REGION 10

Mandulog River Basin:

DREAM Flood Forecasting and Flood Hazard Mapping

TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY

2015

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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.

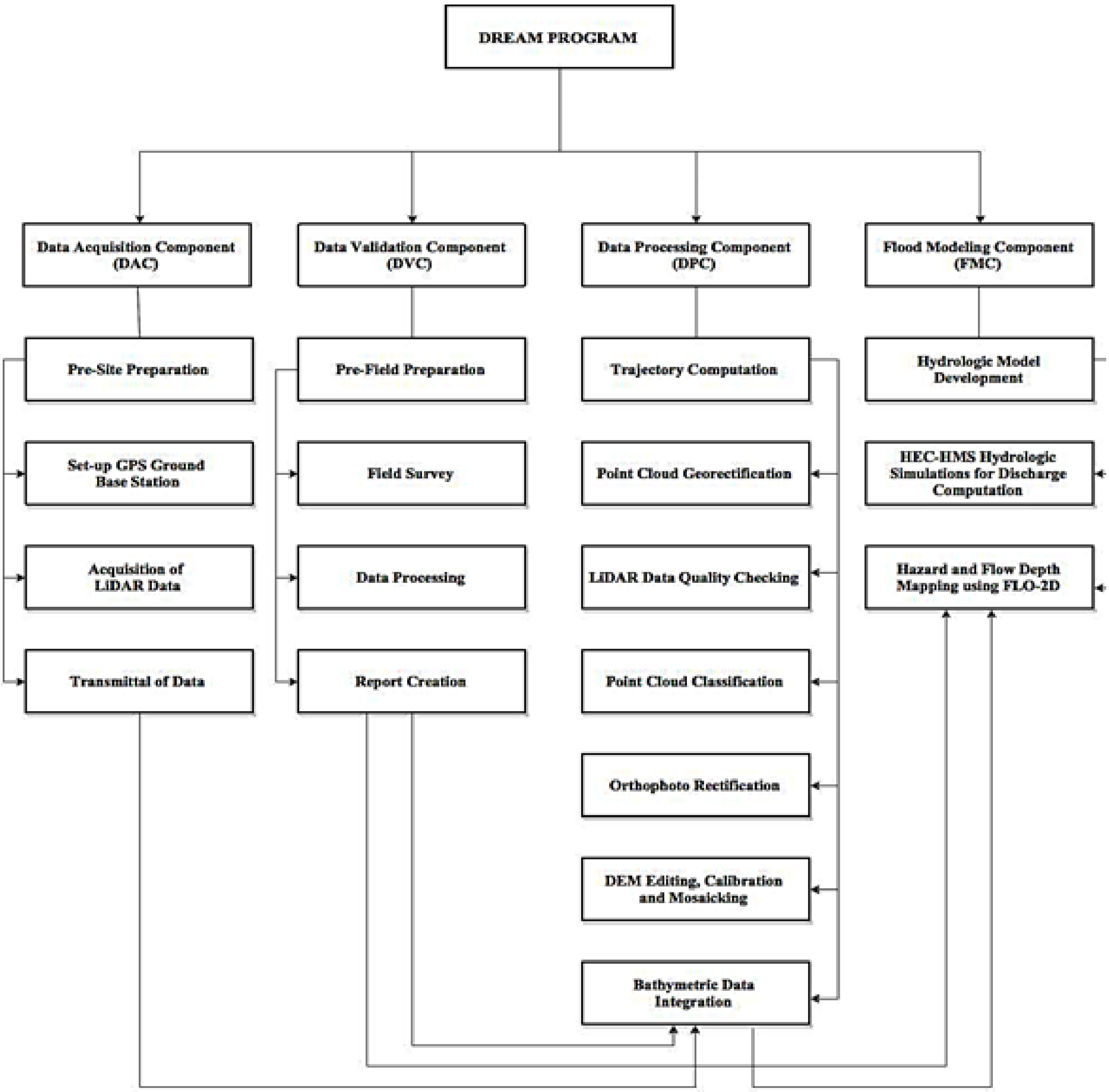


Figure 1. The general methodological framework of the program

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

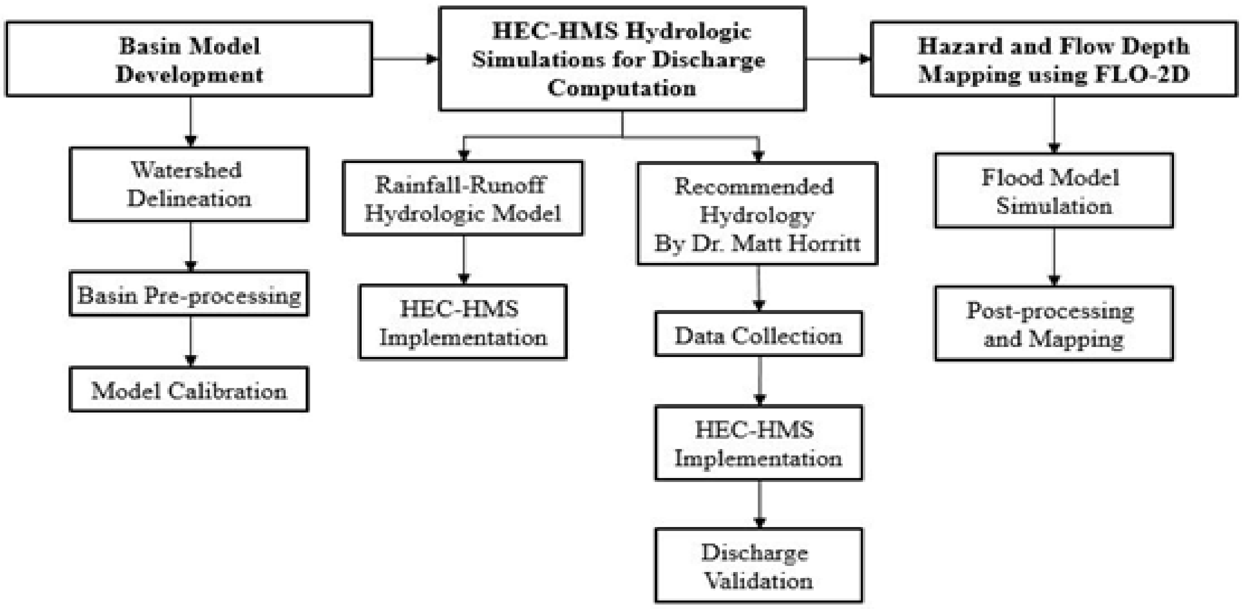


Figure 2. The operational framework and specific work flow of the Flood Modeling Component

The Mandulog River Basin

The Mandulog River Basin

Mandulog River Basin is located in Northern Mindanao. It covers an estimated basin area of 791 square kilometers and flows in the northwest direction. It traverses through Iligan and the municipalities of Lanao del Sur and Misamis Oriental. The location of the Mandulog River Basin is as shown in Figure 3.

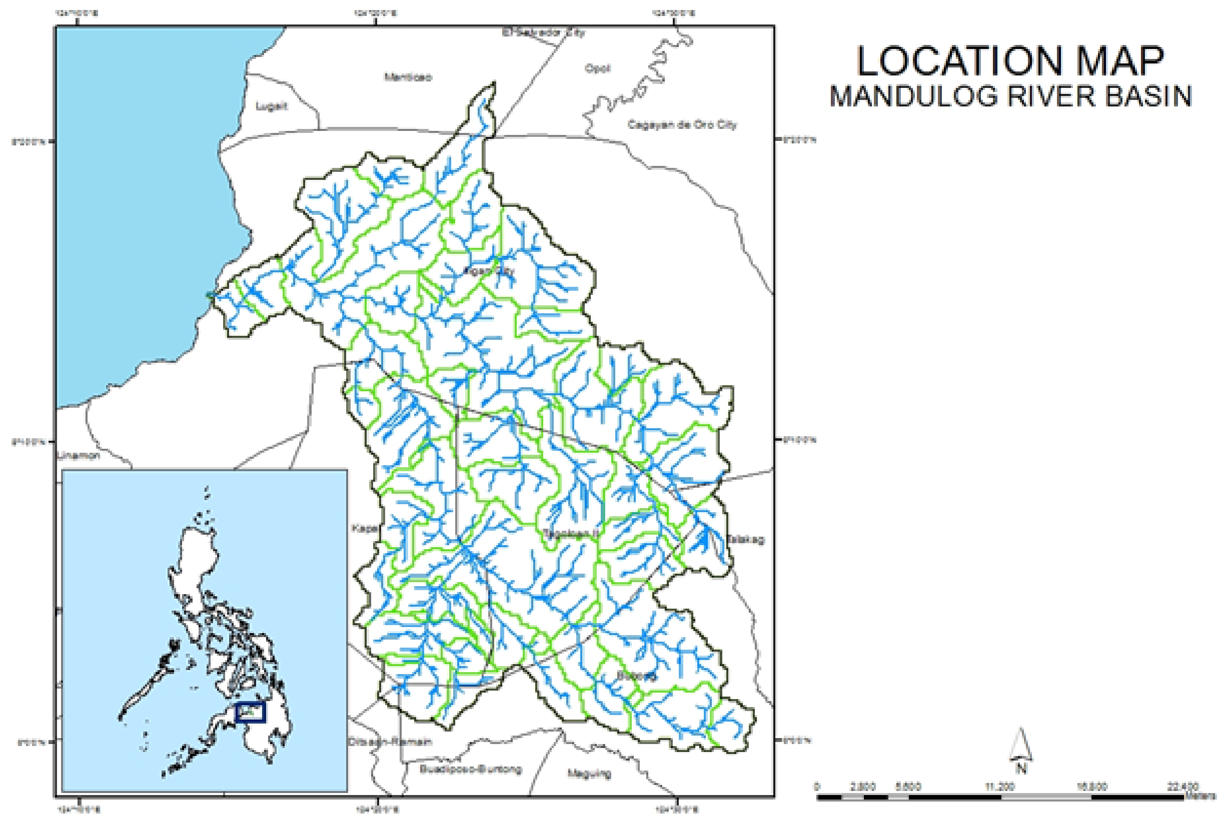


Figure 3. Mandulog River Basin Location Map

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

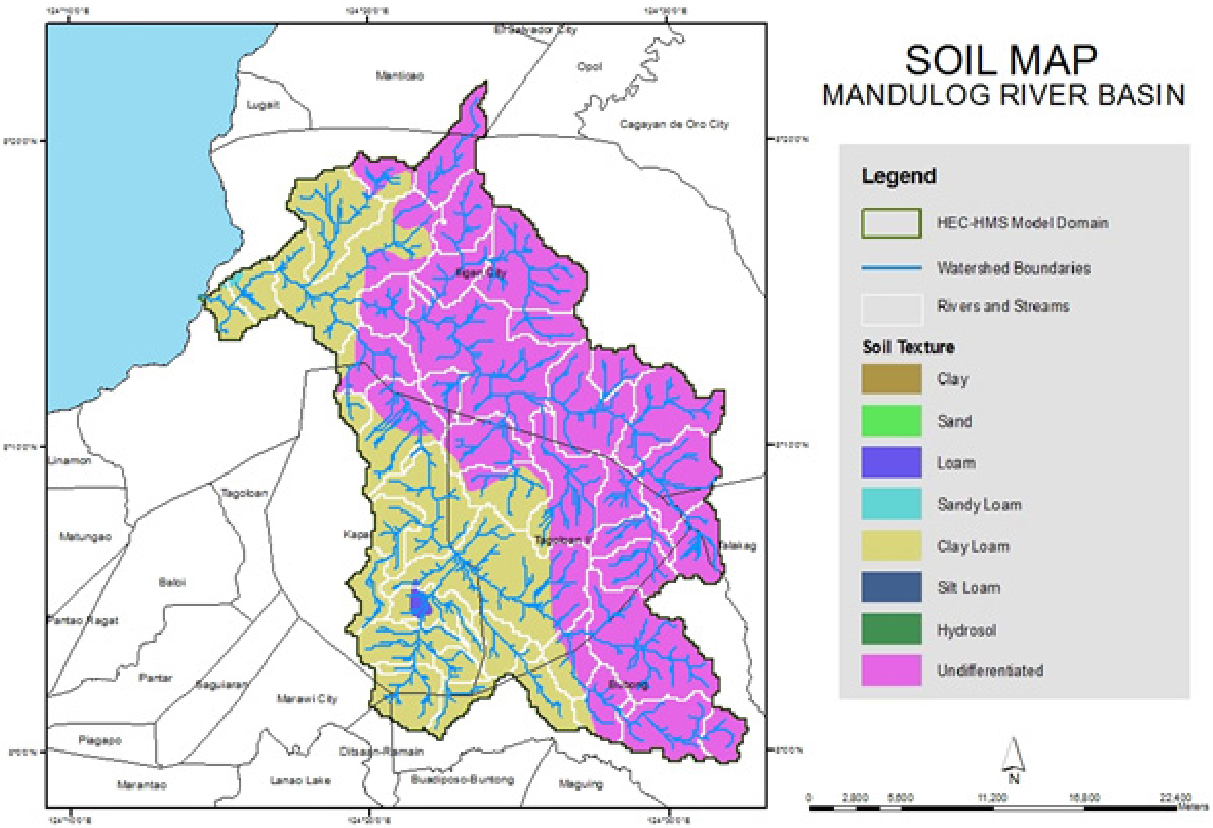


Figure 4. Mandulog River Basin Soil Map

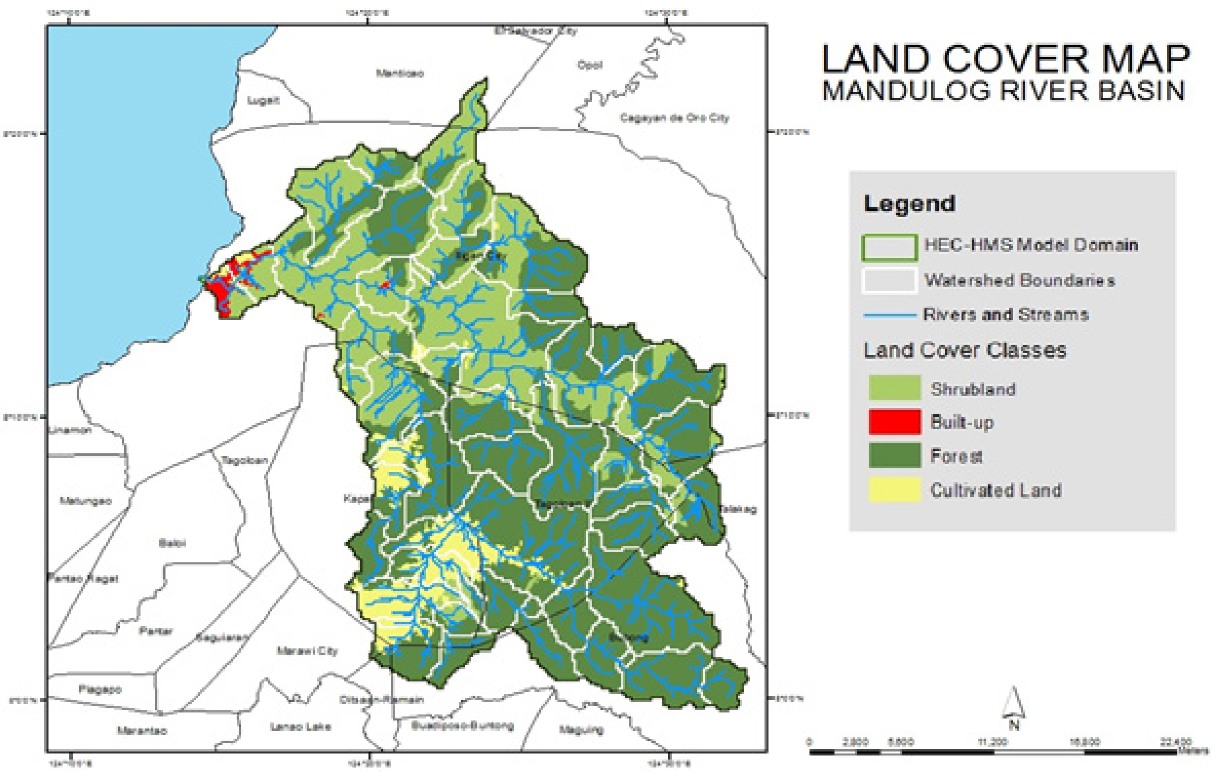


Figure 5. Mandulog River Basin Land Cover Map

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.

