REGION 10

Cagayan de Oro River Basin:

DREAM Flood Forecasting and Flood Hazard Mapping

TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY

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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: ecparingit@up.edu.ph

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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.

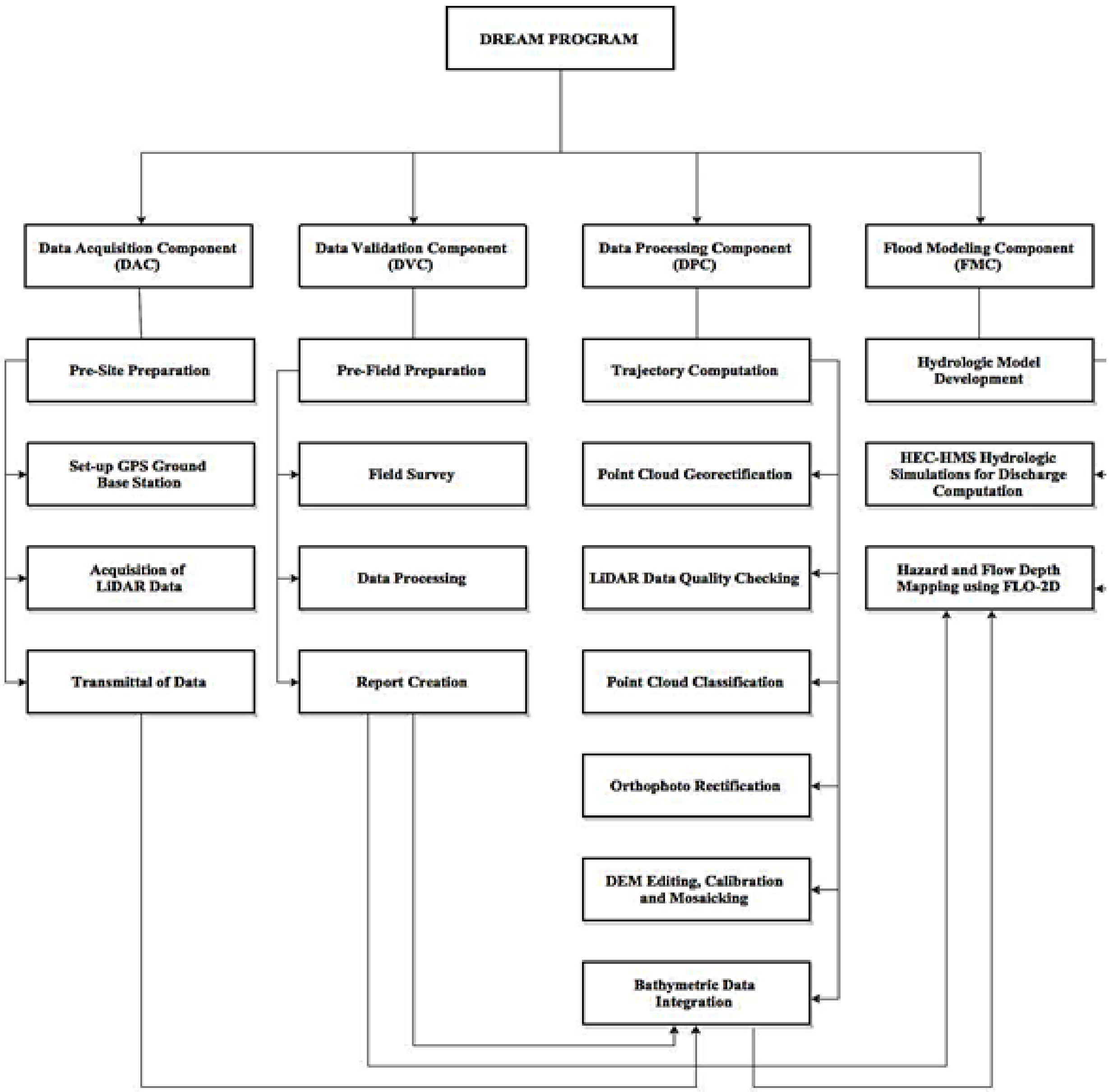


Figure 1. The general methodological framework of the program

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 Cagayan de Oro 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 Cagayan de Oro floodplain using FLO-2D GDS Pro; and

d) To prepare the static flood hazard and flow depth maps for the Cagayan de Oro 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.

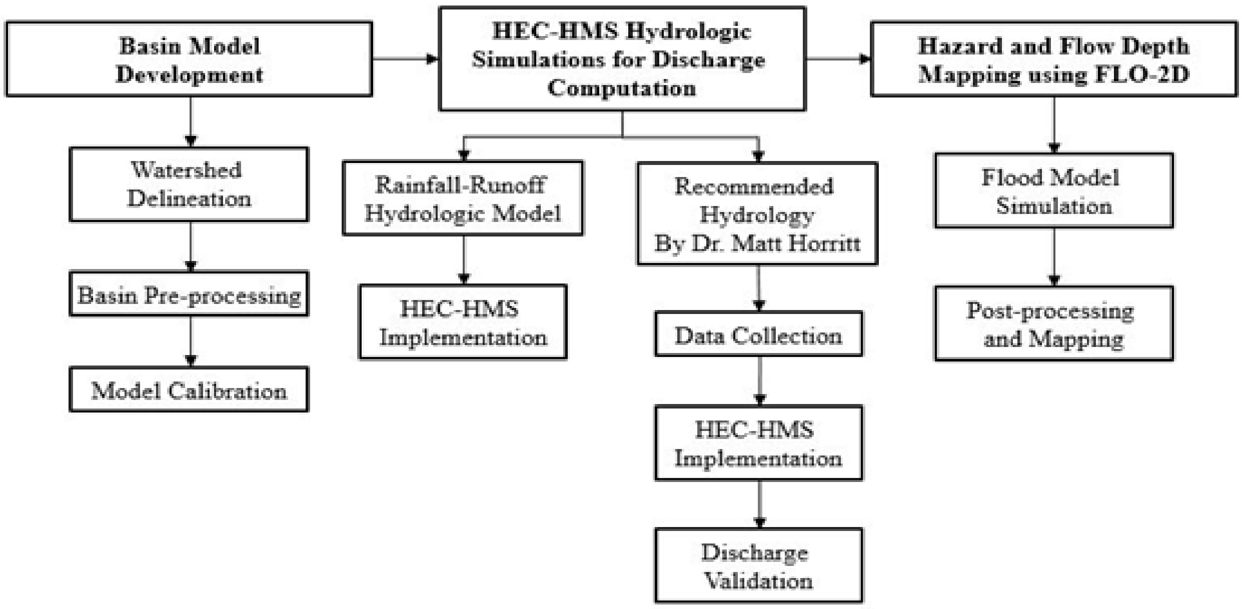


Figure 2. The operational framework and specific work flow of the Flood Modeling Component

The Cagayan de Oro River Basin

The Cagayan de Oro River Basin

The Cagayan de Oro (CDO) River Basin is located in the northern coast of Mindanao. The CDO River Basin is the sixteenth largest river basin in the Philippines with an estimated basin area of 1,521 square kilometres. The location of the Cagayan de Oro River Basin is as shown in Figure 3.

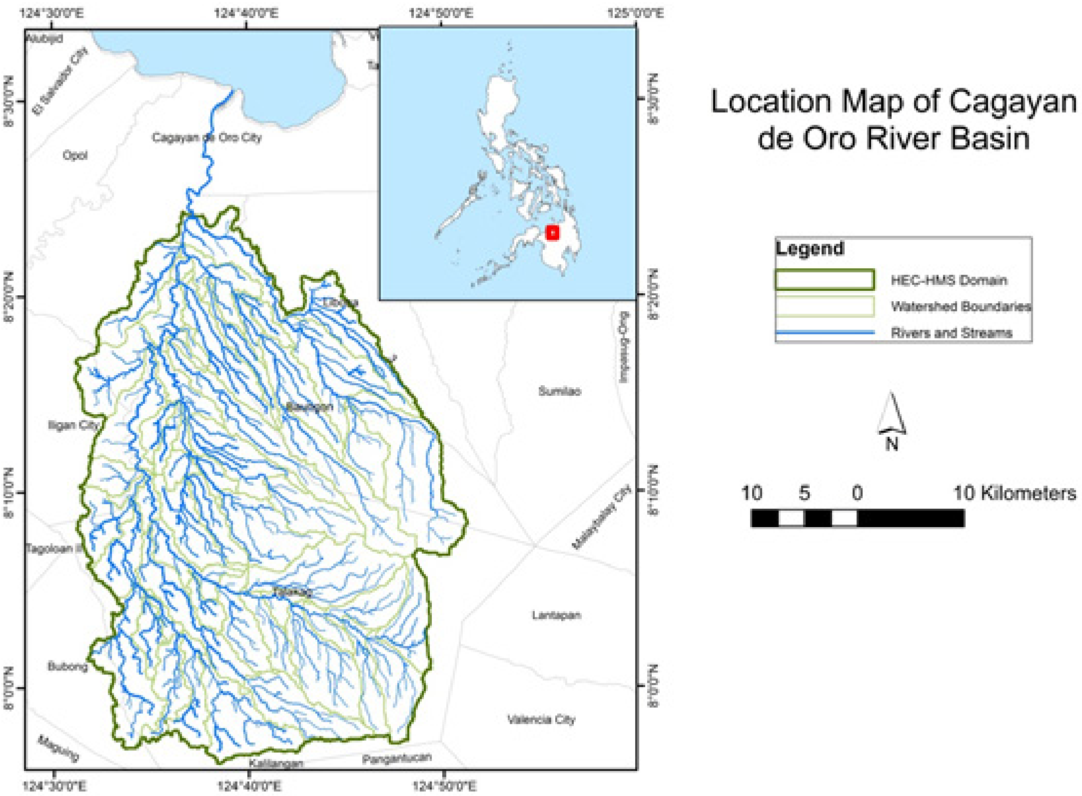


Figure 3. The Cagayan de Oro River Basin Location Map

It includes Cagayan de Oro City in Misamis Oriental and the municipalities of Talakag, Baungon and Libona in Bukidnon. It has Cagayan de Oro River as its main channel with major tributaries including Kalawaig River, Tagite River, Bubunaoan River, and Tumalaong River and discharges the load to Macajalar Bay.

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 Cagayan de Oro River Basin are shown in Figures 4 and 5, respectively.

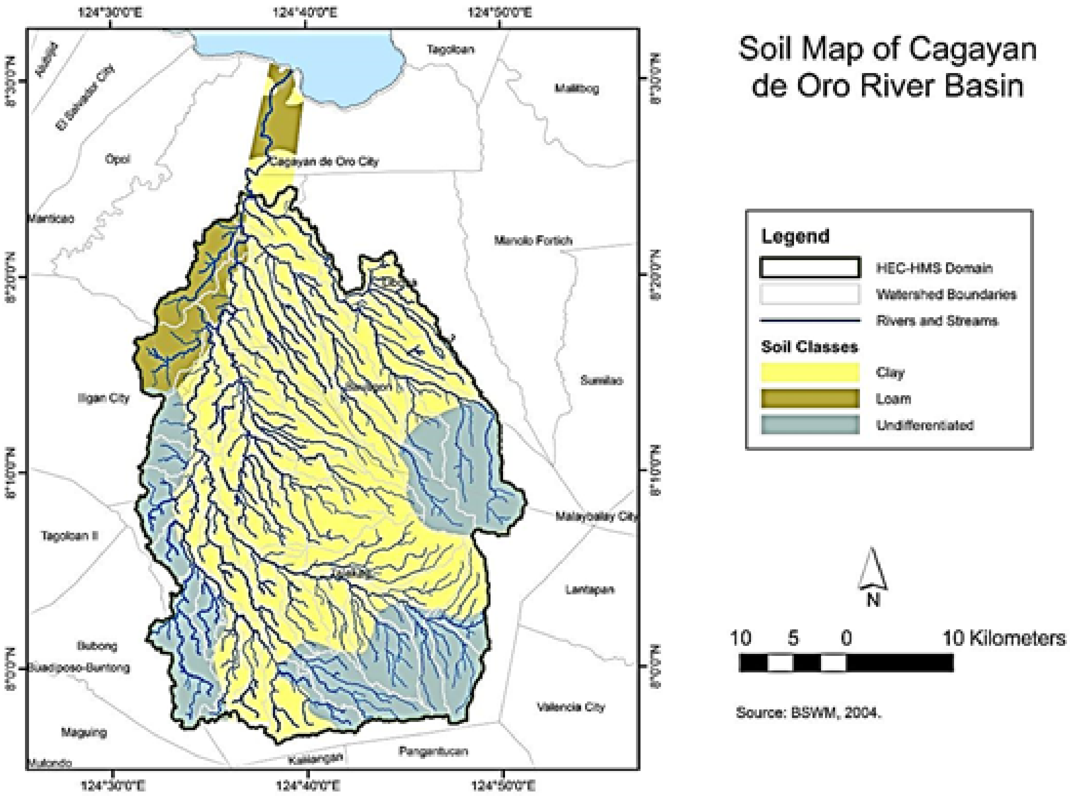


Figure 4. Cagayan de Oro Basin Soil Map

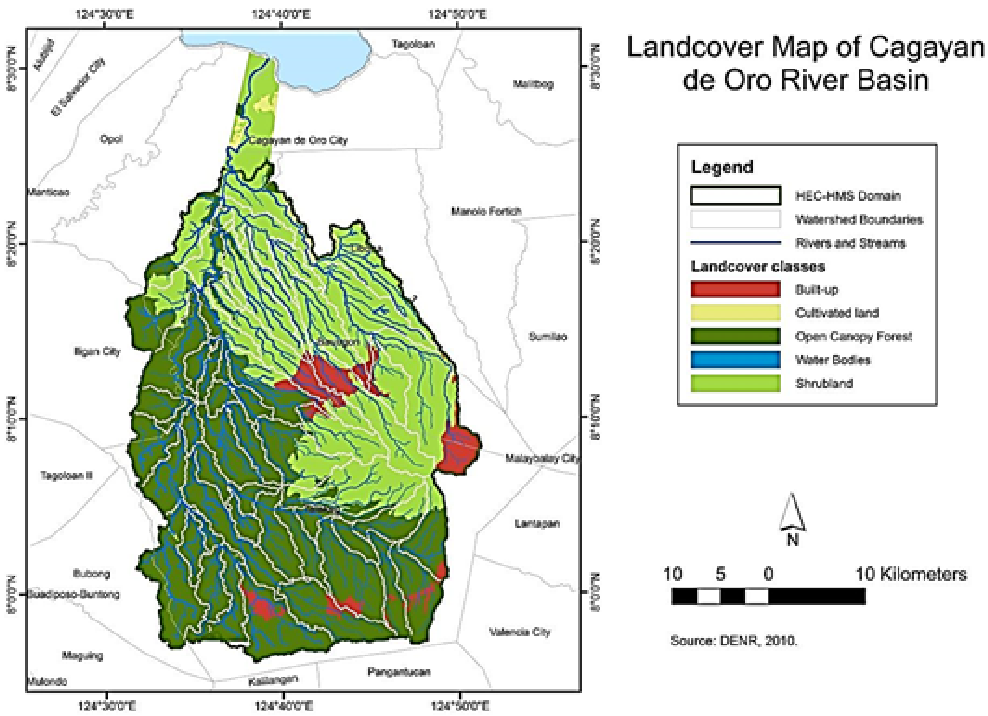


Figure 5. Cagayan de Oro River Basin Land Cover Map

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.

