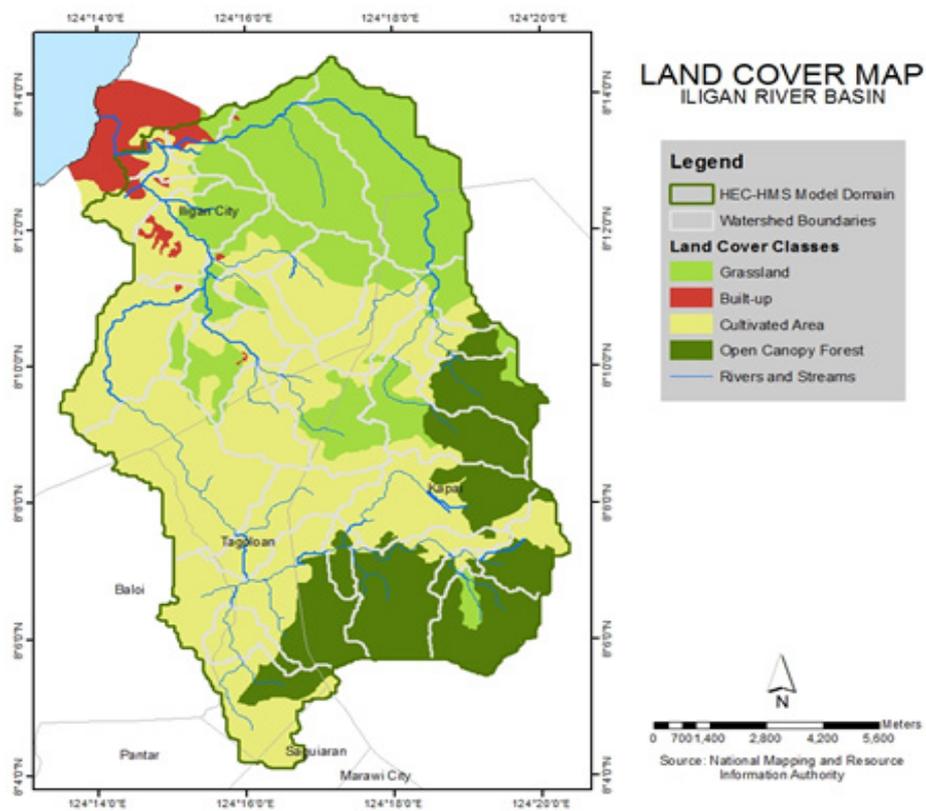


Figure 5. Iligan River Basin Land Cover Map





# 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.

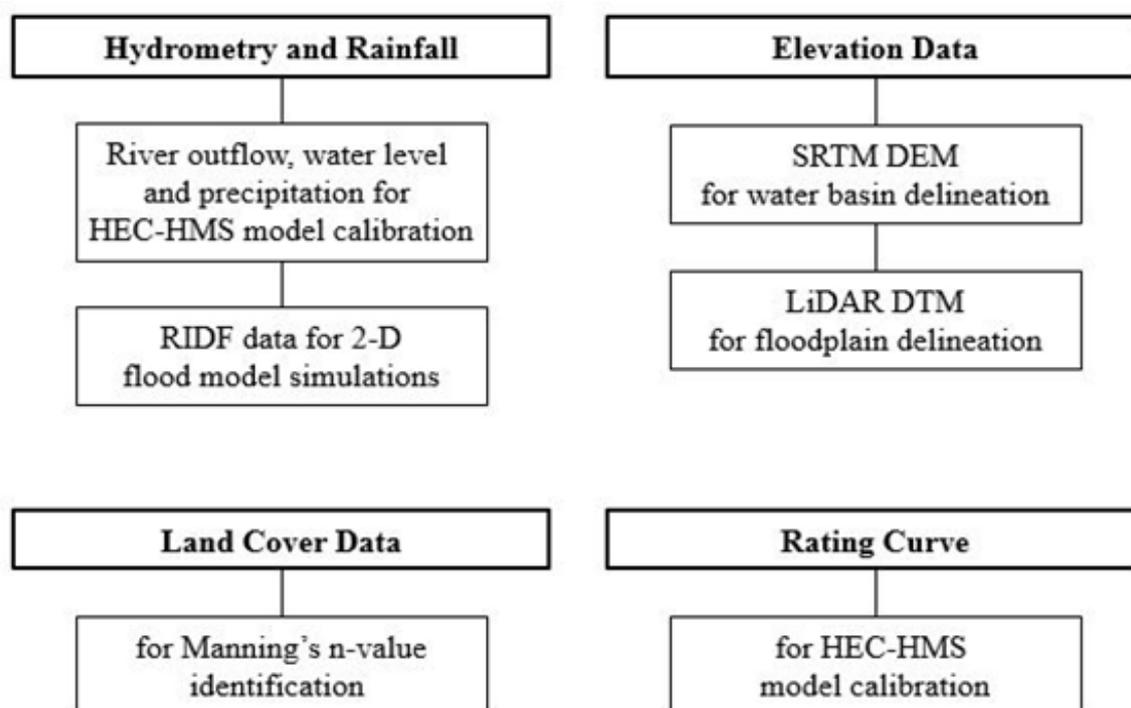


Figure 6. Summary of data needed for the purpose of flood modeling

### 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.

# Methodology

---

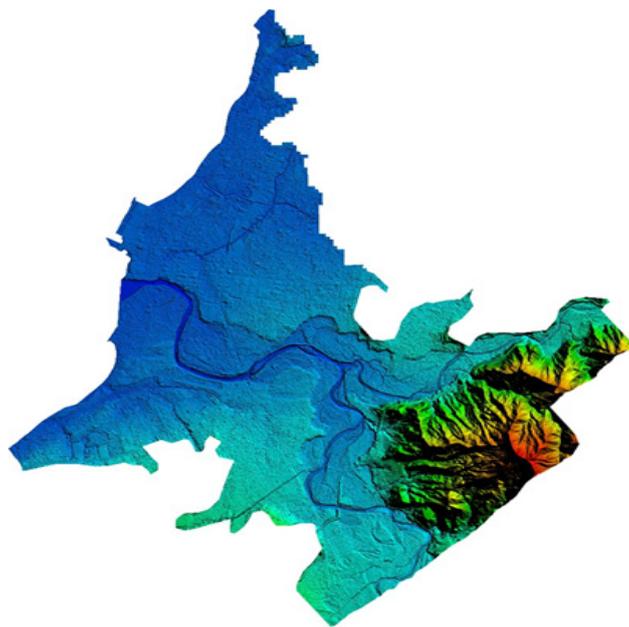


Figure 7. Digital Elevation Model (DEM) of the Iligan River Basin using Light Detection and Ranging (LiDAR) technology

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

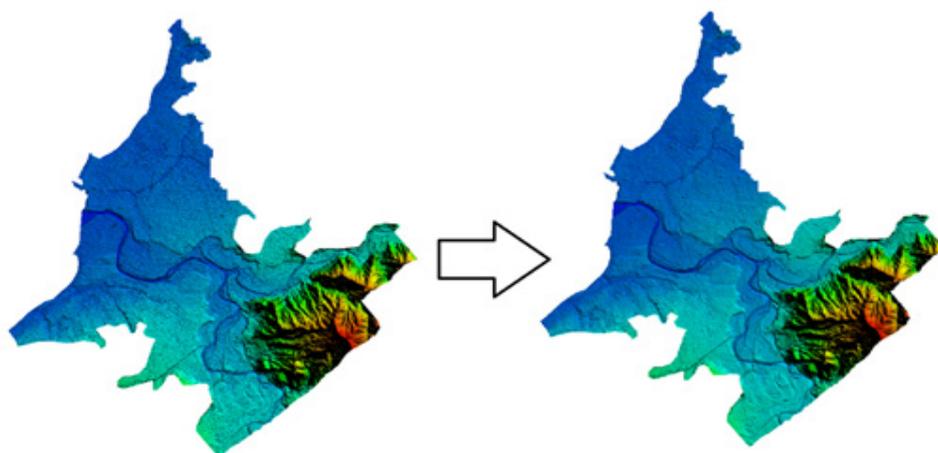


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted.

# Methodology

## 3.1.2 Land Cover and Soil Type

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

A general approach was done for the Iligan 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.

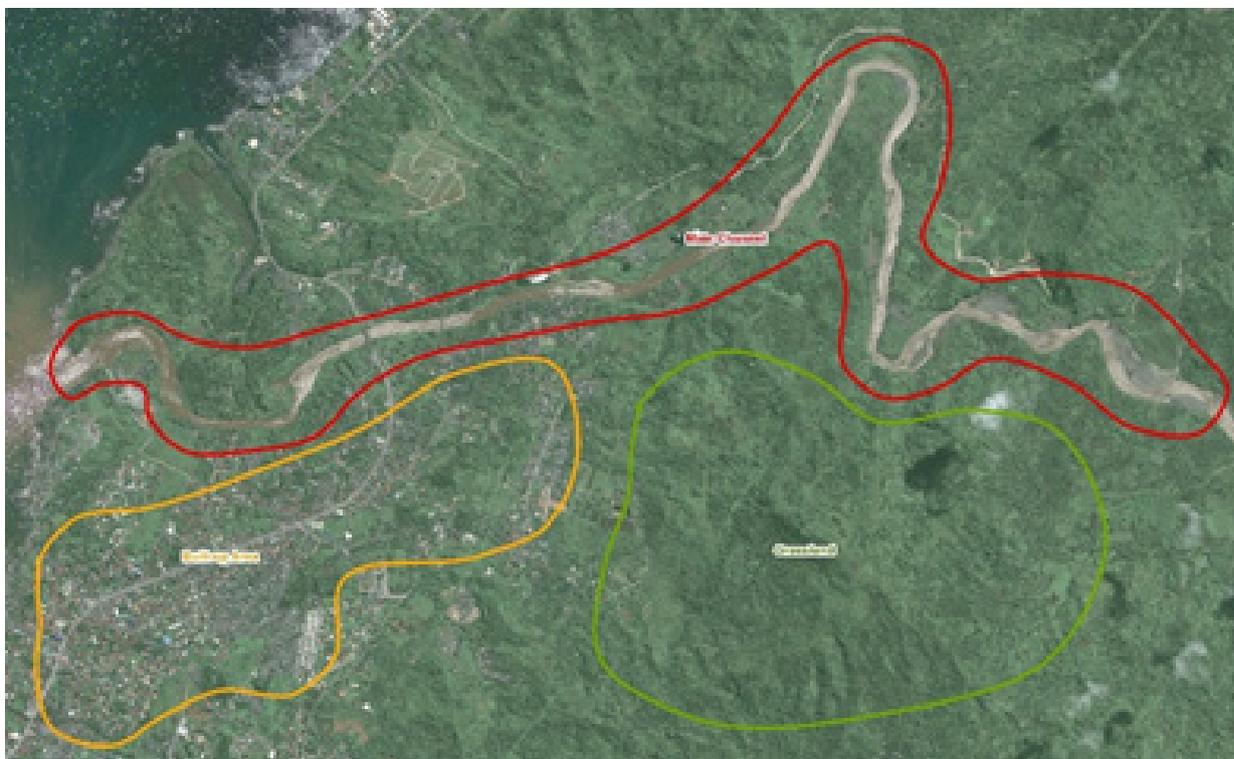


Figure 9. Stitched Quickbird images for the Iligan floodplain

## 3.1.3 Hydrometry and Rainfall Data

### 3.1.3.1 Hydrometry for Abuno Bridge, Iligan City

River outflow from Abuno Bridge ( $8^{\circ}10'59.211''N$ ,  $124^{\circ}15'5.727''E$ ) water level sensor was used to calibrate the HEC-HMS model. This was recorded during 27-29 December, 2012. Peak discharge of 6.4 cms occurred on 27 December, 2012 at 20:40.

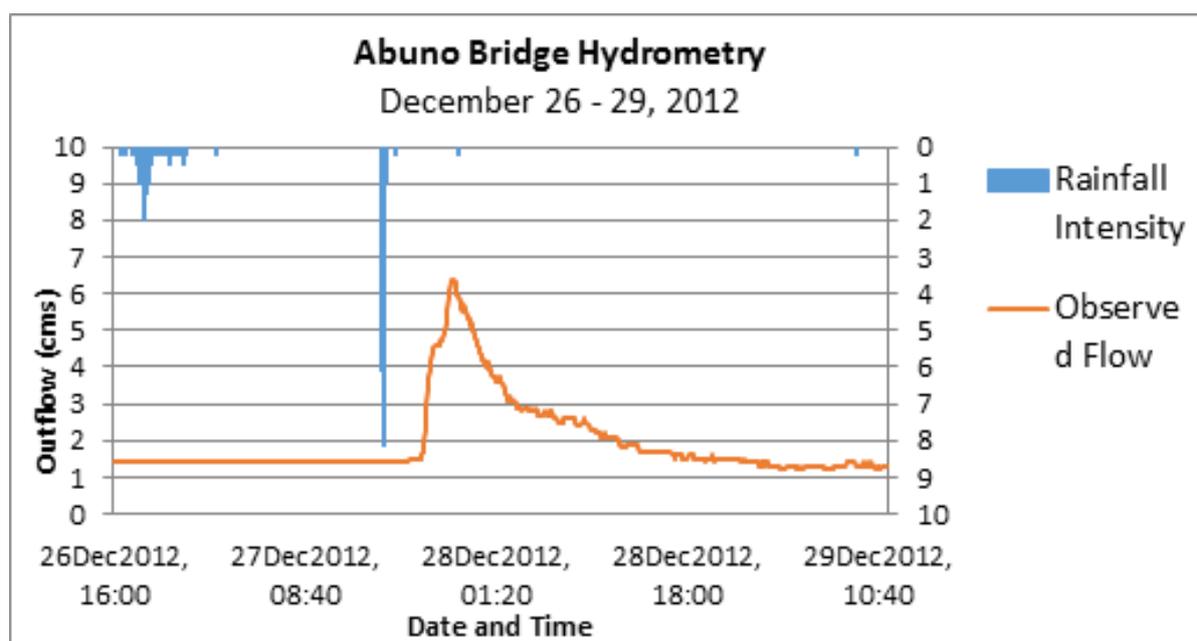


Figure 10. Abuno Bridge, Iligan City rainfall and outflow data used for modeling

### 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 was chosen based on its proximity to the Iligan watershed. The extreme values for this watershed were computed based on a 26-year record.