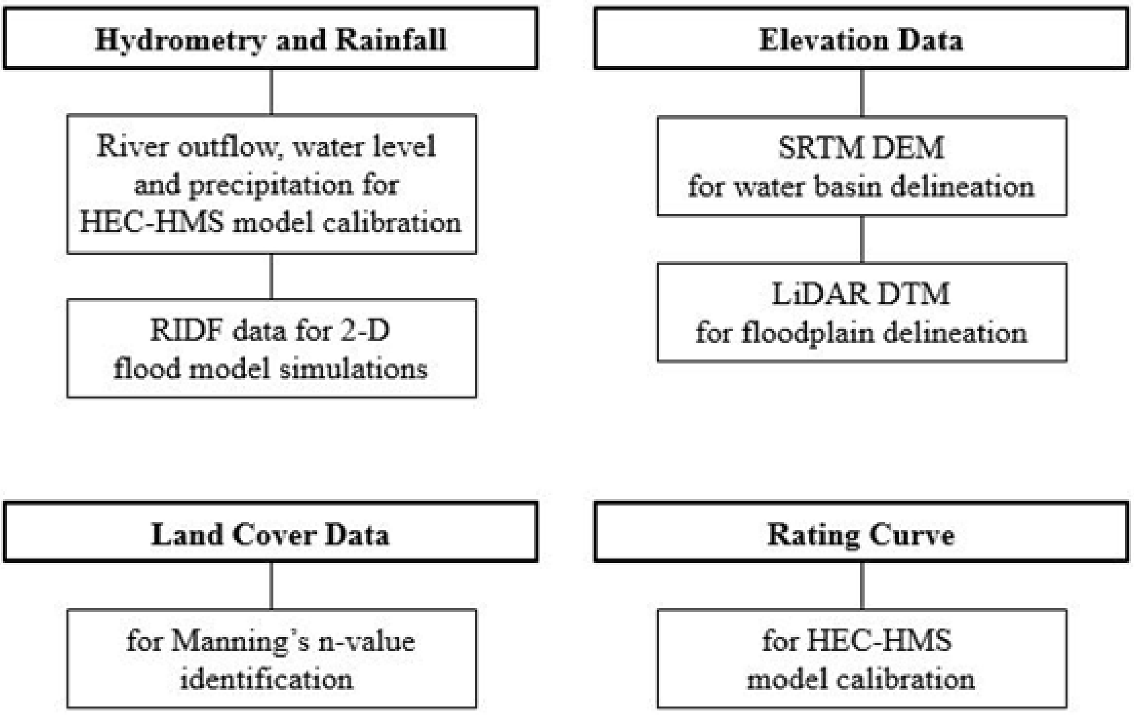


Figure 6. Summary of data needed for the purpose of flood modeling

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.

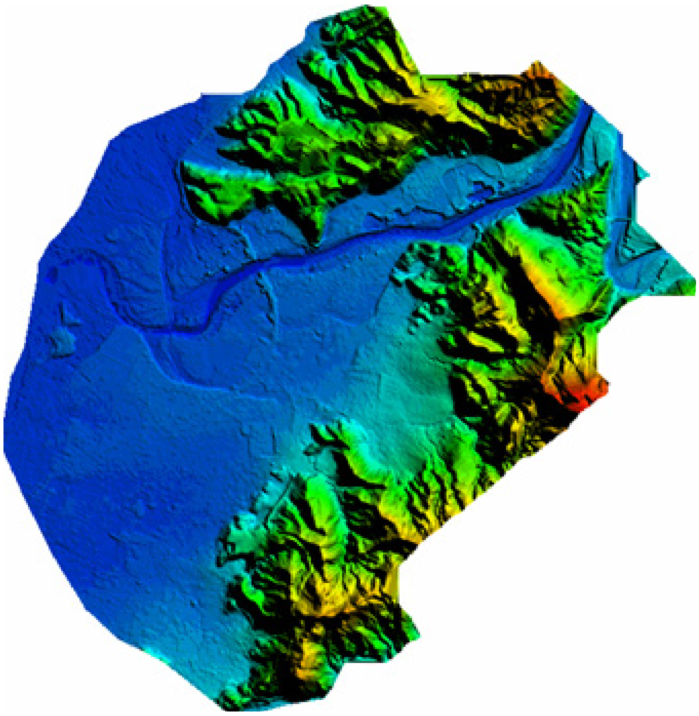


Figure 7. Digital Elevation Model (DEM) of the Mandulog River Basin using Light Detection and Ranging (LiDAR) technology

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

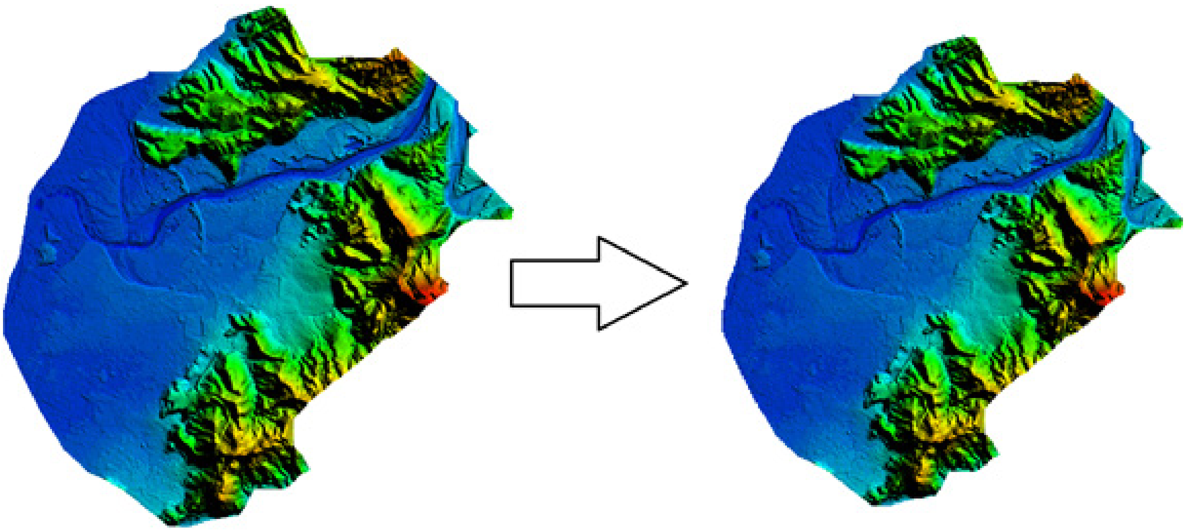


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted.

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 Mandulog 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.

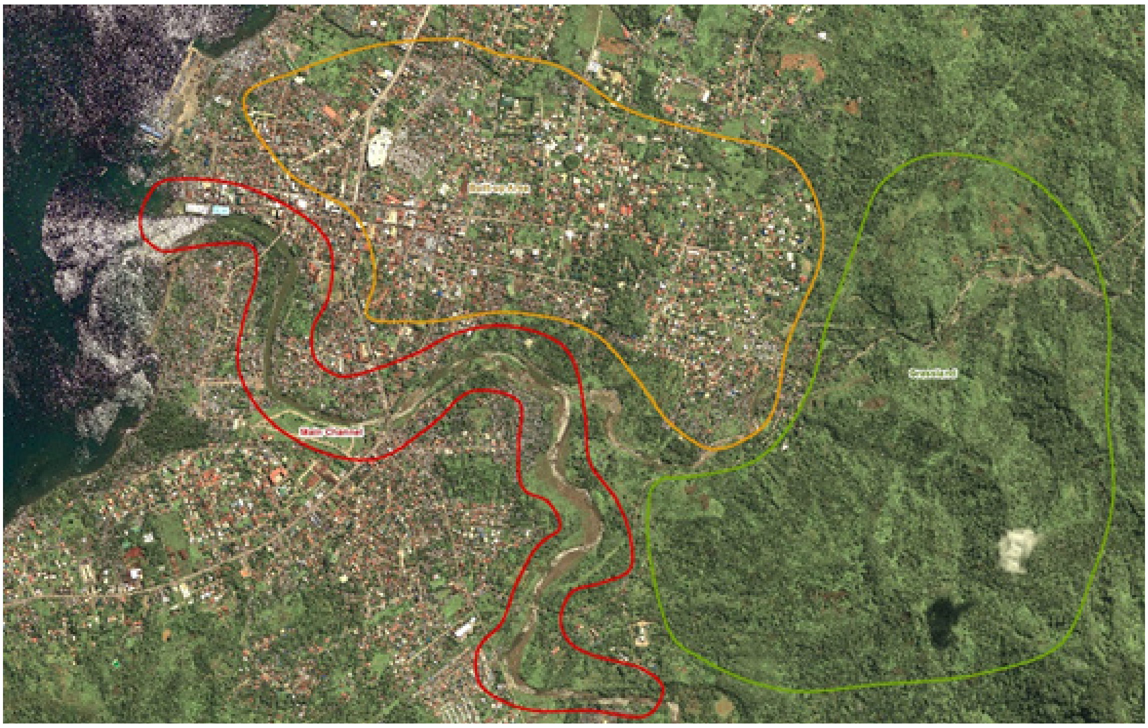


Figure 9. Stitched Quickbird images for the Mandulog floodplain.

3.1.3 Hydrometry and Rainfall Data

3.1.3.1 Hydrometry for Mandulog Bridge 2

River outflow from the Data Validation Component was used to calibrate the HEC-HMS model. This was taken from Mandulog Bridge 2, Mandulog City (8°15'18.57"N, 124°15'36.51"E). This was recorded during typhoon Pablo event on December 4, 2012. Peak discharge is 333.80 at 03:30 PM as is shown in Figure 10.

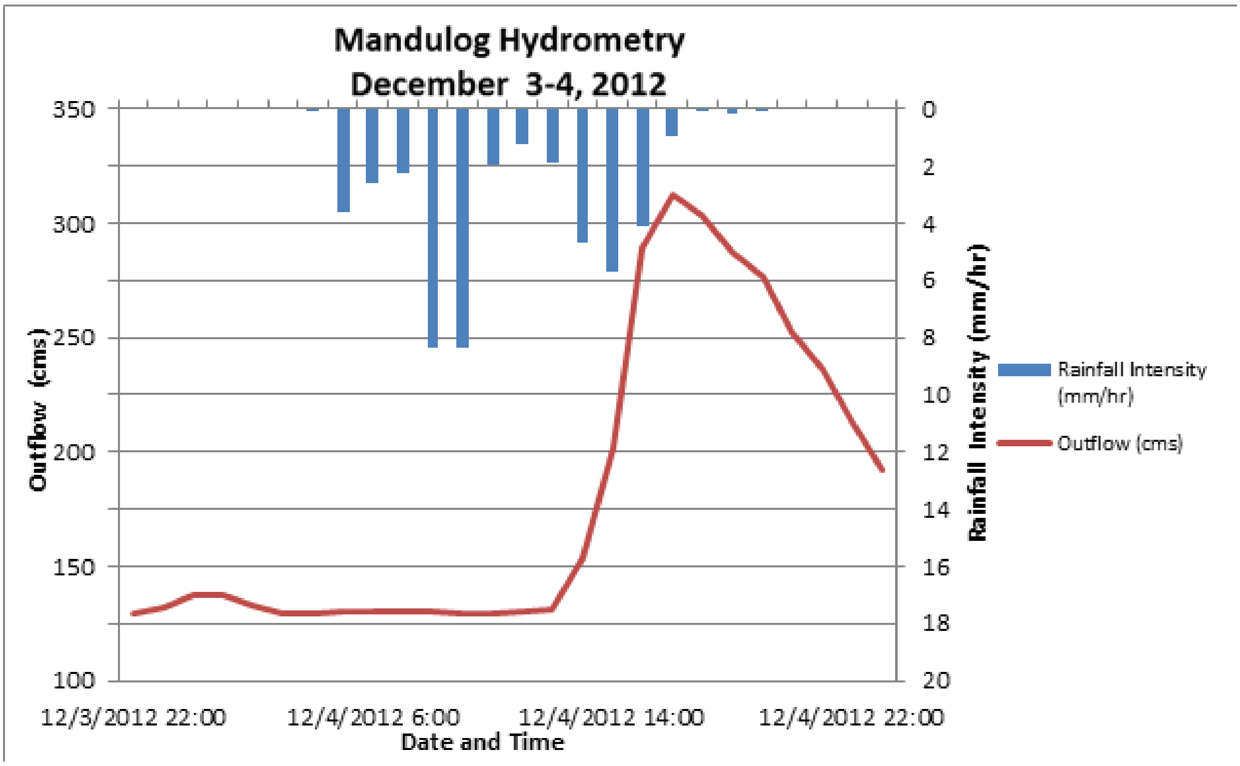


Figure 10. Mandulog Bridge 2 rainfall and outflow data used for modeling.

3.1.3.2 Rainfall Intensity Duration Frequency

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Lumbia Rain Gauge. This station was chosen based on its proximity to the Mandulog 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.

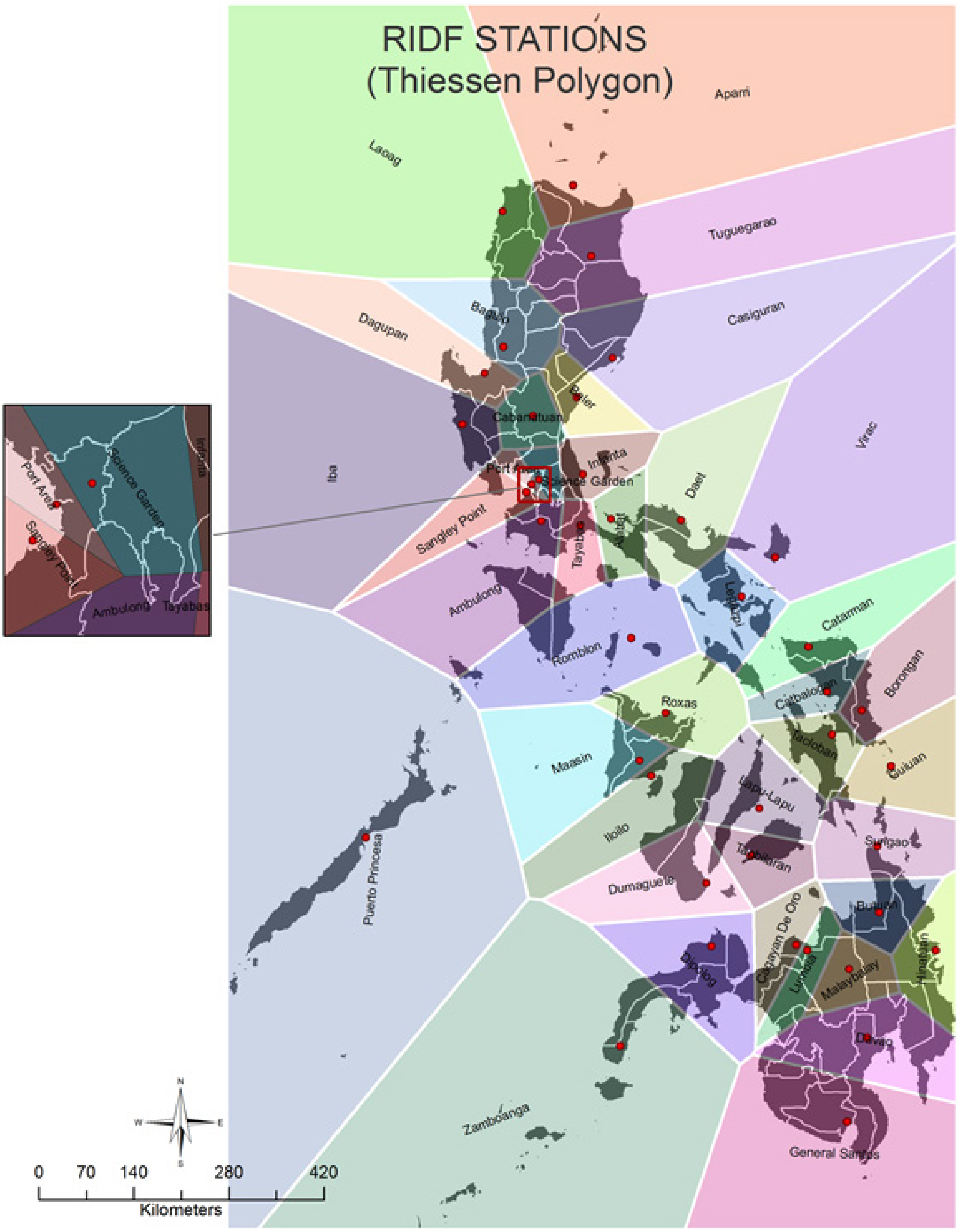


Figure 11. Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines.