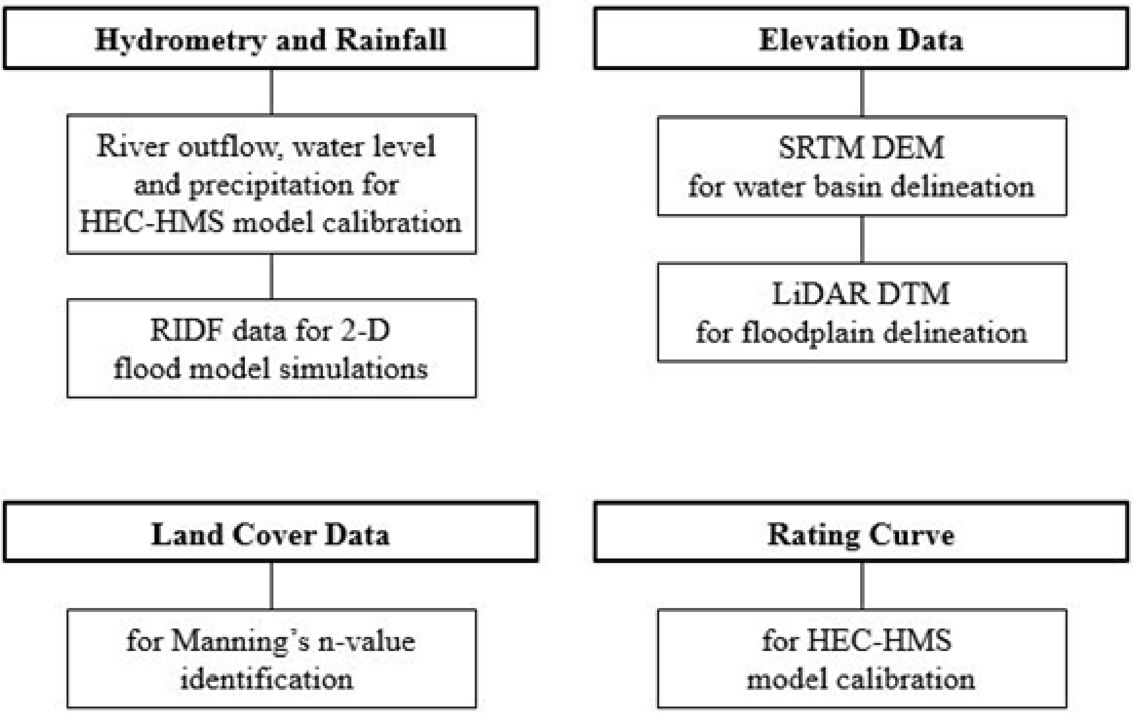


Figure 6. Summary of data needed for the purpose of flood modeling

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.

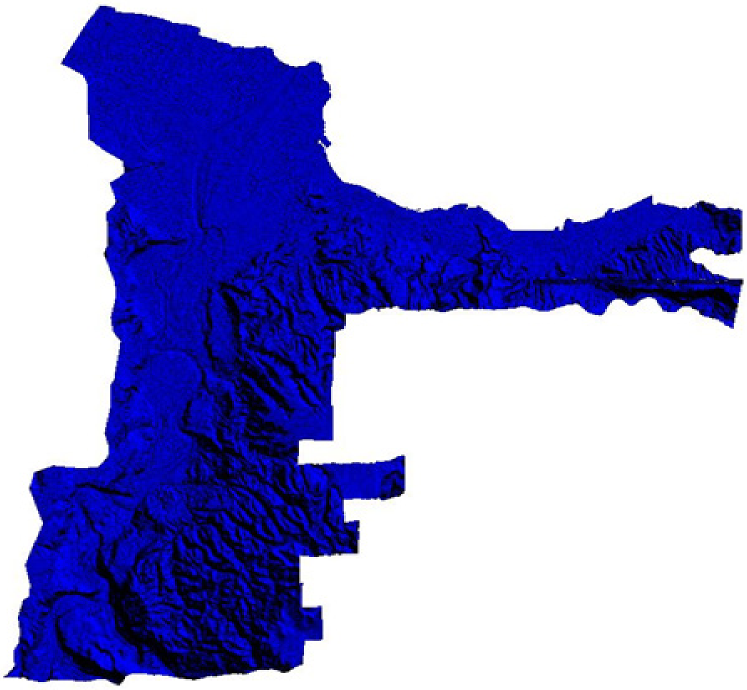


Figure 7. Digital Elevation Model (DEM) of the Cagayan de Oro River Basin using Light Detection and Ranging (LiDAR) technology

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

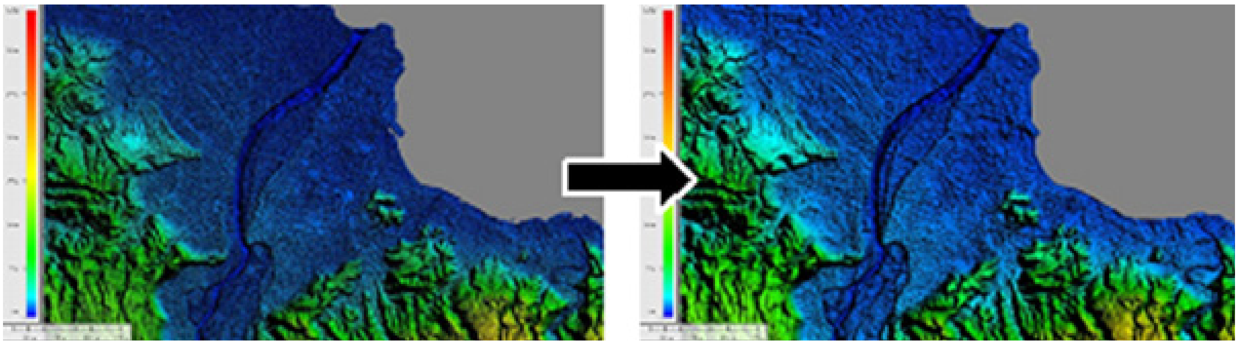


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted.

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 Cagayan de Oro 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 in 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 Cagayan de Oro floodplain.

3.1.3 Hydrometry and Rainfall Data

3.1.3.1 Hydrometry for CDO Bridge - Barangay Macasandig, Cagayan de Oro City

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

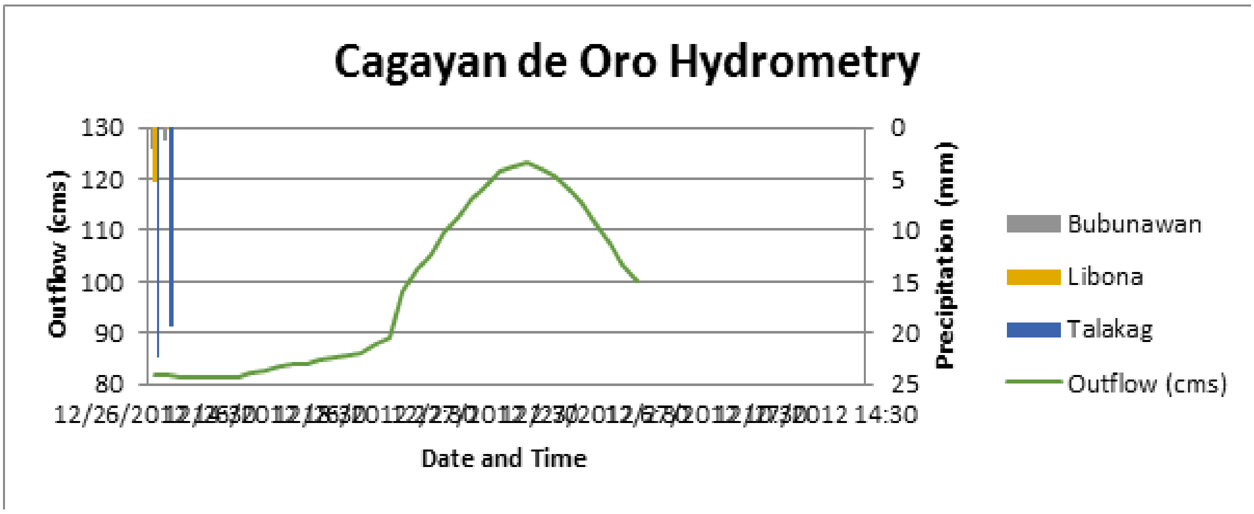


Figure 10. Rainfall and Outflow Data used for Modeling

3.1.3.2 Rainfall Intensity Duration Frequency

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values Lumbia Rain Gauge. This station chosen based on its proximity to the Cagayan de Oro watershed. The extreme values for this watershed were computed based on a 26-year record.

Five return periods were used, namely, 5-, 10-, 25-, 50-, and 100-year RIDFs. All return periods are 24 hours long and peaks after 12 hours. A map of the locations of the different PAGASA rain gauges is shown in Figure 11.

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

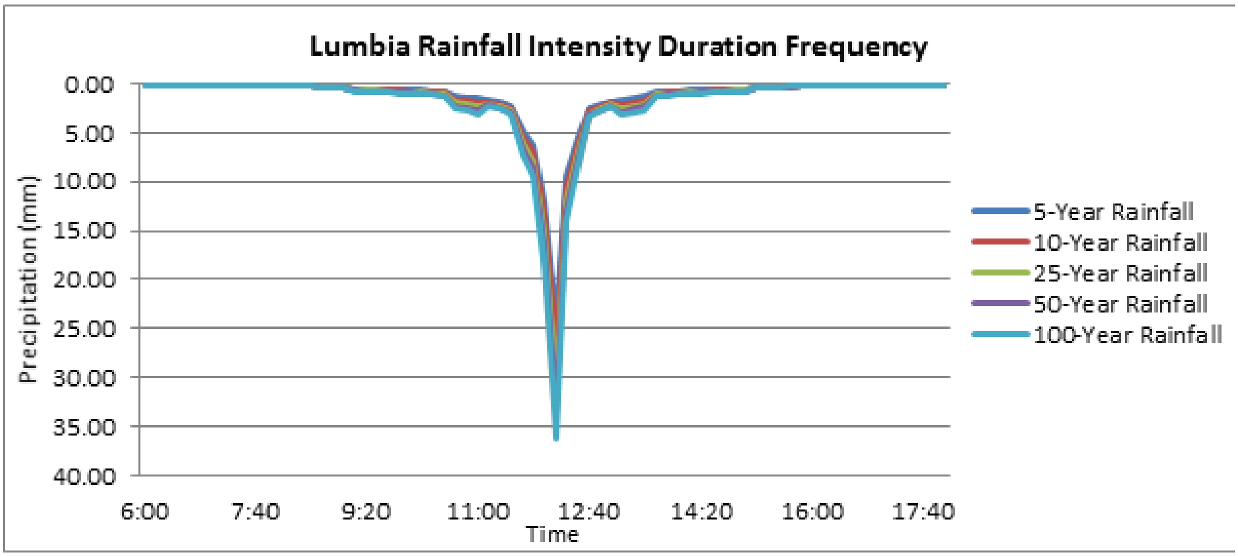


Figure 12. Lumbia Rainfall Intensity Duration Frequency Curves

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

3.1.4 Rating Curves

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

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

$$Q = a^{nh}$$

Equation 1. Rating Curve

For Padre Garcia, the rating curve is expressed as as $Q = 57.668e^{0.3824h}$ as shown in Figure 13.

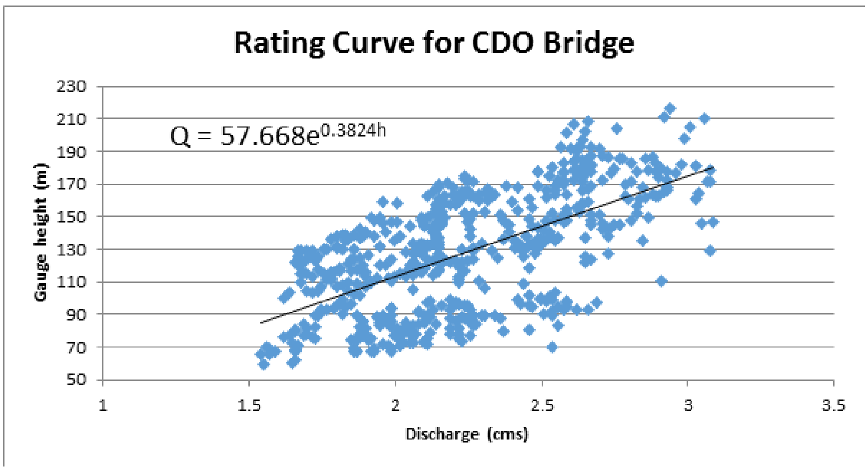


Figure 13. Water level vs. Discharge Curve for Waan Bridge, Cagayan

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Cagayan de Oro 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.

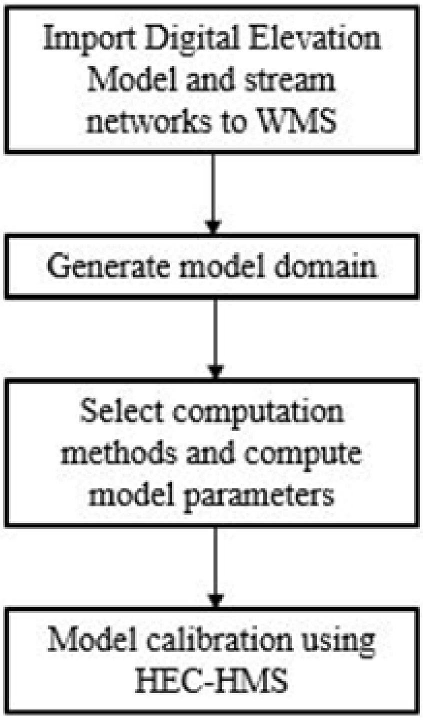


Figure 14. The Rainfall-Runoff Basin Model Development Scheme

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 Cagayan de Oro 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.

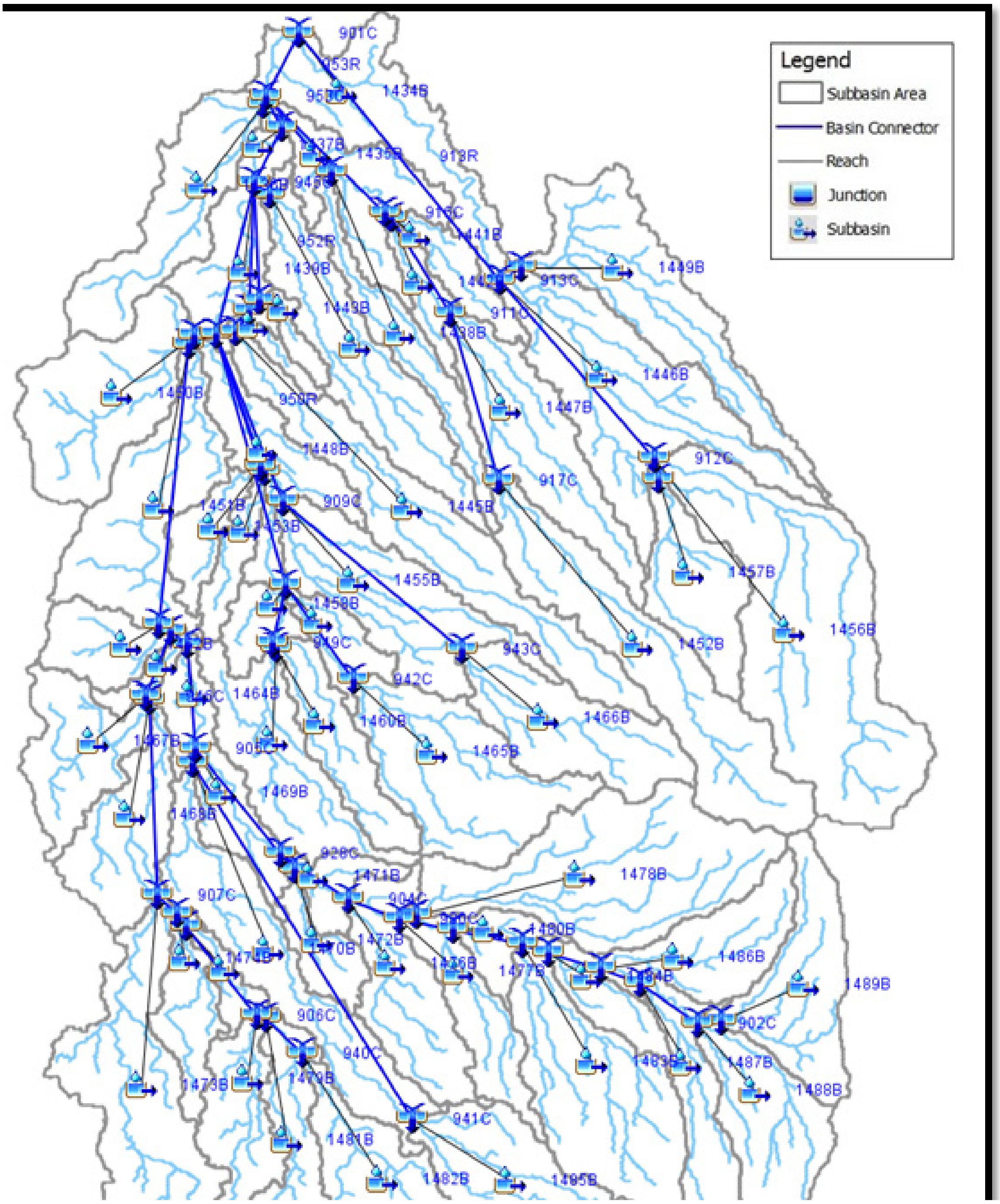


Table 1. Methods used for the different calculation types for the hydrologic elements

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 three automatic rain gauges (ARGs) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). These were the Bubunawan, Libona and Talakag ARGs. The location of the rain gauges is seen in Figure 16.

