REGION 12

Buayan-Malungon River Basin:

DREAM Flood Forecasting and Flood Hazard Mapping

TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY

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List of Abbreviations

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

Introduction

Introduction

1.1 About the DREAM Program

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

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

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

1.2 Objectives and Target Outputs

The program aims to achieve the following objectives:

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

e) To generate the following outputs
1) flood hazard map
2) digital surface model
3) digital terrain model and
4) orthophotograph.

1.3 General Methodological Framework

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

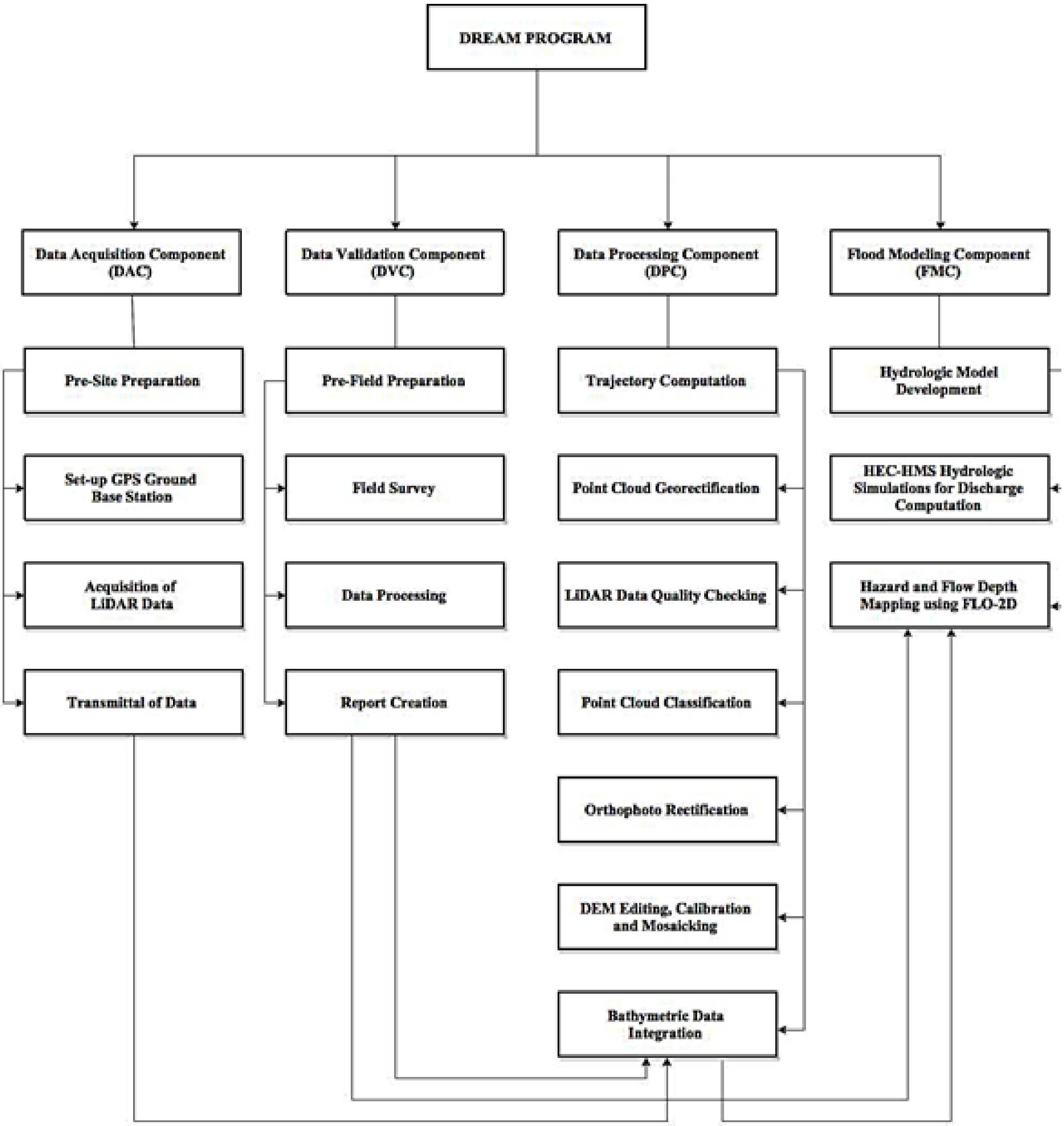


Figure 1. The general methodological framework of the program

1.4 Scope of Work of the Flood Modeling Component

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

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

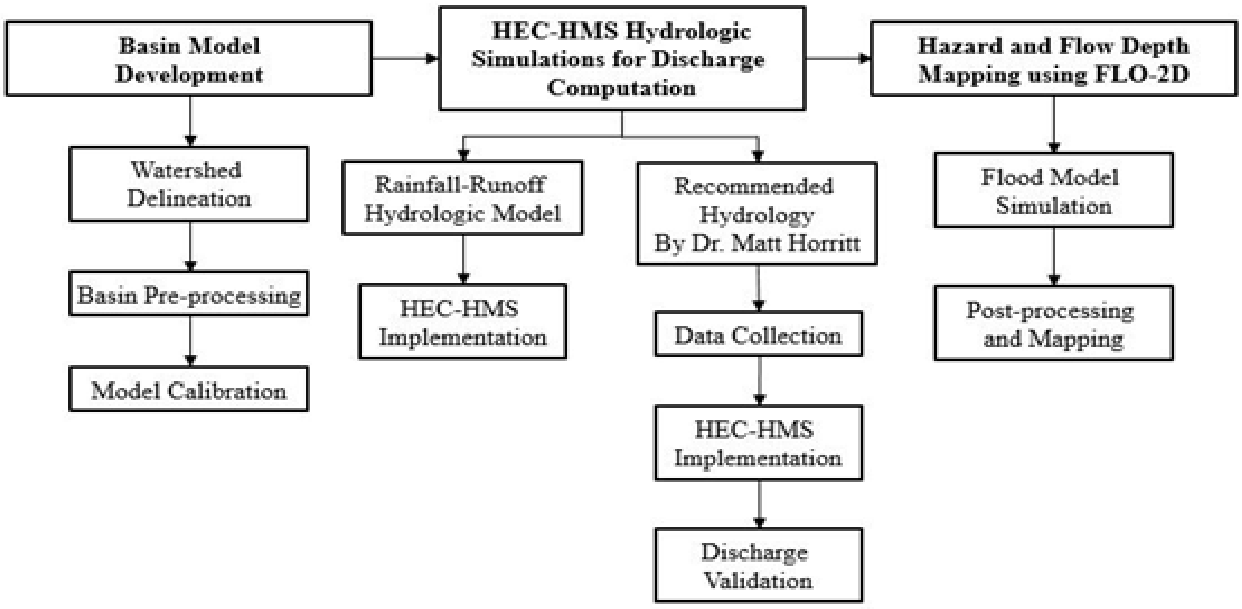


Figure 2. The operational framework and specific work flow of the Flood Modeling Component

The Buayan-Malungon River Basin

The Buayan-Malungon River Basin

The Buayan-Malungon River Basin is located in Central and Southern Mindanao. It traverses through Sarangani, South Cotabato, Davao del Sur, and General Santos City. It is the eighteenth largest river basin in the Philippines. It covers an area of 1,435 square kilometers and travels for 33 kilometers from its source to its mouth. The location of the Buayan-Malungon River Basin is shown in Figure 3.