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

# Methodology

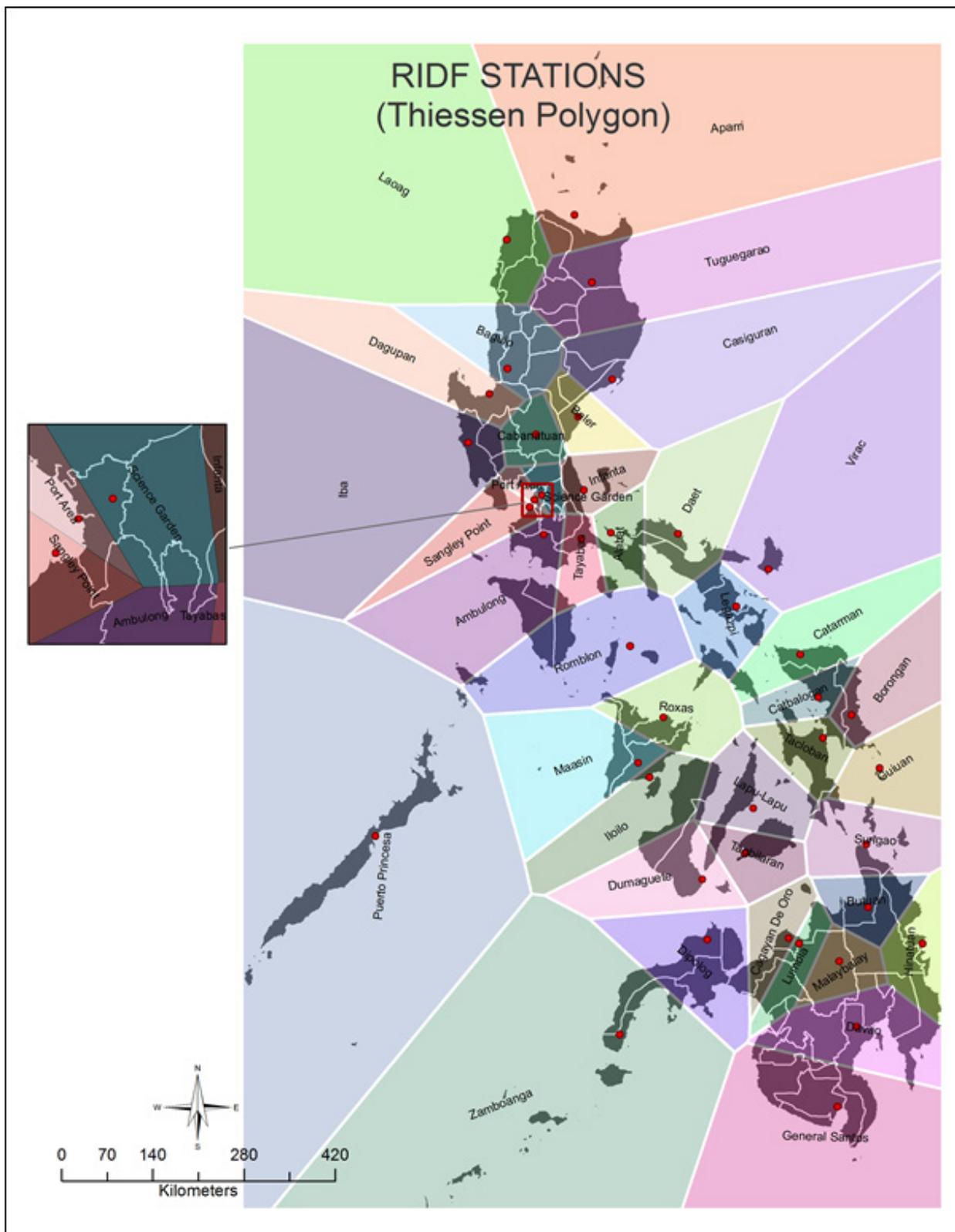


Figure 11. Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines

# Methodology

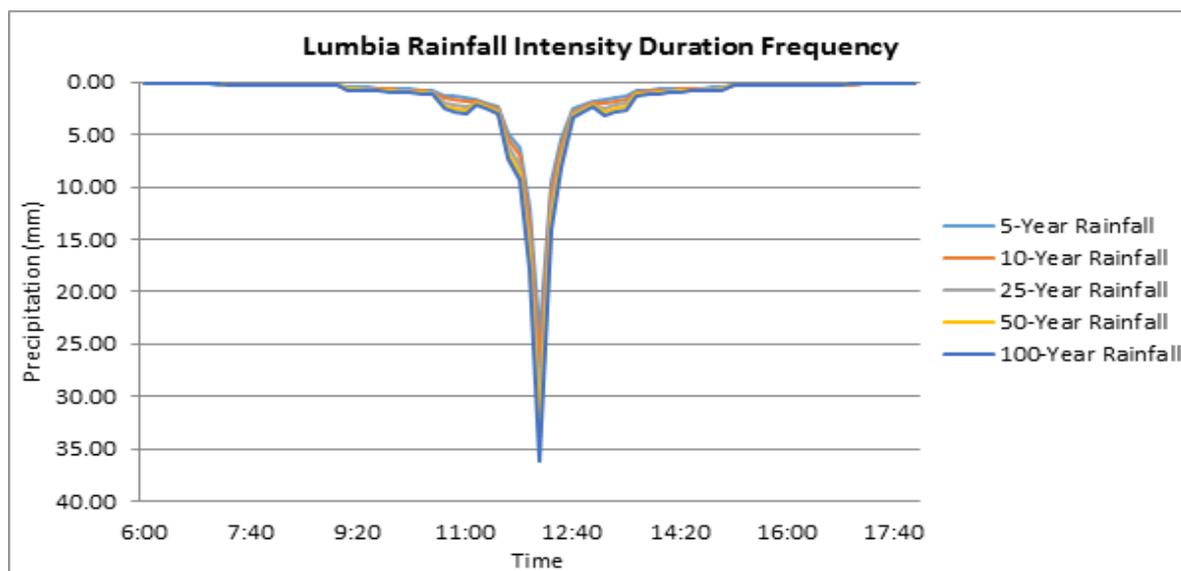


Figure 12. Lumbia Rainfall-Intensity Duration Frequency (RIDF) curves

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

### 3.1.4 Rating Curves

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

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

$$Q = a^{nh}$$

Equation 1. Rating Curve

For Abuno Bridge, the rating curve is expressed as  $Q = 8E-82e^{7.2528h}$  as shown in Figure 13.

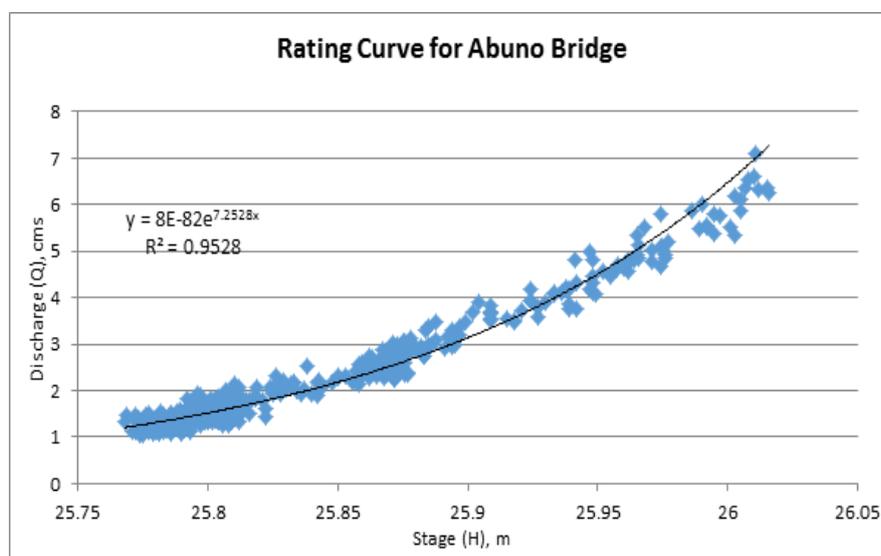


Figure 13. Water level vs. Discharge Curve for Abuno Bridge, Iligan City

## 3.2 Rainfall-Runoff Hydrologic Model Development

### 3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Iligan River Basin was developed using Watershed Modeling System (WMS) version 9.1. The software was developed by Aquaveo, a water resources engineering consulting firm in United States. WMS is a program capable of various watershed computations and hydrologic simulations. The hydrologic model development follows the scheme shown in the Figure 14.

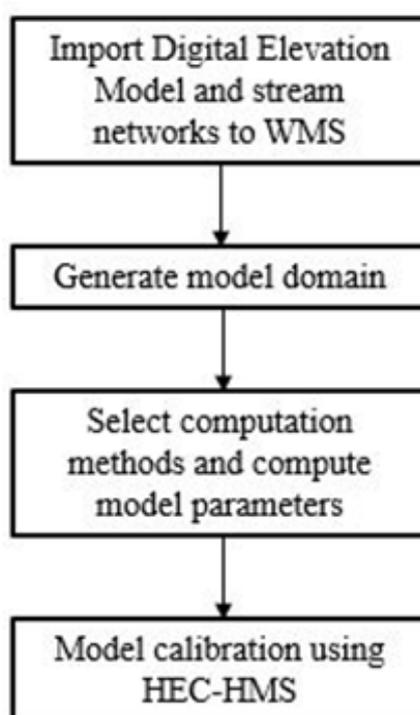


Figure 14. The Rainfall-Runoff Basin Model Development Scheme

Hydro-corrected SRTM DEM was used as the terrain for the basin model. The watershed delineation and its hydrologic elements, namely the subbasins, junctions and reaches, were generated using WMS after importing the elevation data and stream networks.

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

# Methodology

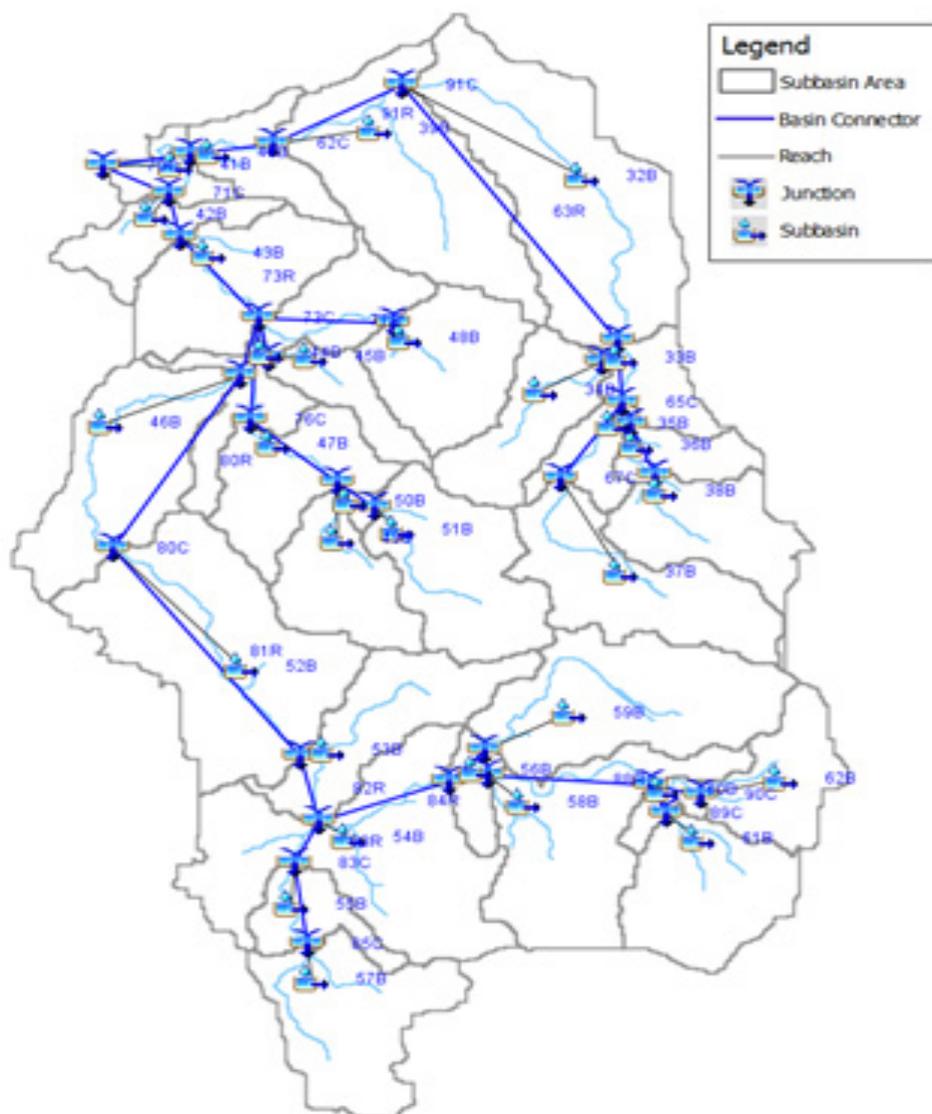


Figure 15. Iligan HEC-HMS Model domain generated by WMS

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

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

# Methodology

## 3.2.2 Basin Model Calibration

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

Precipitation data was taken from Barangay Digkilaan, Iligan City, Lanao del Norte installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). The location of the ARG is seen in Figure 16.

Total rainfall from Brgy. Digkilaan rain gauge is 26.67 mm. Its peak rainfall is 8.128 mm which happened on 27 December, 2012 at 15:30. The lag time between the peak rainfall and peak discharge is five hours and 10 minutes.

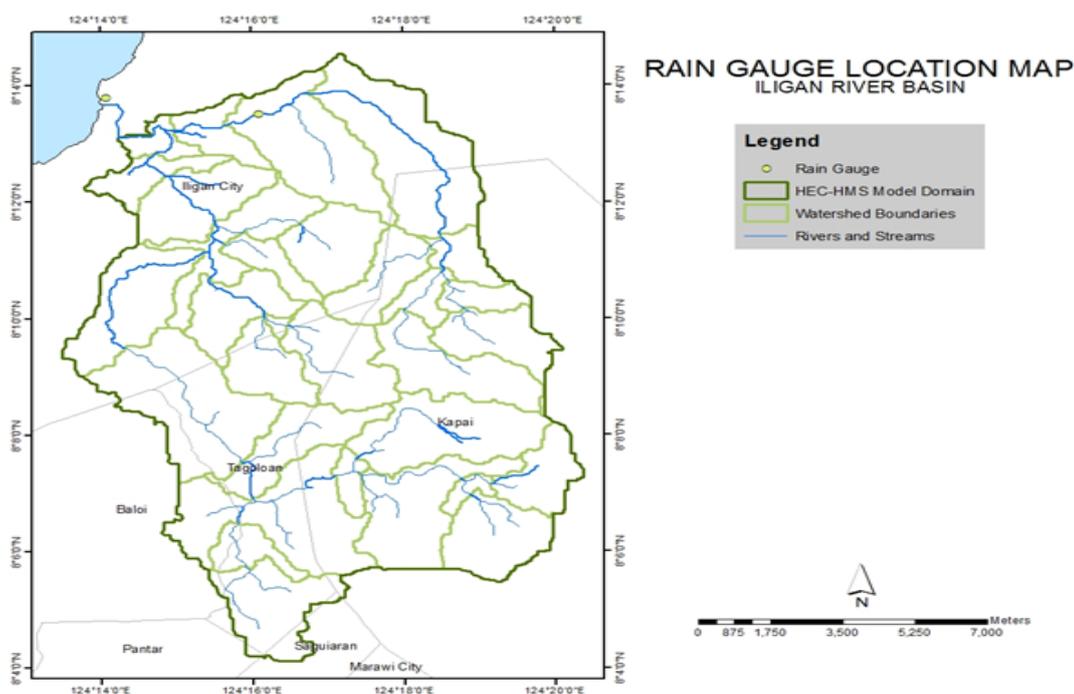


Figure 16. Location of rain gauge used for the calibration of Iligan HEC-HMS Model

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.