Total rain from Bubunawan rain gauge is 5.842 mm. It peaked to 1.016mm on 27 December 2012, 13:30. For Libona, total rain for this event is 7.62mm. Peak rain of 4.064mm was recorded on 26 December 2012, 19:00. For Talakag, total rain is 103.632mm. It peaked to 19.304mm at 27 Dec 2012, 05:15. The lag time between the peak rainfall and discharge is five hours and fifty minutes.

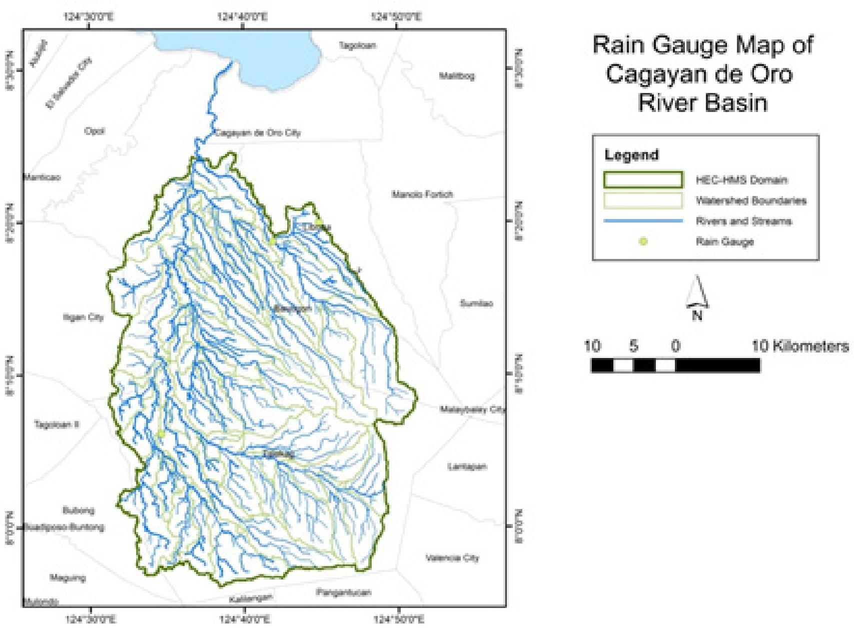


Figure 16. The location map of rain gauges used for the calibration of the Cagayan de Oro

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

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

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

3.3.1 Discharge Computation using Rainfall-Runoff Hydrologic Model

The calibrated rainfall-Runoff Hydrologic Model for the Cagayan de Oro 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 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 the said discharge point. 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 Hy-

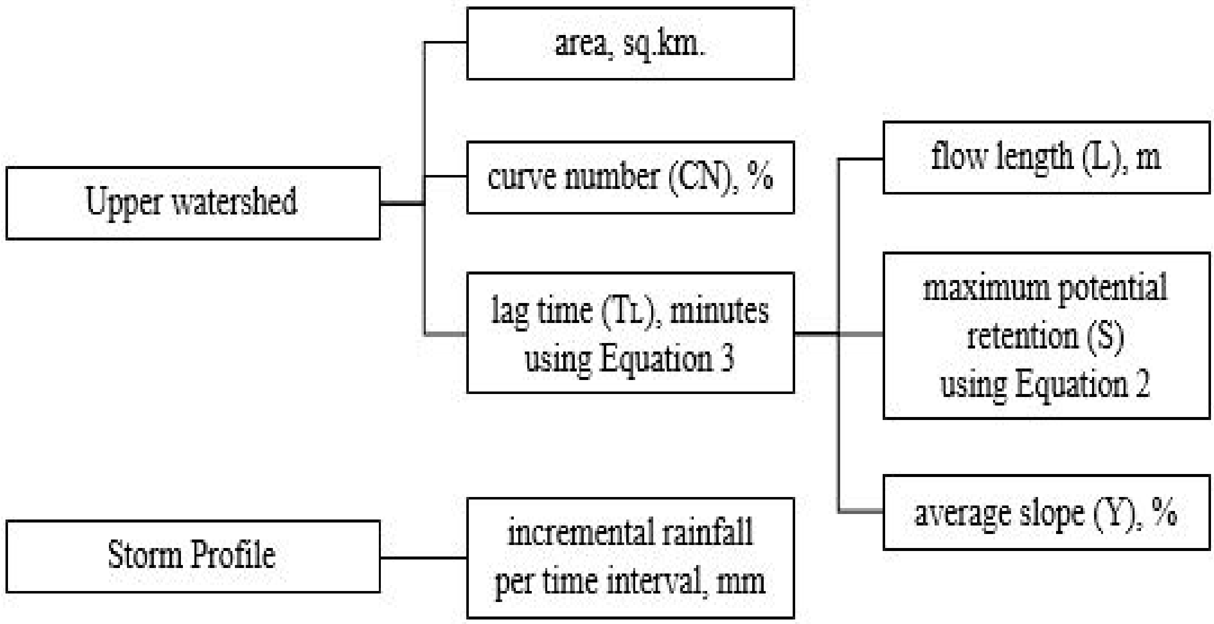


Figure 17. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method.

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

3.3.2.1 Determination of Catchment Properties

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

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

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

Figure 18. Delineation upper watershed for Cagayan de Oro 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.

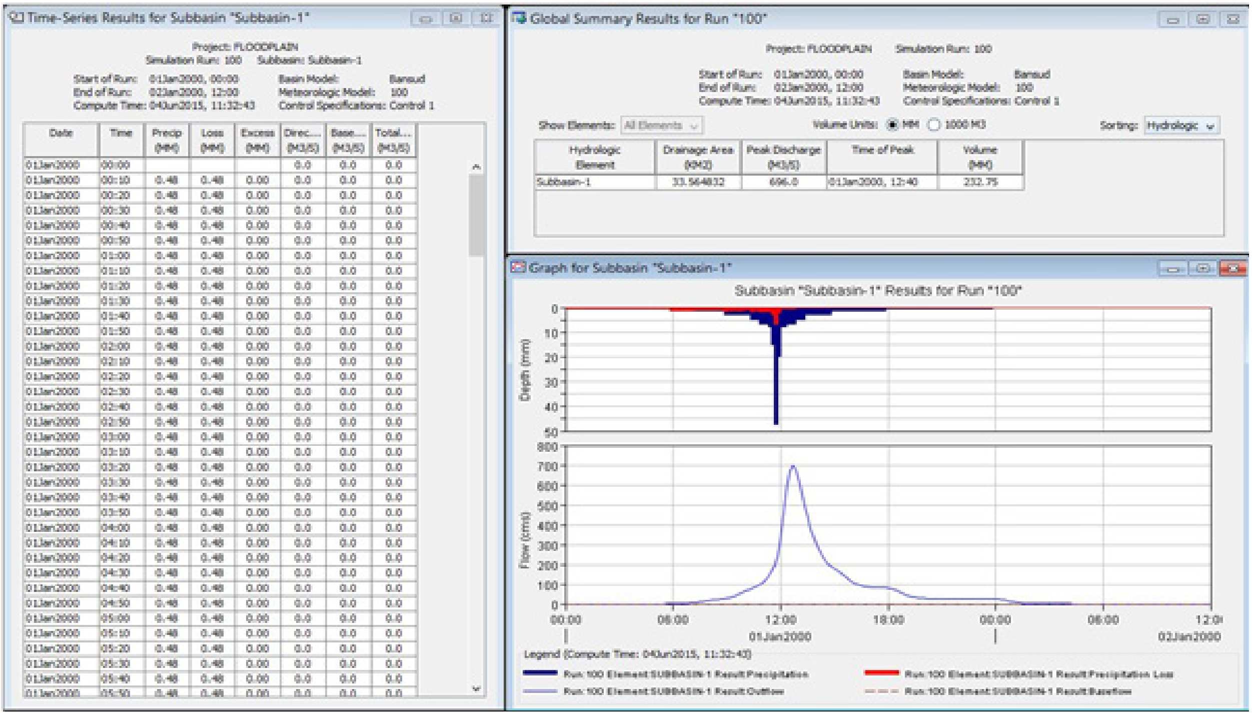


Figure 19. HEC-HMS simulation discharge results using Dr. Horritt's Method

3.3.2.3 Discharge validation against other estimates

As a general rule, the river discharge of a 2-year rain return, QMED, 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 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.

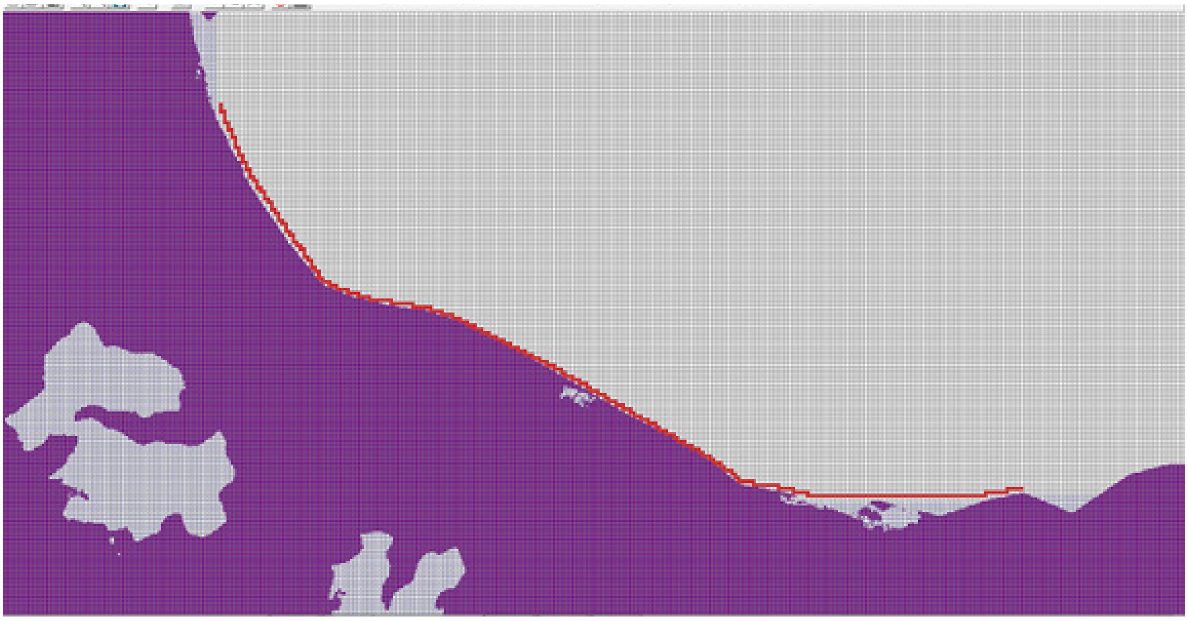


Figure 20. Screenshot showing how boundary grid elements are defined by line

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.

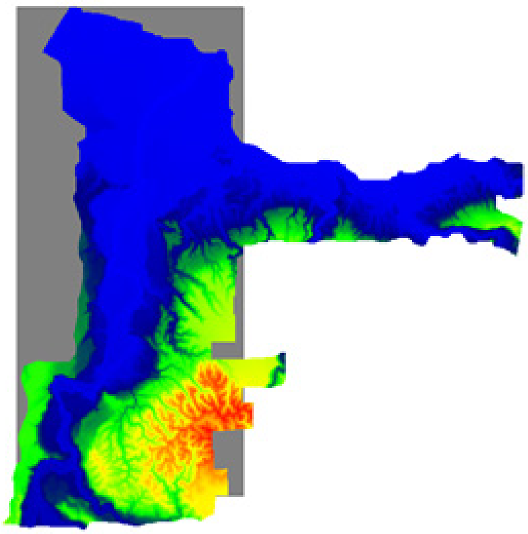


Figure 21. Screenshots of PTS files when loaded into the FLO-2D program

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 Cagayan de Oro floodplain

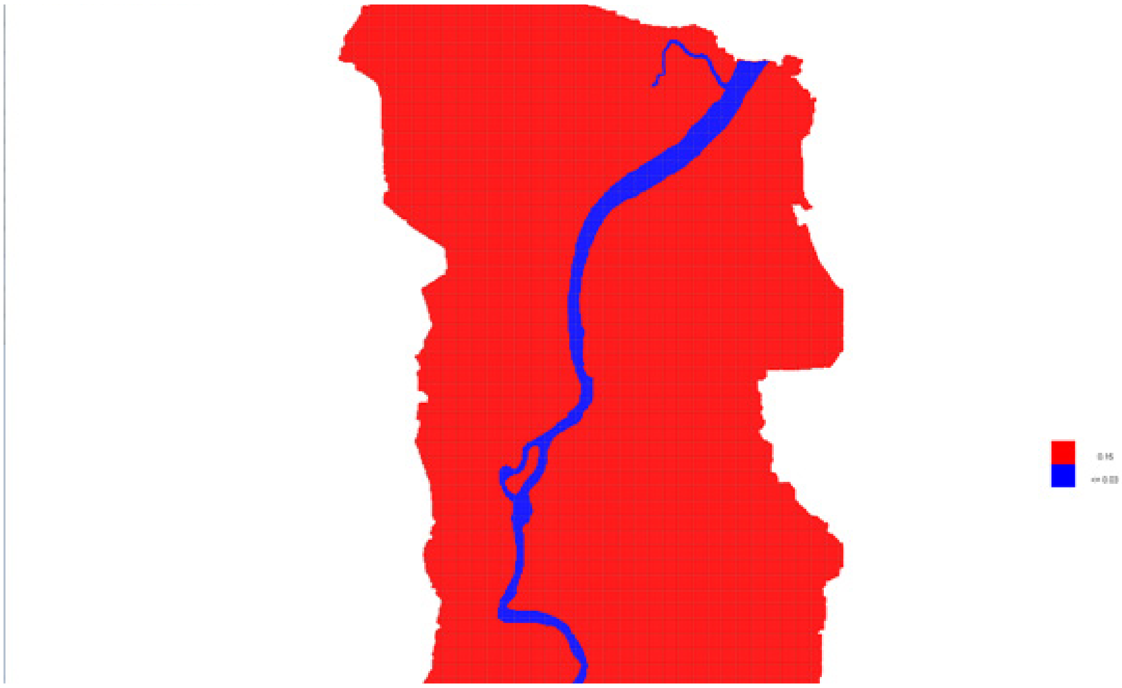


Figure 23. Screenshot of Manning's n-value rendering

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.