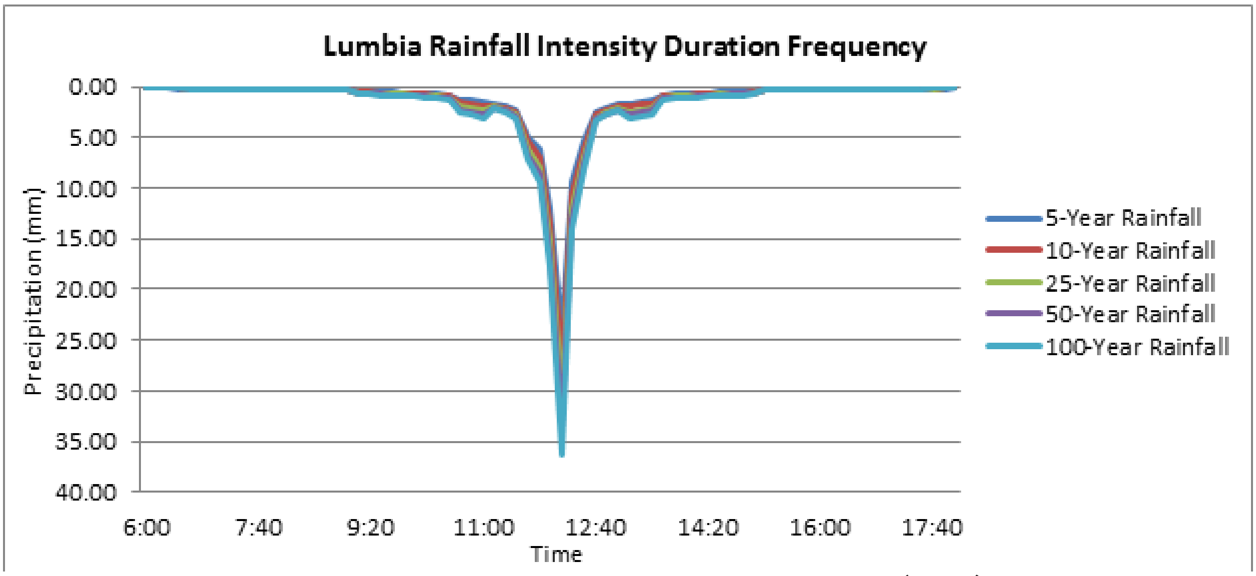


Figure 12. Lumbia Rainfall-Intensity Duration Frequency (RIDF) curves.

The Mandulog 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 Mandulog Bridge 2, the rating curve is expressed as Q = y = 3.7701e1.2882x as shown in

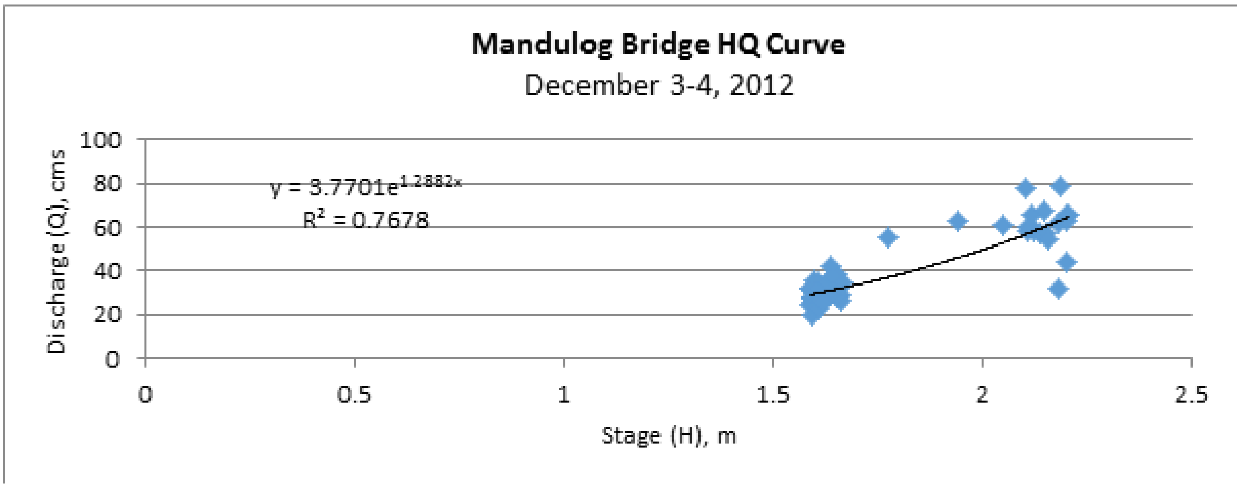


Figure 13. Water level vs. Discharge Curve for Mandulog Bridge 2

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Mandulog 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.

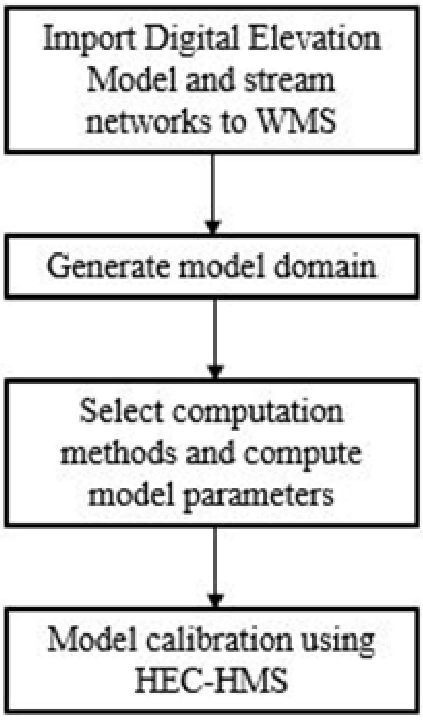


Figure 14. The Rainfall-Runoff Basin Model Development Scheme

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.

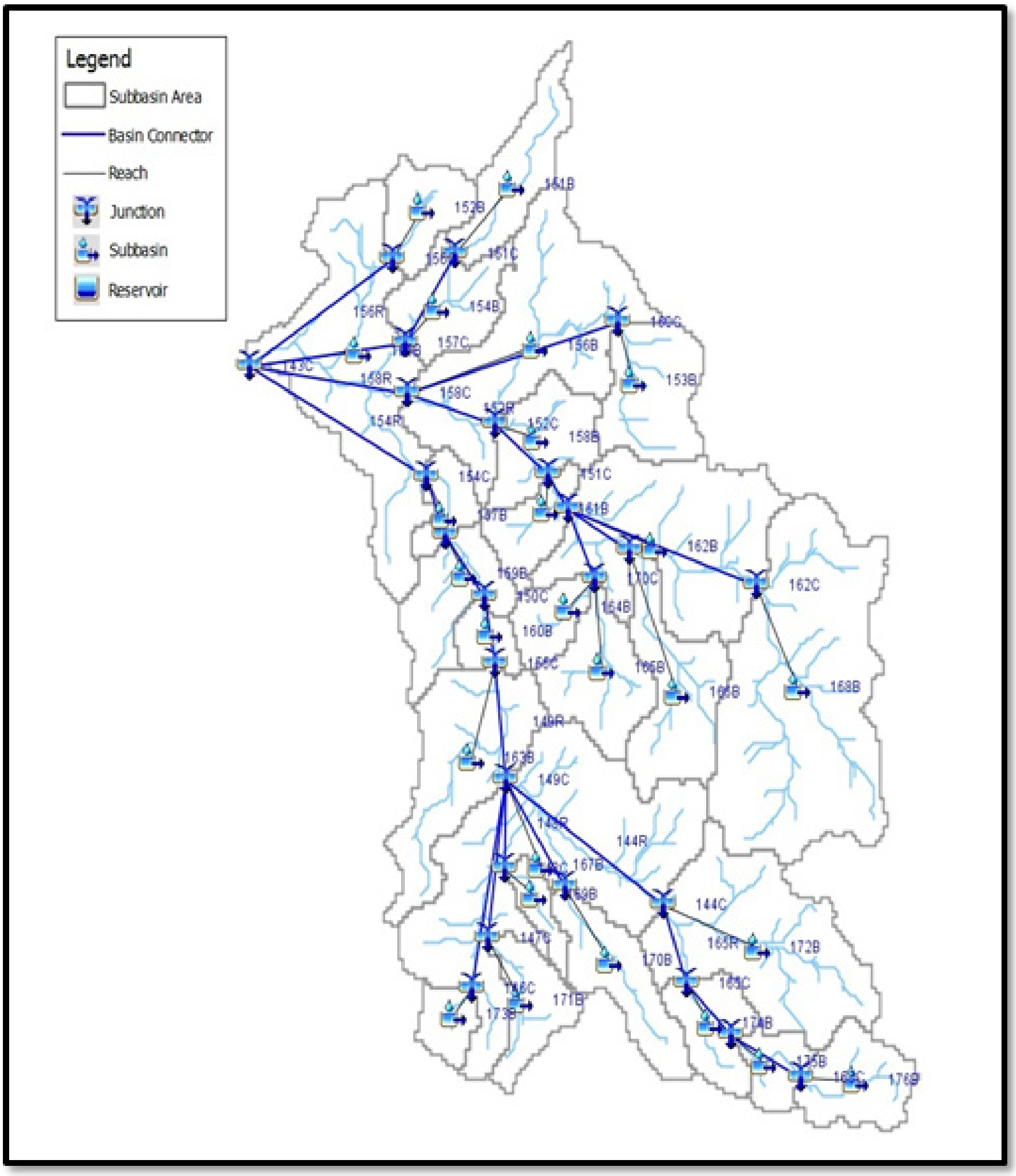


Figure 15. Mandulog HEC-HMS Model domain generated by WMS

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

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

3.2.2 Basin Model Calibration

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

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

Total rain from Digkilaan rain gauge is 150.114 mm. It peaked to 11.938mm on 04December 2012, 08:45. The lag time between the peak rainfall and discharge is six hours and forty five minutes.

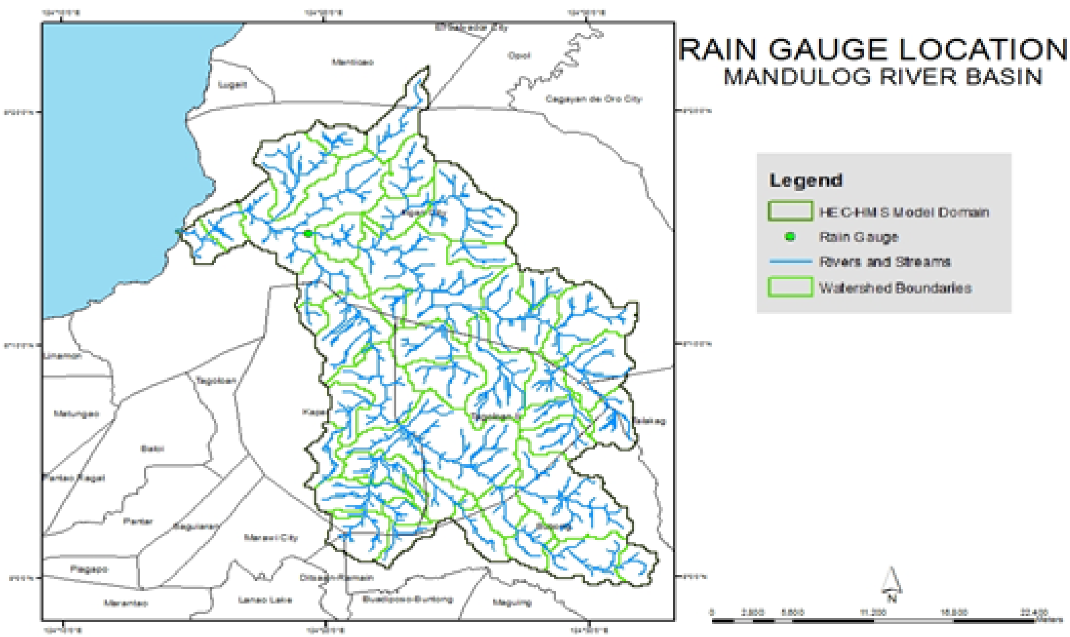


Figure 16. Location of rain gauge used for the calibration of Mandulog HEC-HMS Model.

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

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

3.3.1 Discharge Computation using Rainfall-Runoff Hydrologic Model

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

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

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

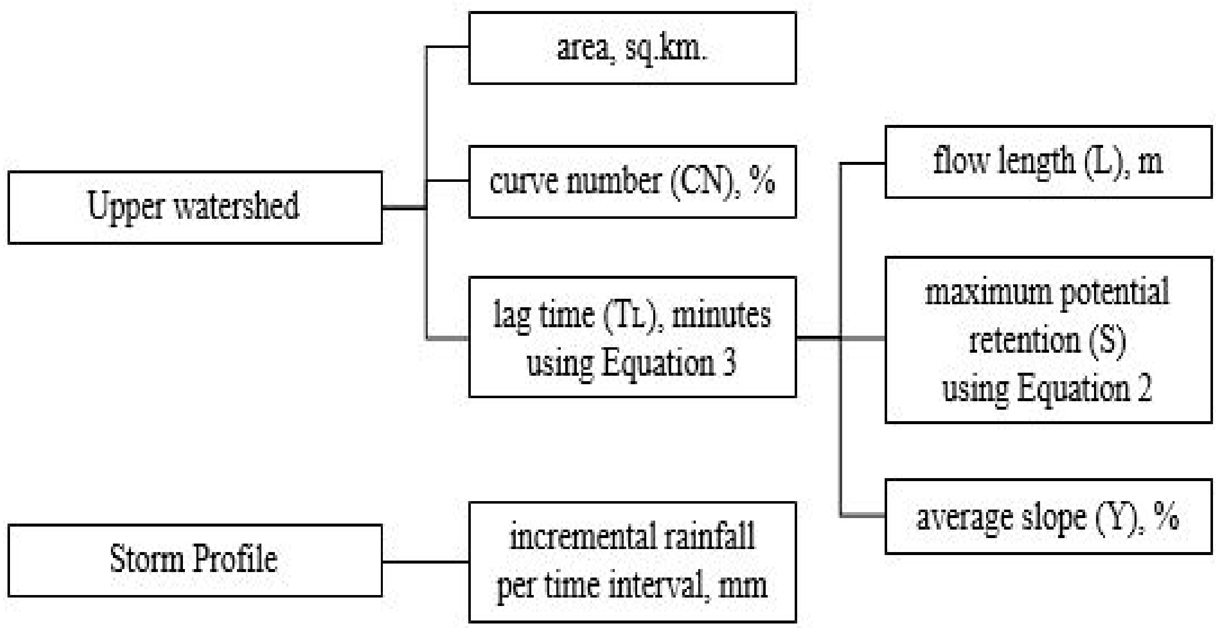


Figure 17. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method.

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 Mandulog floodplain discharge computa-

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.