# Methodology

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

### 3.3.1 Discharge Computation using Rainfall-Runoff Hydrologic Model

The calibrated Rainfall-Runoff Hydrologic Model for the Iligan River Basin using WMS and HEC-HMS was used to simulate the flow for the five return periods, namely, 5-, 10-, 25-, 50- and 100-year RIDFs. Time-series data of the precipitation data using the Lumbia 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 Abuno Bridge. The output for each simulation was an outflow hydrograph from that result, the total inflow to the floodplain and time difference between the peak outflow and peak precipitation could be determined.

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

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

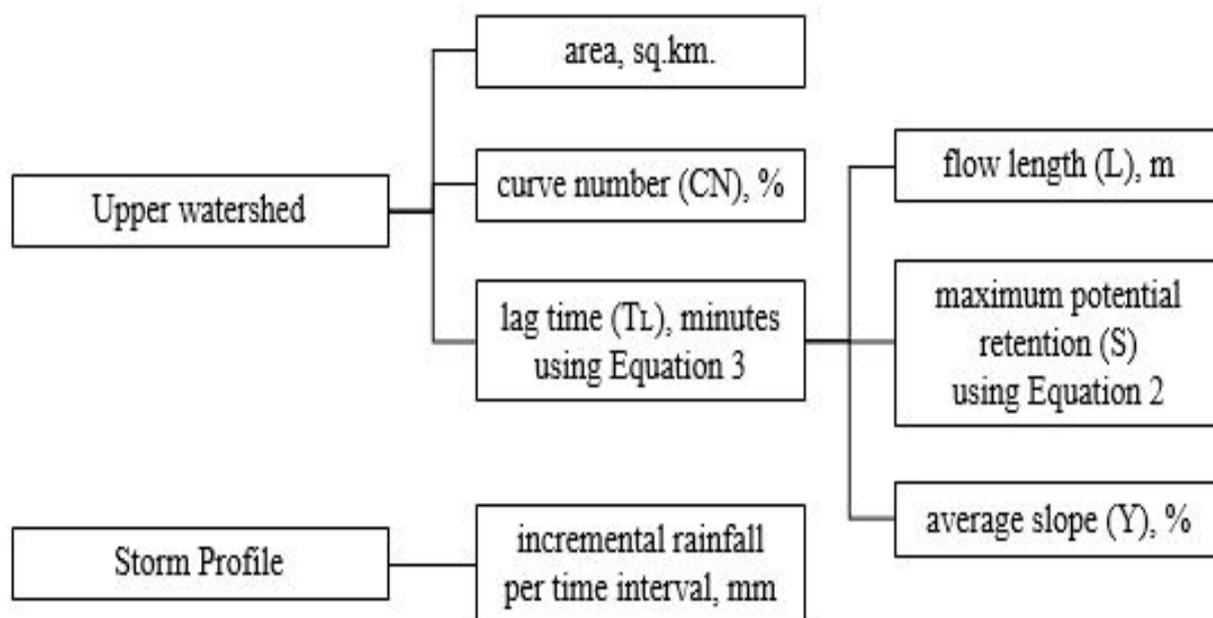


Figure 17. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method

# Methodology

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

## 3.3.2.1 Determination of Catchment Properties

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

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

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



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

# Methodology

---

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

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

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

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

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

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

Equation 3. Lag Time Equation Calibrated for Philippine Setting

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

## 3.3.2.2 HEC-HMS Implementation

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

# Methodology

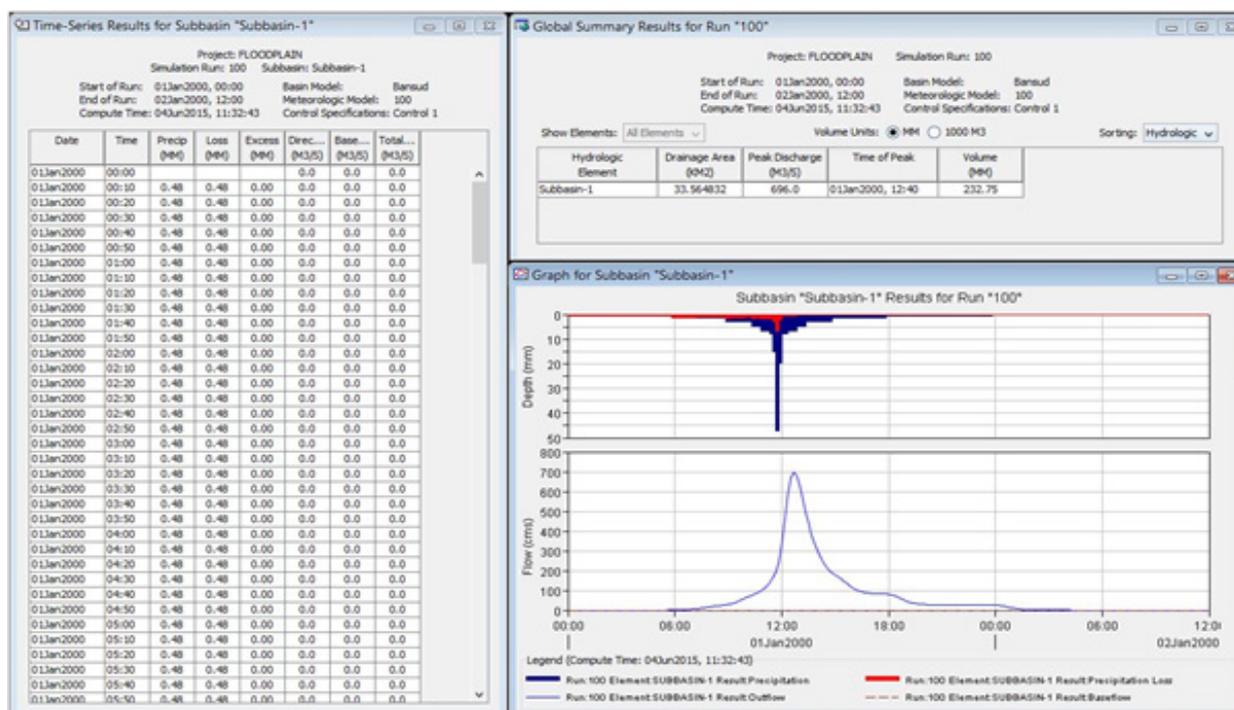


Figure 19. HEC-HMS simulation discharge results using Dr. Horritt’s Method

### 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

## Methodology

---

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

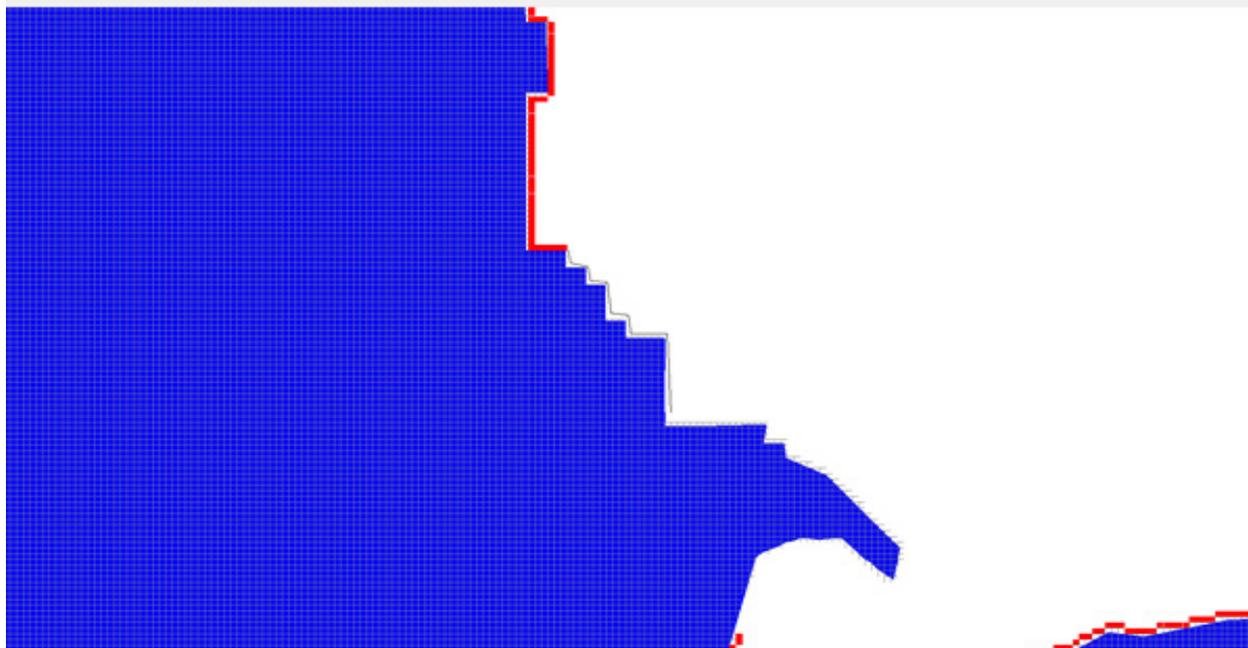


Figure 20. Screenshot showing how boundary grid elements are defined by line

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.