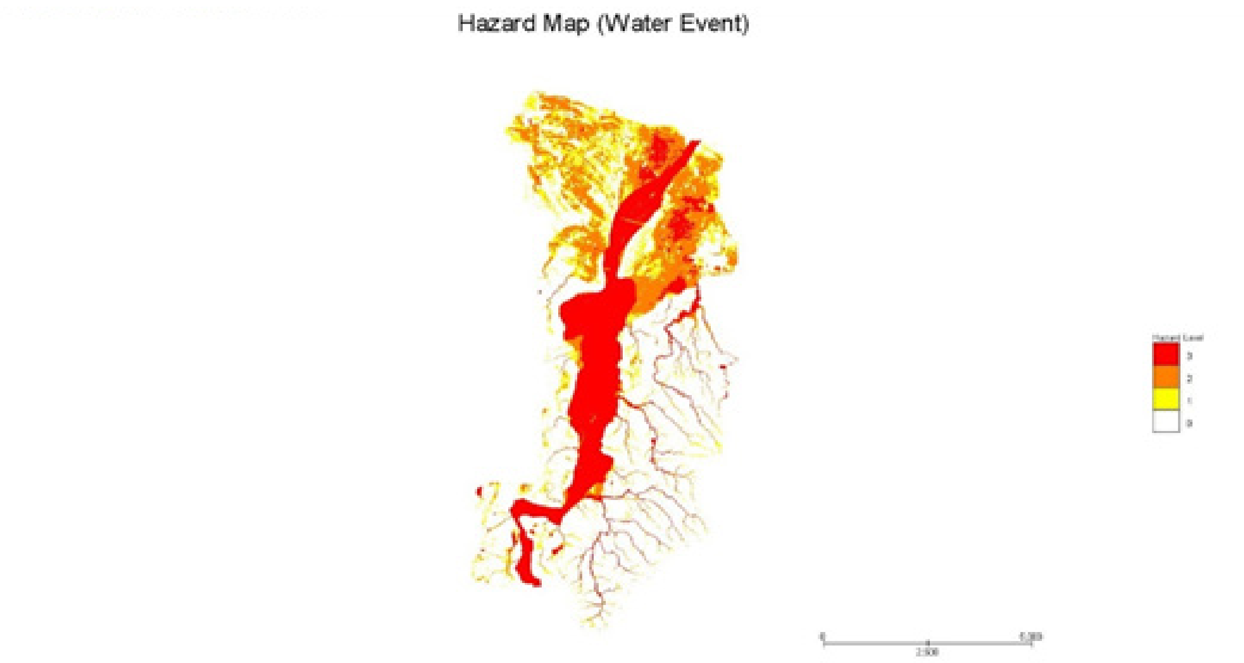


Figure 25. Cagayan de Oro Floodplain Generated Hazard Maps using FLO-2D Mapper

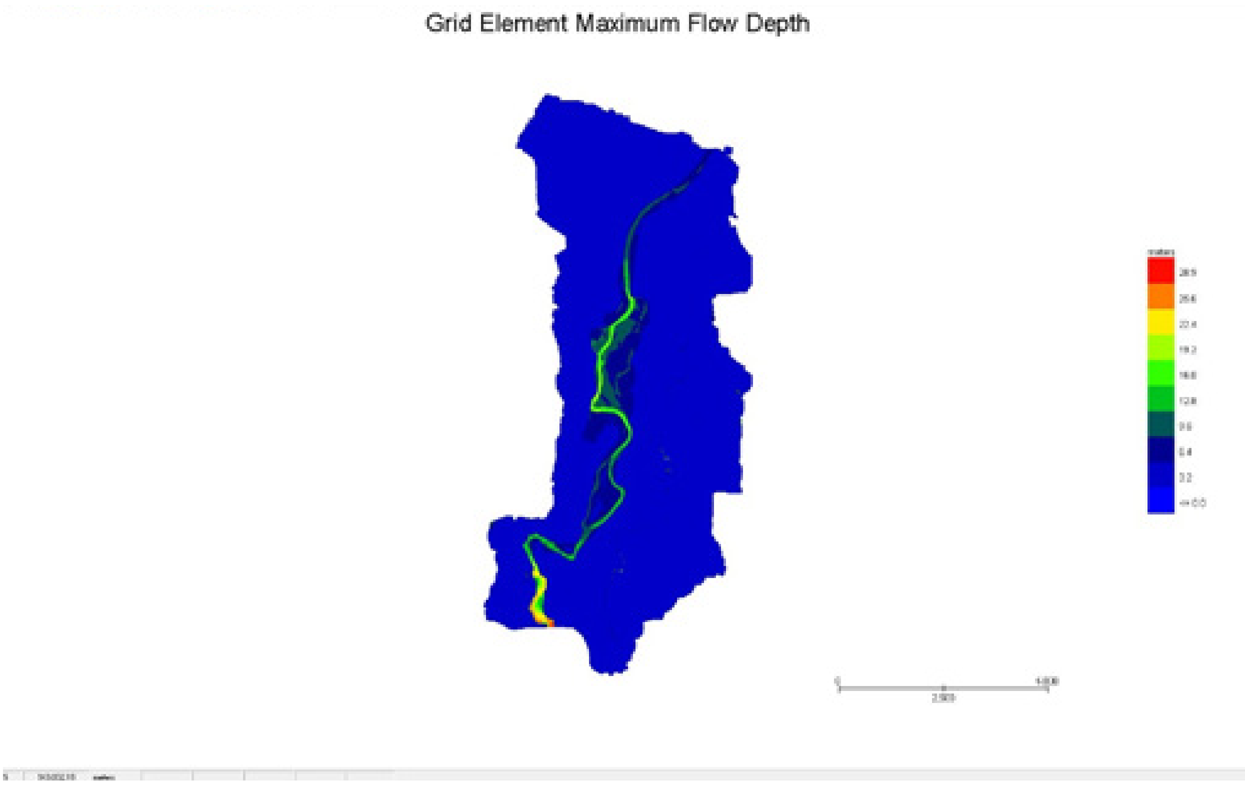
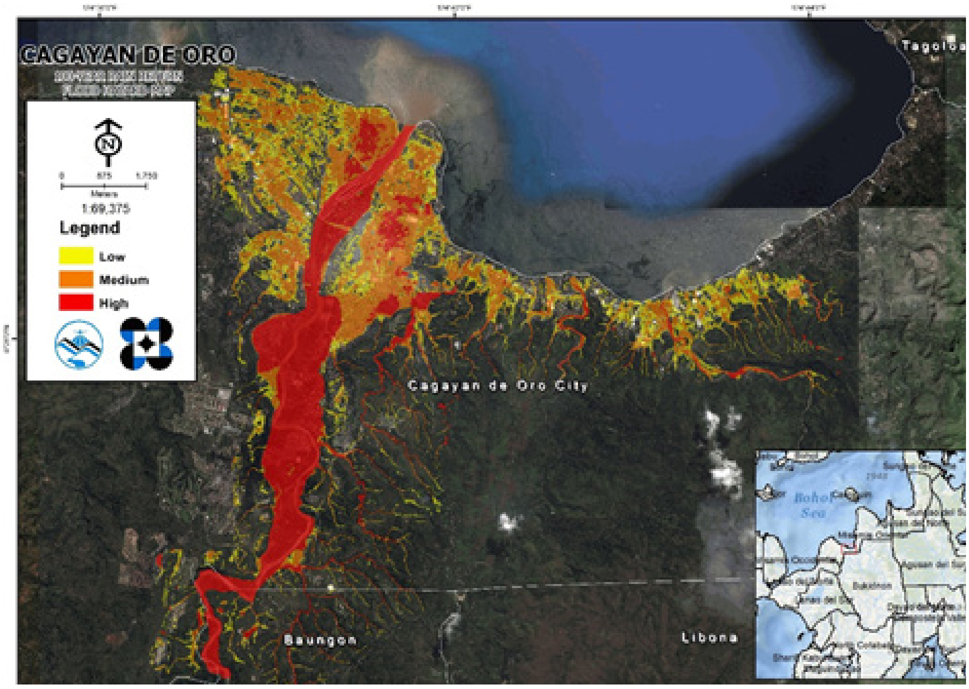


Figure 26. Cagayan de Oro floodplain generated flow depth map using FLO-2D Mapper

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

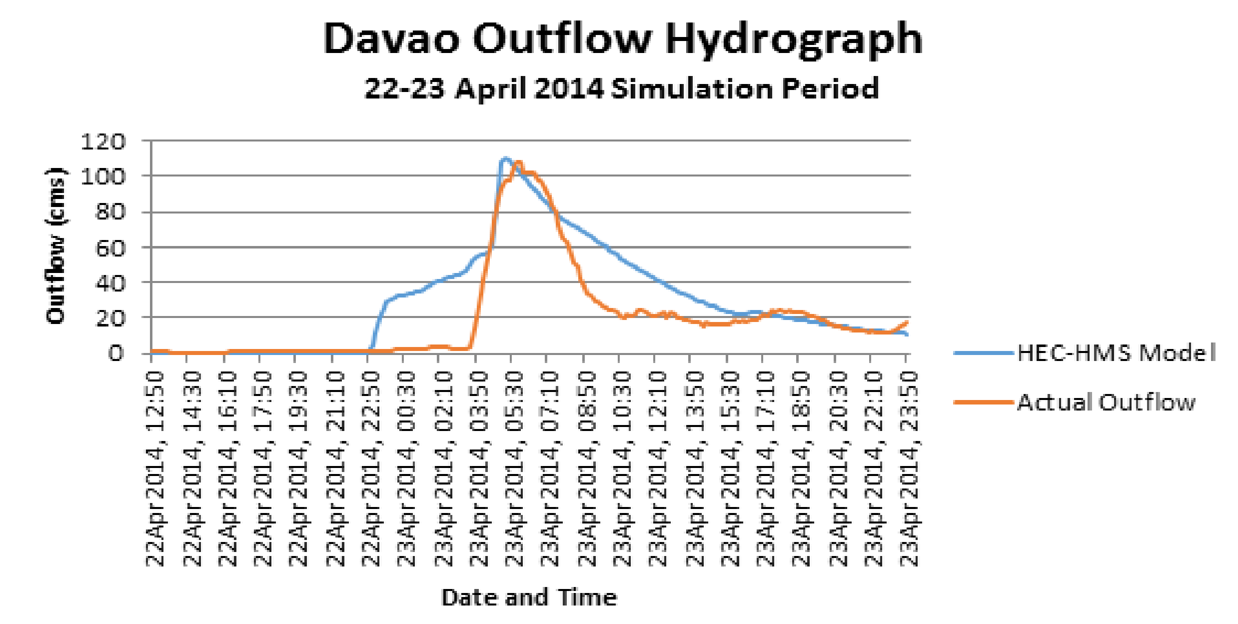


Figure 28. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow.

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

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.385.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.986.

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 0.962.
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 1.579.

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 0.17.

The calibrated models of the other discharge points are used in flood forecasting. DREAM

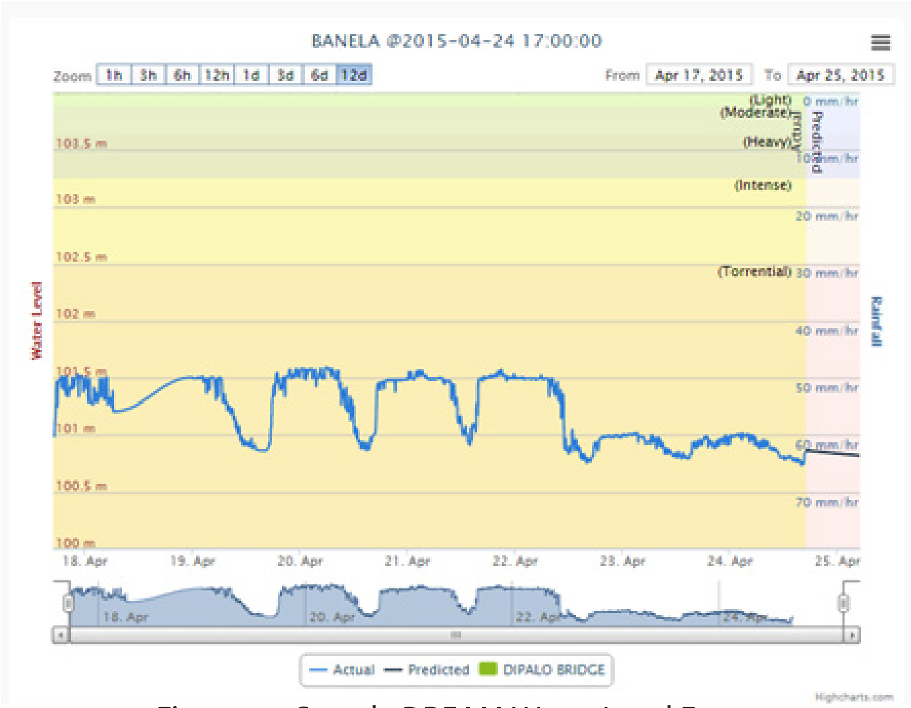


Figure 29. Sample DREAM Water Level Forecast

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 CDO outflow was computed using the Lumbia Rainfail Intensity-Duration-Frequency curves (RIDF) in five different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

In the 5-year return period graph shown in Figure 30, the peak outflow is 128.1 cms. This occurs after 4 hours and 20 minutes after the peak precipitation of 24.5 mm.

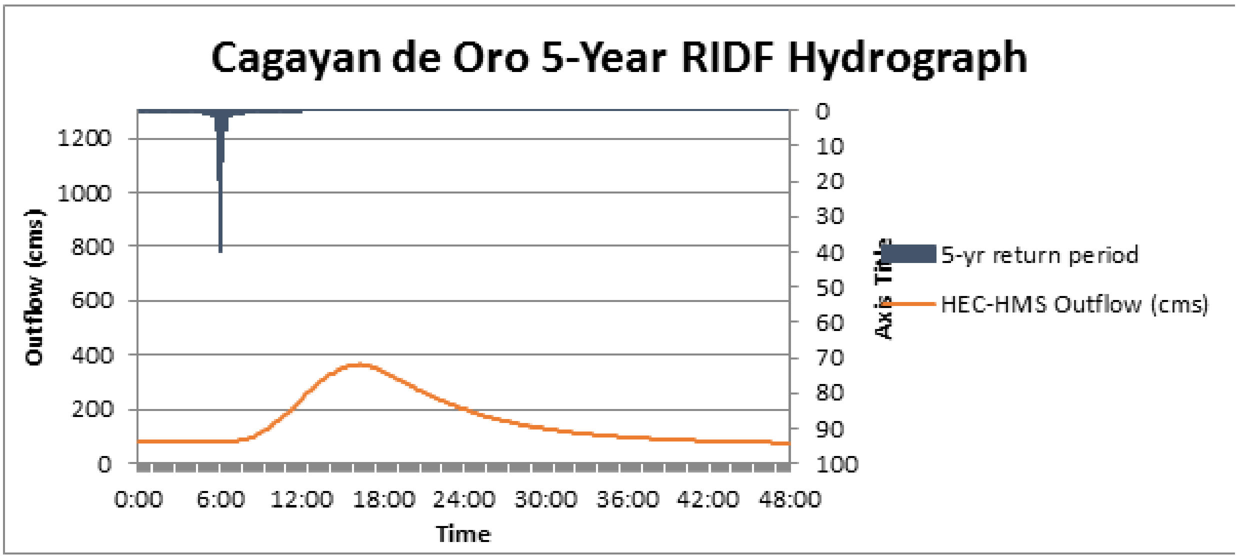


Figure 30. Outflow hydrograph generated using the Lumbia 5-Year RIDF inputted in HEC-HMS

In the 10-year return period graph shown in Figure 31, the peak outflow is 516.5 cms. This occurs after 4 hours and 10 minutes after the peak precipitation of 516.5 mm.