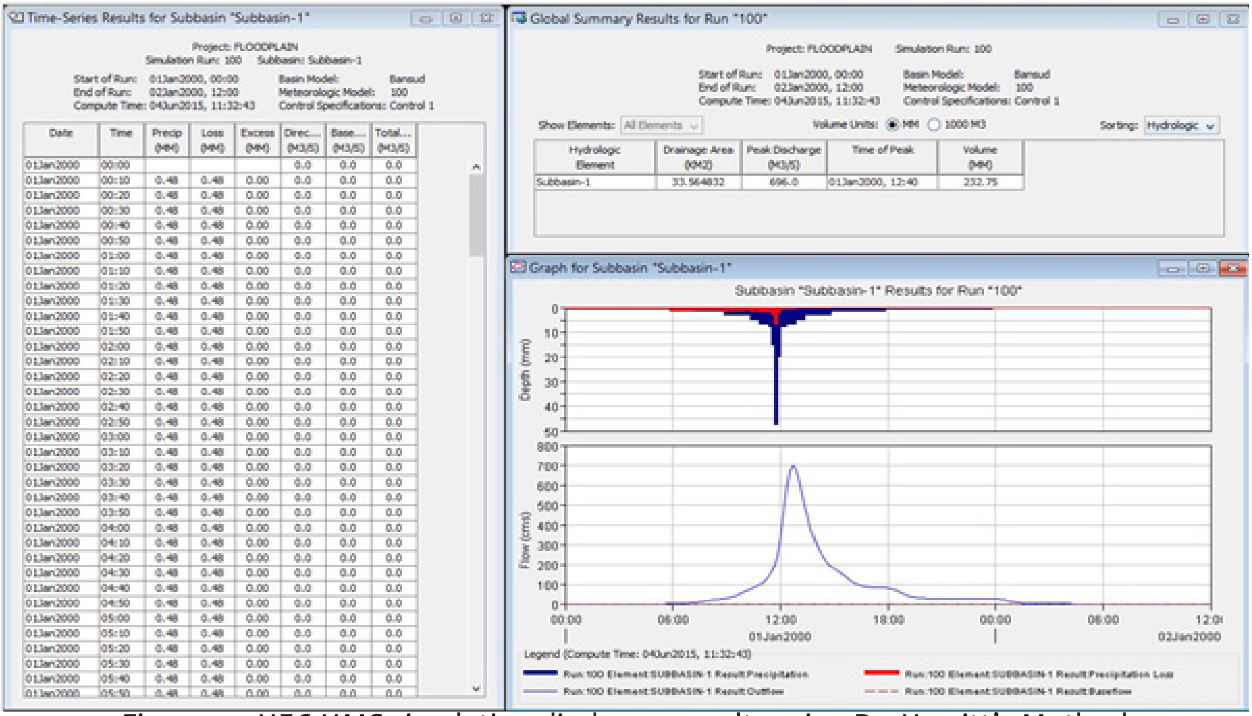


Figure 19. HEC-HMS simulation discharge results using Dr. Horritt's Method

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

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

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

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

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

Equation 5. Discharge validation equation using bankful method

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

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

Equation 6. Bankful discharge equation using measurable channel parameters

3.4 Hazard and Flow Depth Mapping using FLO-2D

3.4.1 Floodplain Delineation

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

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

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

3.4.2 Flood Model Generation

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

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

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

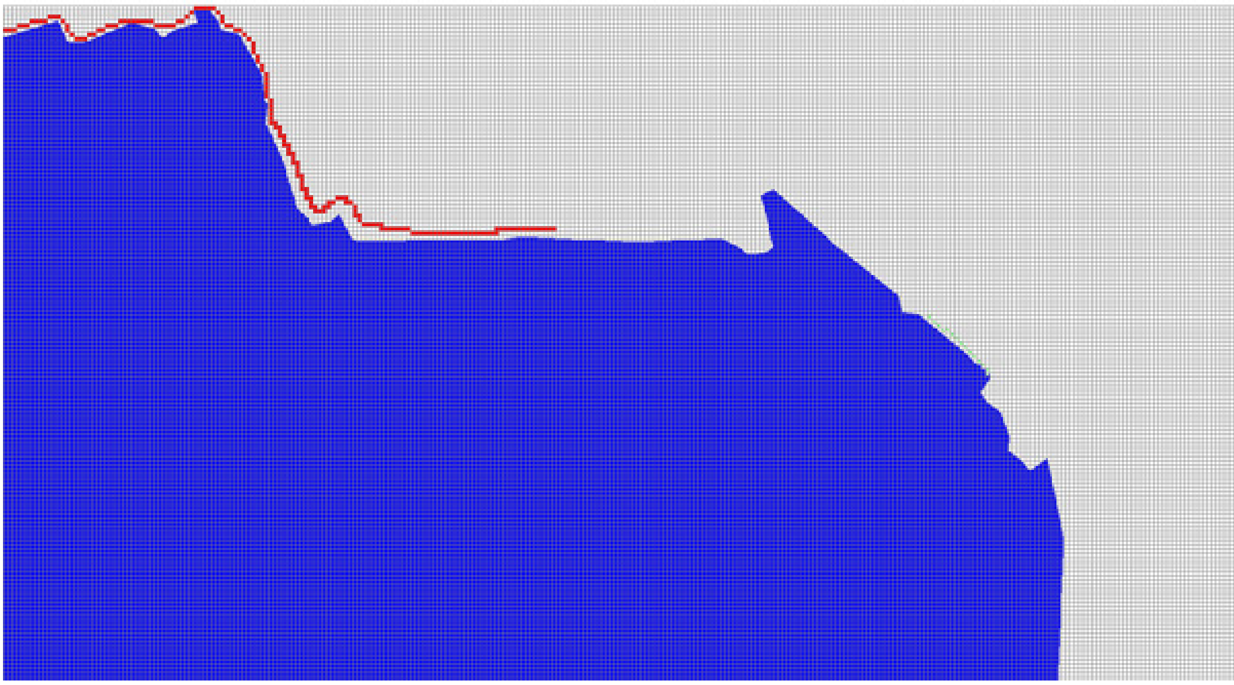


Figure 20. Screenshot showing how boundary grid elements are defined by line

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

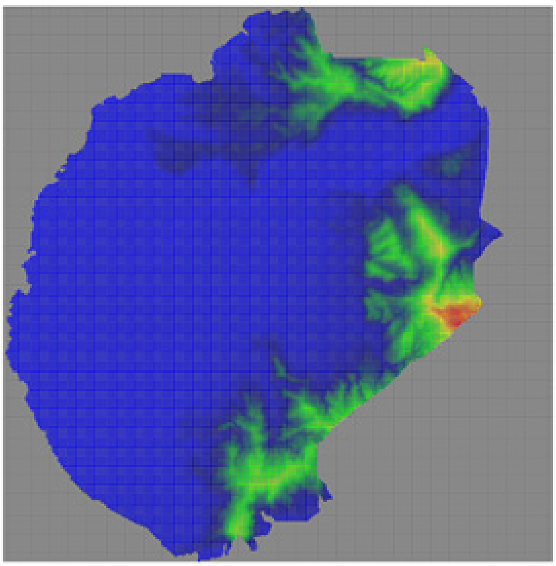


Figure 21. Screenshots of PTS files when loaded into the FLO-2D program

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

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

Figure 22. Areal image of Mandulog floodplain

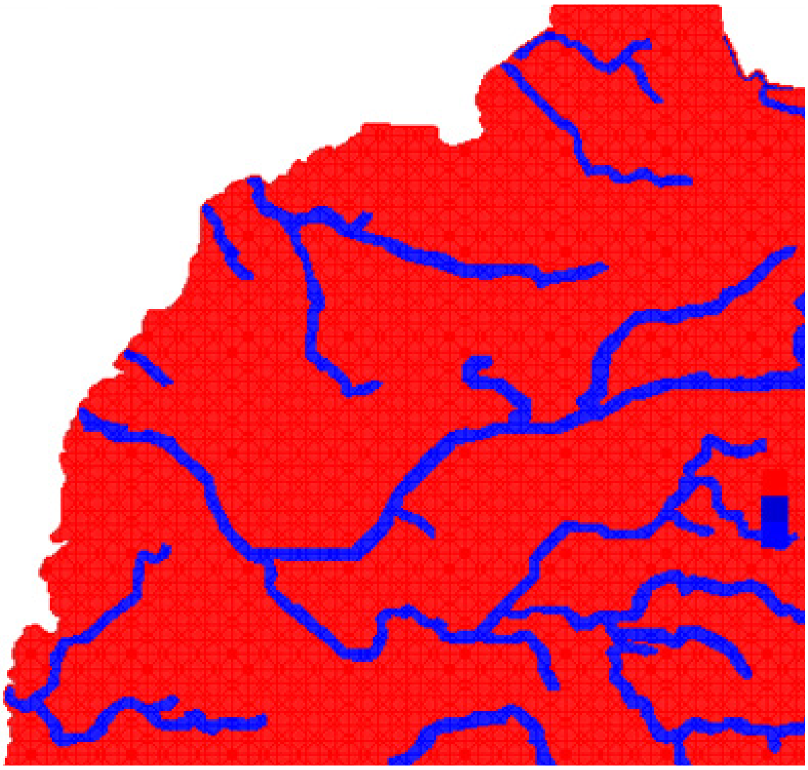


Figure 23. Screenshot of Manning's n-value rendering

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.

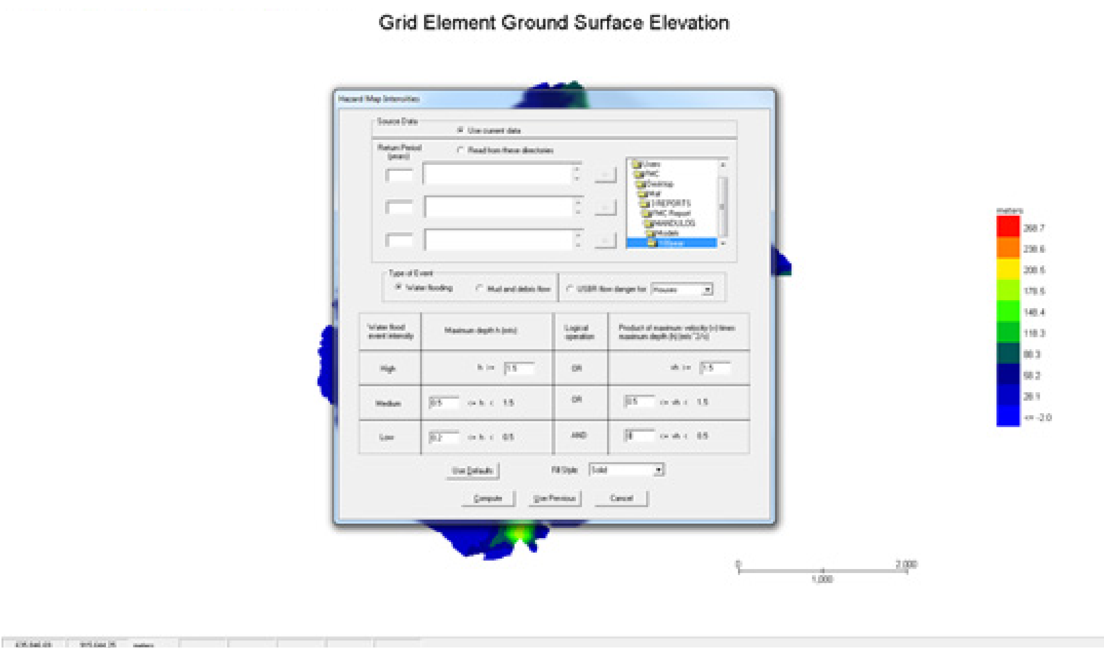


Figure 24. Flo-2D Mapper Pro General Procedure

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.

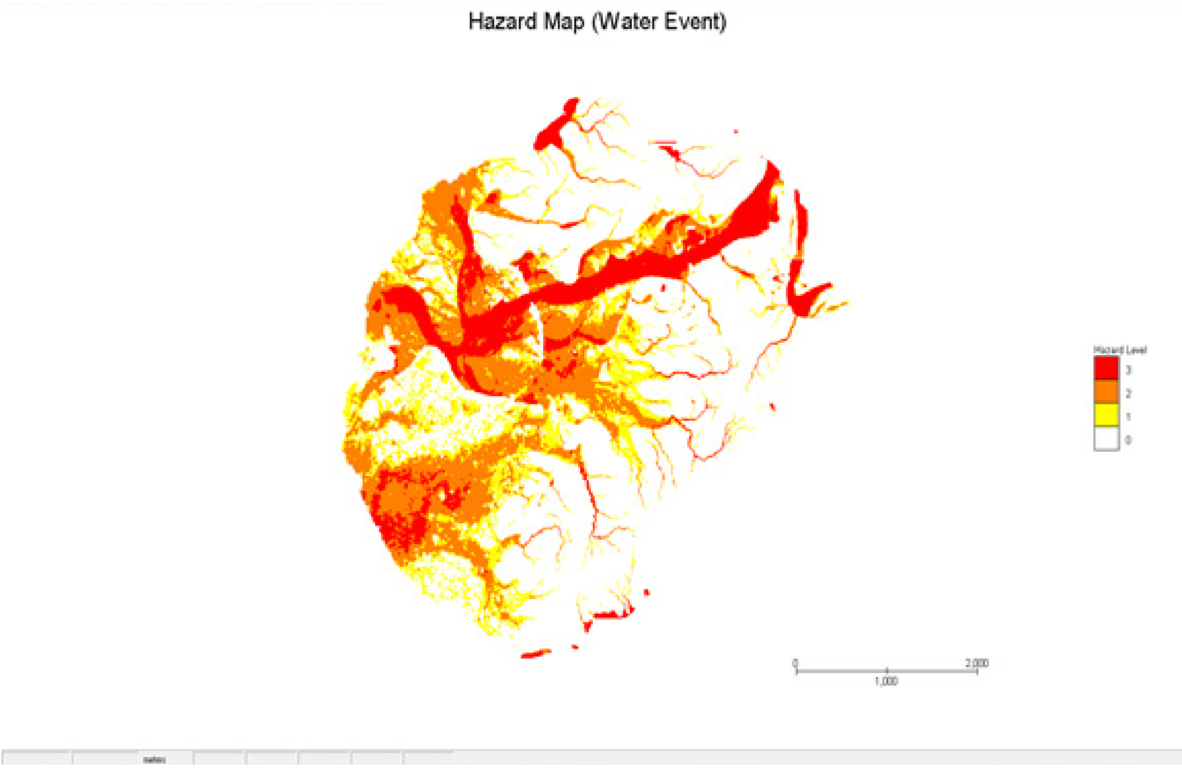


Figure 25. Mandulog Floodplain Generated Hazard Maps using FLO-2D Mapper

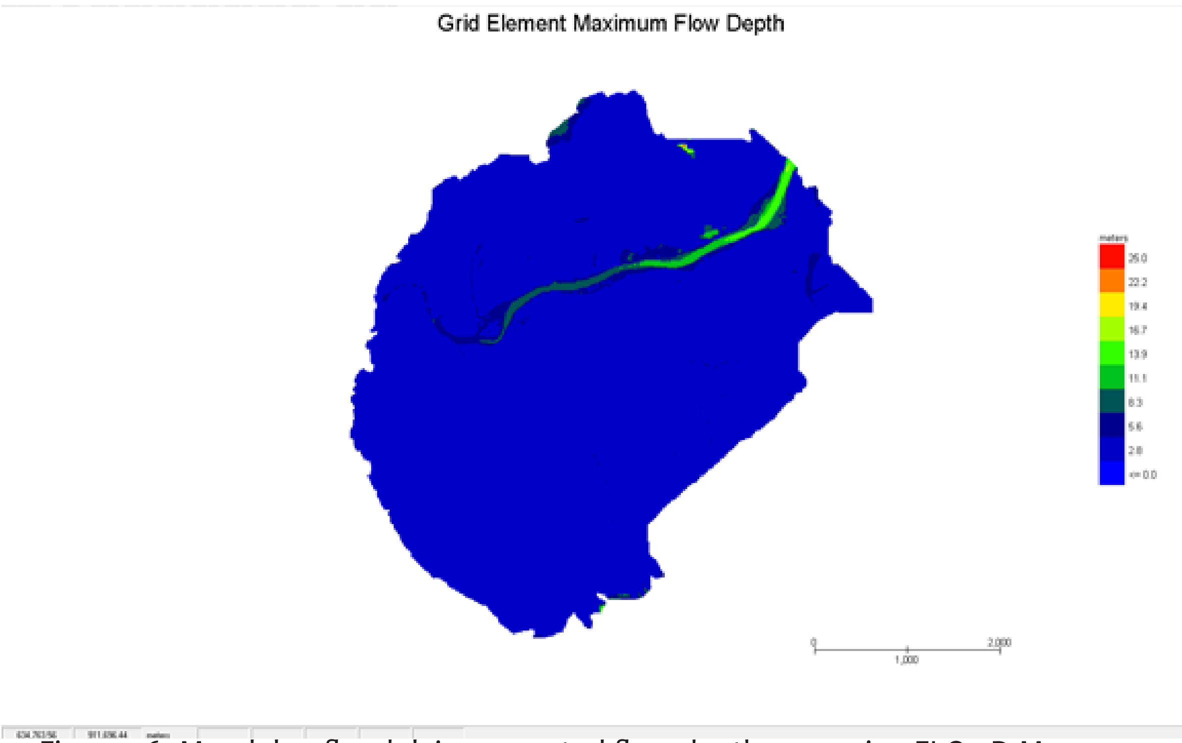
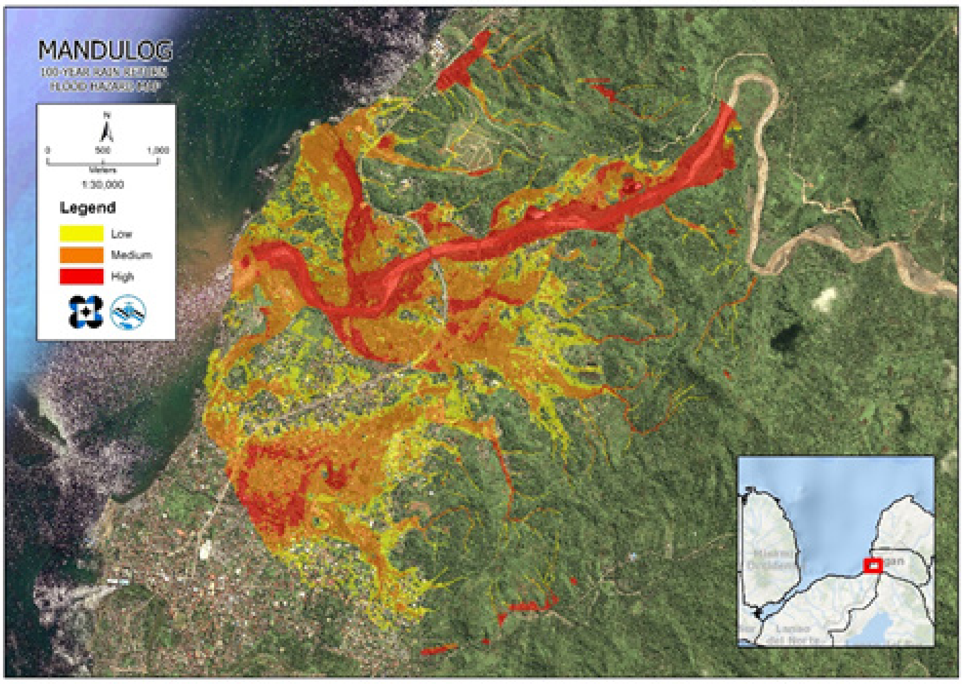