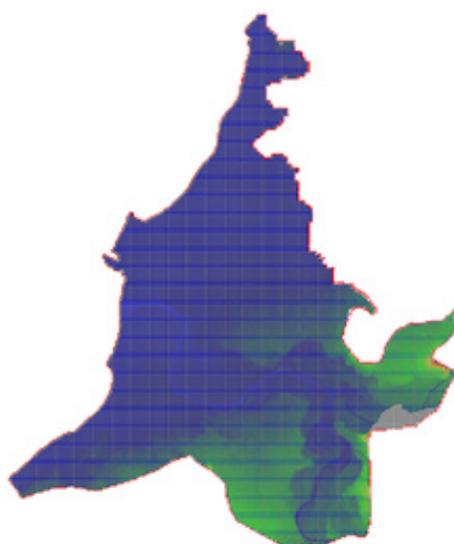


Figure 21. Screenshots of PTS files when loaded into the FLO-2D program

# Methodology

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

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

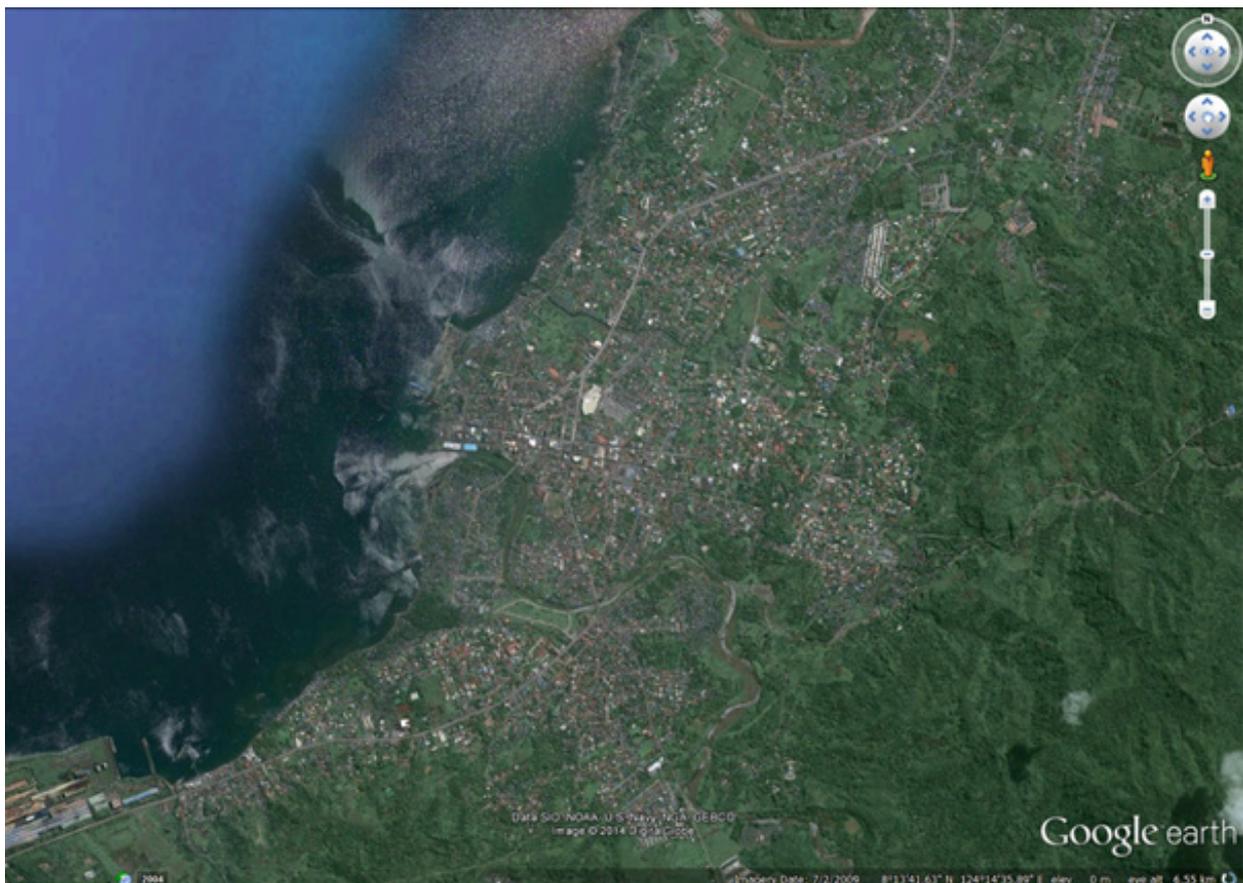


Figure 22. Areal image of Iligan floodplain

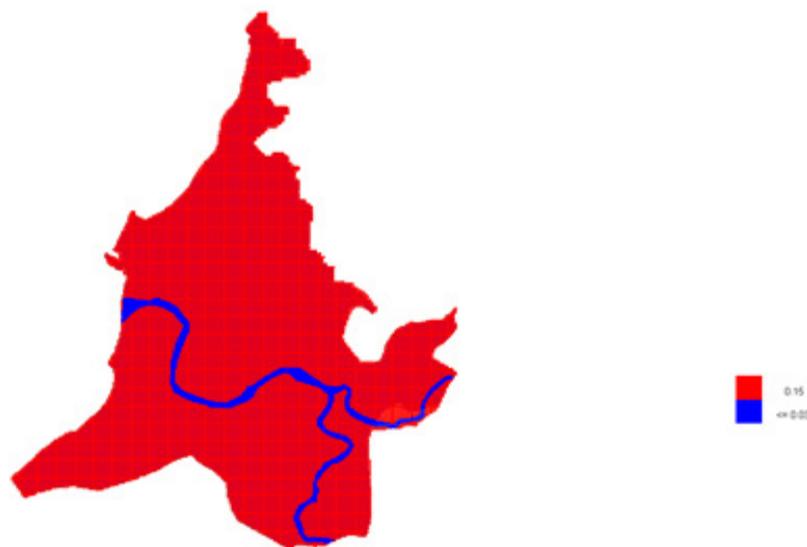


Figure 23. Screenshot of Manning's n-value rendering

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

# Methodology

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

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

## 3.4.3 Flow Depth and Hazard Map Simulation

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

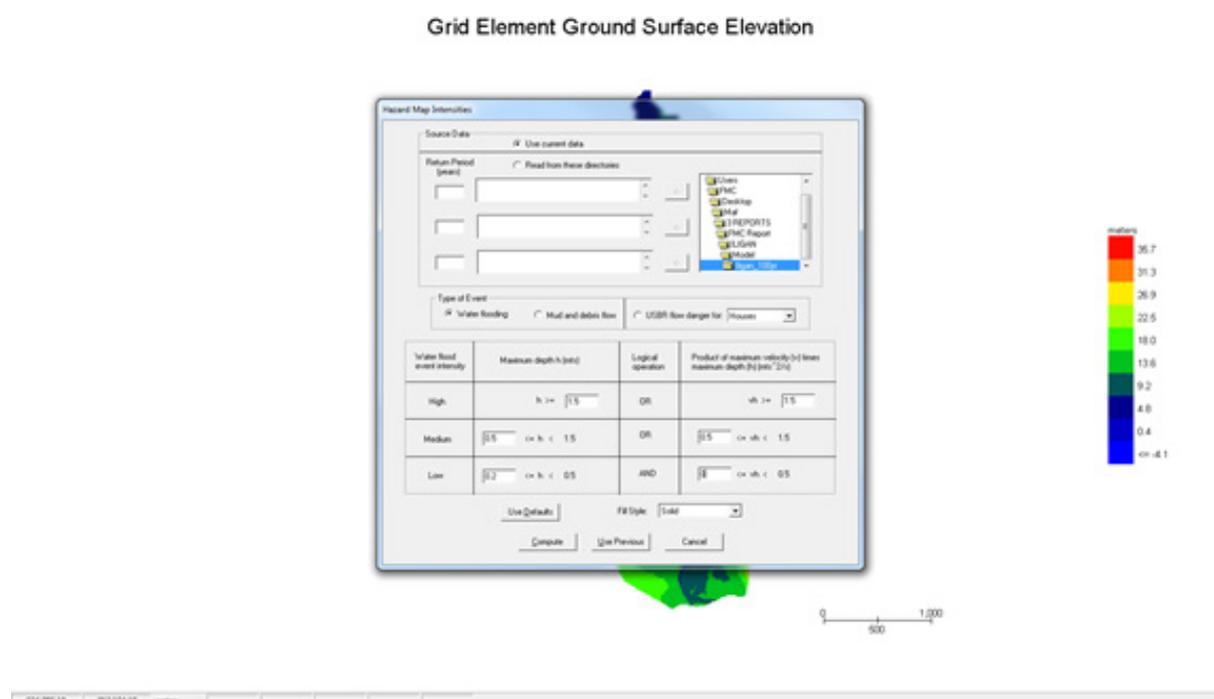


Figure 24. Flo-2D Mapper Pro General Procedure

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.

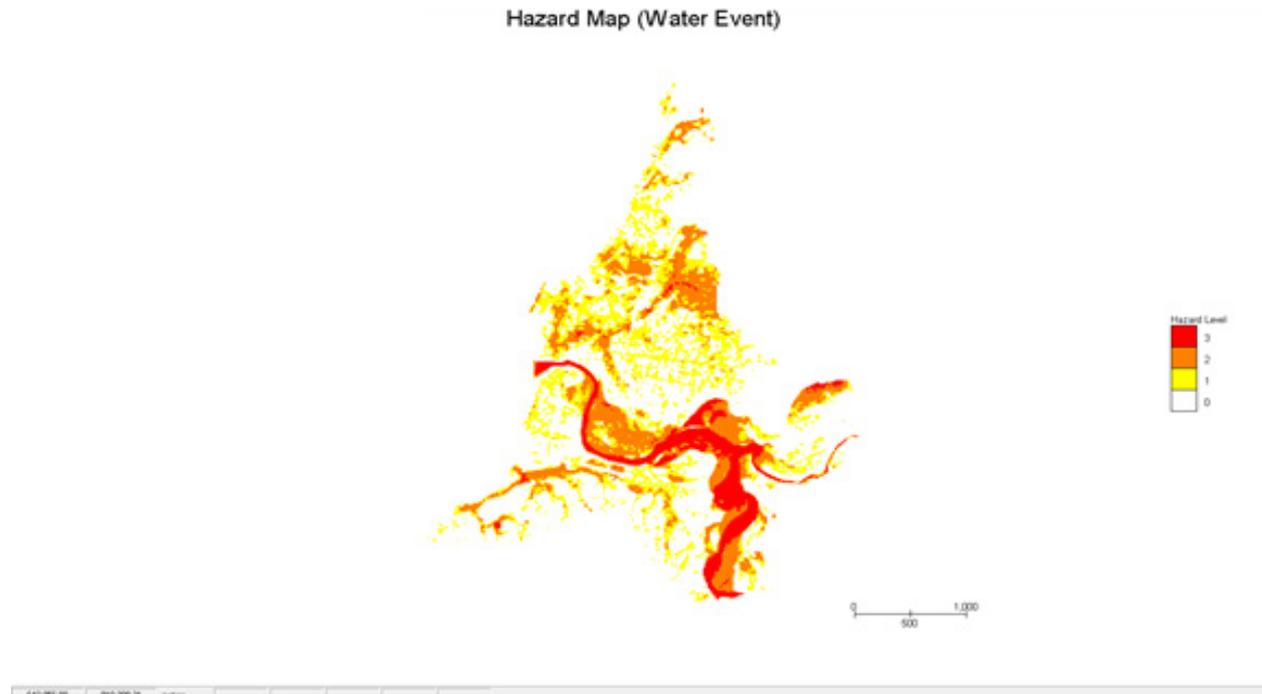


Figure 25. Iligan Floodplain Generated Hazard Maps using FLO-2D Mapper

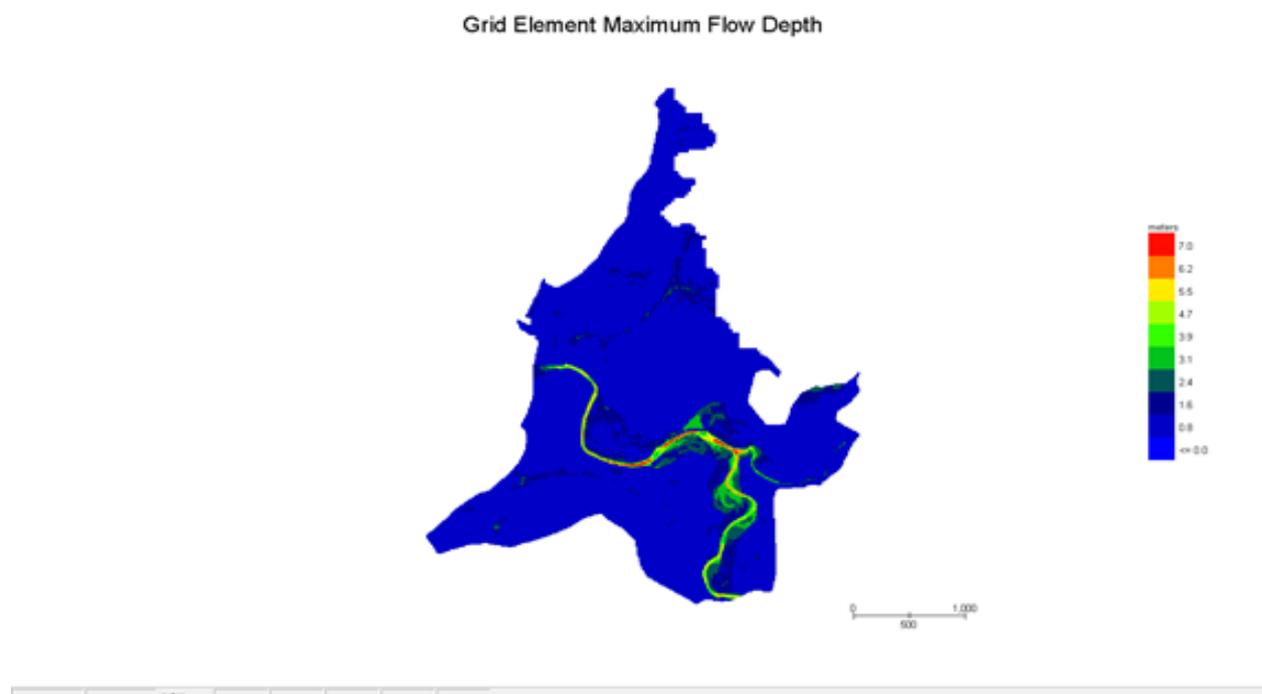
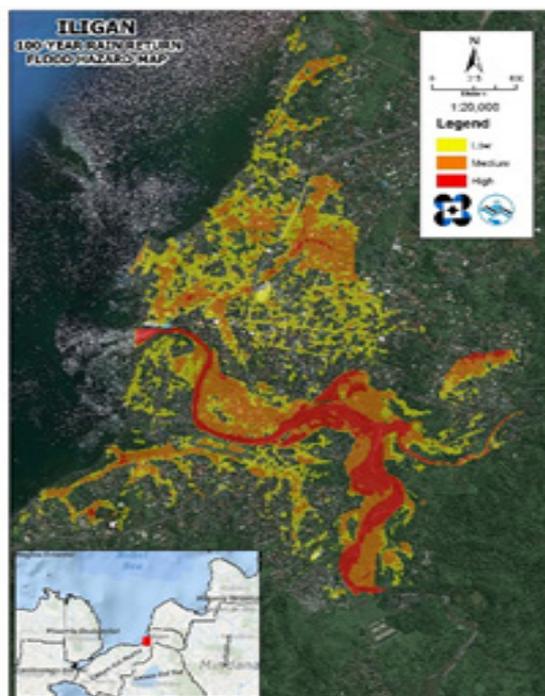


Figure 26. Iligan floodplain generated flow depth map using FLO-2D Mapper

# Methodology

## 3.4.4 Hazard Map and Flow Depth Map Creation

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

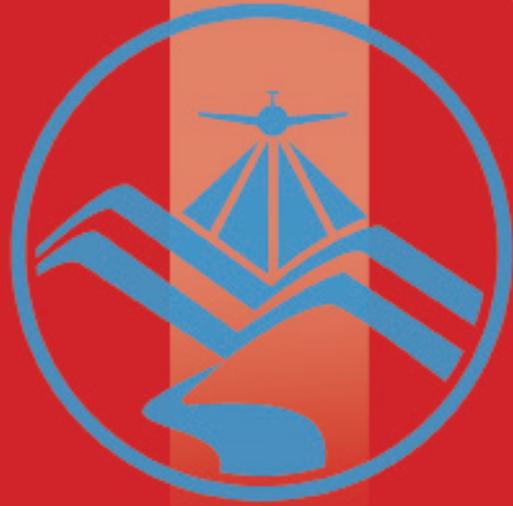


### ELEMENTS

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

Figure 27. Basic Layout and Elements of the Hazard Maps





# Results and Discussion

# Results and Discussion

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

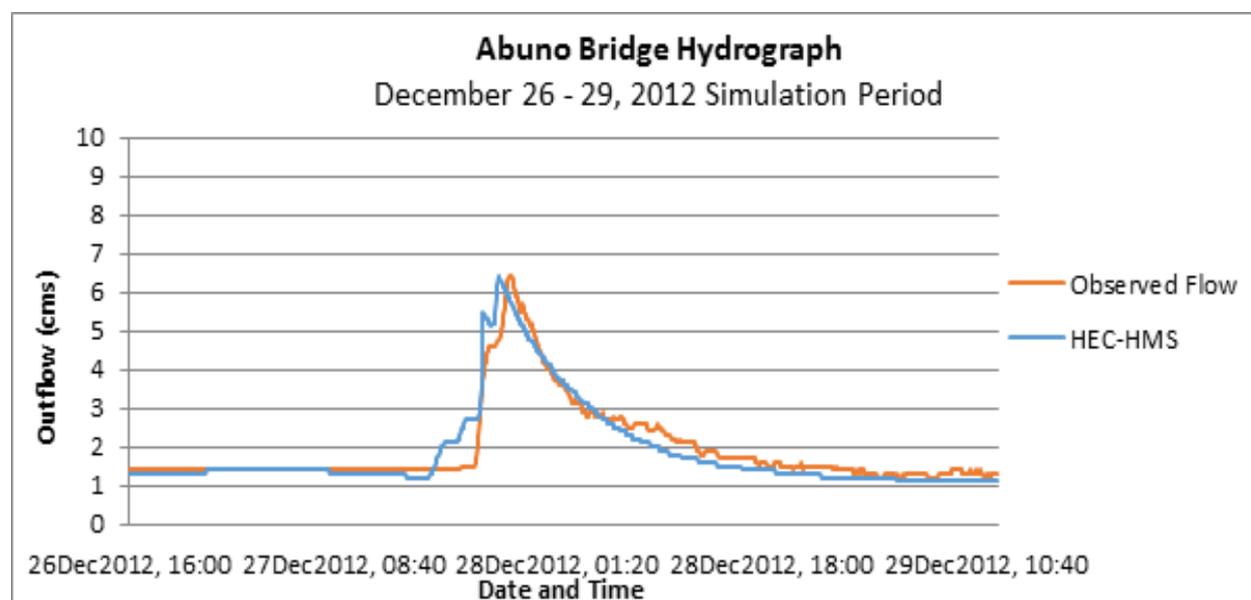


Figure 28. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow

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

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 2.1.