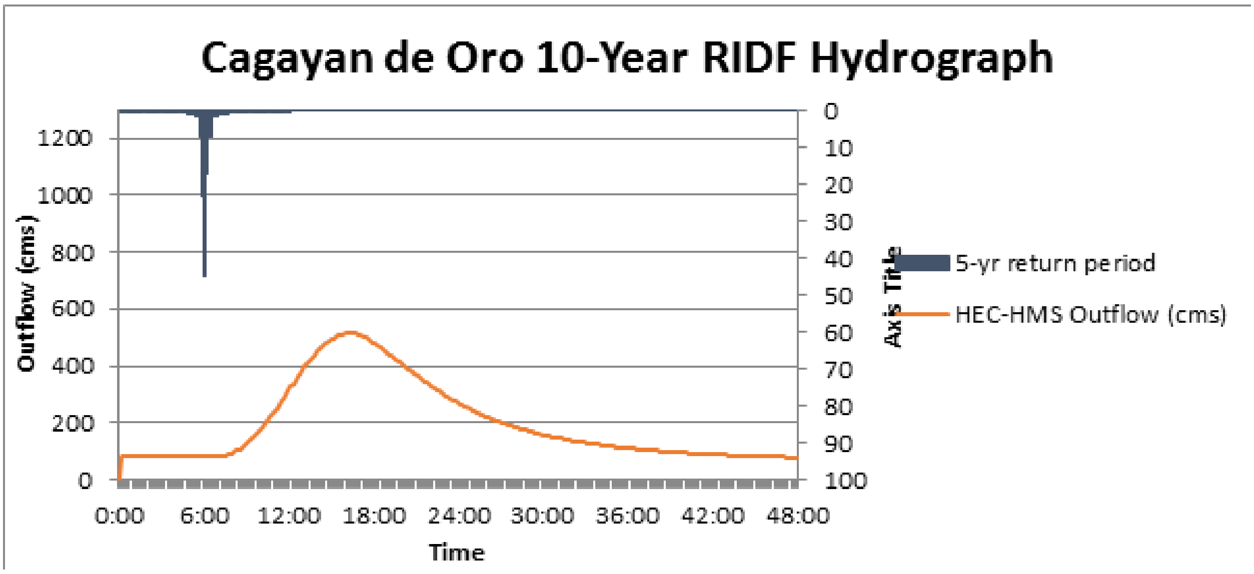


Figure 31. Outflow hydrograph generated using the Lumbia 10-Year RIDF inputted in HEC-HMS

In the 25-year return period graph shown in Figure 32, the peak outflow is753.4 cms. This occurs after 4 hours and 10 minutes after the peak precipitation of 44 mm.

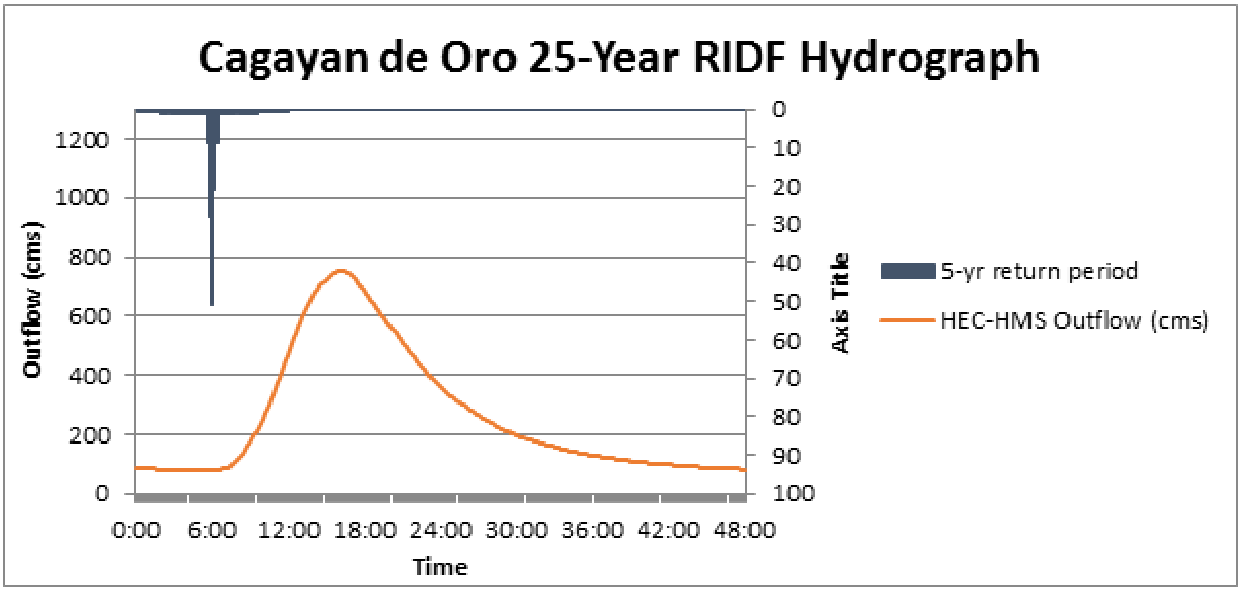


Figure 32. Outflow hydrograph generated using the Lumbia 25-Year RIDF inputted in HEC-HMS.

In the 50-year return period graph shown in Figure 33, the peak outflow is 953.8 cms. This occurs after 4 hours after the peak precipitation of 49.2 mm.

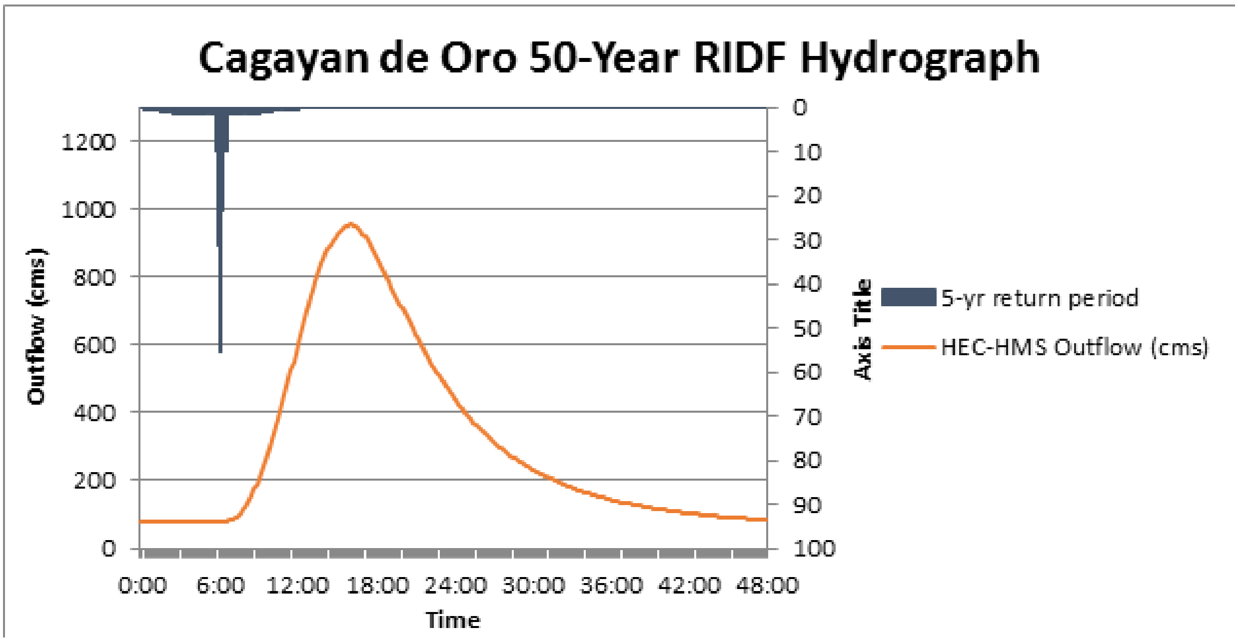


Figure 33. Outflow hydrograph generated using the Lumbia 50-Year RIDF inputted in HEC-HMS

In the 100-year return period graph shown in Figure 34, the peak outflow is 1180.4 cms. This occurs after 4 hours after the peak precipitation of 54.4 mm.

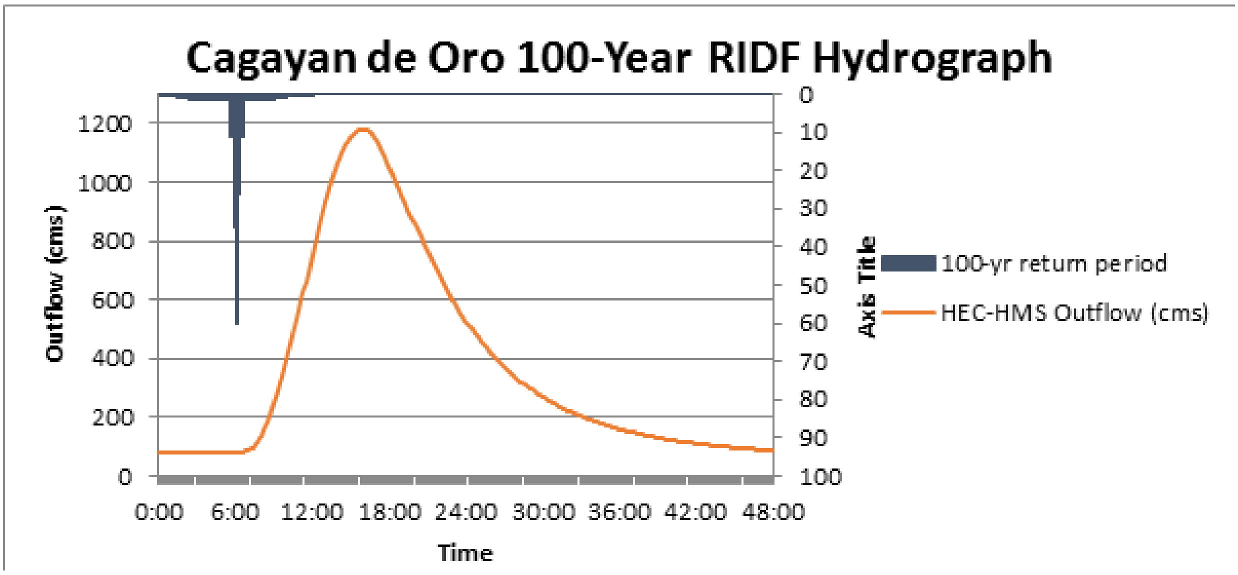


Figure 34. Outflow hydrograph generated using the Lumbia 100-Year RIDF inputted in HEC-HMS

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

Table 2.Summary of peak values of the Cagayan de Oro outflow using the Lumbia RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	128.1	24.5	363.7	4 hours and 20 minutes
10-Year	152.1	37	516.5	4 hours and 10 minutes
25-Year	182.4	44	753.4	4 hours and 10 minutes
50-Year	204.9	49.2	953.8	4 hours
100-Year	227.3	54.4	1180.4	4 hours

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

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

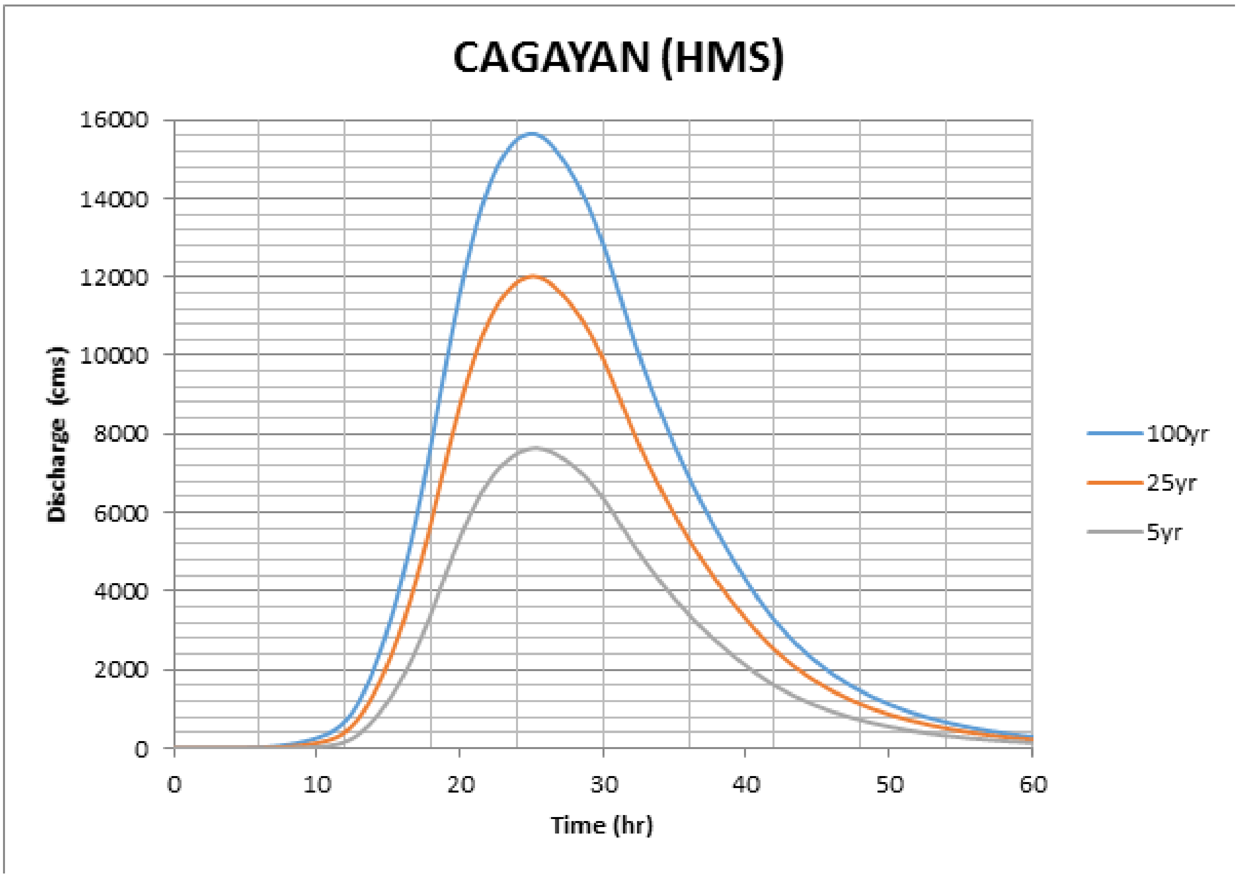


Figure 35. Outflow hydrograph generated for Cagayan de Oro using the Lumbia 5-, 25-, and

Table 3. Summary of Cagayan de Oro River discharge using the recommended hydrological method by Dr. Horritt

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	1,297.6	23 hours, 20 minutes
25-Year	2,430.0	23 hours, 20 minutes
100-Year	3,478.7	23 hours, 20 minutes

The comparison of discharge values obtained from HEC-HMS, QMED, and from the bankful discharge method, $Q_{bankful}$, are shown in Table 4. Using values from the DTM of Cagayan de Oro, the bankful discharge for the river was computed.

Table 4. Validation of river discharge estimate

Discharge Point	Qbankful, cms	QMED, cms	Validation
CDO (1)	1,300.27	1,141.89	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 was also used for an area in the floodplain that was modeled. It is recommended, therefore, to use the actual value of the river discharge for higher-accuracy modeling.