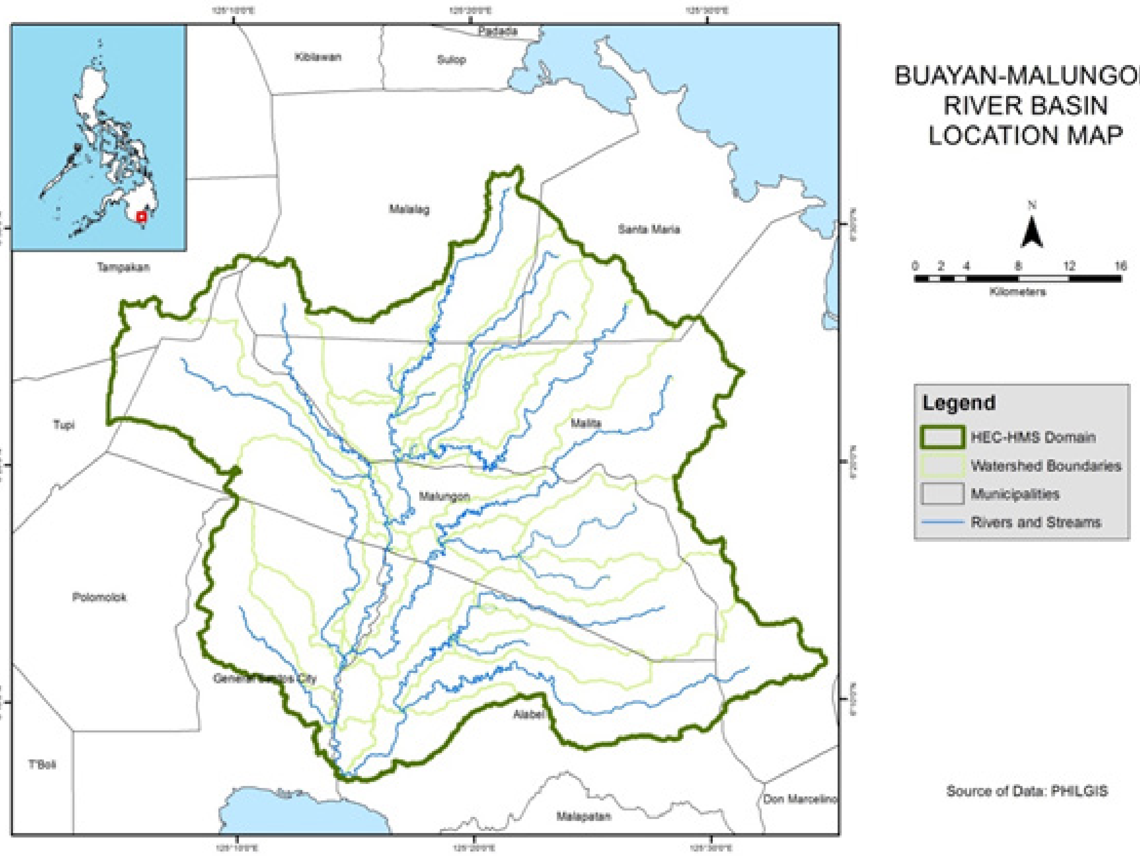


Figure 3. Buayan-Malungon River Basin Location Map

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

The Buayan-Malungon River Basin

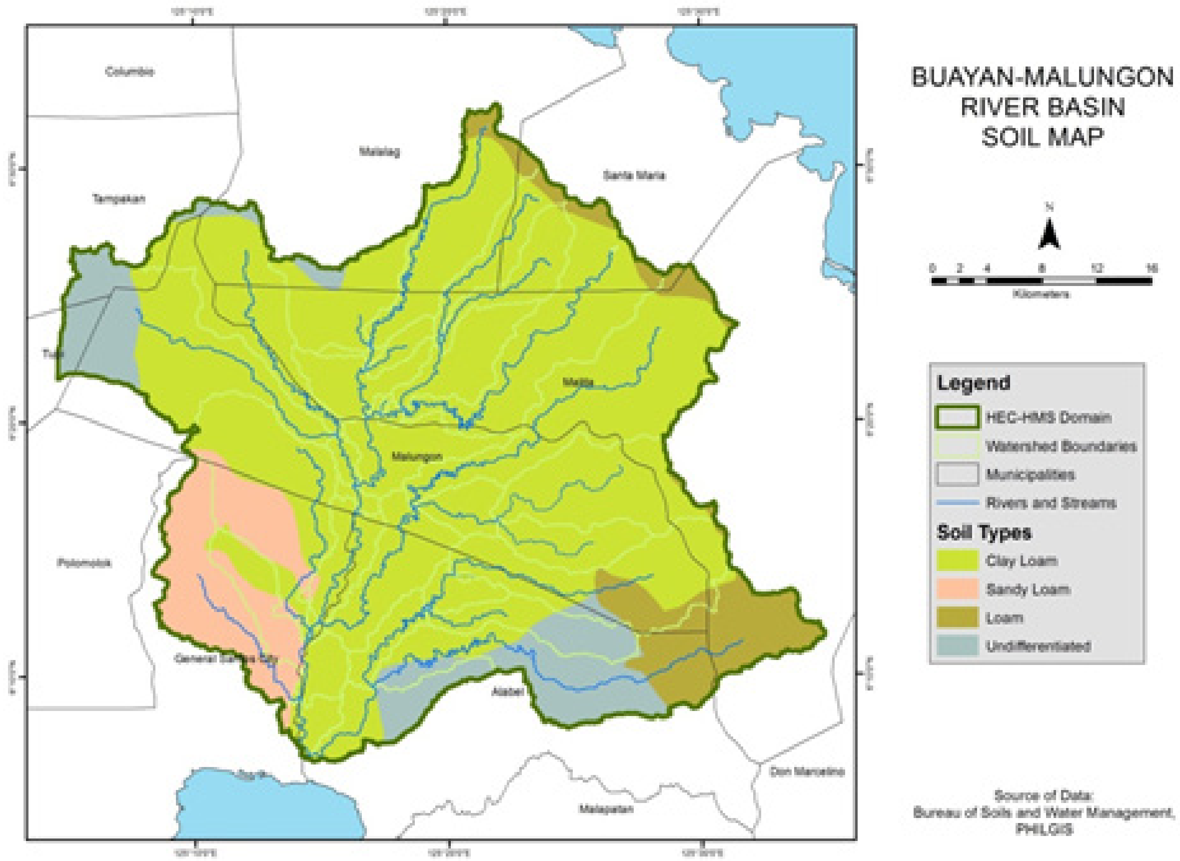