The Pearson correlation coefficient ( $r^2$ ) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.832951809.

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 0.506480479.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is -0.84.

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 0.56.

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.

# Results and Discussion

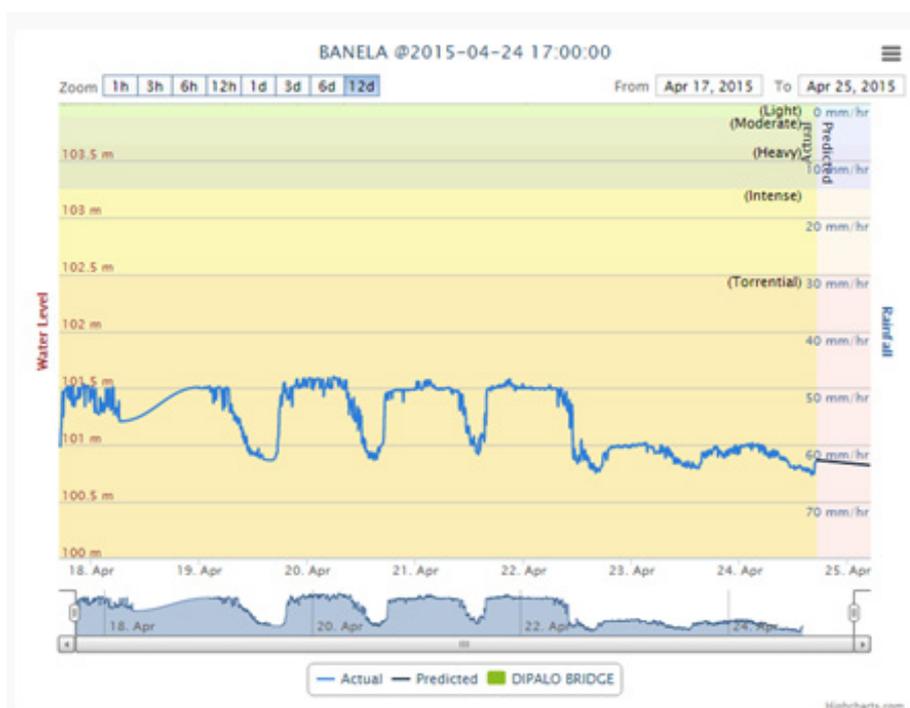


Figure 29. Sample DREAM Water Level Forecast

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

In the 5-year return period graph, the peak outflow is 109.1 cms. This occurs after 15 hours and 20 minutes, and a precipitation of 24.22 mm, as shown on Figure 30.

# Results and Discussion

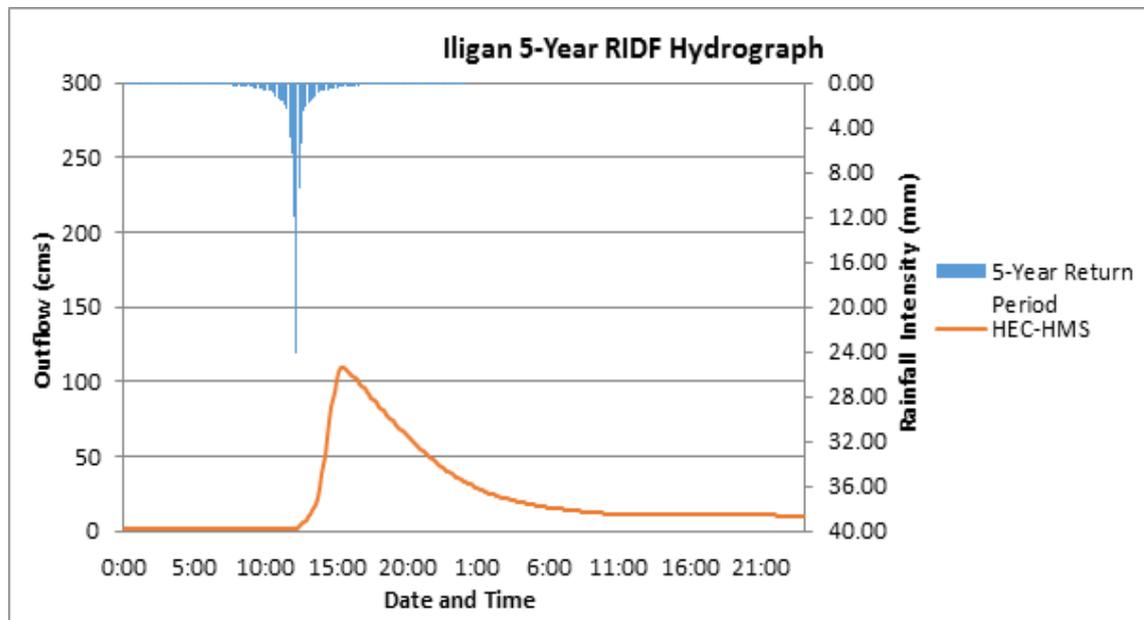


Figure 30. Iligan Outflow hydrograph generated using the Lumbia 5-Year RIDF in HEC-HMS

In the 10-year return period graph, the peak outflow is 132.3 cms. This occurs after 15 hours and 20 minutes, and a precipitation of 27.12 mm, as shown on Figure 31.

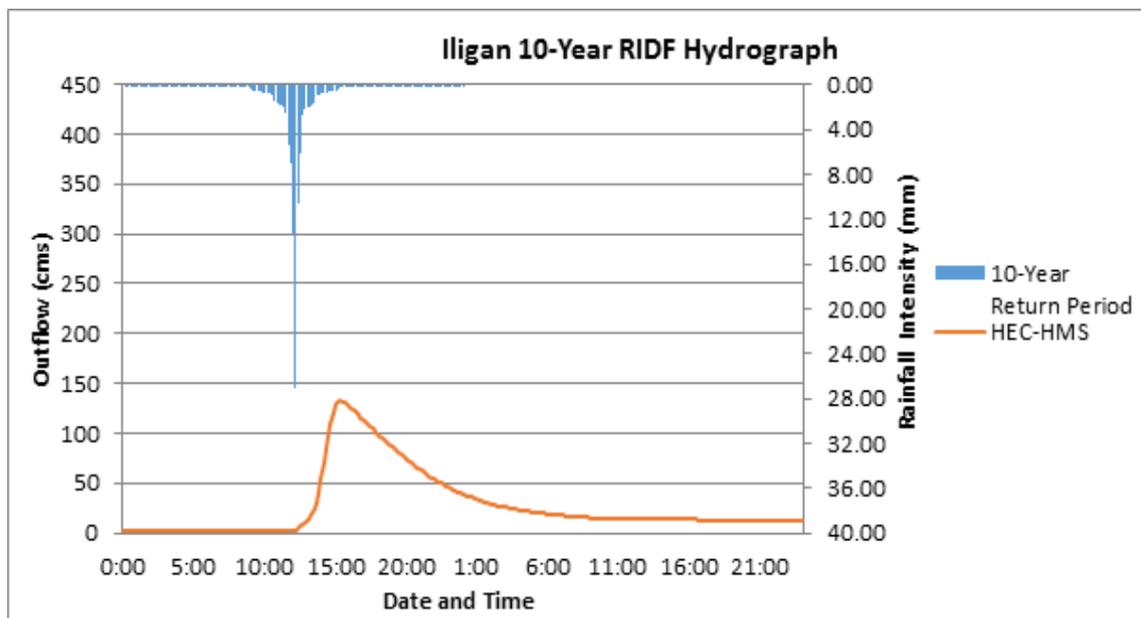


Figure 31. Iligan Outflow hydrograph generated using the Lumbia 10-Year RIDF in HEC-HMS



# Results and Discussion

In the 25-year return period graph, the peak outflow is 165.5 cms. This occurs after 15 hours and 10 minutes, and a precipitation of 30.79 mm, as shown on Figure 32.

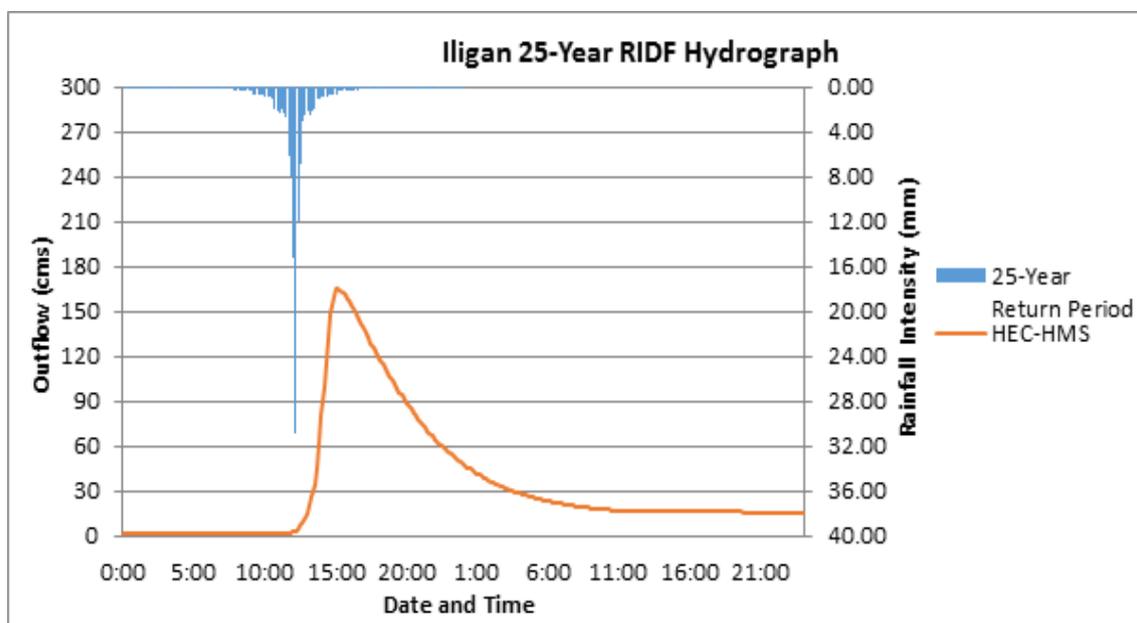


Figure 32. Iligan Outflow hydrograph generated using the Lumbia 25-Year RIDF in HEC-HMS

In the 50-year return period graph, the peak outflow is 190.8 cms. This occurs after 15 hours, and a precipitation of 33.54 mm, as shown on Figure 33.

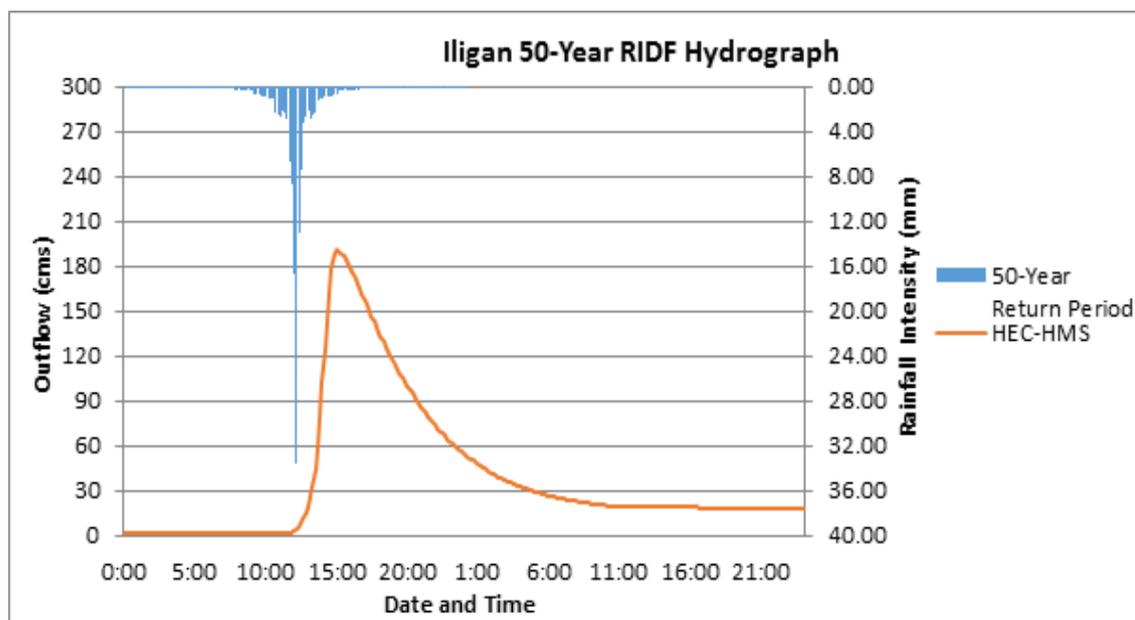


Figure 33. Iligan Outflow hydrograph generated using the Lumbia 50-Year RIDF in HEC-HMS

# Results and Discussion

In the 100-year return period graph, the peak outflow is 216.5 cms. This occurs after 15 hours, and a precipitation of 36.20 mm, as shown on Figure 34.