4.3 Flood Hazard and Flow Depth Maps

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

Flood Hazard Maps and Flow Depth Maps

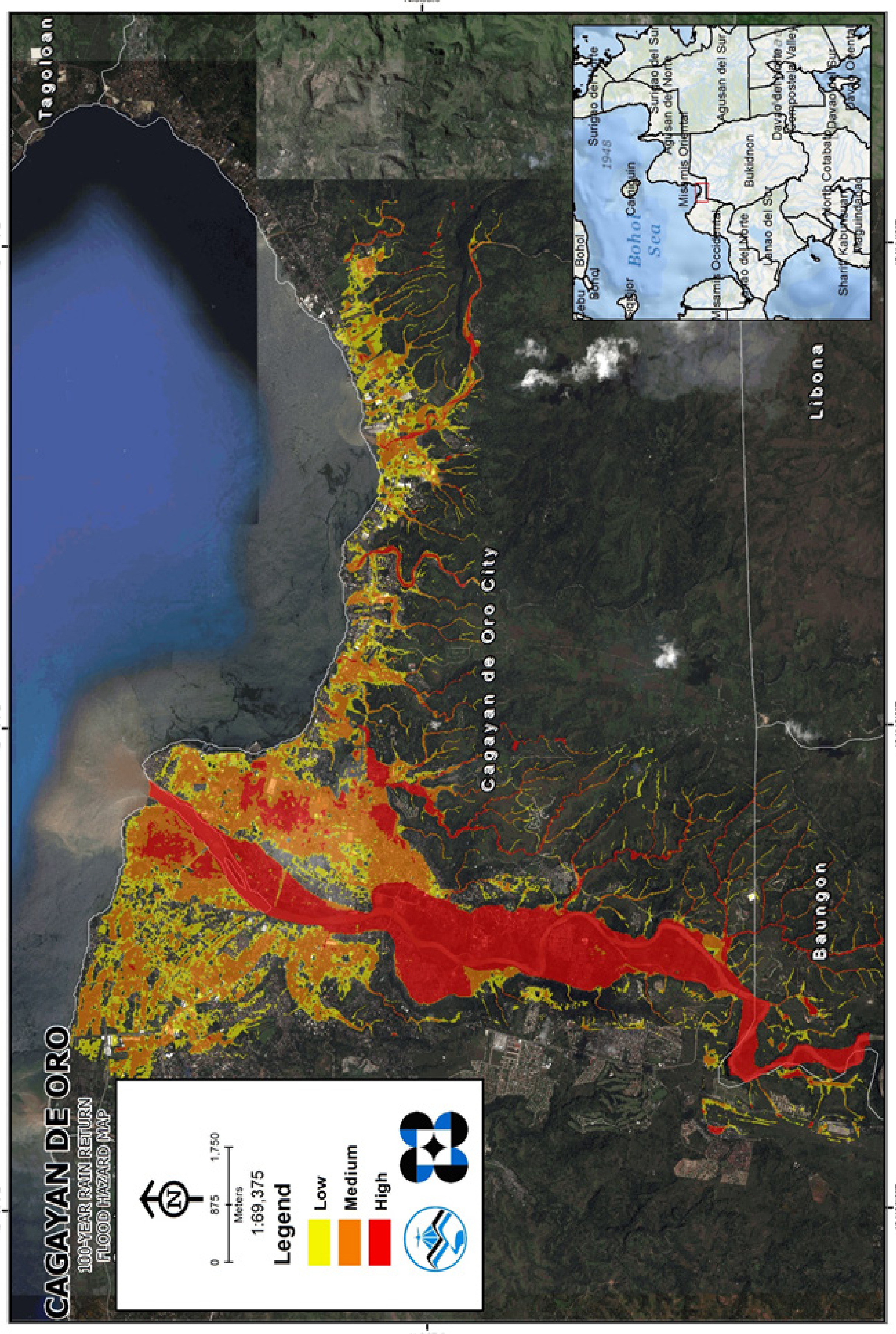


Figure 36. 100-year Flood Hazard Map for Cagayan de Oro River Basin

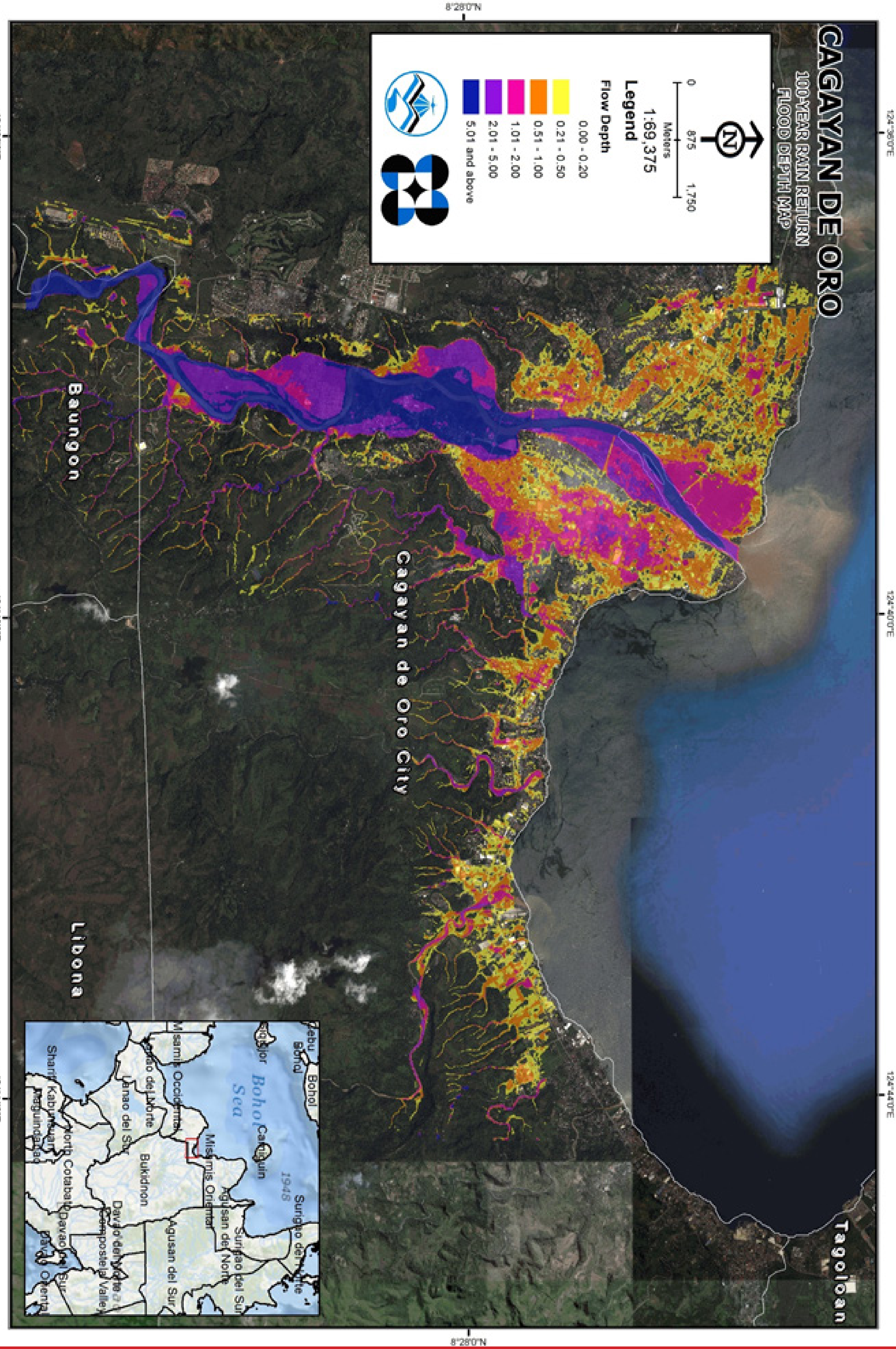


Figure 37. 100-year Flow Depth Map for Cagayan de Oro River Basin

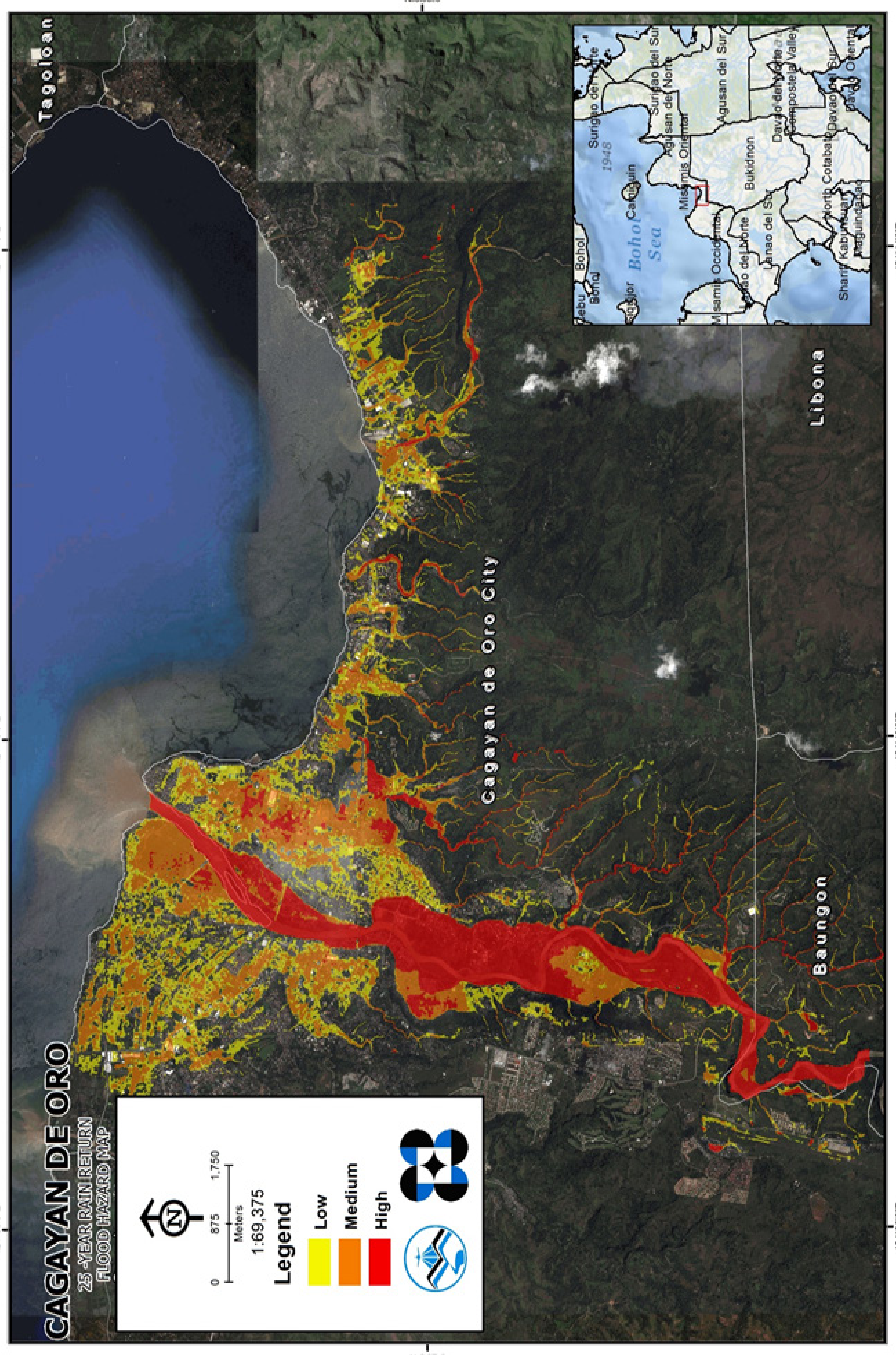


Figure 38.25-year Flood Hazard Map for Cagayan de Oro River Basin

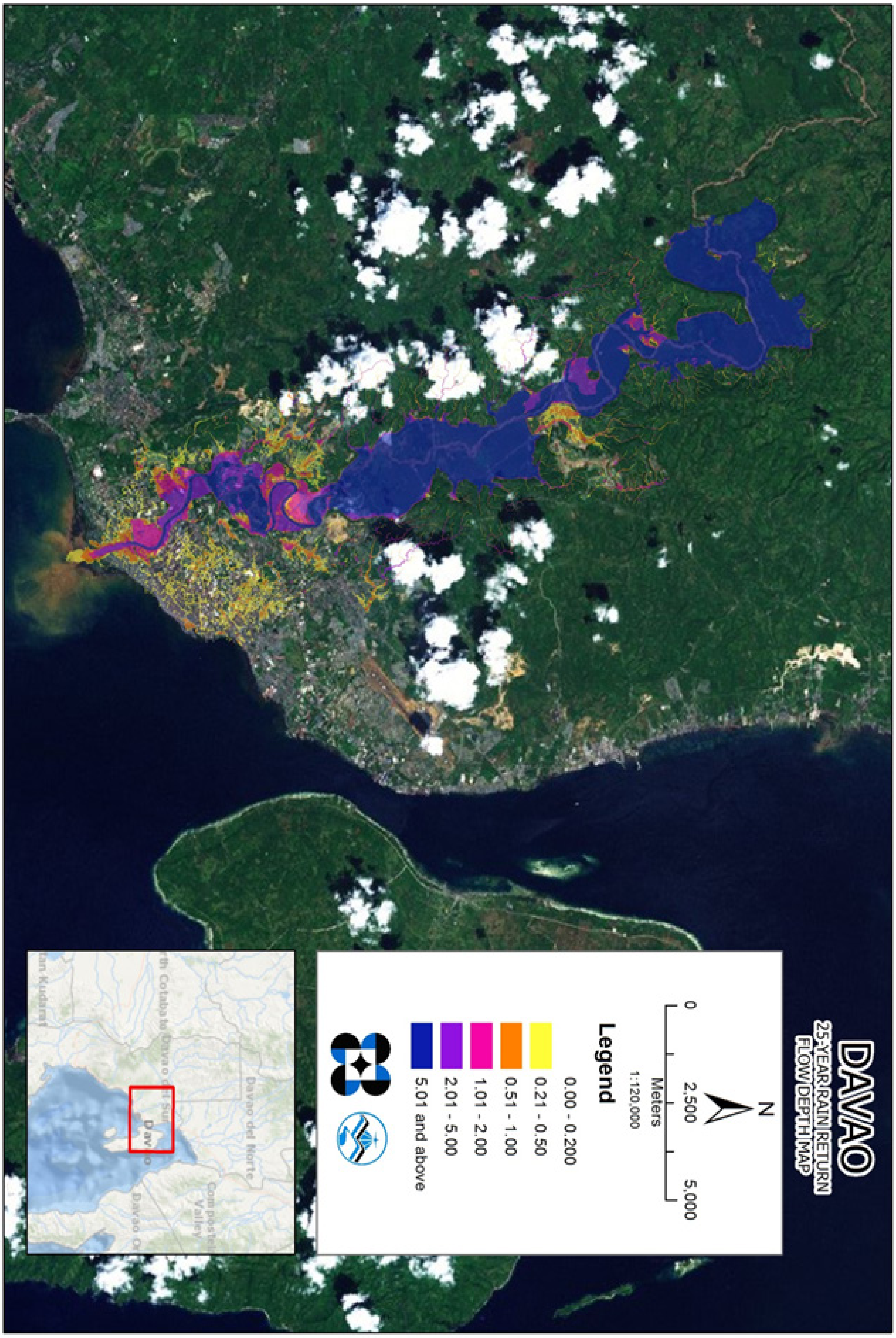


Figure 39.25-year Flow Depth Map for Cagayan de Oro River

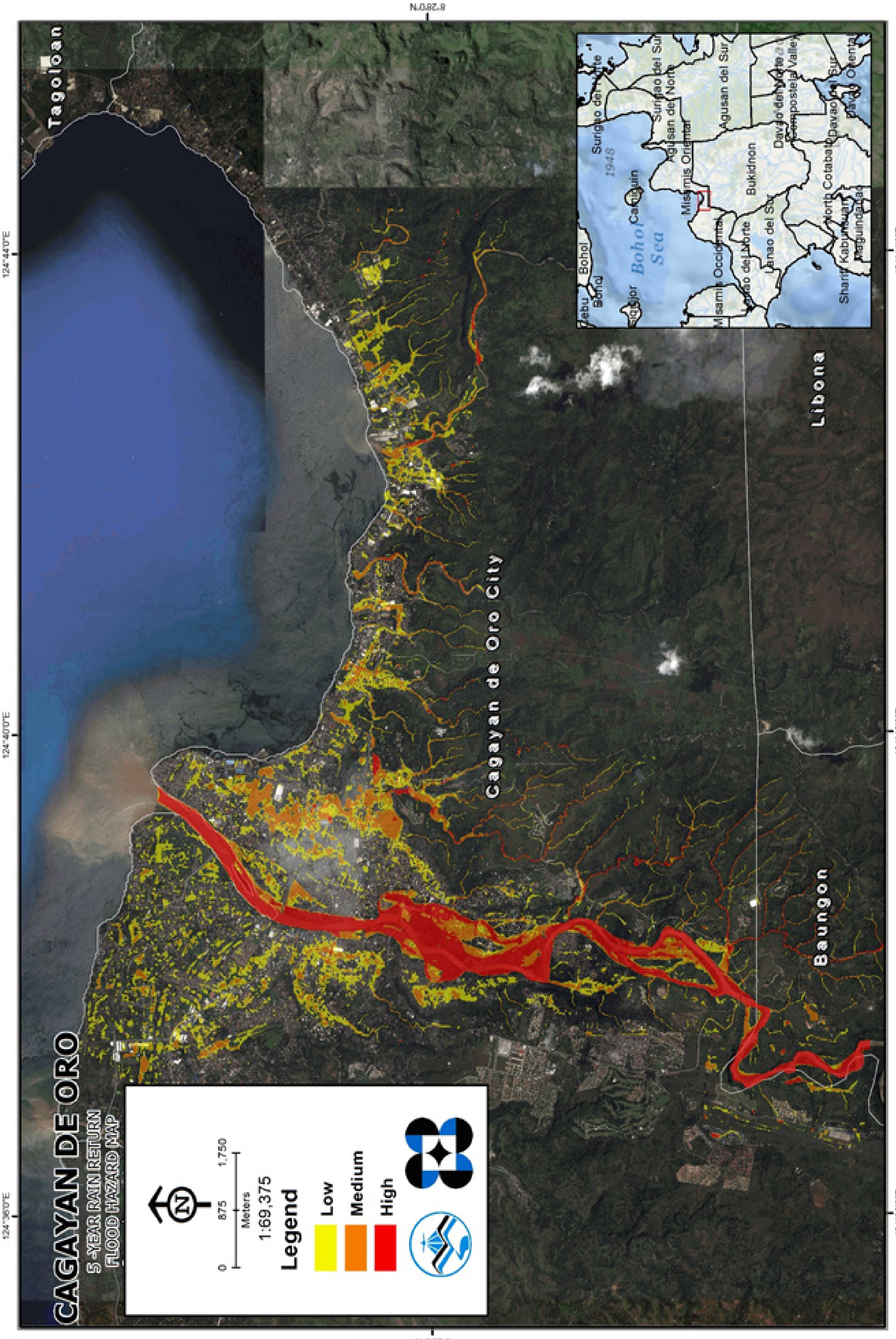


Figure 40. 5-year Flood Hazard Map for Cagayan de Oro River Basin

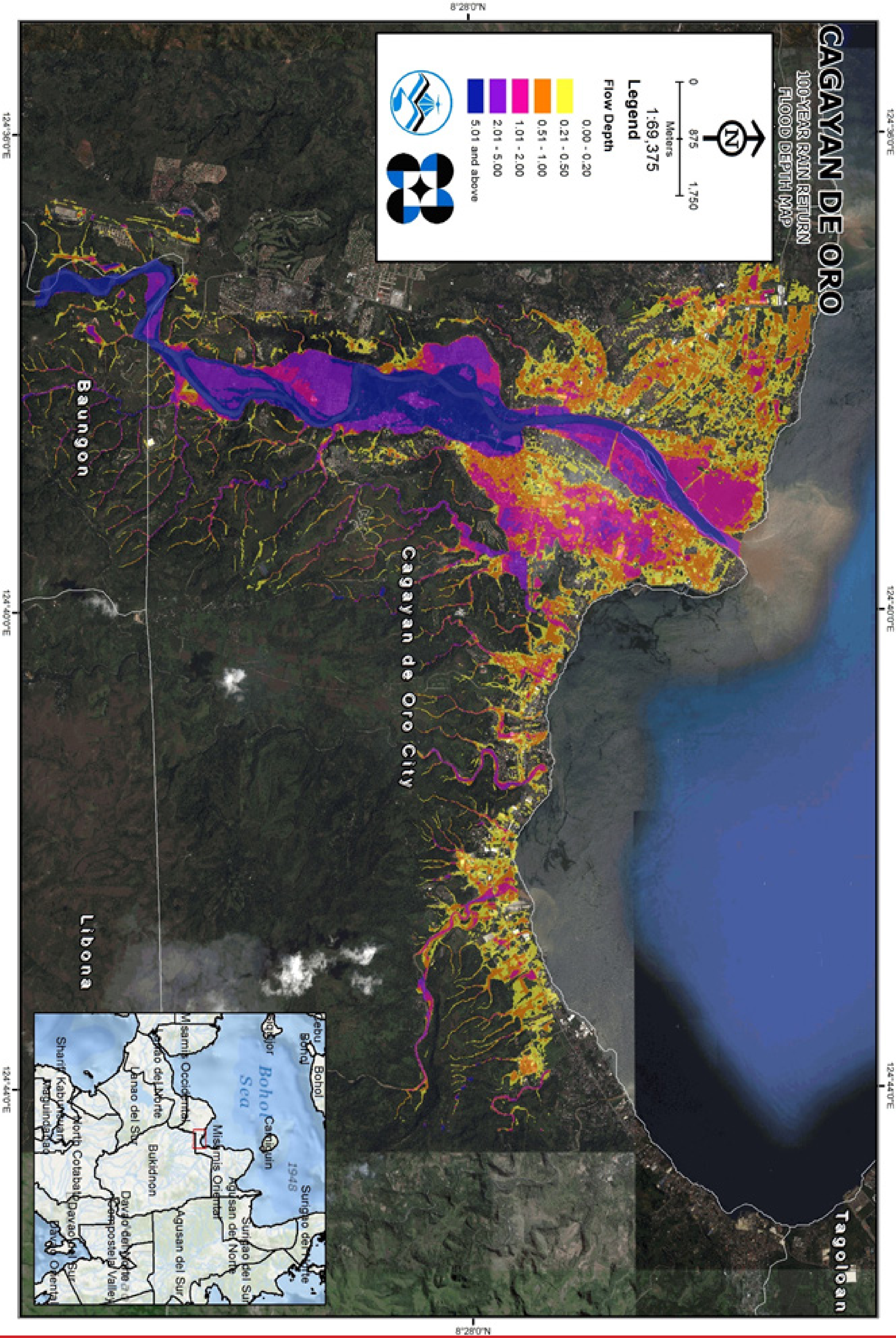


Figure 41. 5-year Flood Hazard Map for Cagayan de Oro River Basin

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Appendix

Appendix A. Cagayan de Oro 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
1434B	180.222	48.65595	0	5.5688	0.9153	Discharge	0.011471	0.0240899	Ratio to Peak	0.01
1435B	26.91	46.87515	0	3.5428	0.450342	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1436B	59.079	12.19995	0	4.1453	0.286074	Discharge	0.037183	0.0780847	Ratio to Peak	0.01
1437B	19.416	53.53635	0	0.25176	0.60834	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1438B	26.806	52.1283	0	26.887	2.1312	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1439B	27.348	52.3236	0	8.2567	1.5837	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1440B	19.442	52.59975	0	8.5556	1.49148	Discharge	0.025294	0.053117	Ratio to Peak	0.01
1441B	38.95	53.07435	0	3.8605	0.236592	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1442B	26.1	23.96625	0	3.6163	0.2223	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1443B	49.064	48.5268	0	3.6246	0.356934	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1444B	19.474	36.9768	0	1.463	0.476376	Discharge	0.017207	0.0361349	Ratio to Peak	0.01

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
1445B	96.468	51.99075	0	14.255	1.48668	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1446B	19.479	46.08135	0	8.1976	0.95712	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1447B	43.601	50.60895	0	3.073	0.330426	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1448B	43.135	37.00515	0	5.4045	0.88404	Discharge	0.087111	0.18293	Ratio to Peak	0.01
1449B	19.54	46.76595	0	27.082	1.4322	Discharge	0.025295	0.0531184	Ratio to Peak	0.01
1450B	41.583	37.23405	0	2.4525	0.52452	Discharge	0.087111	0.18293	Ratio to Peak	0.01
1451B	28.402	36.8319	0	19.529	0.75108	Discharge	0.060435	0.12691	Ratio to Peak	0.01
1452B	42.138	39.5493	0	12.23	2.37582	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1453B	28.006	36.9579	0	2.5212	0.5658	Discharge	0.087111	0.18293	Ratio to Peak	0.01
1454B	19.672	16.4073	0	1.8599	0.56784	Discharge	0.087111	0.18293	Ratio to Peak	0.01
1455B	29.972	36.9348	0	5.4863	0.72588	Discharge	0.060431	0.1269	Ratio to Peak	0.01

Appendix

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
1456B	19.203	18.3771	0	6.6952	0.461034	Discharge	0.025295	0.0531184	Ratio to Peak	0.01
1457B	42.8	18.53355	0	6.5488	0.361272	Discharge	0.017207	0.0361349	Ratio to Peak	0.01
1458B	41.397	36.93375	0	1.5027	0.40116	Discharge	0.12805	0.268905	Ratio to Peak	0.01
1459B	27.916	36.9348	0	3.4279	0.5112	Discharge	0.12805	0.268905	Ratio to Peak	0.01
1460B	18.447	36.93585	0	4.3982	0.65388	Discharge	0.19208	0.403368	Ratio to Peak	0.01
1461B	15.084	39.49995	0	5.0472	0.7308	Discharge	0.13067	0.274407	Ratio to Peak	0.01
1462B	93.702	38.82795	0	0.59805	0.2658	Discharge	0.441	0.9261	Ratio to Peak	0.01
1463B	24.476	44.9253	0	1.4235	0.31848	Discharge	0.441	0.9261	Ratio to Peak	0.01
1464B	64.62	36.8445	0	0.2	0.10692	Discharge	0.11701	0.245721	Ratio to Peak	0.01
1465B	64.62	36.8445	0	0.2	0.10692	Discharge	0.26328	0.552888	Ratio to Peak	0.01
1466B	18.657	38.27775	0	2.7821	0.46236	Discharge	0.087111	0.18293	Ratio to Peak	0.01

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
1467B	18.317	37.09755	0	3.0168	0.47496	Discharge	0.28268	0.593628	Ratio to Peak	0.01
1468B	27.454	37.5837	0	8.013	0.97656	Discharge	0.441	0.9261	Ratio to Peak	0.01