Figure 4. Buayan-Malungon River Basin Soil Map

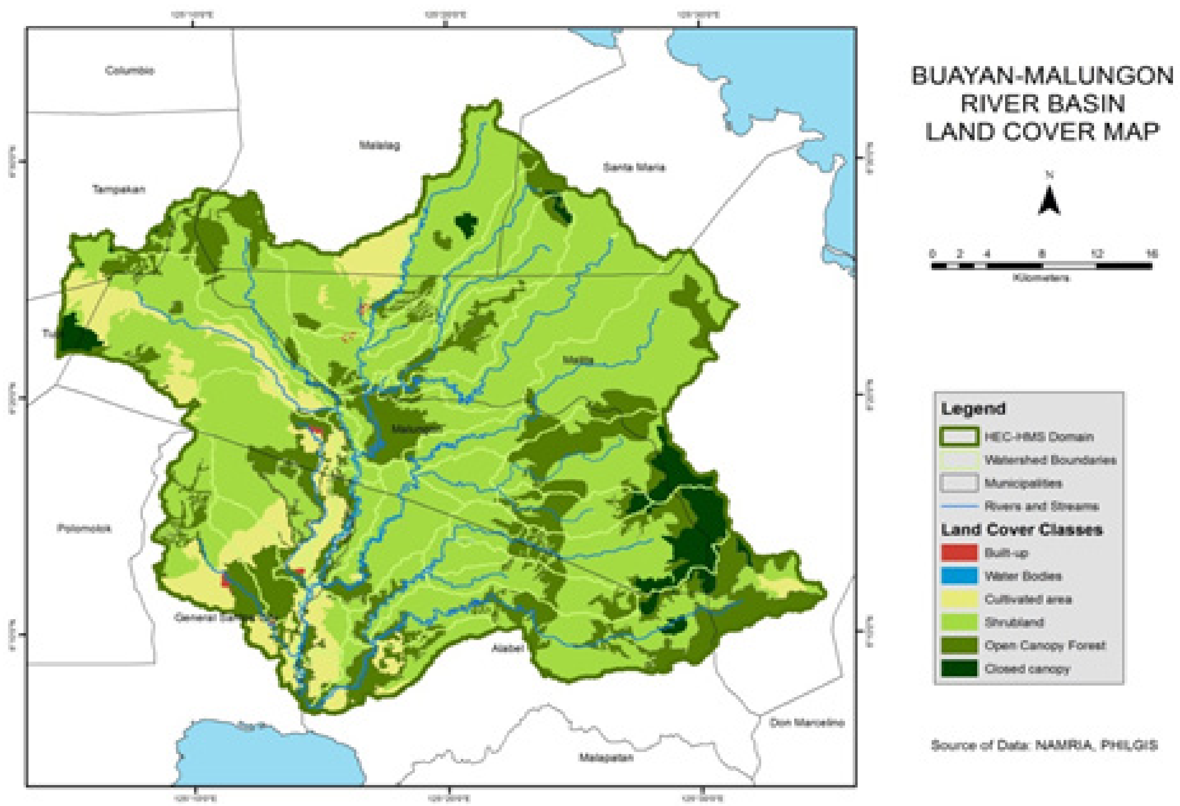


Figure 5. Buayan-Malungon River Bain Land Cover Map

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.