Figure 26. Mandulog floodplain generated flow depth map using FLO-2D Mapper

3.4.4 Hazard Map and Flow Depth Map Creation

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



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

Figure 27. Basic Layout and Elements of the Hazard Maps

Results and Discussion

Results and Discussion

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

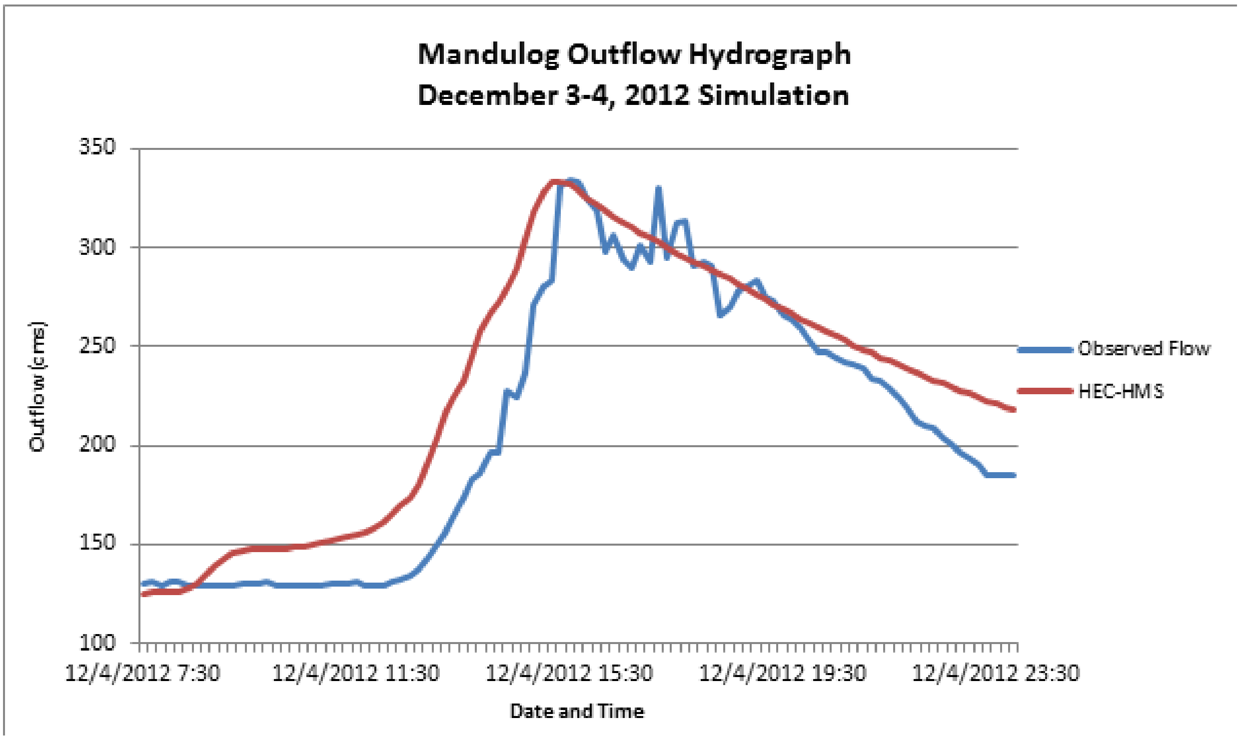


Figure 28. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow.

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 2.966.

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 0.995.

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 0.986.

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 -0.027.

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 is quantified. The model has an RSR value of 0.116.

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

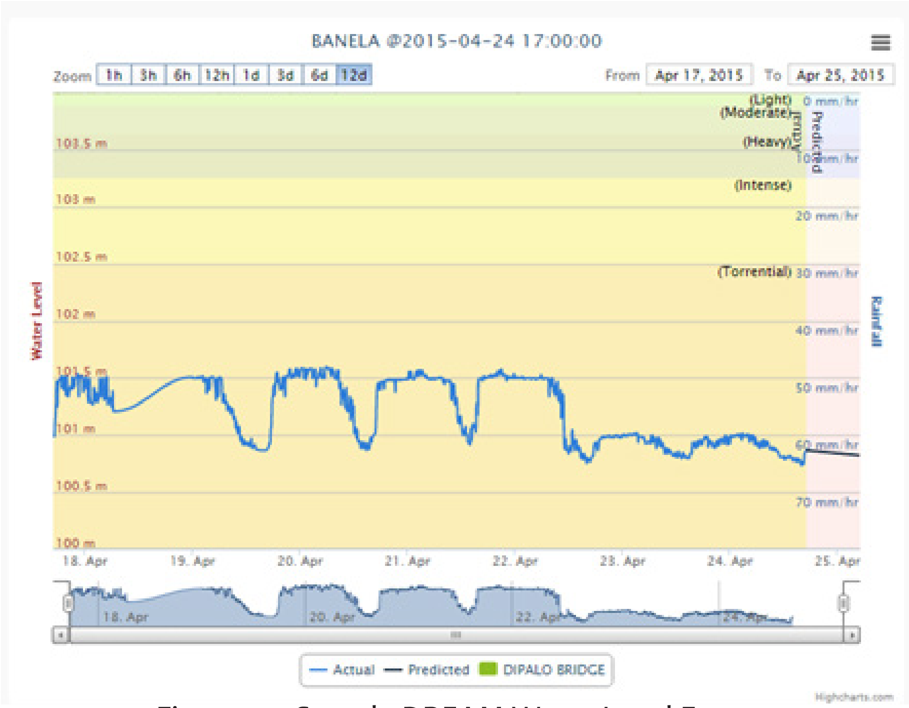


Figure 29. Sample DREAM Water Level Forecast

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

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

4.2.1 Hydrograph using the Rainfall-Runoff Model

The outflow of Mandulog 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 (Figure 30), the peak outflow is 180.5 cms. This occurs after 3 hours after the peak precipitation of 27.1mm.

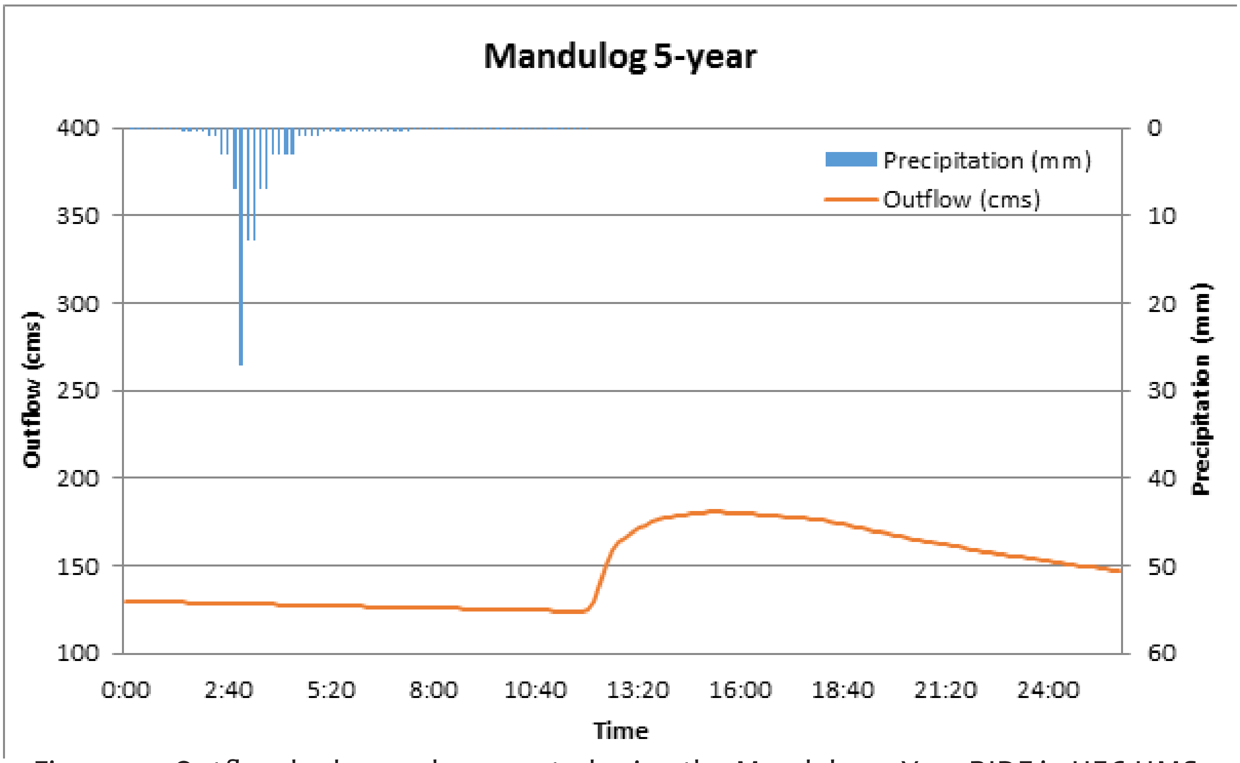


Figure 30. Outflow hydrograph generated using the Mandulog 5-Year RIDF in HEC-HMS.

In the 10-year return period graph (Figure 31), the peak outflow is 127.1 cms. This occurs after 3 hours after the peak precipitation of 30.2mm.

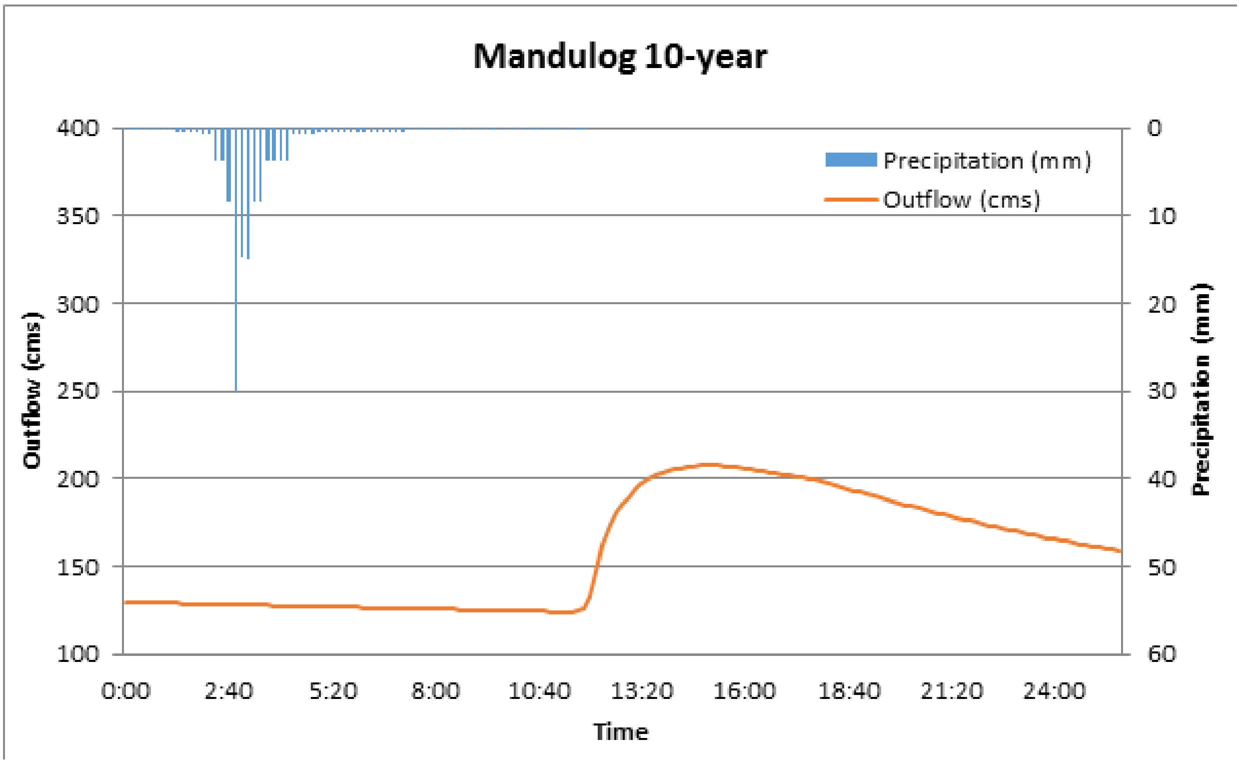


Figure 31. Outflow hydrograph generated using the Mandulog 10-Year RIDF in HEC-HMS.

In the 25-year return period graph (Figure 32), the peak outflow is 148.2 cms. This occurs after 3 hours after the peak precipitation of 34.2 mm.

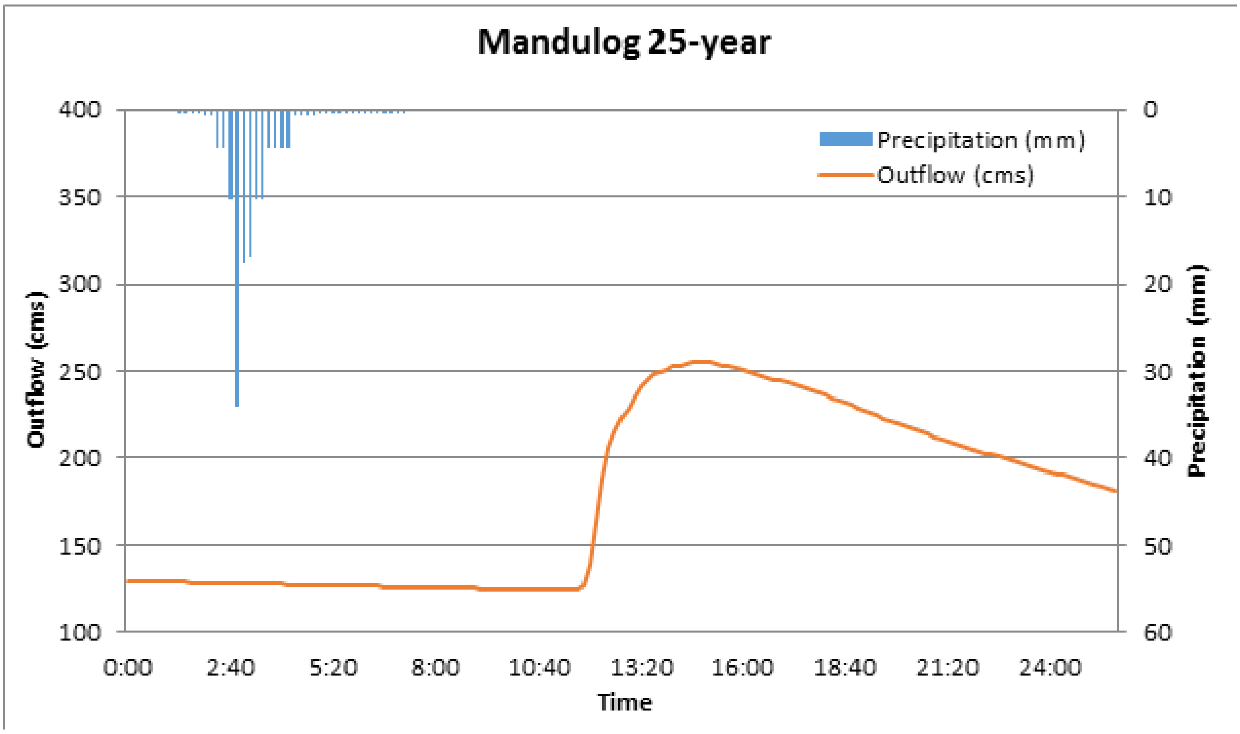


Figure 32. Outflow hydrograph generated using the Mandulog 25-Year RIDF in HEC-HMS.