1469B	71.784	36.89595	0	13.162	0.55824	Discharge	0.2646	0.55566	Ratio to Peak	0.01
1470B	21.481	36.9348	0	33.645	1.14792	Discharge	0.294	0.6174	Ratio to Peak	0.01
1471B	28.172	36.93585	0	2.1467	0.38652	Discharge	0.441	0.9261	Ratio to Peak	0.01
1472B	32.248	36.93585	0	8.4508	0.45348	Discharge	0.294	0.6174	Ratio to Peak	0.01
1473B	28.097	40.22655	0	9.4276	1.08804	Discharge	0.441	0.9261	Ratio to Peak	0.01
1474B	28.084	36.9348	0	2.9623	0.60696	Discharge	0.441	0.9261	Ratio to Peak	0.01
1475B	18.683	37.0083	0	6.6656	0.46368	Discharge	0.441	0.9261	Ratio to Peak	0.01
1476B	18.833	36.9117	0	4.2279	0.59436	Discharge	0.441	0.9261	Ratio to Peak	0.01
1477B	28.18	36.93585	0	8.769	0.55584	Discharge	0.3	0.63	Ratio to Peak	0.01

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
1478B	28.086	37.11435	0	15.136	0.6144	Discharge	0.294	0.6174	Ratio to Peak	0.01
1479B	62.613	36.9348	0	6.6561	0.67596	Discharge	0.441	0.9261	Ratio to Peak	0.01
1480B	28.179	37.1028	0	2.0692	0.30924	Discharge	0.441	0.9261	Ratio to Peak	0.01
1481B	10.929	37.1385	0	14.037	0.783	Discharge	0.28812	0.605052	Ratio to Peak	0.01
1482B	32.03	40.1898	0	4.0337	0.79356	Discharge	0.441	0.9261	Ratio to Peak	0.01
1483B	27.348	60.8265	0	5.7267	0.55476	Discharge	0.441	0.9261	Ratio to Peak	0.01
1484B	42.042	39.7887	0	6.885	0.37524	Discharge	0.45	0.945	Ratio to Peak	0.01
1485B	27.791	36.87075	0	6.8891	0.57252	Discharge	0.45	0.945	Ratio to Peak	0.01
1486B	62.468	39.80865	0	3.5508	0.40668	Discharge	0.44775	0.940275	Ratio to Peak	0.01
1487B	41.929	38.8122	0	7.2403	0.45096	Discharge	0.44775	0.940275	Ratio to Peak	0.01
1488B	18.756	40.0071	0	6.53	0.45756	Discharge	0.45	0.945	Ratio to Peak	0.01

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
1489B	62.516	37.296	0	3.0414	0.37356	Discharge	0.45	0.945	Ratio to Peak	0.01

Appendix B. Cagayan de Oro Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
908R	Automatic Fixed Interval	52105.14	0.1322	0.51758	Trapezoid	30	45
909R	Automatic Fixed Interval	33143.37	0.1482	0.14593	Trapezoid	30	45
910R	Automatic Fixed Interval	4541.102	0.143	0.36493	Trapezoid	30	45
911R	Automatic Fixed Interval	17658.37	0.1679	0.0129075	Trapezoid	30	45
912R	Automatic Fixed Interval	41044.55	0.1868	0.0583198	Trapezoid	30	45
913R	Automatic Fixed Interval	58307.61	0.01834	0.0257314	Trapezoid	30	45
914R	Automatic Fixed Interval	3678.926	0.5475	0.16116	Trapezoid	30	45
915R	Automatic Fixed Interval	3085.722	0.5393	0.0964029	Trapezoid	30	45
916R	Automatic Fixed Interval	27502.19	0.2057	0.032599	Trapezoid	30	45
917R	Automatic Fixed Interval	26217.71	0.2116	0.16228	Trapezoid	30	45
918R	Automatic Fixed Interval	1225.716	0.062	0.012923	Trapezoid	30	45
919R	Automatic Fixed Interval	3361.405	0.1541	0.16218	Trapezoid	30	45
920R	Automatic Fixed Interval	3604.334	0.2008	0.0622848	Trapezoid	30	45
921R	Automatic Fixed Interval	2648.707	0.0996	0.40264	Trapezoid	30	45
922R	Automatic Fixed Interval	32126.11	0.0484	1	Trapezoid	30	45
923R	Automatic Fixed Interval	27656.05	0.1403	0.0331806	Trapezoid	30	45
924R	Automatic Fixed Interval	2026.455	0.1915	0.12201	Trapezoid	30	45
925R	Automatic Fixed Interval	3268.213	0.1626	0.089933	Trapezoid	30	45
926R	Automatic Fixed Interval	1201.095	0.8	0.10165	Trapezoid	30	45
927R	Automatic Fixed Interval	2377.086	0.4985	0.0445988	Trapezoid	30	45
928R	Automatic Fixed Interval	21346.58	0.1359	0.10106	Trapezoid	30	45
929R	Automatic Fixed Interval	3618.808	0.2258	0.0141271	Trapezoid	30	45
930R	Automatic Fixed Interval	8337.668	0.1351	0.14252	Trapezoid	30	45
931R	Automatic Fixed Interval	9937.166	0.4501	0.0711747	Trapezoid	30	45
932R	Automatic Fixed Interval	6606.517	0.2801	0.24419	Trapezoid	30	45
933R	Automatic Fixed Interval	3962.694	0.461	0.10584	Trapezoid	30	45
934R	Automatic Fixed Interval	4472.585	0.0173	0.10824	Trapezoid	30	45
935R	Automatic Fixed Interval	8494.313	0.2412	0.0666753	Trapezoid	30	45
936R	Automatic Fixed Interval	2569.065	0.2613	0.0427846	Trapezoid	30	45
937R	Automatic Fixed Interval	3958.792	0.0745	0.0724078	Trapezoid	30	45
938R	Automatic Fixed Interval	2129.473	0.1806	0.0708996	Trapezoid	30	45
939R	Automatic Fixed Interval	1515.696	0.1863	0.0715752	Trapezoid	30	45
940R	Automatic Fixed Interval	8446.354	0.0001	0.11028	Trapezoid	30	45