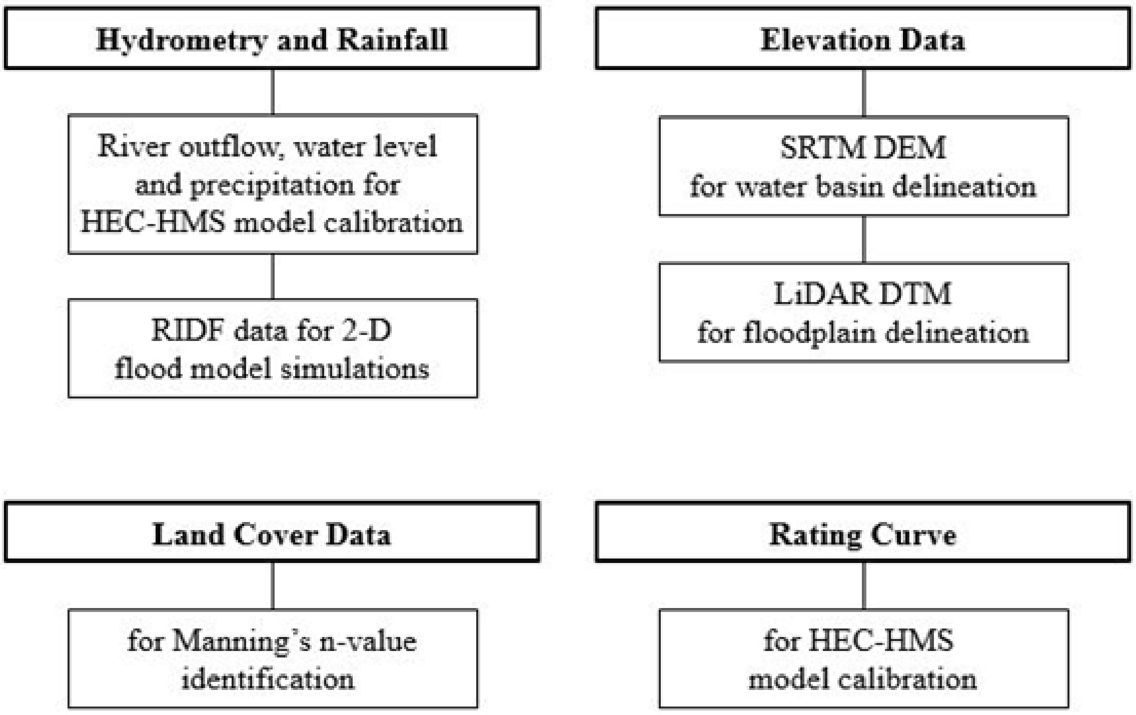


Figure 6. Summary of data needed for the purpose of flood modeling

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.

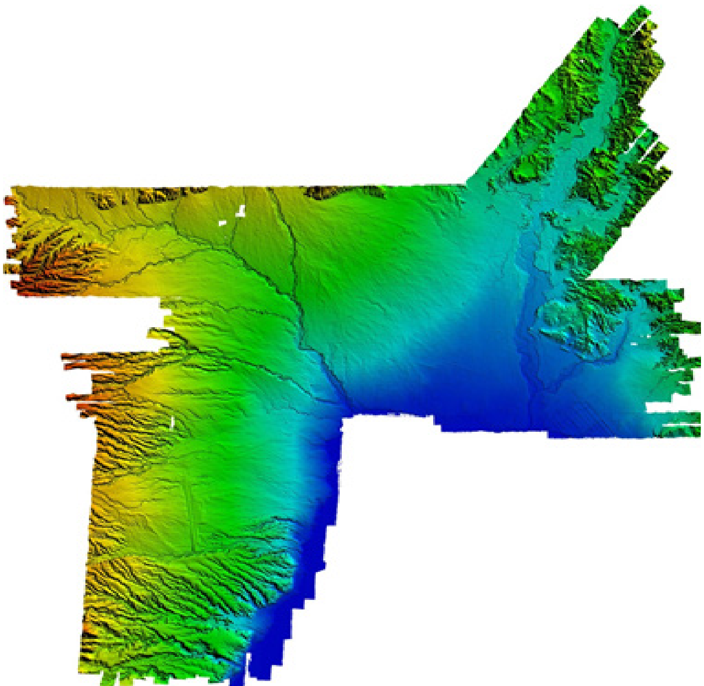


Figure 7. Digital Elevation Model (DEM) of the Buayan River Basin using Light Detection and Ranging (LiDAR) technology