In the 50-year return period graph (Figure 33), the peak outflow is 163.9 cms. This occurs after 3 hours after the peak precipitation of 37.2 mm.

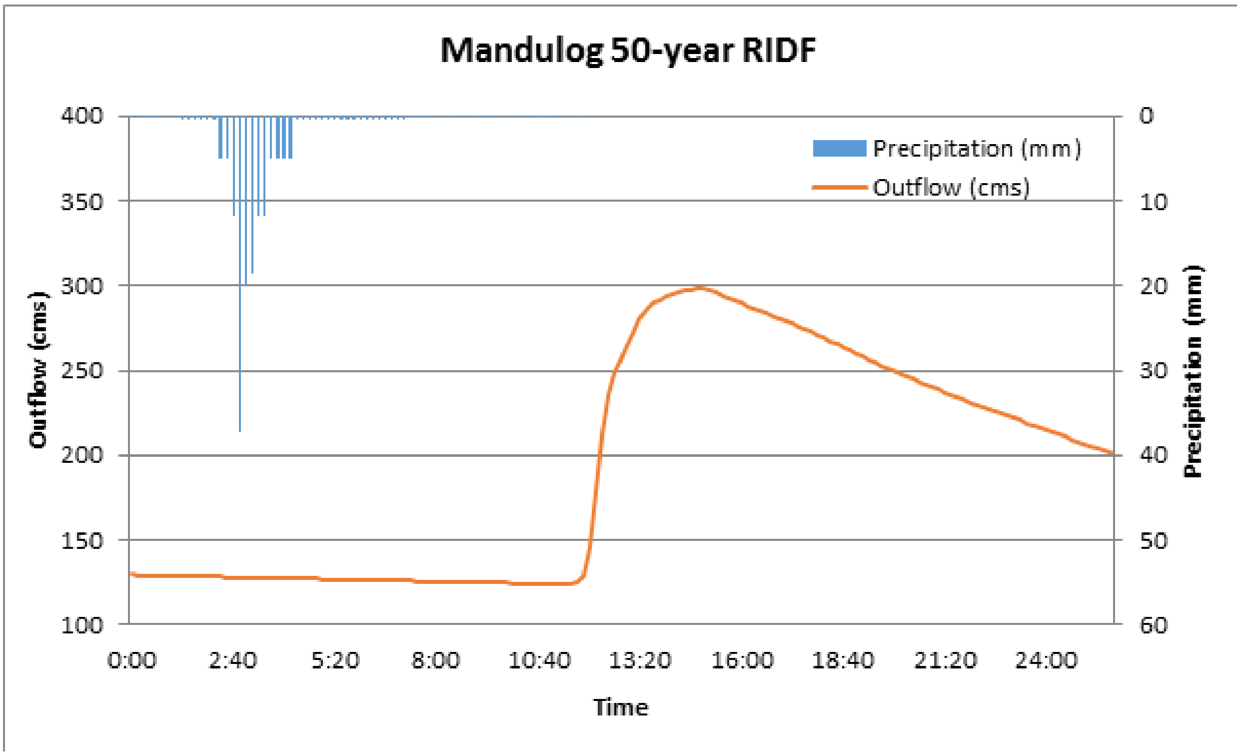


Figure 33. Outflow hydrograph generated using the Mandulog 50-Year RIDF in HEC-HMS.

In the 100-year return period graph (Figure 34), the peak outflow is 160.4 cms. This occurs after 3 hours after the peak precipitation of 39q.20 mm.

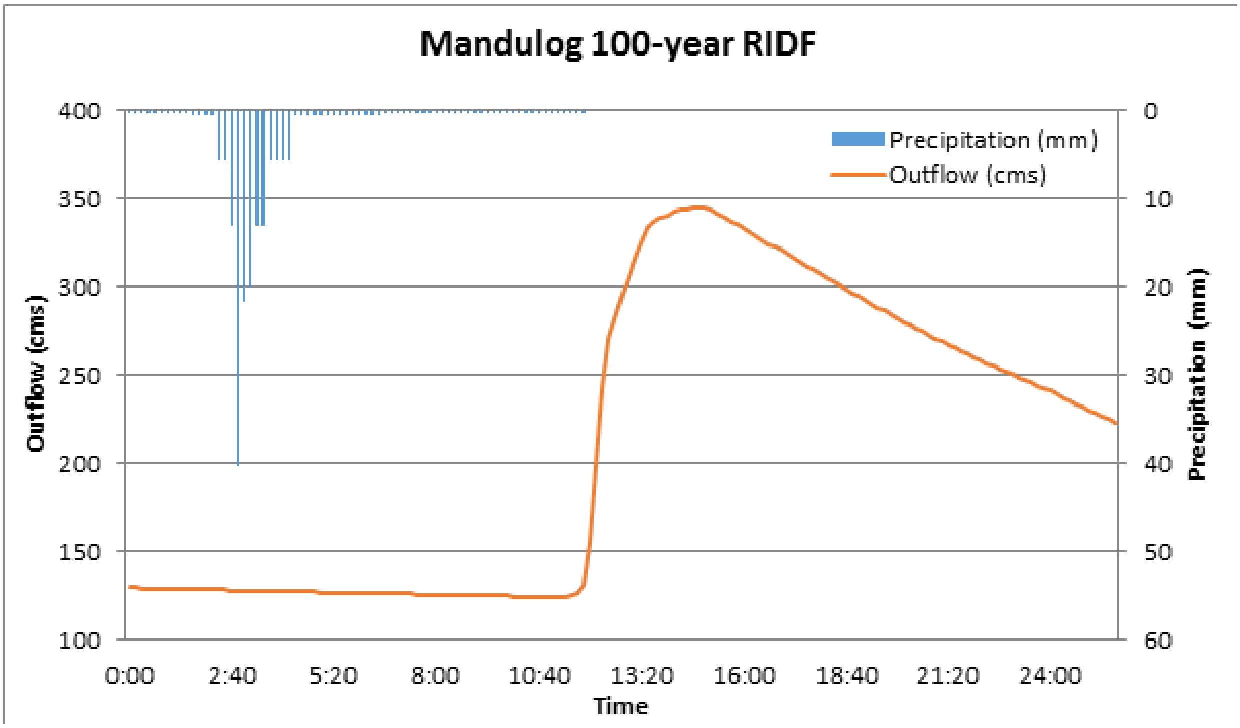


Figure 34. Outflow hydrograph generated using the Mandulog 100-Year RIDF in HEC-HMS.

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

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

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	110.4	27.1	180.5	3 hours
10-Year	127.1	30.2	208.1	3 hours
25-Year	148.2	34.2	255.6	3 hours
50-Year	163.9	37.2	298	3 hours
100-Year	179.4	40.2	345.4	3 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.

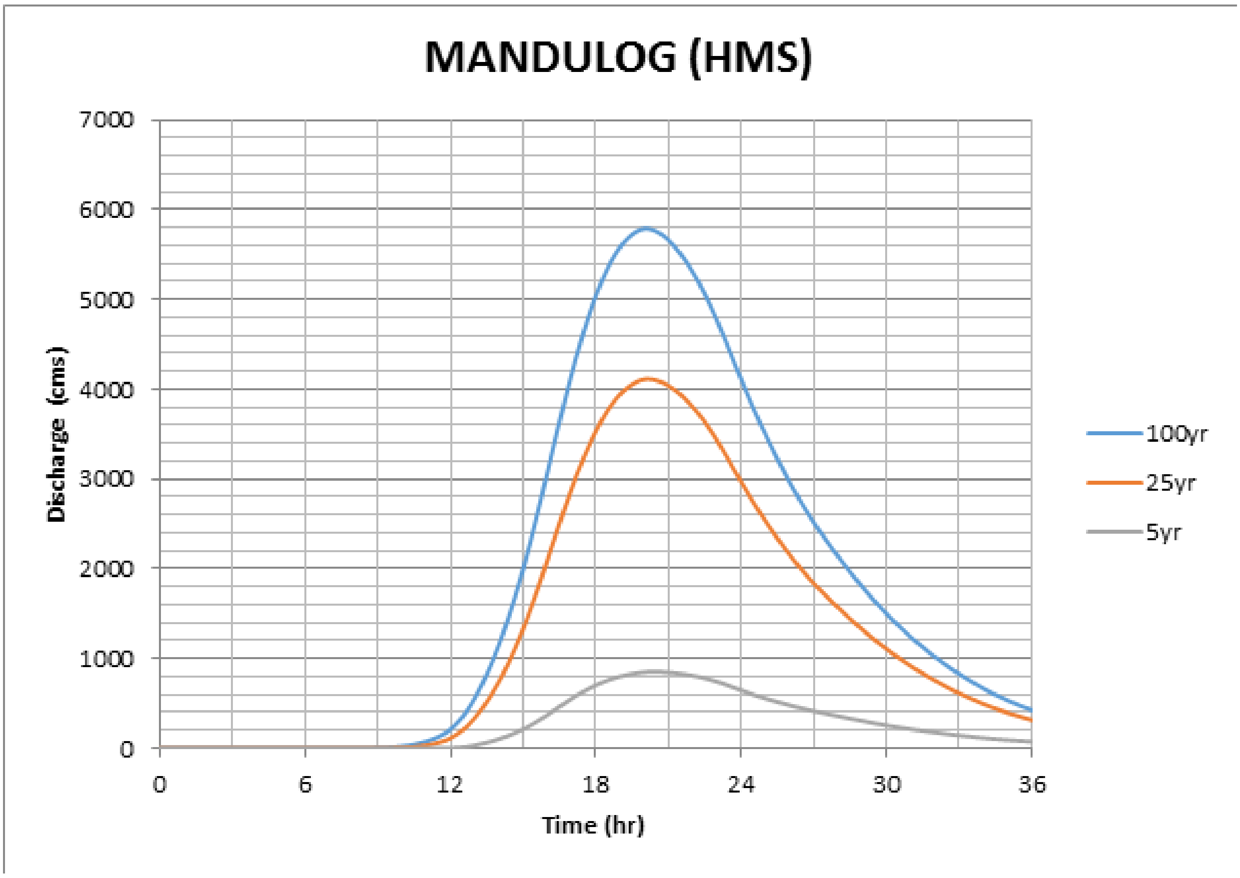


Figure 35. Outflow hydrograph generated using the Mandulog 5-, 25-, 100-Year RIDF in HEC-

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

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	853.5	20 hours, 20 minutes
25-Year	4,113.6	20 hours, 10 minutes
100-Year	5,789.1	20 hours

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

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

Discharge Point	Qbankful, cms	QMED, cms	Validation
Mandulog	633.85	751.08	Pass

The value from the HEC-HMS discharge estimate was able to satisfy the condition for validating the computed discharge using the bankful method. Since the computed value is 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 Mandulog river basin.