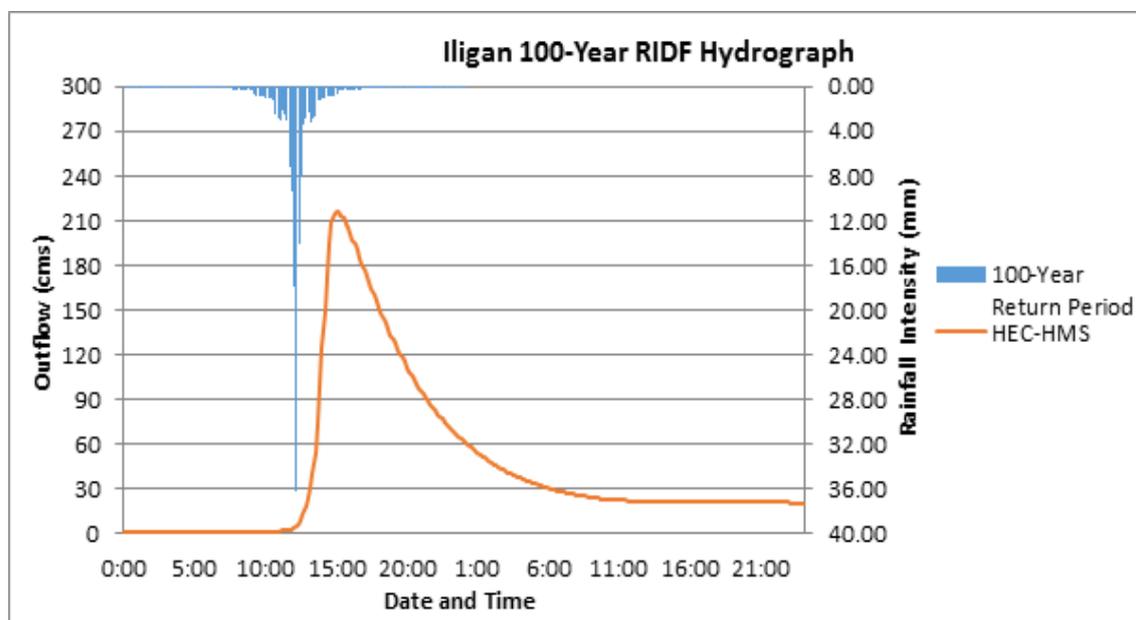


Figure 34. Iligan Outflow hydrograph generated using the Lumbia 100-Year RIDF in HEC-HMS

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

Table 2. Summary of Iligan discharge using the Lumbia Station Rainfall Intensity Duration Frequency (RIDF)

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	109.1	24.22	109.1	3 hours, 10 minutes
10-Year	132.3	27.12	132.3	3 hours, 10 minutes
25-Year	165.5	30.79	165.5	3 hours
50-Year	190.8	33.54	190.8	2 hours, 50 minutes
100-Year	216.5	36.20	216.5	2 hours, 50 minutes



# Results and Discussion

## 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.

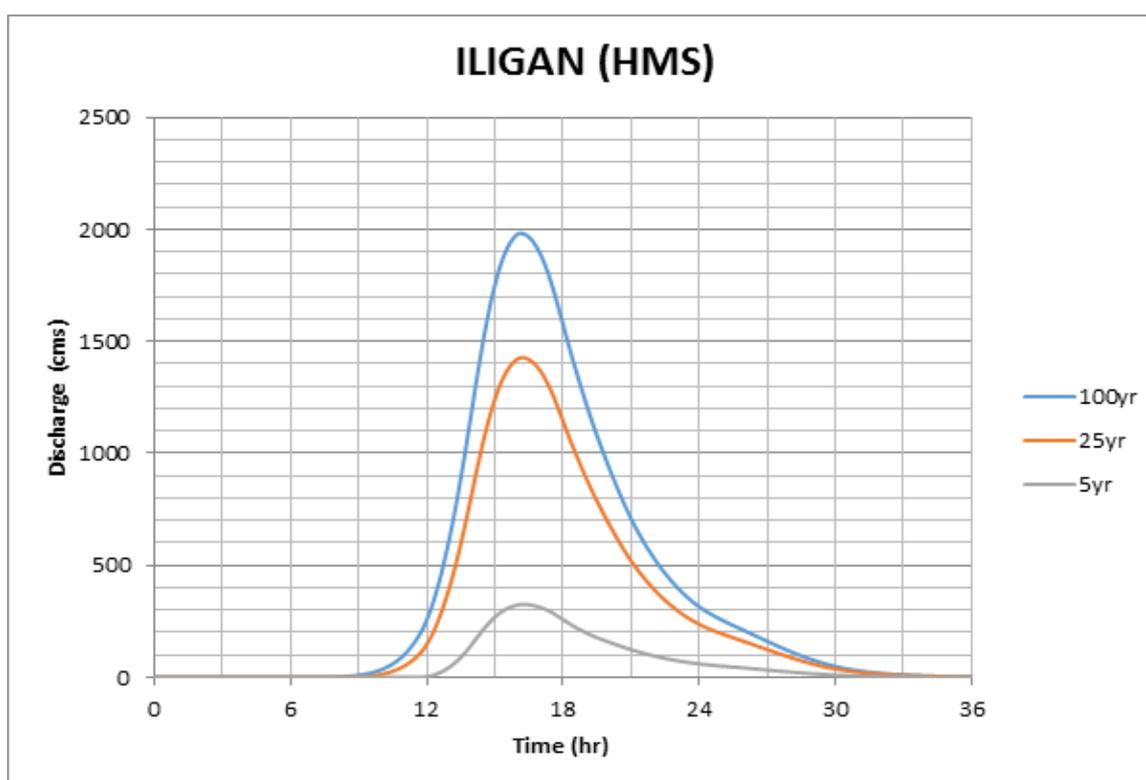


Figure 35. Outflow hydrograph generated for Iligan using the Lumbia 5-,25-, 100-Year RIDF in HEC-HMS

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

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	325.8	16 hours, 10 minutes
25-Year	1427.4	16 hours, 10 minutes
100-Year	1982.4	16 hours, 10 minutes

The comparison of discharge values obtained from HEC-HMS, Q<sub>5yr</sub>, and from the bankful discharge method, Q<sub>bankful</sub>, are shown in Table 4. Using values from the DTM of Iligan, the bankful discharge for the river was computed.