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

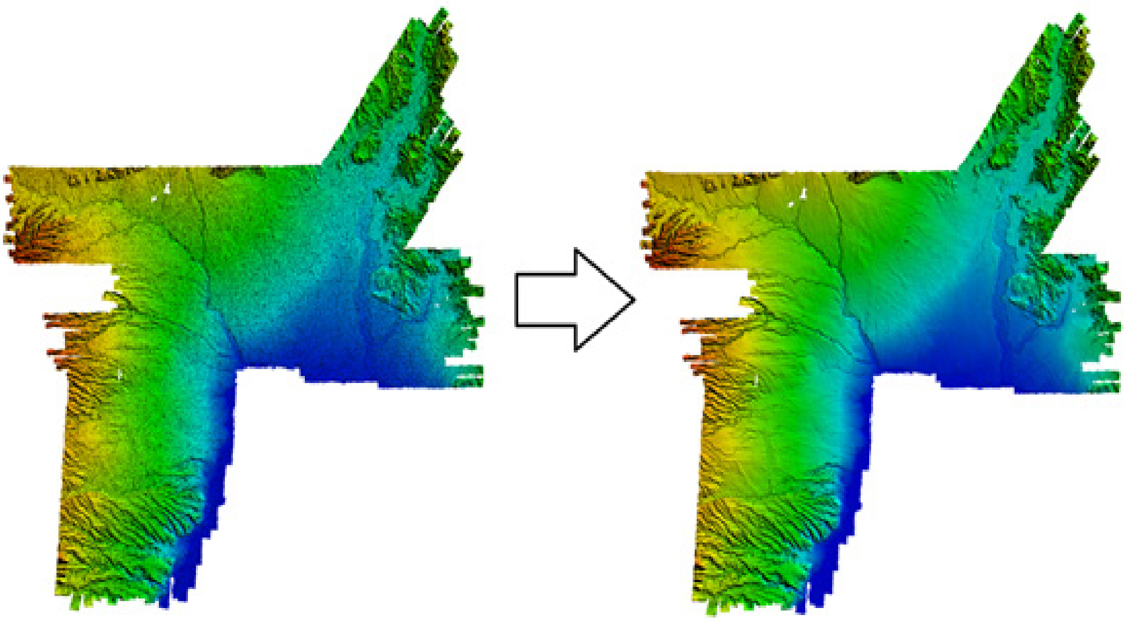


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted.

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 Buayan 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 Buayan floodplain.

3.1.3 Hydrometry and Rainfall Data

3.1.3.1 Hydrometry for Upper Buayan Bridge

The river outflow from Upper Buayan Bridge (6° 19' 19.00"N, 125° 15' 44.13"E) water level sensor was used to calibrate the HEC-HMS model. This was recorded during 27 November, 2014. Peak discharge is 172.6 cms.

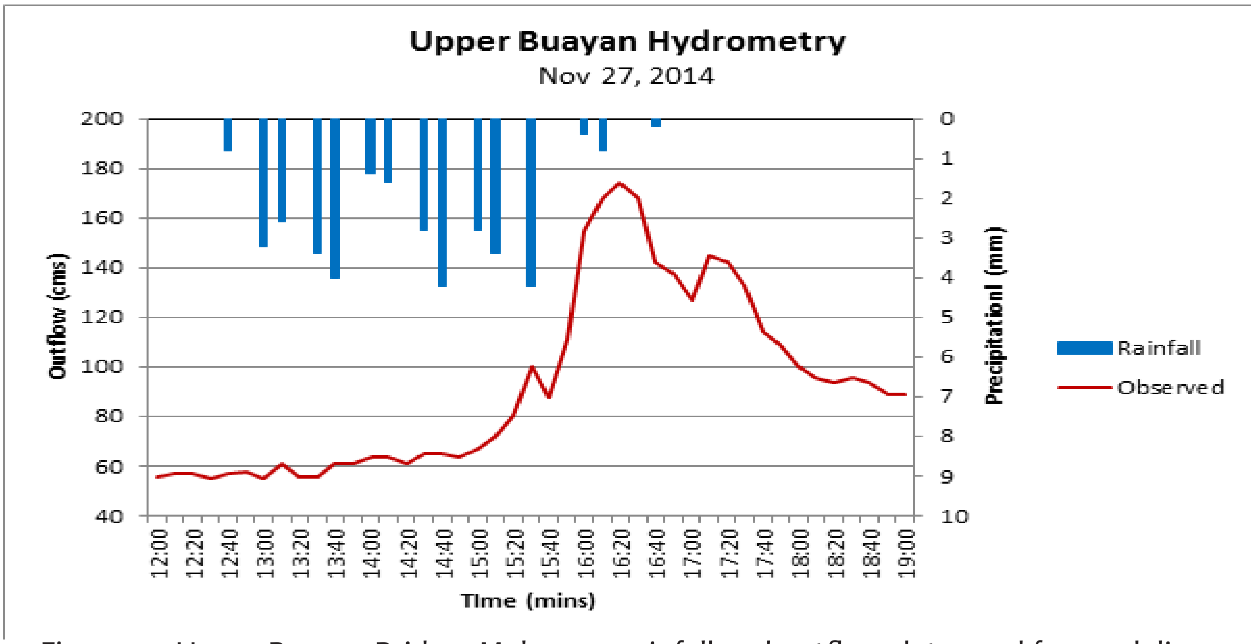


Figure 10. Upper Buayan Bridge, Malungon rainfall and outflow data used for modeling.

3.1.3.2 Rainfall Intensity Duration Frequency

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the General Santos Rain Gauge. This station was chosen based on its proximity to the Buayan-Malungon watershed. The extreme values for this watershed were computed based on a 26-year record.