Results and Discussion

Flood Hazard Maps and Flow Depth Maps

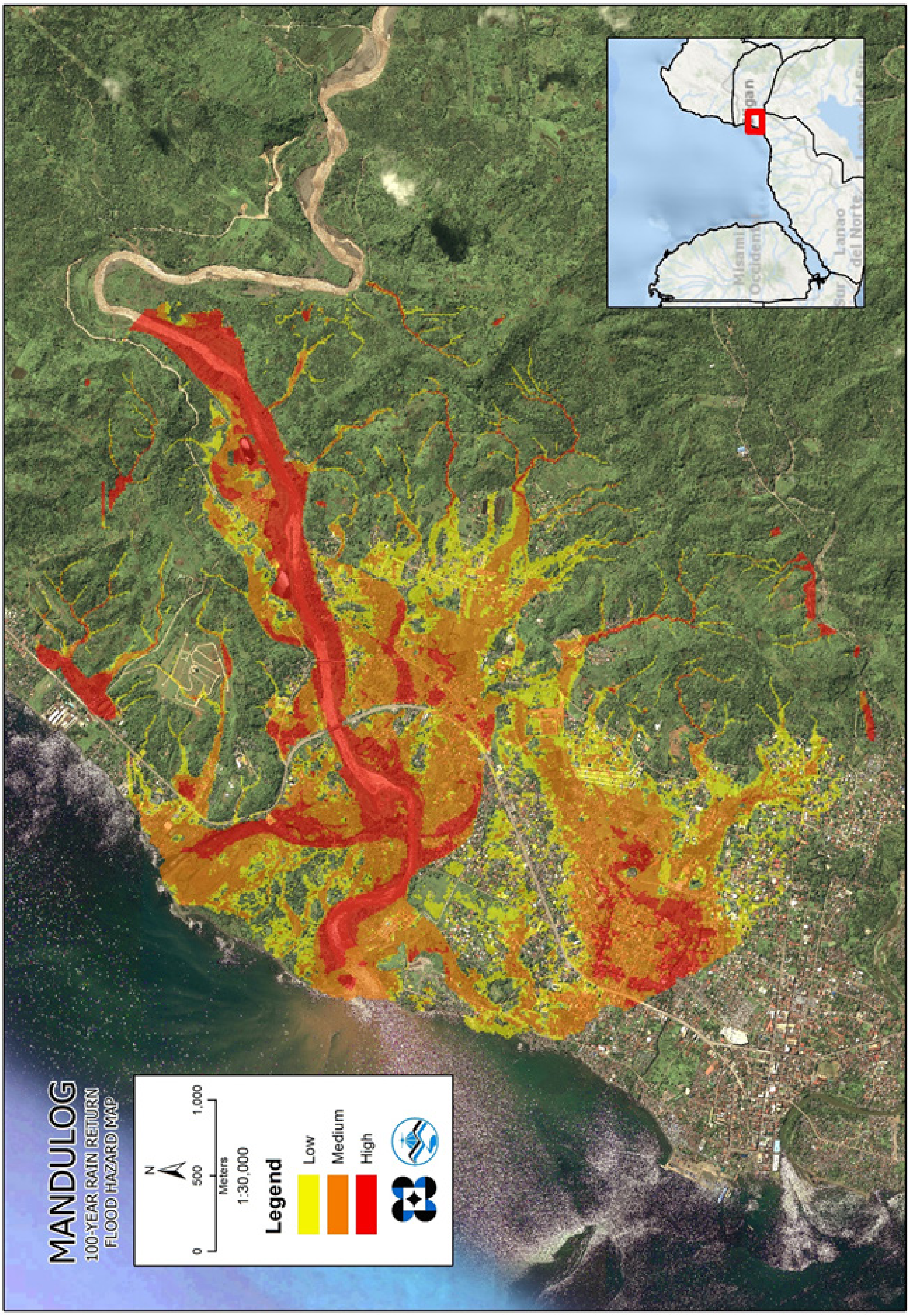


Figure 36. 100-year Flood Hazard Map for Mandulog River Basin

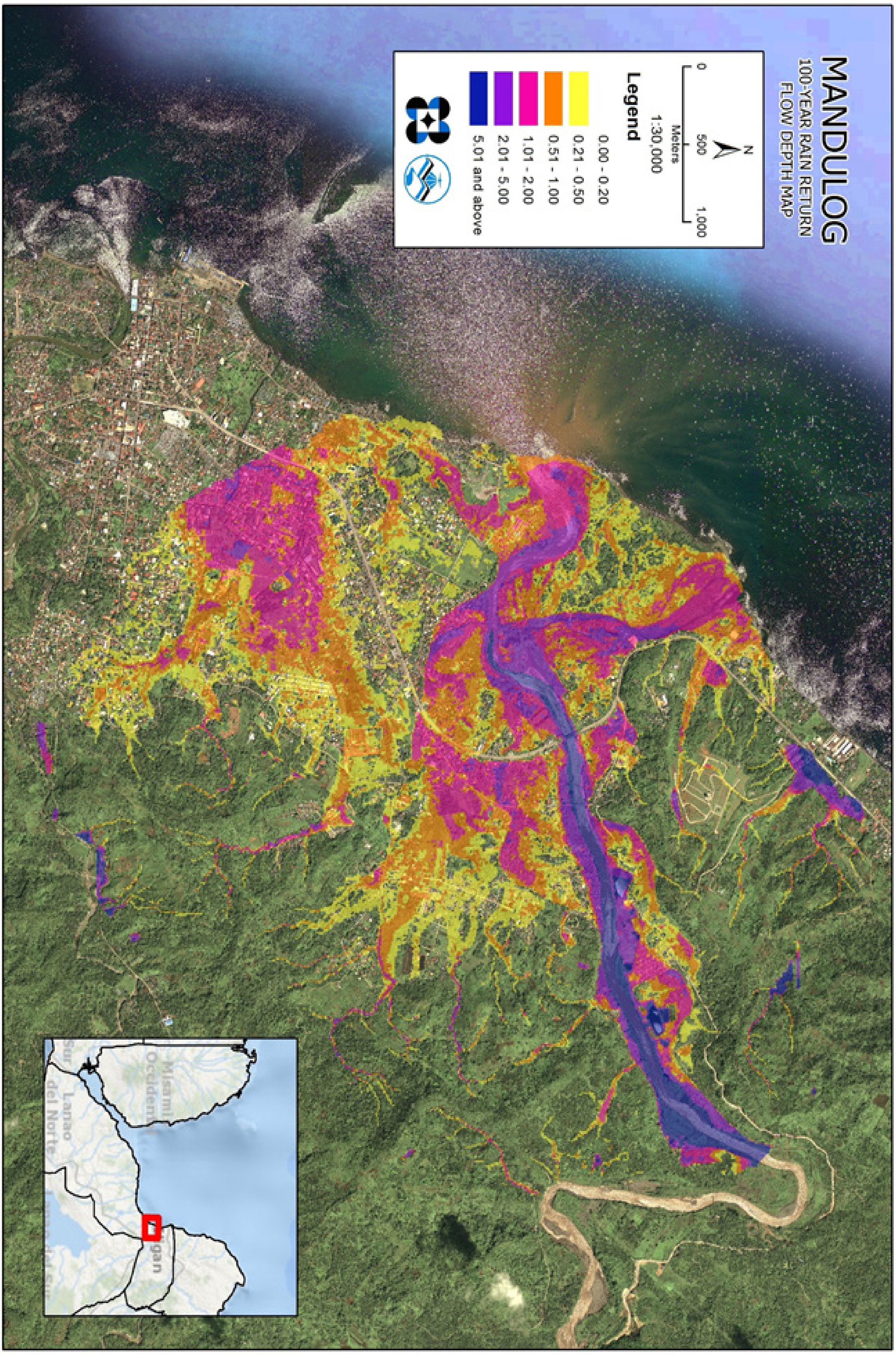


Figure 37. 100-year Flow Depth Map for Mandulog River Basin

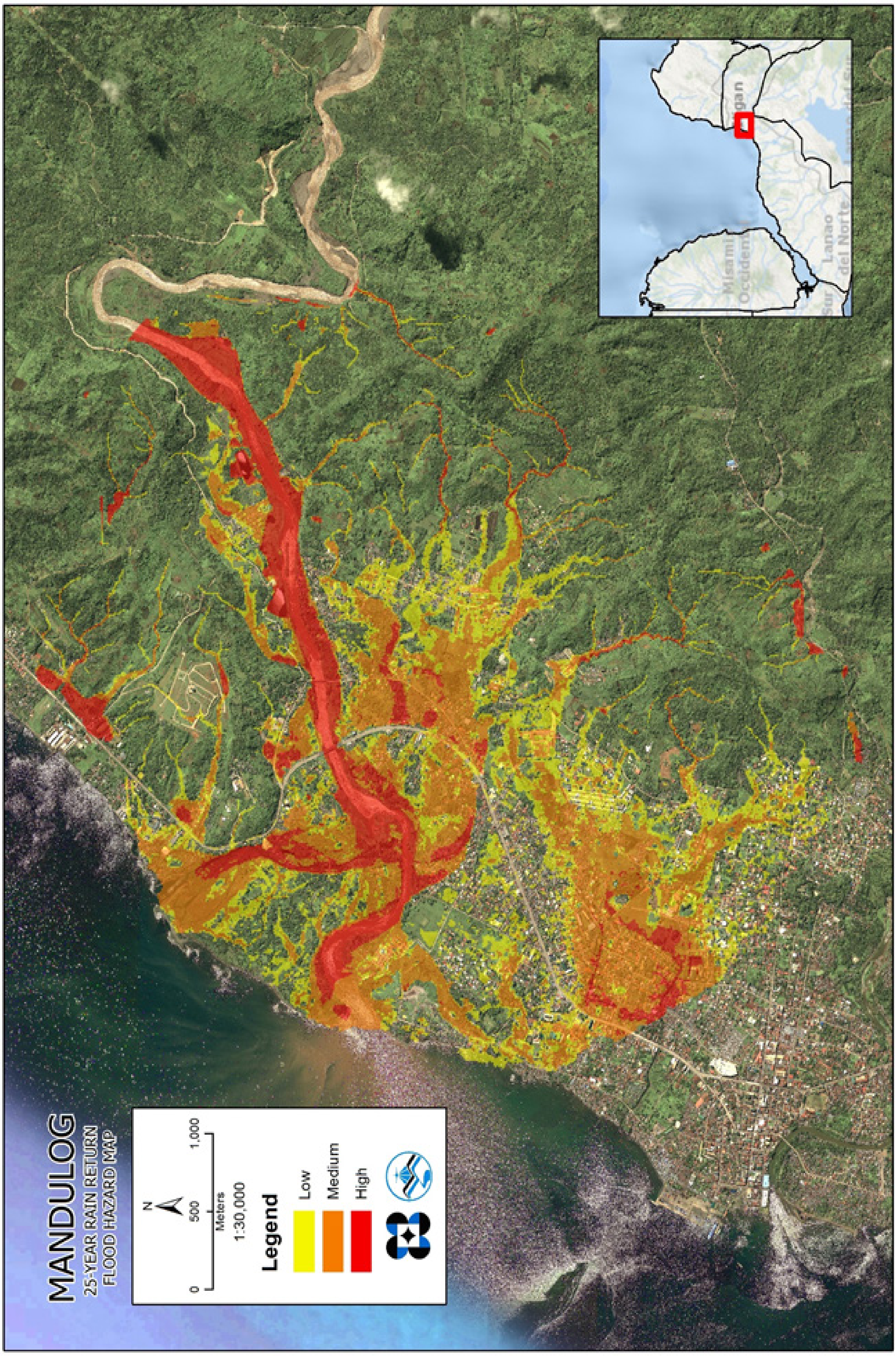


Figure 38. 25-year Flood Hazard Map for Mandulog River Basin

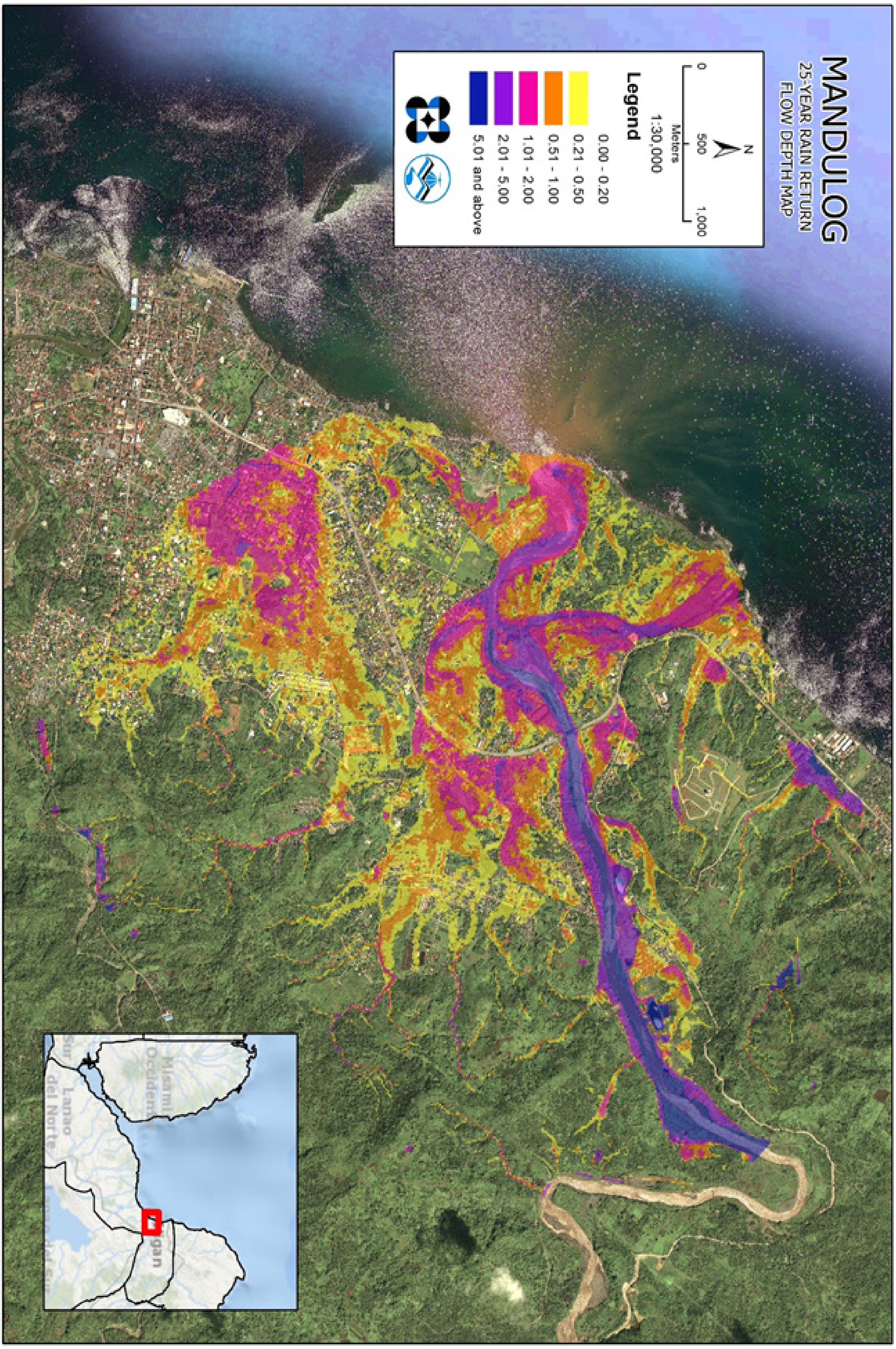


Figure 39. 25-year Flow Depth Map for Mandulog River Basin

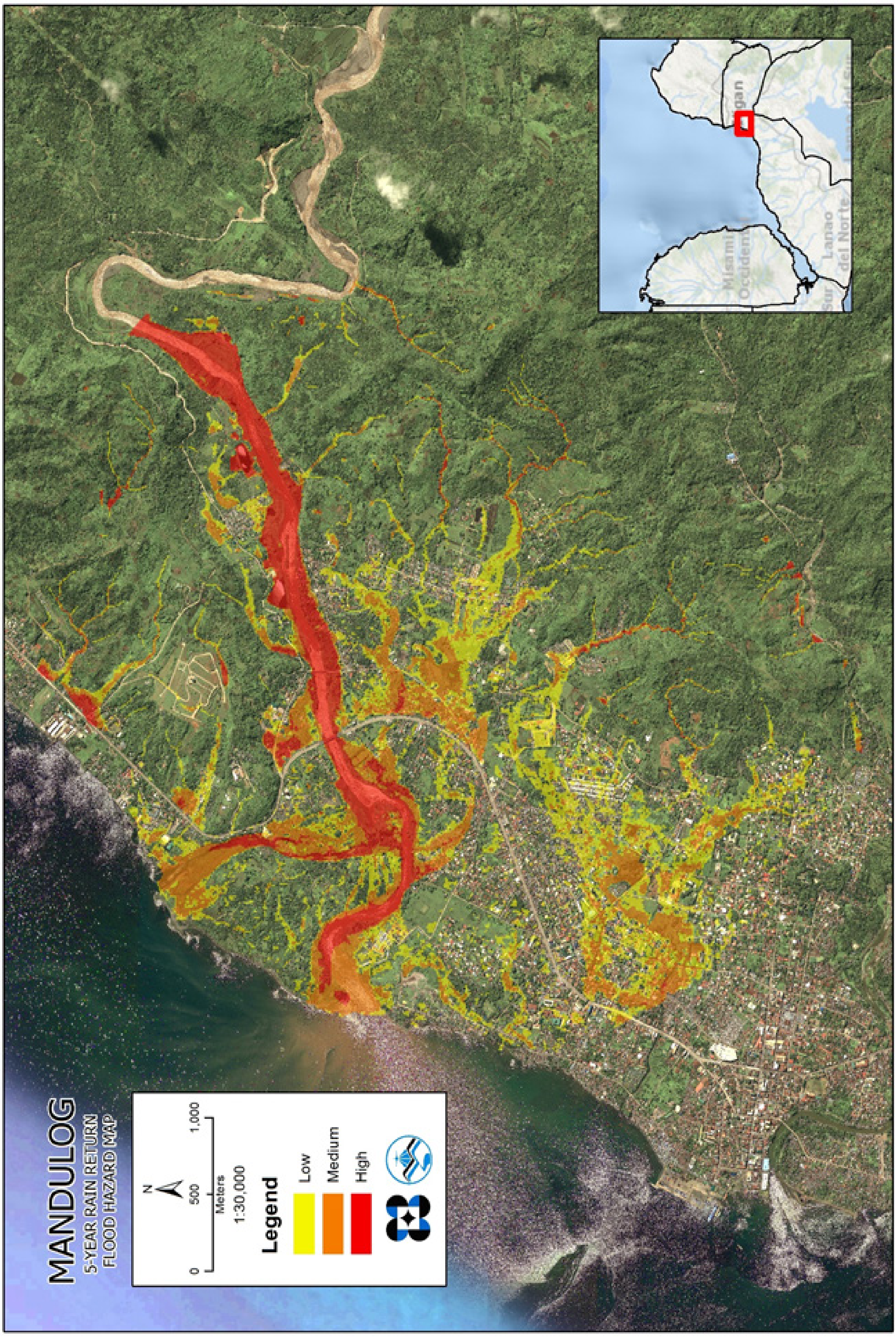


Figure 40. 5-year Flood Hazard Map for Mandulog River Basin

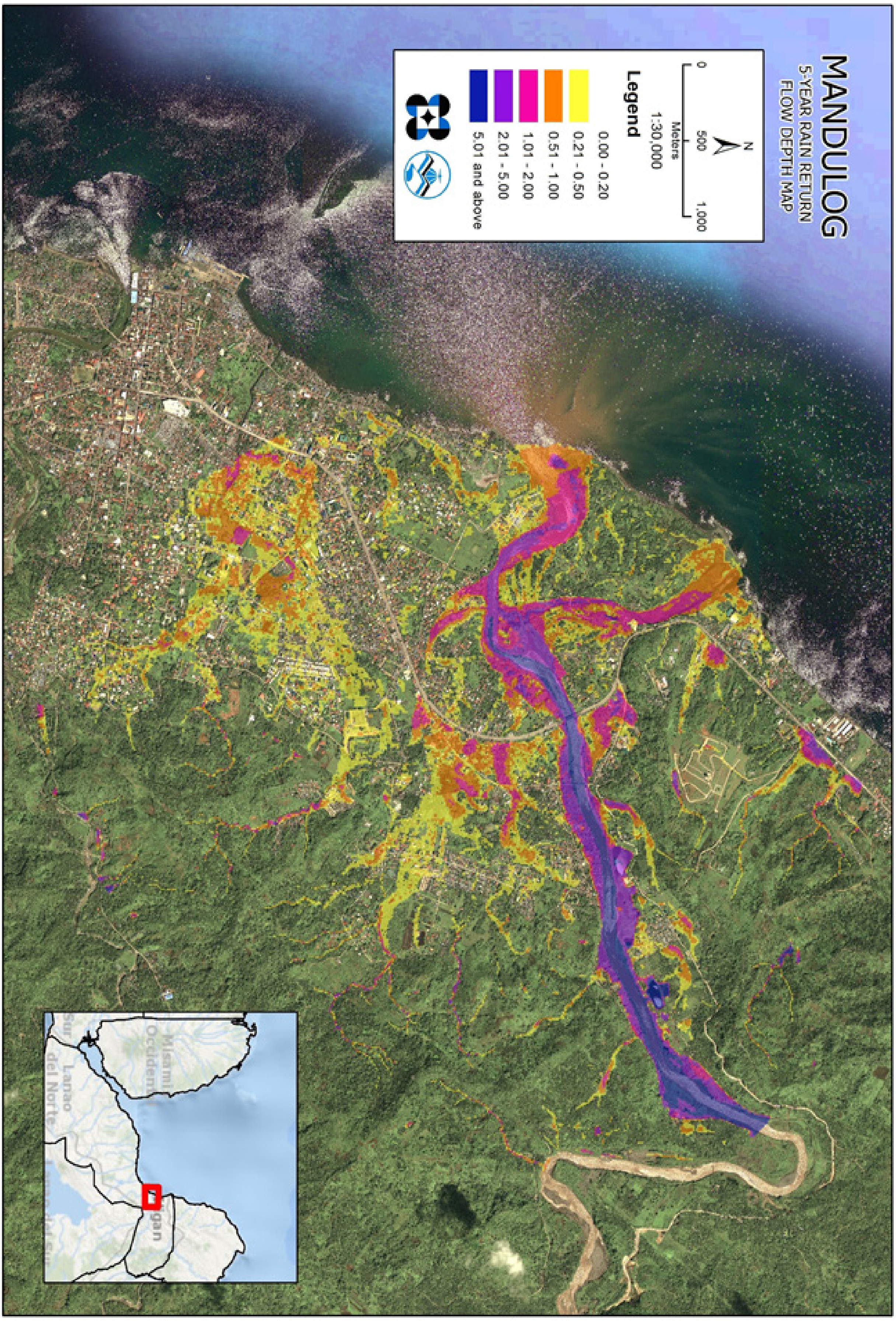


Figure 41. 5-year Flow Depth Map for Mandulog River Basin

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Appendix

Appendix A. Mandulog 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
151B	28.168	24.121	0	0.02	7.026	Discharge	3.4437	0.936	Ratio to Peak	0.01
152B	73.715	31.797	0	0.02	23.870	Discharge	2.4437	0.936	Ratio to Peak	0.01
153B	23.772	27.287	0	0.02	23.940	Discharge	4.1250	0.936	Ratio to Peak	0.01
154B	61.644	35.852	0	0.02	16.067	Discharge	3.2937	0.859	Ratio to Peak	0.01
155B	85.030	42.075	0	0.02	7.213	Discharge	11.100	0.936	Ratio to Peak	0.01
156B	85.030	42.075	0	0.02	7.213	Discharge	10.393	0.936	Ratio to Peak	0.01
157B	80.354	34.534	0	0.02	7.213	Discharge	1.4812	0.936	Ratio to Peak	0.01
158B	61.647	36.775	0	0.02	16.011	Discharge	3.2312	0.936	Ratio to Peak	0.01
159B	85.030	42.075	0	0.02	10.724	Discharge	3.4562	0.936	Ratio to Peak	0.01
160B	85.030	42.075	0	0.02	6.845	Discharge	1.1937	0.936	Ratio to Peak	0.01
161B	85.030	35.615	0	0.02	10.765	Discharge	2.0500	0.936	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
162B	85.030	32.948	0	0.02	10.656	Discharge	10.206	0.936	Ratio to Peak	0.01
163B	80.306	34.484	0	0.02	7.040	Discharge	6.5124	0.936	Ratio to Peak	0.01
164B	53.600	30.538	0	0.02	15.988	Discharge	1.6812	0.859	Ratio to Peak	0.01
165B	38.169	29.920	0	0.02	6.336	Discharge	3.8500	0.936	Ratio to Peak	0.01
166B	38.169	33.100	0	0.02	10.701	Discharge	4.8374	0.858	Ratio to Peak	0.01
167B	36.048	32.587	0	0.02	23.870	Discharge	15.187	0.936	Ratio to Peak	0.01
168B	35.376	35.705	0	0.02	12.137	Discharge	16.062	0.859	Ratio to Peak	0.01
169B	80.354	34.322	0	0.02	8.238	Discharge	1.0687	0.936	Ratio to Peak	0.01
170B	50.322	35.361	0	0.02	23.393	Discharge	3.5937	0.936	Ratio to Peak	0.01
171B	17.093	42.075	0	0.02	10.226	Discharge	2.4625	0.936	Ratio to Peak	0.01
172B	20.637	33.543	0	0.02	10.722	Discharge	9.4749	0.859	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
173B	45.979	31.442	0	0.02	15.982	Discharge	1.2875	0.936	Ratio to Peak	0.01
174B	73.686	29.202	0	0.02	6.125	Discharge	2.5125	0.936	Ratio to Peak	0.01
175B	16.991	35.863	0	0.02	10.610	Discharge	1.5000	0.858	Ratio to Peak	0.01
176B	14.275	40.235	0	0.02	23.673	Discharge	3.0562	0.858	Ratio to Peak	0.01

Appendix B. Mandulog 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
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

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
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. Mandulog 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
0.16666667	0	0	0	6.166666667	0	0	0
0.33333333	0	0	0	6.333333333	0	0	0
0.5	0	0	0	6.5	0	0	0
0.66666667	0	0	0	6.666666667	0	0	0
0.83333333	0	0	0	6.833333333	0	0	0
1	0	0	0	7	0.1	0	0
1.16666667	0	0	0	7.166666667	0.1	0	0
1.33333333	0	0	0	7.333333333	0.2	0	0
1.5	0	0	0	7.5	0.4	0	0
1.66666667	0	0	0	7.666666667	0.6	0	0
1.83333333	0	0	0	7.833333333	0.9	0.1	0
2	0	0	0	8	1.2	0.1	0
2.16666667	0	0	0	8.166666667	1.7	0.2	0
2.33333333	0	0	0	8.333333333	2.2	0.4	0
2.5	0	0	0	8.5	2.9	0.5	0
2.66666667	0	0	0	8.666666667	3.8	0.8	0
2.83333333	0	0	0	8.833333333	4.8	1.1	0
3	0	0	0	9	5.9	1.4	0
3.16666667	0	0	0	9.166666667	7.5	1.9	0
3.33333333	0	0	0	9.333333333	9.5	2.7	0
3.5	0	0	0	9.5	12	3.7	0
3.66666667	0	0	0	9.666666667	15	4.9	0
3.83333333	0	0	0	9.833333333	18.8	6.6	0
4	0	0	0	10	23.5	8.7	0
4.16666667	0	0	0	10.16666667	29.2	11.4	0
4.33333333	0	0	0	10.33333333	36	14.6	0
4.5	0	0	0	10.5	43.9	18.5	0
4.66666667	0	0	0	10.66666667	53.4	23.3	0
4.83333333	0	0	0	10.83333333	64.4	29	0
5	0	0	0	11	77.2	35.7	0
5.16666667	0	0	0	11.16666667	91.9	43.7	0
5.33333333	0	0	0	11.33333333	108.9	53	0.1
5.5	0	0	0	11.5	128.5	64	0.2
5.66666667	0	0	0	11.66666667	151.4	77.1	0.4
5.83333333	0	0	0	11.83333333	178.6	93.1	1

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
12	214.1	115.1	2.9	18.33333333	5260.6	3697.6	742.3
12.16666667	254.8	140.8	5.8	18.5	5358	3771	760
12.33333333	300.7	169.9	9.2	18.66666667	5442.1	3834.6	775.4
12.5	352.8	203.4	13.3	18.83333333	5516	3890.8	788.6
12.66666667	413.5	243	18.7	19	5581.3	3941	800.7
12.83333333	483	289.1	26	19.16666667	5637.9	3985	811.8
13	559	339.7	34.4	19.33333333	5685.4	4022.6	821.7
13.16666667	641.1	394.8	43.5	19.5	5723.3	4053.2	830.2
13.33333333	729.8	454.4	53.4	19.66666667	5753.7	4078.5	837.5
13.5	826.6	519.9	64.7	19.83333333	5776	4098.1	844
13.66666667	929.4	589.9	77.1	20	5789.1	4111.2	849.5
13.83333333	1037.9	664	90.1	20.16666667	5787.7	4113.6	852.5
14	1152.8	742.6	103.9	20.33333333	5777.1	4109.3	853.5
14.16666667	1276.2	827.6	119.1	20.5	5758.9	4099.6	853.3
14.33333333	1407.3	918.3	135.7	20.66666667	5733.1	4084.5	852.2