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
941R	Automatic Fixed Interval	71352.06	0.2146	0.11463	Trapezoid	30	45
942R	Automatic Fixed Interval	18306.43	0.1506	0.0224857	Trapezoid	30	45
943R	Automatic Fixed Interval	40479.43	0.2375	0.0858422	Trapezoid	30	45
83R	Automatic Fixed Interval	32337.5	0.00	0.0012	Trapezoid	15	45
84R	Automatic Fixed Interval	43199.3	0.01	0.0033	Trapezoid	15	45
85R	Automatic Fixed Interval	15752.4	0.03	0.0012	Trapezoid	15	45
86R	Automatic Fixed Interval	19948.5	0.00	0.0013	Trapezoid	15	45
87R	Automatic Fixed Interval	40384.2	0.01	0.0003	Trapezoid	15	45
88R	Automatic Fixed Interval	34330.5	0.00	0.0011	Trapezoid	15	45
89R	Automatic Fixed Interval	45395.1	0.02	0.0009	Trapezoid	15	45
90R	Automatic Fixed Interval	10816.0	0.01	0.0004	Trapezoid	15	45
91R	Automatic Fixed Interval	33575.5	0.01	0.0032	Trapezoid	15	45
944R	Automatic Fixed Interval	1389.935	0.8	0.31426	Trapezoid	30	45
945R	Automatic Fixed Interval	10605.6	0.0965	0.24046	Trapezoid	30	45
946R	Automatic Fixed Interval	12120.06	0.3439	0.0686921	Trapezoid	30	45
947R	Automatic Fixed Interval	46779.03	0.1718	0.36279	Trapezoid	30	45
948R	Automatic Fixed Interval	865.2062	0.2133	0.11192	Trapezoid	30	45
949R	Automatic Fixed Interval	9059.753	0.2077	0.0001	Trapezoid	30	45
950R	Automatic Fixed Interval	27419.59	0.2081	0.0450158	Trapezoid	30	45
951R	Automatic Fixed Interval	22693.72	0.0363	0.0468937	Trapezoid	30	45
952R	Automatic Fixed Interval	21166.23	0.0924	0.13579	Trapezoid	30	45
953R	Automatic Fixed Interval	11966.26	0.1394	0.12071	Trapezoid	30	45
954R	Automatic Fixed Interval	5333.186	0.0016	0.3156	Trapezoid	30	45
955R	Automatic Fixed Interval	15459.52	0.1227	0.0561444	Trapezoid	30	45

Appendix C. CDO 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	6	0	0	0
0.1667	0	0	0	6.1667	0	0	0
0.3333	0	0	0	6.3333	0	0	0
0.5	0	0	0	6.5	0	0	0
0.6667	0	0	0	6.6667	0	0	0
0.8333	0	0	0	6.8333	0	0	0
1	0	0	0	7	0	0	0
1.1667	0	0	0	7.1667	0	0	0
1.3333	0	0	0	7.3333	0	0	0
1.5	0	0	0	7.5	0	0	0
1.6667	0	0	0	7.6667	0	0	0
1.8333	0	0	0	7.8333	0.1	0	0
2	0	0	0	8	0.1	0	0
2.1667	0	0	0	8.1667	0.1	0	0
2.3333	0	0	0	8.3333	0.2	0	0
2.5	0	0	0	8.5	0.3	0	0
2.6667	0	0	0	8.6667	0.4	0	0
2.8333	0	0	0	8.8333	0.6	0	0
3	0	0	0	9	0.7	0	0
3.1667	0	0	0	9.1667	0.9	0.1	0
3.3333	0	0	0	9.3333	1.2	0.1	0
3.5	0	0	0	9.5	1.5	0.1	0
3.6667	0	0	0	9.6667	1.8	0.2	0
3.8333	0	0	0	9.8333	2.2	0.2	0
4	0	0	0	10	2.6	0.3	0
4.1667	0	0	0	10.167	3.1	0.4	0
4.3333	0	0	0	10.333	3.7	0.5	0
4.5	0	0	0	10.5	4.3	0.6	0
4.6667	0	0	0	10.667	5.1	0.7	0
4.8333	0	0	0	10.833	5.9	0.9	0
5	0	0	0	11	6.7	1.1	0
5.1667	0	0	0	11.167	7.9	1.4	0
5.3333	0	0	0	11.333	9.5	1.9	0
5.5	0	0	0	11.5	11.4	2.6	0.1
5.6667	0	0	0	11.667	14.3	3.8	0.3
5.8333	0	0	0	11.833	18.8	6.1	0.9

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
12	27	11.2	3.2	19.667	2785.4	1932.2	1030.2
12.167	37.8	18.1	6.5	19.833	2851.5	1979.1	1056.1
12.333	50.4	26.2	10.4	20	2915.2	2024.3	1081.2
12.5	64.9	35.6	14.9	20.167	2974.3	2066.2	1104.5
12.667	81.1	46.1	19.8	20.333	3027.8	2104.1	1125.4
12.833	99.9	58.3	25.6	20.5	3078	2139.6	1144.8
13	123.7	74.2	33.5	20.667	3125.5	2173.3	1163.2
13.167	151.1	92.8	42.9	20.833	3170.7	2205.5	1180.7
13.333	180.9	113	53.3	21	3213.4	2236	1197.5
13.5	213	134.9	64.6	21.167	3252.1	2263.8	1212.9
13.667	246.7	157.8	76.5	21.333	3284.4	2286.9	1225.4
13.833	282.2	182	88.9	21.5	3313.1	2307.3	1236.3
14	320.6	208.3	102.6	21.667	3339.4	2326	1246.1
14.167	361.5	236.3	117.2	21.833	3363.2	2343.1	1254.9
14.333	404	265.4	132.6	22	3385.4	2359.1	1263.2
14.5	448	295.6	148.4	22.167	3405.5	2373.7	1270.7
14.667	493.4	326.7	164.8	22.333	3422.2	2385.9	1276.7
14.833	540.6	359	181.6	22.5	3436.9	2396.7	1282
15	590.9	393.4	199.7	22.667	3450	2406.5	1286.7
15.167	644.8	430.6	219.3	22.833	3461.5	2415.2	1290.8
17.333	1595.4	1091.7	570.3	23	3471.1	2422.8	1294.5
17.5	1687.9	1156.7	605.4	23.167	3477.9	2428.6	1297.2
17.667	1781.9	1223	641.3	23.333	3478.7	2430	1297.6
17.833	1876.3	1289.6	677.5	23.5	3474.9	2428	1295.8
18	1970.2	1356	713.7	23.667	3467.9	2423.9	1292.9
18.167	2062	1420.8	749	23.833	3458.2	2417.8	1288.8
18.333	2151.5	1484	783.5	24	3446.6	2410.5	1284.1
18.5	2239.6	1546.2	817.4	24.167	3433.1	2401.9	1278.7
18.667	2326.2	1607.4	851	24.333	3417.3	2391.7	1272.4
18.833	2411.4	1667.7	884.2	24.5	3399.7	2380.3	1265.4
19	2494.5	1726.6	916.9	24.667	3380.8	2368	1257.9
19.167	2572.8	1782.1	947.6	24.833	3360.8	2355.1	1250.1
19.333	2646.4	1834	976.2	25	3339.7	2341.5	1241.9
18.8333333	2838.5	2070.8	1209.6	25.167	3317.5	2327.2	1233.4
19	2937.2	2144	1253.6	25.333	3293.6	2311.7	1224.3
19.1666667	3031	2213.7	1295.8	25.5	3268	2295	1214.5
19.3333333	3118.1	2278.5	1334.9	25.667	3240.9	2277.4	1204.3
19.5	2717.1	1884	1003.7	25.833	3212.6	2258.9	1193.7

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
26	3182.9	2239.5	1182.7	32.333	1556.8	1120.2	575
26.167	3151.9	2219.3	1171.2	32.5	1523.2	1096.4	562.5
26.333	3118.8	2197.6	1159.1	32.667	1491.1	1073.8	550.8
26.5	3082.6	2173.6	1145.8	32.833	1460	1051.9	539.6
26.667	3044.2	2148	1131.6	33	1429.5	1030.4	528.5
26.833	3004.2	2121.2	1116.8	33.167	1399.5	1009.3	517.8
27	2962.5	2093.2	1101.4	33.333	1369.8	988.4	507.1
27.167	2919.3	2064.2	1085.6	33.5	1340.3	967.6	496.5
27.333	2874.1	2033.7	1069.1	33.667	1311.2	947	486
27.5	2825.6	2000.8	1051.2	33.833	1282.1	926.4	475.6
27.667	2775.1	1966.2	1032.4	34	1253.1	905.9	465.2
27.833	2723.1	1930.6	1013	34.167	1224.3	885.4	454.7
28	2669.9	1894	992.9	34.333	1195.6	865	444.3
28.167	2616.1	1856.8	972.5	34.5	1167.3	844.8	434
28.333	2562.1	1819.4	952	34.667	1139.6	825	423.9
28.5	2509.2	1782.8	931.9	34.833	1112.6	805.7	414.1
28.667	2457.4	1747.1	912.3	35	1086.2	786.7	404.5
28.833	2406.4	1711.7	893	35.167	1060.2	768	395.1
29	2356	1676.8	873.8	35.333	1034.5	749.5	385.7
29.167	2306.2	1642.1	854.7	35.5	1009.2	731.2	376.4
29.333	2257.3	1608	835.8	35.667	984.1	713.1	367.2
29.5	2210.8	1575.6	818	35.833	959.3	695.2	358.1
29.667	2166.8	1545.1	801.2	36	934.7	677.4	349
29.833	2124.1	1515.6	785.1	36.167	910.5	659.8	340
30	2082.4	1486.7	769.5	36.333	886.5	642.3	331
30.167	2041.3	1458.2	754	36.5	863	625.2	322.2
30.333	2000.6	1430	738.8	36.667	840.3	608.5	313.5
30.5	1960.9	1402.5	723.9	36.833	819	593	305.5
30.667	1922.2	1375.6	709.5	37	798.5	578	297.8
30.833	1883.9	1349	695.3	37.167	778.6	563.6	290.4
31	1845.8	1322.5	681.2	37.333	759.4	549.6	283.2
31.167	1807.8	1296.1	667.2	37.5	740.5	535.9	276.2
31.333	1770.1	1269.7	653.2	37.667	722	522.4	269.3
31.5	1732.9	1243.7	639.5	37.833	703.9	509.3	262.5
31.667	1696.8	1218.4	626.2	38	686	496.3	255.8
31.833	1661.3	1193.6	613.2	38.167	668.3	483.4	249.2
32	1626.1	1168.9	600.4	38.333	650.8	470.7	242.6
32.167	1591.3	1144.5	587.6	38.5	633.6	458.3	236.2

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
38.667	616.8	446.1	229.9	46.167	189.1	136.8	70.5
38.833	600.6	434.4	223.8	46.333	184.2	133.3	68.6
39	585.1	423.1	218	46.5	179.3	129.8	66.8
39.167	570.1	412.2	212.4	46.667	174.6	126.3	65.1
39.333	555.4	401.7	206.9	46.833	169.9	123	63.3
39.5	541.1	391.3	201.6	47	165.4	119.7	61.6
39.667	527.1	381.2	196.4	47.167	161.2	116.6	60
39.833	513.4	371.3	191.3	47.333	157	113.6	58.5
40	499.9	361.5	186.3	47.5	153	110.7	57
40.167	486.7	351.9	181.3	47.667	149.2	107.9	55.6
40.333	473.7	342.5	176.5	47.833	145.4	105.2	54.2
40.5	460.9	333.3	171.7	48	141.7	102.5	52.8
40.667	448.4	324.3	167	48.167	138.1	99.9	51.5
40.833	436.4	315.6	162.5	48.333	134.5	97.3	50.1
41	425	307.4	158.3	48.5	131	94.8	48.8
41.167	414	299.4	154.2	48.667	127.5	92.3	47.6
41.333	403.4	291.7	150.2	48.833	124.2	89.9	46.3
41.5	393	284.3	146.4	49	120.9	87.5	45.1
41.667	382.9	277	142.7	49.167	117.7	85.2	43.9
41.833	373	269.9	139	49.333	114.7	83	42.7
42	363.3	262.9	135.4	49.5	111.7	80.8	41.6
42.167	353.7	256	131.8	49.667	108.9	78.8	40.6
42.333	344.3	249.2	128.3	49.833	106.1	76.7	39.5
42.5	335	242.5	124.9	50	103.4	74.8	38.5
42.667	326	235.9	121.5	50.167	100.7	72.8	37.5
42.833	317.2	229.5	118.2	50.333	98	70.9	36.6
43	308.9	223.5	115	50.5	95.4	69	35.6
43.167	300.9	217.8	112.1	50.667	92.9	67.2	34.6
43.333	293.3	212.3	109.2	50.833	90.4	65.4	33.7
43.5	286	206.9	106.5	51	87.9	63.6	32.8
43.667	278.8	201.7	103.8	51.167	85.6	61.9	31.9
45	226.3	163.7	84.3	51.333	83.4	60.3	31
45.167	220.5	159.5	82.1	51.5	81.3	58.8	30.3
45.333	215	155.5	80	51.667	79.2	57.3	29.5
45.5	209.6	151.6	78	51.833	77.3	55.9	28.8
45.667	204.3	147.8	76.1	52	75.3	54.5	28
45.833	199.1	144.1	74.2	52.167	73.5	53.1	27.3
46	194.1	140.4	72.3	52.333	71.6	51.8	26.7

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
52.5	69.8	50.5	26	58.833	26.1	18.9	9.8
52.667	68	49.2	25.3	59	25.3	18.3	9.5
52.833	66.3	47.9	24.7	59.167	24.5	17.8	9.2
53	64.6	46.7	24	59.333	23.7	17.2	8.9
53.167	62.9	45.5	23.4	59.5	23	16.7	8.6
53.333	61.4	44.4	22.8	59.667	22.2	16.1	8.3
53.5	59.9	43.3	22.3	59.833	21.5	15.6	8.1
53.667	58.5	42.3	21.8	60	20.7	15.1	7.8
53.833	57.2	41.3	21.3				
54	55.9	40.4	20.8				
54.167	54.7	39.5	20.3				
54.333	53.4	38.6	19.9				
54.5	52.2	37.7	19.4				
54.667	51	36.9	19				
54.833	49.9	36	18.6				
55	48.7	35.2	18.1				
55.167	47.6	34.4	17.7				
55.333	46.5	33.6	17.3				
55.5	45.4	32.8	16.9				
55.667	44.3	32	16.5				
55.833	43.2	31.2	16.1				
56	42.1	30.5	15.7				
56.167	41.1	29.7	15.4				
56.333	40.1	29	15				
56.5	39	28.2	14.6				
56.667	38	27.5	14.2				
56.833	37	26.8	13.9				
57	36.1	26.1	13.5				
57.167	35.1	25.4	13.1				
57.333	34.1	24.7	12.8				
57.5	33.2	24	12.4				
57.667	32.2	23.3	12.1				
57.833	31.3	22.7	11.7				
58	30.4	22	11.4				
58.167	29.5	21.3	11				
58.333	28.6	20.7	10.7				
58.5	27.7	20.1	10.4				
58.667	26.9	19.5	10.1				

DREAM

Disaster RIsk and Exposure Assessment for Mitigation