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

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

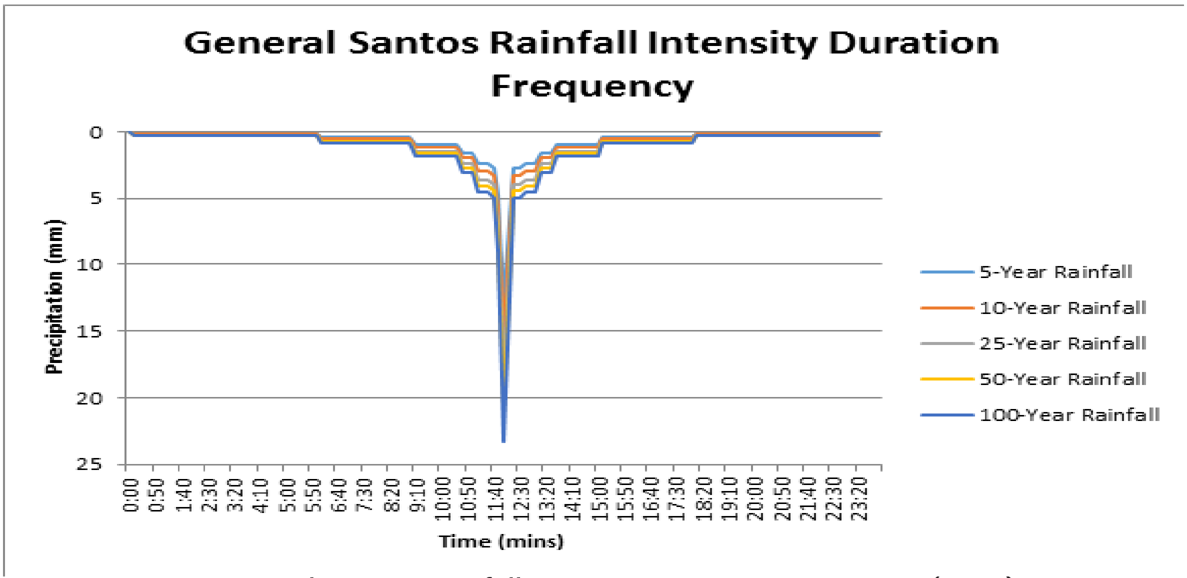


Figure 12. General Santos Rainfall-Intensity Duration Frequency (RIDF) curves.

The Buayan 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 Upper Buayan Bridge, the rating curve is expressed as Q = Q = 2E-101e1.6728x as shown in Figure 13.

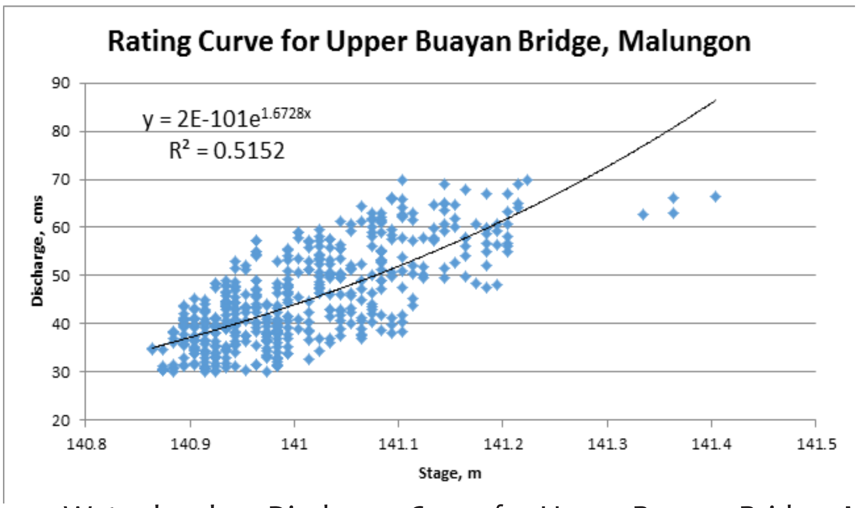


Figure 13. Water level vs. Discharge Curve for Upper Buayan Bridge, Malungon

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Buayan 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.

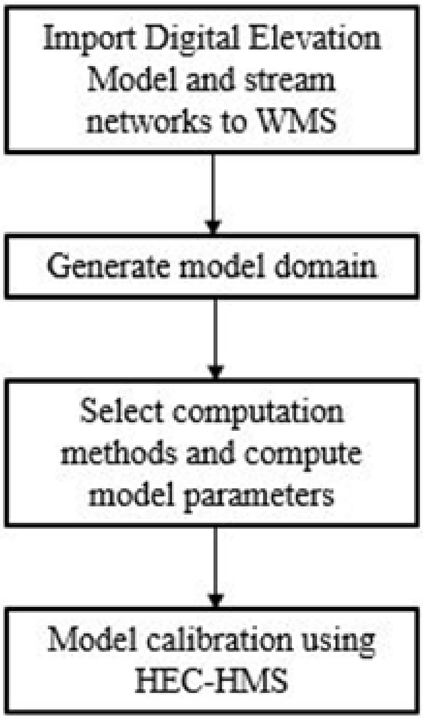


Figure 14. The Rainfall-Runoff Basin Model Development Scheme

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.