14.5	1544.3	1013.5	153.4	20.83333333	5700.2	4064.3	850
14.66666667	1687.5	1113.3	172	21	5660.5	4039	846.8
14.83333333	1838.3	1218.7	191.8	21.16666667	5615	4009.7	842.5
15	1999.5	1332.1	213.8	21.33333333	5564.2	3976.5	837.7
15.16666667	2166.2	1449.9	237.4	21.5	5507.9	3939.3	832.1
15.33333333	2337.7	1571.4	262.1	21.66666667	5444.9	3897.2	825.6
15.5	2514.3	1697	287.8	21.83333333	5377.5	3851.8	818.3
15.66666667	2697.7	1827.8	315.2	22	5305.7	3803.2	810.4
15.83333333	2885.4	1962.3	344.2	22.16666667	5229.2	3751.1	801.8
16	3075.1	2098.7	374.2	22.33333333	5146.5	3694.5	792.1
16.16666667	3265.4	2236	404.9	22.5	5058.2	3633.6	781.3
16.33333333	3453.8	2372.2	435.7	22.66666667	4965.9	3569.7	769.5
16.5	3637.8	2505.4	465.9	22.83333333	4869.4	3502.7	757.1
16.66666667	3819	2637	495.9	23	4768.6	3432.5	743.8
16.83333333	3996.9	2766.5	525.7	23.16666667	4661.8	3357.7	729.1
17	4170	2892.9	555.2	23.33333333	4552.3	3280.7	713.4
17.16666667	4333.8	3012.7	583.1	23.5	4441.3	3202.4	697.2
17.33333333	4490	3127.1	609.3	23.66666667	4329.3	3123.4	680.5
17.5	4640.1	3237.4	634.7	23.83333333	4218.9	3045.3	664
17.66666667	4783.2	3342.9	659.4	24	4109.9	2968.3	647.7
17.83333333	4917.2	3442.1	682.8	24.16666667	4001.6	2891.6	631.5
18	5039.7	3533	704	24.33333333	3894.8	2815.8	615.3
18.16666667	5154.2	3618.1	723.6	24.5	3790.4	2741.7	599.5

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
24.66666667	3690.7	2671.2	584.8	31	1242.5	919.3	215
24.83333333	3593.5	2602.4	570.8	31.16666667	1202.8	890.1	208.3
25	3498.1	2534.8	557.1	31.33333333	1164.6	862.2	201.9
25.16666667	3404.6	2468.5	543.6	31.5	1127.4	834.8	195.7
25.33333333	3313.3	2403.8	530.6	31.66666667	1090.9	808.1	189.6
25.5	3224.1	2340.6	517.9	31.83333333	1055.3	781.9	183.6
25.66666667	3136.6	2278.6	505.6	32	1020.4	756.1	177.7
25.83333333	3050.8	2217.7	493.3	32.16666667	986.2	730.9	171.8
26	2967	2158.3	481.2	32.33333333	952.8	706.3	166.1
26.16666667	2886	2100.8	469.6	32.5	920.3	682.3	160.5
26.33333333	2807.1	2044.8	458.3	32.66666667	888.8	659	155.1
26.5	2730.4	1990.3	447.2	32.83333333	858.7	636.8	149.9
26.66666667	2656.2	1937.5	436.3	33	829.5	615.2	144.8
26.83333333	2585.4	1887.2	425.9	33.16666667	800.9	594	139.9
27	2517.3	1838.8	416	33.33333333	773.1	573.4	135.1
27.16666667	2450.9	1791.6	406.4	33.5	745.9	553.3	130.4
27.33333333	2386.2	1745.5	396.9	33.66666667	719.3	533.6	125.7
27.5	2322.9	1700.4	387.6	33.83333333	693.4	514.4	121.2
27.66666667	2260.9	1656.1	378.3	34	668.3	495.8	116.8
27.83333333	2199.6	1612.3	369	34.16666667	644	477.8	112.5
28	2139.2	1569.1	359.8	34.33333333	620.9	460.6	108.4
28.16666667	2079.7	1526.4	350.6	34.5	598.6	444.1	104.5
28.33333333	2021.8	1484.9	341.6	34.66666667	577	428	100.8
28.5	1965.1	1444.1	332.8	34.83333333	556	412.5	97.1
28.66666667	1909.3	1403.9	324.1	35	535.7	397.4	93.6
28.83333333	1854.4	1364.4	315.4	35.16666667	516	382.8	90.1
29	1800.3	1325.3	306.7	35.33333333	497.1	368.7	86.8
29.16666667	1747	1286.8	298.1	35.5	478.8	355.1	83.6
29.33333333	1694.6	1248.8	289.6	35.66666667	461.3	342.1	80.5
29.5	1643.3	1211.6	281.1	35.83333333	444.8	329.9	77.6
29.66666667	1593.4	1175.3	272.8	36	428.9	318.1	74.9
29.83333333	1545.8	1140.7	265	36.16666667	413.6	306.7	72.2
30	1499.7	1107.2	257.4	36.33333333	398.8	295.7	69.6
30.16666667	1454.6	1074.3	250	36.5	384.5	285.2	67.1
30.33333333	1410.6	1042.2	242.8	36.66666667	370.8	274.9	64.7
30.5	1367.4	1010.6	235.7	36.83333333	357.4	265.1	62.4
30.66666667	1324.9	979.6	228.7	37	344.6	255.5	60.2
30.83333333	1283.3	949.2	221.8	37.16666667	332.3	246.4	58

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
37.33333333	320.6	237.7	55.9	42.83333333	98.6	73	17.2
37.5	309.3	229.4	54	43	95.2	70.6	16.6
37.66666667	298.4	221.2	52.1	43.16666667	92	68.2	16
37.83333333	287.8	213.4	50.2	43.33333333	88.8	65.9	15.5
38	277.5	205.8	48.5	43.5	85.8	63.6	15
38.16666667	267.6	198.5	46.7	43.66666667	82.8	61.4	14.5
38.33333333	258	191.4	45.1	43.83333333	79.8	59.2	14
38.5	248.8	184.5	43.4	44	77	57.1	13.5
38.66666667	239.9	177.9	41.9	44.16666667	74.2	55.1	13
38.83333333	231.5	171.6	40.4	44.33333333	71.4	53	12.5
39	223.3	165.6	39	44.5	68.8	51.1	12.1
39.16666667	215.4	159.7	37.6	44.66666667	66.2	49.2	11.6
39.33333333	207.7	154	36.2	44.83333333	63.7	47.3	11.2
39.5	200.2	148.4	34.9	45	61.2	45.5	10.8
39.66666667	193	143.1	33.7	45.16666667	58.8	43.7	10.4
39.83333333	186	137.9	32.4	45.33333333	56.4	42	10
40	179.2	132.9	31.2	45.5	54.1	40.3	9.6
40.16666667	172.8	128.1	30.1	45.66666667	51.9	38.7	9.2
40.33333333	166.8	123.6	29	45.83333333	49.7	37.1	8.8
40.5	160.9	119.3	28	46	47.6	35.5	8.5
40.66666667	155.3	115.1	27	46.16666667	45.5	33.9	8.1
40.83333333	149.8	111	26.1	46.33333333	43.4	32.4	7.8
41	144.5	107.1	25.1	46.5	41.4	31	7.5
41.16666667	139.4	103.3	24.2	46.66666667	39.4	29.5	7.1
41.33333333	134.5	99.6	23.4	46.83333333	37.5	28.1	6.8
41.5	129.8	96.1	22.5	47	35.6	26.7	6.5
41.66666667	125.3	92.8	21.8	47.16666667	33.8	25.4	6.2
41.83333333	121.1	89.7	21	47.33333333	32	24	5.9
42	117	86.7	20.3	47.5	30.2	22.7	5.6
42.16666667	113.1	83.8	19.6	47.66666667	28.5	21.4	5.3
42.33333333	109.3	81	19	47.83333333	26.8	20.2	5
42.5	105.6	78.2	18.4	48	25.1	19	4.7
42.66666667	102	75.6	17.7				

DREAM

Disaster RIsk and Exposure Assessment for Mitigation