# Results and Discussion

---

Table 4. Validation of river discharge estimate

Floodplain	Qbankful, cms	Q5yr, cms	Validation
Iligan	347.8	286.7	Pass

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

## 4.3 Flood Hazard and Flow Depth Maps

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



# Results and Discussion

## Flood Hazard Maps and Flow Depth Maps

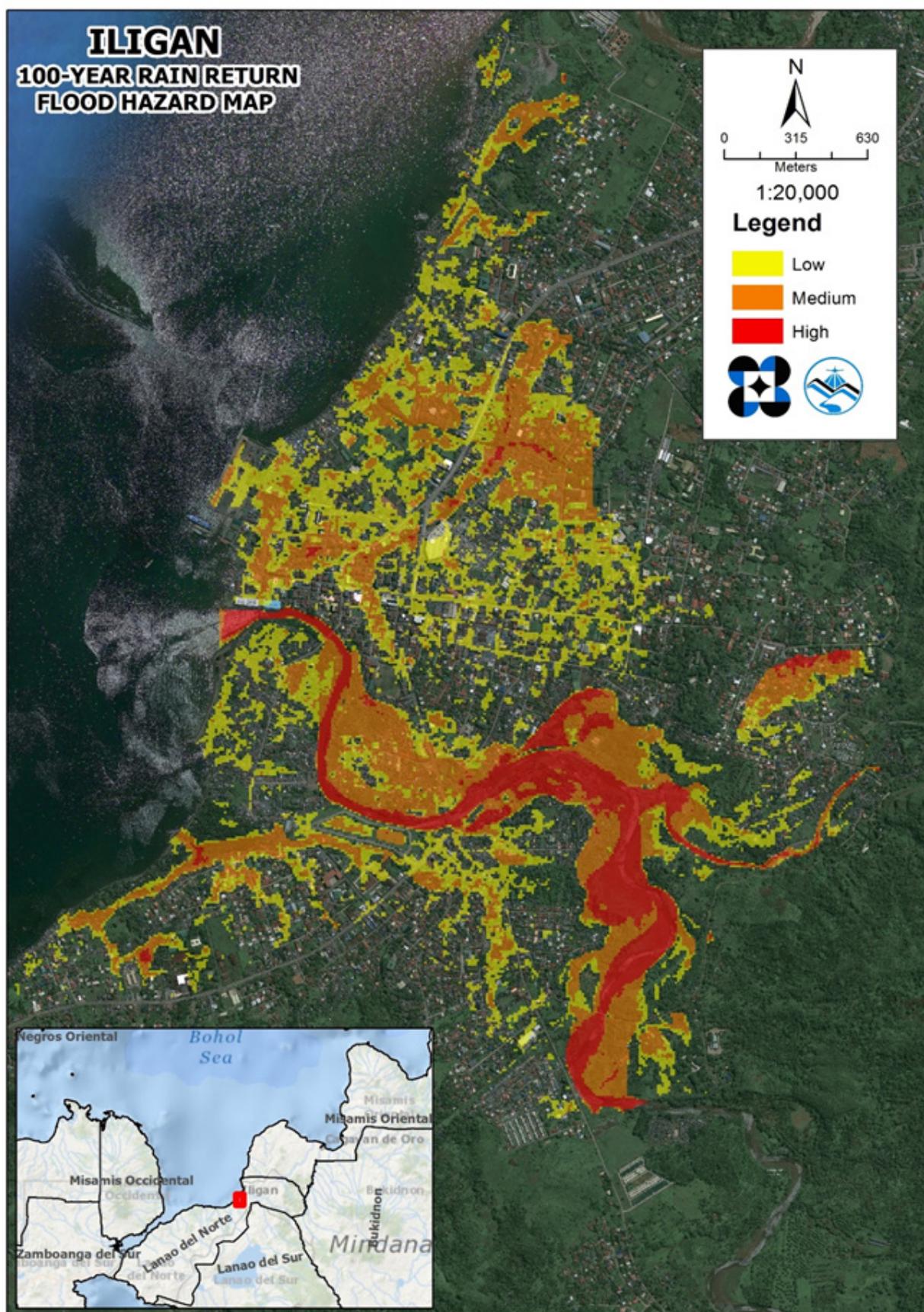


Figure 36. 100-year Flood Hazard Map for Iligan River Basin

# Results and Discussion

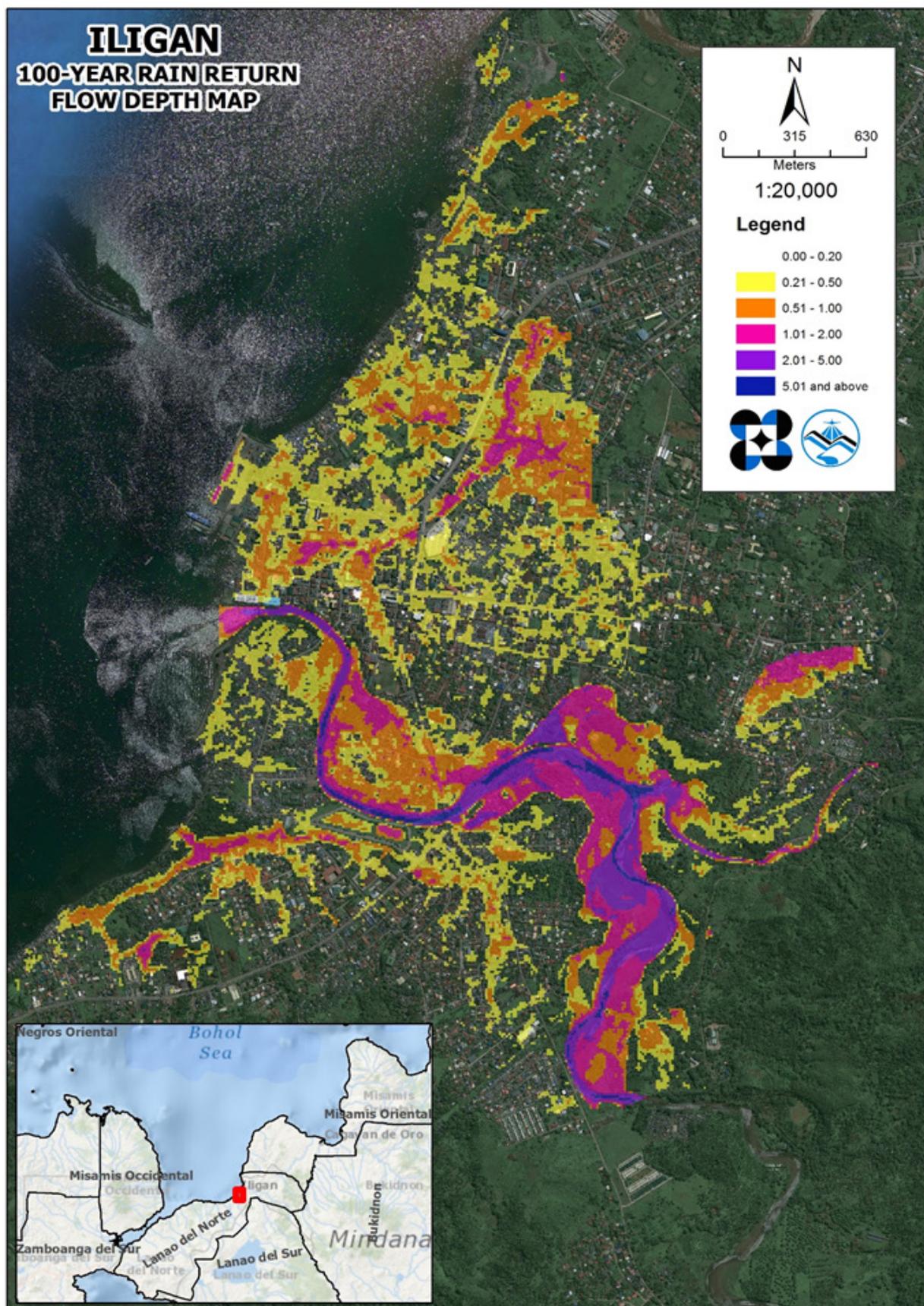


Figure 37. 100-year Flow Depth Map for Iligan River Basin

# Results and Discussion

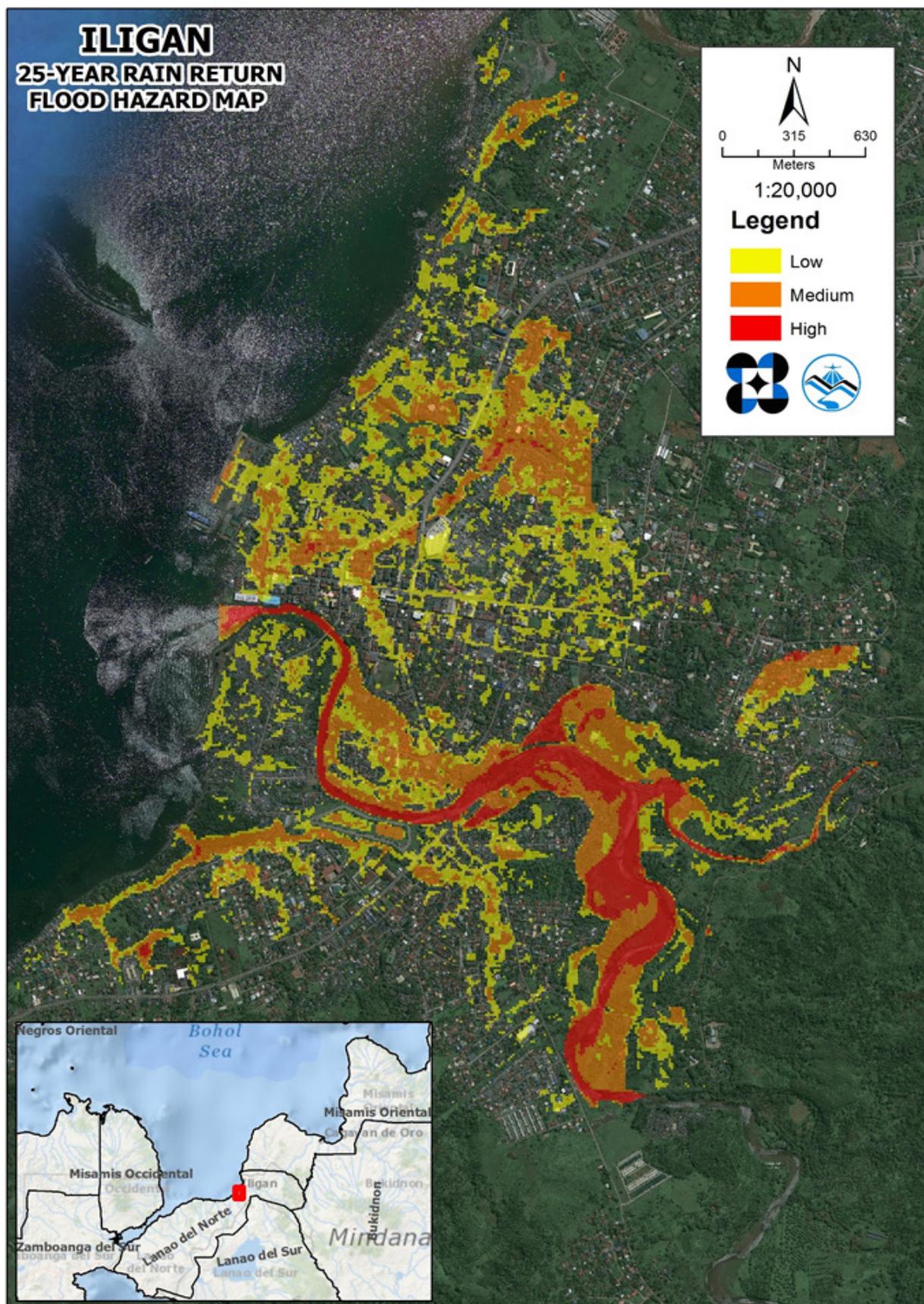


Figure 38. 25-year Flood Hazard Map for Iligan River Basin

# Results and Discussion

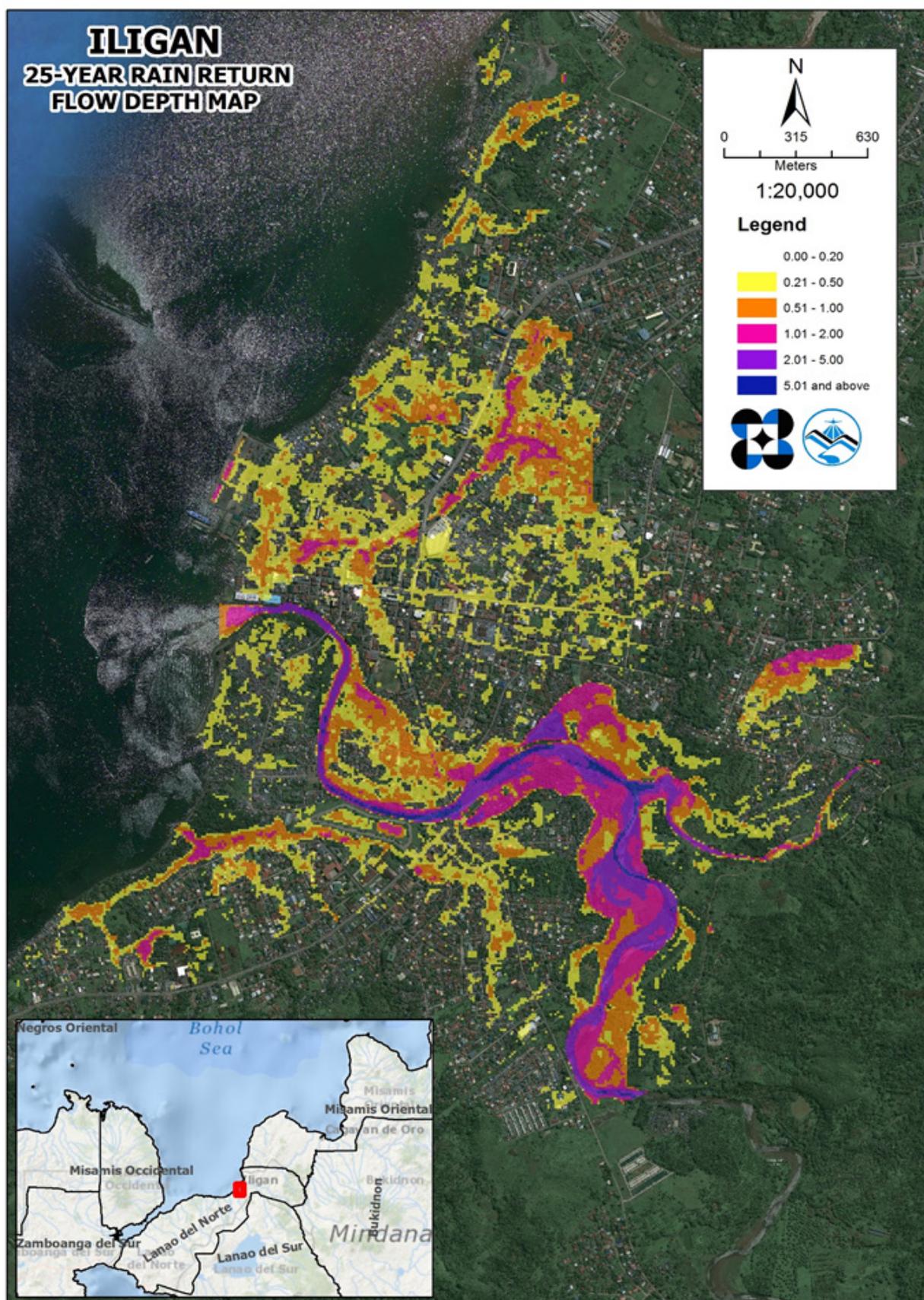


Figure 39. 25-year Flow Depth Map for Iligan River Basin

# Results and Discussion

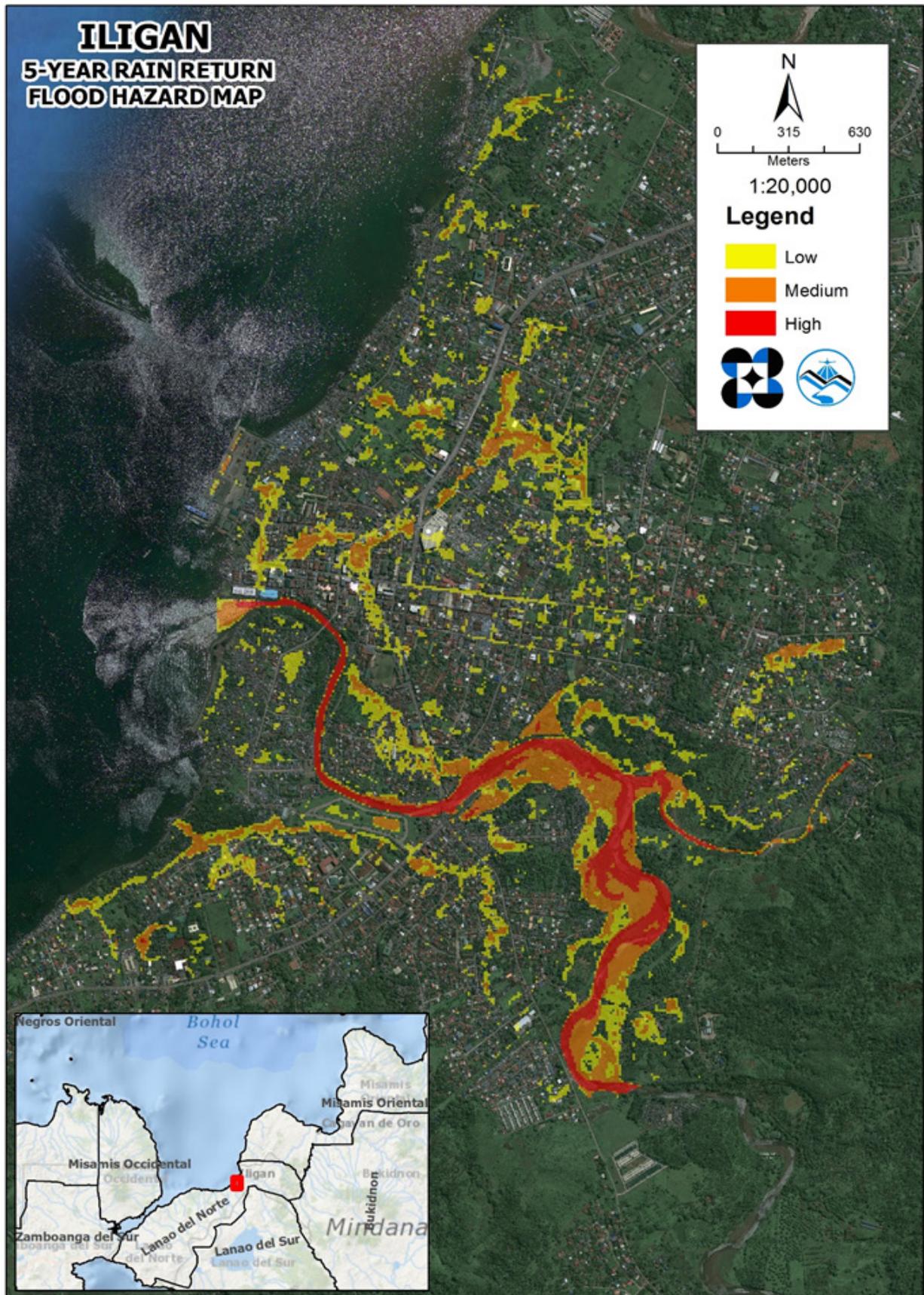


Figure 40. 5-year Flood Hazard Map for Iligan River Basin

# Results and Discussion

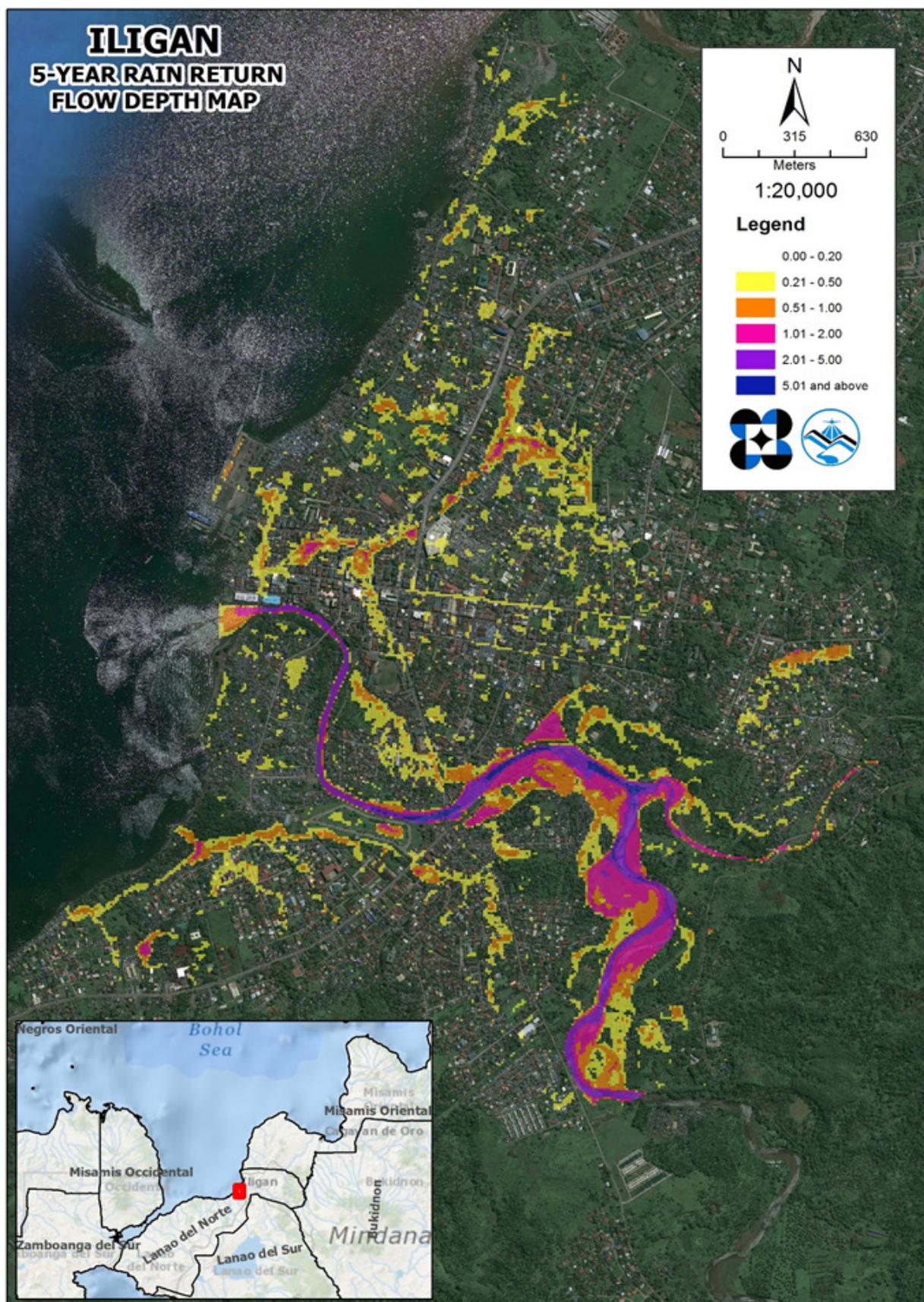


Figure 41. 5-year Flood Hazard Map for Iligan River Basin

---

## Bibliography

- Aquaveo. (2012). Watershed Modeling - HEC HMS Interface. Aquaveo.
- Feldman, A. D. (2000). Hydrologic Modeling System HEC-HMS Technical Reference Manual. Davis, CA: US Army Corps of Engineers - Hydrologic Engineering Center.
- FLO-2D Software, I. Flo-2D Reference Manual. FLO-2D Software, Inc.
- Merwade, V. (2012). Terrain Processing and HMS- Model Development using GeoHMS. Lafayette, Indiana.
- Santillan, J. (2011). Profile and Cross Section Surveys, Inflow measurement and flood modeling of Surigao River, Surigao City for Flood Hazard Assessment Purposes. Quezon City: Training Center for Applied Geodesy and Photogrammetry (TCAGP).
- Scharffenberg, W. A., & Fleming, M. J. (2010). Hydrologic Modeling System HEC-HMS User's Manual. Davis, California: U.S Army Corps of Engineers - Hydrologic Engineering Center.