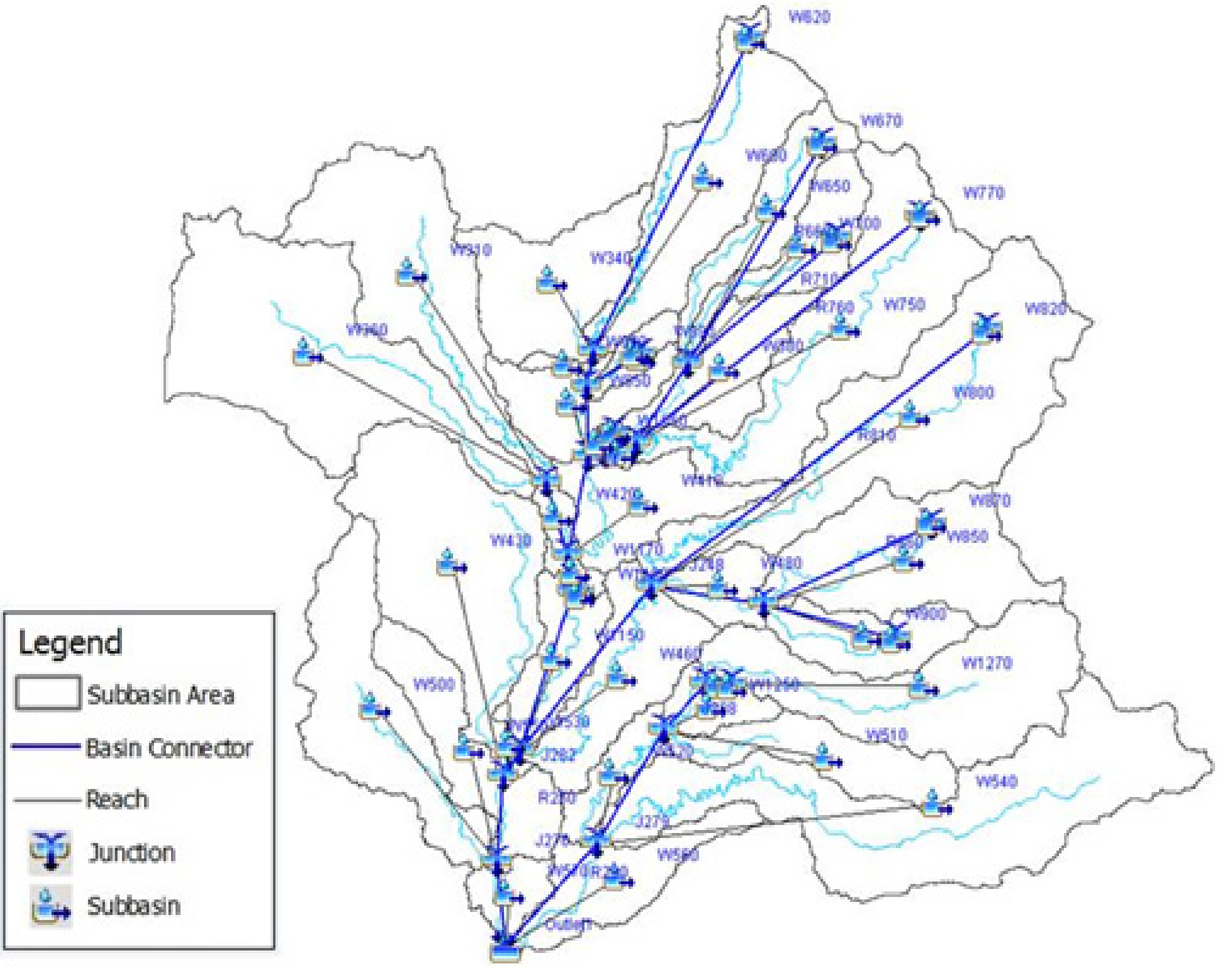


Figure 15. Buayan-Malungon HEC-HMS Model domain generated by WMS

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 automatic rain gauges (ARGs) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). There is only one (1) ARG located in the watershed. The location of the ARG is seen in Figure 16.

Total rain from Malungon Bridge rain gauge is 35.8 mm. It peaked to 4.2 mm on 27, November 2014, 02:45pm. The lag time between the peak rainfall and discharge is one hour and thirty five minutes.

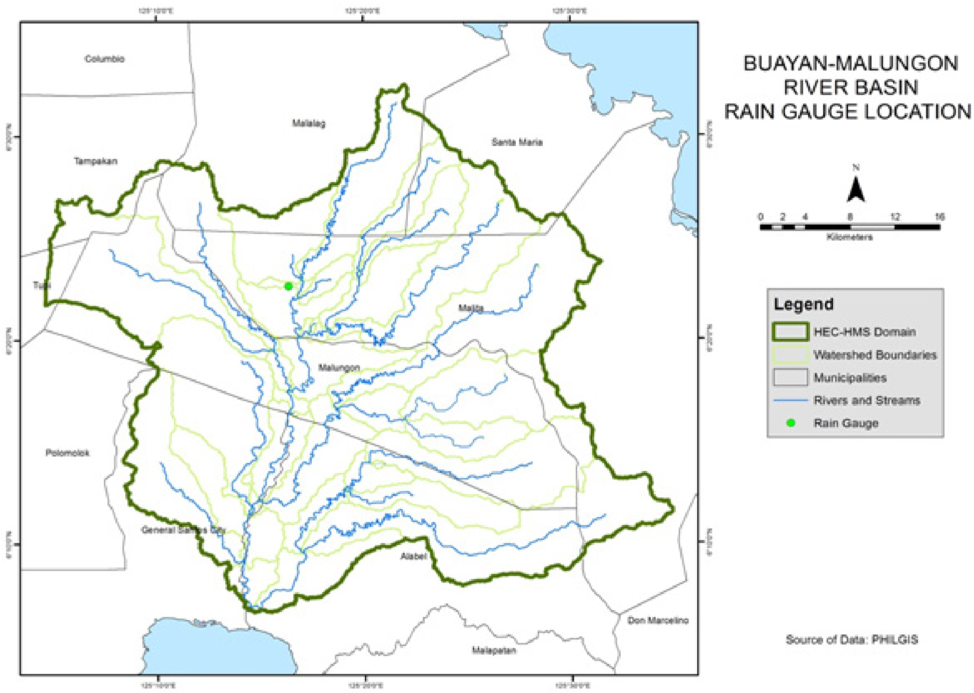


Figure 16. Location of rain gauge used for the calibration of Buayan-Malungon HEC-HMS Model.