# Appendix



## Appendix A. Iligan 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 (M <sup>3</sup> /S)	Recession Constant	Threshold Type	Ratio to Peak
32B	0	73.15	0	1.1875	7.7475	Discharge	0.22173	0.9	Ratio to Peak	0.1
33B	0	73.91	0	0.41875	2.7225	Discharge	0.0392608	0.9	Ratio to Peak	0.1
34B	0	74.7175	0	0.8375	5.4675	Discharge	0.0740036	0.9	Ratio to Peak	0.1
35B	0	74.841	0	0.475	3.0825	Discharge	0.0325792	0.9	Ratio to Peak	0.1
36B	0	74.746	0	0.3625	2.37	Discharge	0.0322771	0.9	Ratio to Peak	0.1
37B	0	74.822	0	0.7625	4.9625	Discharge	0.11988	0.9	Ratio to Peak	0.1
38B	0	74.879	0	0.63125	4.13	Discharge	0.0810401	0.9	Ratio to Peak	0.1
39B	0	73.15	0	1	6.545	Discharge	0.17504	0.9	Ratio to Peak	0.1
40B	0	76.4845	0	0.45	2.9275	Discharge	0.0483193	0.9	Ratio to Peak	0.1
41B	0	79.2015	0	0.73125	4.765	Discharge	0.0277233	0.9	Ratio to Peak	0.1
42B	0	76.2375	0	0.49375	3.22	Discharge	0.0466522	0.9	Ratio to Peak	0.1



# Appendix

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	ImperVIOUS (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M <sup>3</sup> /S)	Recession Constant	Threshold Type	Ratio to Peak
43B	0	75.145	0	1.35625	8.86	Discharge	0.10387	0.9	Ratio to Peak	0.1
44B	0	74.081	0	0.6875	4.4675	Discharge	0.0983398	0.9	Ratio to Peak	0.1
45B	0	74.632	0	0.5625	3.67	Discharge	0.0378788	0.9	Ratio to Peak	0.1
46B	3.56994	73.2756375	0	1.19375	7.8075	Discharge	0.13166	0.9	Ratio to Peak	0.1
47B	0	74.347	0	0.71875	4.685	Discharge	0.0838759	0.9	Ratio to Peak	0.1
48B	0	74.3565	0	0.36875	2.395	Discharge	0.0950603	0.9	Ratio to Peak	0.1
49B	0	75.0215	0	0.63125	4.14	Discharge	0.0723195	0.9	Ratio to Peak	0.1
50B	0	75.05	0	0.2375	1.5475	Discharge	0.0058131	0.9	Ratio to Peak	0.1
51B	0	74.727	0	0.58125	3.7925	Discharge	0.11408	0.9	Ratio to Peak	0.1
52B	11.12166	73.599825	0	1.1125	7.2675	Discharge	0.21542	0.9	Ratio to Peak	0.1
53B	14.10102	76.2581625	0	0.8375	5.4525	Discharge	0.0942277	0.9	Ratio to Peak	0.1

# Appendix

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M <sup>3</sup> /S)	Recession Constant	Threshold Type	Ratio to Peak
54B	7.24806	74.6279625	0	0.6125	3.995	Discharge	0.20322	0.9	Ratio to Peak	0.1
55B	7.67286	73.7017125	0	0.4375	2.8525	Discharge	0.0400953	0.9	Ratio to Peak	0.1
56B	21.258	74.229675	0	0.28125	1.8325	Discharge	0.0230259	0.9	Ratio to Peak	0.1
57B	9.43938	76.4989875	0	1.0125	6.615	Discharge	0.11536	0.9	Ratio to Peak	0.1
58B	16.29324	73.98885	0	0.9125	5.975	Discharge	0.13803	0.9	Ratio to Peak	0.1
59B	6.51744	76.2766875	0	1.2	7.82	Discharge	0.15719	0.9	Ratio to Peak	0.1
60B	24.1794	74.8132125	0	0.35	2.2625	Discharge	0.0153324	0.9	Ratio to Peak	0.1
61B	27.0756	72.9607125	0	0.625	4.095	Discharge	0.0995821	0.9	Ratio to Peak	0.1
62B	23.2812	74.933625	0	0.49375	3.2125	Discharge	0.0662571	0.9	Ratio to Peak	0.1



# Appendix

## Appendix B. Iligan Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
62R	Automatic Fixed Interval	4935.759	0.00384	0.05	Trapezoid	30	45
63R	Automatic Fixed Interval	24041.53	0.01991	0.05	Trapezoid	30	45
64R	Automatic Fixed Interval	1892.622	0.05411	0.05	Trapezoid	30	45
65R	Automatic Fixed Interval	4233.445	0.03017	0.05	Trapezoid	30	45
66R	Automatic Fixed Interval	1655.183	0.0431	0.05	Trapezoid	30	45
67R	Automatic Fixed Interval	5953.455	0.02714	0.05	Trapezoid	30	45
68R	Automatic Fixed Interval	4377.017	0.10667	0.05	Trapezoid	30	45
69R	Automatic Fixed Interval	5739.175	0.00064	0.05	Trapezoid	30	45
71R	Automatic Fixed Interval	8363.596	0.00132	0.05	Trapezoid	30	45
72R	Automatic Fixed Interval	3797.302	0.00173	0.05	Trapezoid	30	45
73R	Automatic Fixed Interval	6999.166	0.00326	0.05	Trapezoid	30	45
74R	Automatic Fixed Interval	3029.178	0.0056	0.05	Trapezoid	30	45
75R	Automatic Fixed Interval	4118.509	0.00865	0.05	Trapezoid	30	45
76R	Automatic Fixed Interval	6930.18	0.00699	0.05	Trapezoid	30	45
77R	Automatic Fixed Interval	8578.942	0.02643	0.05	Trapezoid	30	45
78R	Automatic Fixed Interval	6550.96	0.01123	0.05	Trapezoid	30	45
79R	Automatic Fixed Interval	2797.351	0.04108	0.05	Trapezoid	30	45
80R	Automatic Fixed Interval	17932.95	0.01472	0.009173	Trapezoid	30	45
81R	Automatic Fixed Interval	17519.57	0.03004	0.01	Trapezoid	30	45
82R	Automatic Fixed Interval	5098.83	0.01363	0.009898	Trapezoid	30	45
82R	Automatic Fixed Interval	5098.83	0.01363	0.009898	Trapezoid	30	45
83R	Automatic Fixed Interval	3222.255	0.05117	0.009757	Trapezoid	30	45
84R	Automatic Fixed Interval	8569.592	0.03102	0.01	Trapezoid	30	45
85R	Automatic Fixed Interval	6023.056	0.05471	0.009989	Trapezoid	30	45
86R	Automatic Fixed Interval	2245.552	0.03067	0.009974	Trapezoid	30	45
87R	Automatic Fixed Interval	3246.81	0.06633	0.009985	Trapezoid	30	45
88R	Automatic Fixed Interval	11309.93	0.05688	0.01	Trapezoid	30	45
89R	Automatic Fixed Interval	2488.722	0.04988	0.01	Trapezoid	30	45
90R	Automatic Fixed Interval	3477.008	0.02801	0.01	Trapezoid	30	45
91R	Automatic Fixed Interval	8253.098	0.00919	0.05	Trapezoid	30	45

# Appendix

## Appendix C. Iligan Floodplain HEC-HMS Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	5.833333	0	0	0
0.166667	0	0	0	6	0	0	0
0.333333	0	0	0	6.166667	0	0	0
0.5	0	0	0	6.333333	0	0	0
0.666667	0	0	0	6.5	0	0	0
0.833333	0	0	0	6.666667	0	0	0
1	0	0	0	6.833333	0.1	0	0
1.166667	0	0	0	7	0.2	0	0
1.333333	0	0	0	7.166667	0.3	0	0
1.5	0	0	0	7.333333	0.5	0	0
1.666667	0	0	0	7.5	0.8	0.1	0
1.833333	0	0	0	7.666667	1.1	0.1	0
2	0	0	0	7.833333	1.6	0.2	0
2.166667	0	0	0	8	2.3	0.4	0
2.333333	0	0	0	8.166667	3	0.5	0
2.5	0	0	0	8.333333	4	0.8	0
2.666667	0	0	0	8.5	5.2	1.1	0
2.833333	0	0	0	8.666667	6.6	1.5	0
3	0	0	0	8.833333	8.3	2.1	0
3.166667	0	0	0	9	10.2	2.7	0
3.333333	0	0	0	9.166667	12.6	3.6	0
3.5	0	0	0	9.333333	15.5	4.7	0
3.666667	0	0	0	9.5	19	6.2	0
3.833333	0	0	0	9.666667	23.4	8.1	0
4	0	0	0	9.833333	28.6	10.6	0
4.166667	0	0	0	10	34.7	13.7	0
4.333333	0	0	0	10.16667	42	17.4	0
4.5	0	0	0	10.33333	50.5	21.9	0
4.666667	0	0	0	10.5	60.3	27.2	0
4.833333	0	0	0	10.66667	71.8	33.6	0
5	0	0	0	10.83333	85.1	41.2	0
5.166667	0	0	0	11	100.5	50.1	0
5.333333	0	0	0	11.16667	118.3	60.6	0.1
5.5	0	0	0	11.33333	138.6	72.8	0.1
5.666667	0	0	0	11.5	161.6	86.8	0.3



# Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
11.66667	188.1	103.3	0.7	18	1575.2	1144.2	258
11.83333	218.4	122.5	1.4	18.16667	1513.2	1099.5	247.1
12	256.2	147.3	3.4	18.33333	1452.1	1055.4	236.4
12.16667	299.5	176.3	6.6	18.5	1394.1	1013.6	226.6
12.33333	350.9	211.3	11.3	18.66667	1337.3	972.6	217.2
12.5	409.2	251.7	17.8	18.83333	1282.3	932.9	208.4
12.66667	473.4	296.7	25.6	19	1228.7	894.3	200
12.83333	544	346.6	34.9	19.16667	1176.5	856.7	192
13	620	400.8	45.7	19.33333	1126.4	820.6	184.5
13.16667	703.3	460.7	58.3	19.5	1078.4	786	177.5
13.33333	791.8	524.8	72.7	19.66667	1032.5	753	171
13.5	887.9	594.9	89.1	19.83333	987.8	720.9	164.7
13.66667	988.9	669.1	107.6	20	944.1	689.5	158.4
13.83333	1094.5	747	127.7	20.16667	901.3	658.7	152.3
14	1202.8	827.4	149.3	20.33333	859.9	628.9	146.3
14.16667	1309.7	907.2	171.6	20.5	819.7	600.1	140.5
14.33333	1412.4	984.1	193.4	20.66667	780.7	572.1	134.8
14.5	1510.7	1058.1	214.9	20.83333	743.4	545.2	129.2
14.66667	1599.3	1125.2	234.6	21	708	519.7	123.8
14.83333	1680.8	1187.2	252.9	21.16667	675.1	496.1	118.7
15	1752.2	1242	269.3	21.33333	643.9	473.6	113.9
15.16667	1813.9	1289.7	283.5	21.5	614.1	452.2	109.2
15.33333	1865.7	1330.2	295.6	21.66667	585.6	431.7	104.7
15.5	1906.6	1362.7	305.4	21.83333	558.8	412.4	100.4
15.66667	1939.5	1389.1	313.2	22	533.2	394	96.3
15.83333	1963.2	1408.9	319.4	22.16667	508.8	376.4	92.4
16	1978.7	1422.6	323.8	22.33333	485.5	359.7	88.6
16.16667	1982.4	1427.4	325.8	22.5	463.5	343.8	84.9
16.33333	1977.9	1426	325.7	22.66667	442.9	329	81.6
16.5	1966.2	1419.2	324.3	22.83333	423.3	314.9	78.4
16.66667	1947.3	1407.1	321.5	23	404.6	301.5	75.3
16.83333	1922.2	1390.4	317.6	23.16667	387	288.8	72.3
17	1890.4	1368.7	312.6	23.33333	370.5	276.9	69.6
17.16667	1852.4	1342.2	306.3	23.5	355.2	265.9	67.1
17.33333	1806.8	1310.1	298.7	23.66667	340.8	255.6	64.7
17.5	1755.7	1273.8	290	23.83333	327.4	246	62.5
17.66667	1698.3	1232.8	280.1	24	315.1	237.1	60.4
17.83333	1637.3	1188.9	269.2	24.16667	303.7	228.9	58.6



# Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
24.33333	293.1	221.3	56.8	30.66667	35.3	27.4	7.5
24.5	283.1	214	55.2	30.83333	32.5	25.2	6.9
24.66667	273.5	207.2	53.6	31	30	23.3	6.3
24.83333	264.5	200.6	52.1	31.16667	27.7	21.6	5.9
25	255.9	194.4	50.6	31.33333	25.6	19.9	5.4
25.16667	247.6	188.4	49.2	31.5	23.7	18.4	5
25.33333	239.5	182.5	47.8	31.66667	21.9	17.1	4.7
25.5	231.6	176.7	46.5	31.83333	20.3	15.8	4.3
25.66667	223.9	171	45.1	32	18.7	14.6	4
25.83333	216.2	165.3	43.7	32.16667	17.3	13.5	3.7
26	208.4	159.5	42.3	32.33333	16	12.5	3.4
26.16667	200.6	153.7	40.8	32.5	14.8	11.5	3.2
26.33333	192.7	147.8	39.3	32.66667	13.6	10.6	3
26.5	184.9	141.9	37.8	32.83333	12.6	9.8	2.7
26.66667	176.9	135.9	36.3	33	11.6	9.1	2.5
26.83333	169	130	34.7	33.16667	10.7	8.4	2.3
27	161.2	124	33.2	33.33333	9.9	7.7	2.2
27.16667	153.4	118.1	31.6	33.5	9.2	7.2	2
27.33333	145.7	112.2	30.1	33.66667	8.5	6.6	1.9
27.5	138.2	106.5	28.6	33.83333	7.8	6.1	1.7
27.66667	130.7	100.8	27.1	34	7.2	5.7	1.6
27.83333	123.5	95.2	25.7	34.16667	6.7	5.3	1.5
28	116.3	89.7	24.2	34.33333	6.2	4.9	1.4
28.16667	109.3	84.4	22.8	34.5	5.7	4.5	1.3
28.33333	102.5	79.2	21.4	34.66667	5.3	4.2	1.2
28.5	96	74.1	20.1	34.83333	4.9	3.8	1.1
28.66667	89.7	69.3	18.8	35	4.5	3.5	1
28.83333	83.6	64.6	17.5	35.16667	4.2	3.3	0.9
29	77.8	60.2	16.3	35.33333	3.9	3	0.9
29.16667	72.3	55.9	15.2	35.5	3.6	2.8	0.8
29.33333	67	51.9	14.1	35.66667	3.3	2.6	0.7
29.5	62.1	48	13.1	35.83333	3	2.4	0.7
29.66667	57.4	44.4	12.1	36	2.8	2.2	0.6
29.83333	53	41	11.2				
30	48.9	37.9	10.3				
30.16667	45.1	35	9.5				
30.33333	41.6	32.3	8.8				
30.5	38.4	29.8	8.1				







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