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

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

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

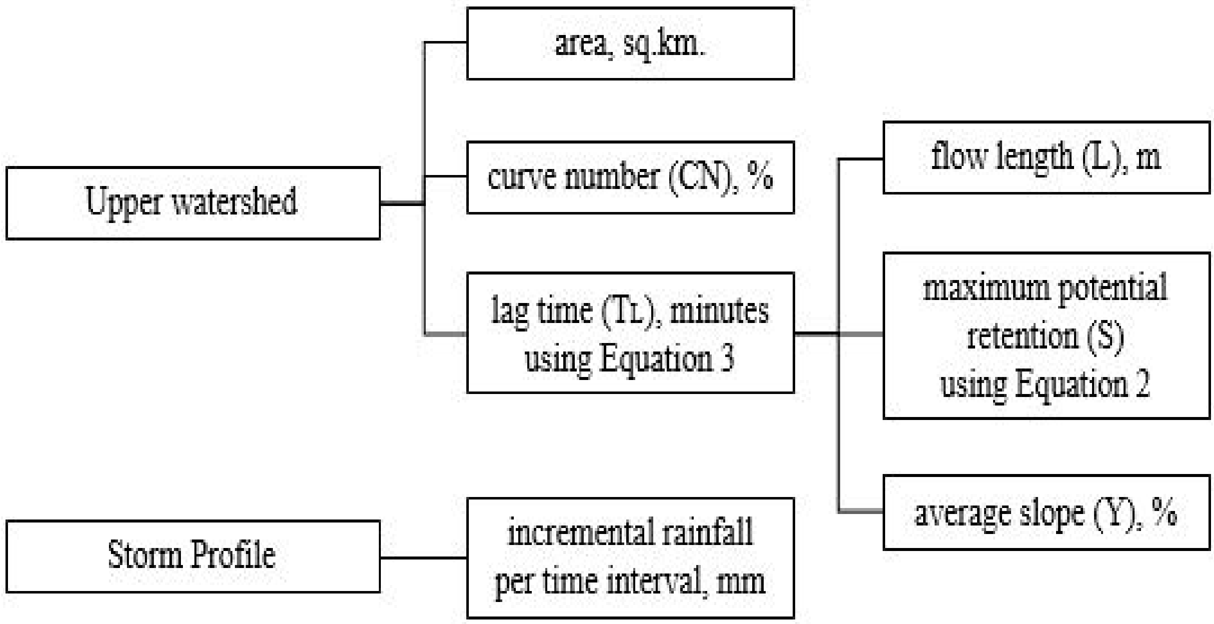


Figure 17. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method.

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

3.3.2.1 Determination of Catchment Properties

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

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

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

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

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

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

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

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

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

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

Equation 3. Lag Time Equation Calibrated for Philippine Setting

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

3.3.2.2 HEC-HMS Implementation

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

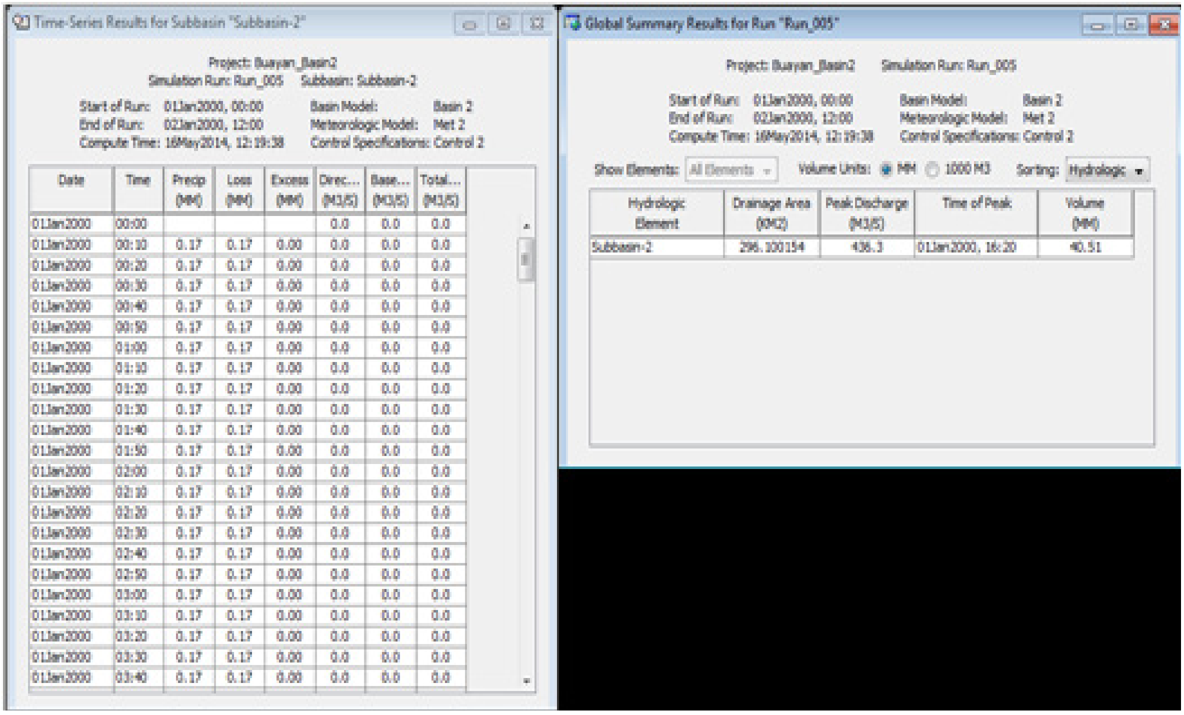


Figure 19. HEC-HMS simulation discharge results using Dr. Horritt's Method

3.3.2.3 Discharge validation against other estimates

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

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

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

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

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

Equation 5. Discharge validation equation using bankful method

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

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

Equation 6. Bankful discharge equation using measurable channel parameters

3.4 Hazard and Flow Depth Mapping using FLO-2D

3.4.1 Floodplain Delineation

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

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

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

3.4.2 Flood Model Generation

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

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

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

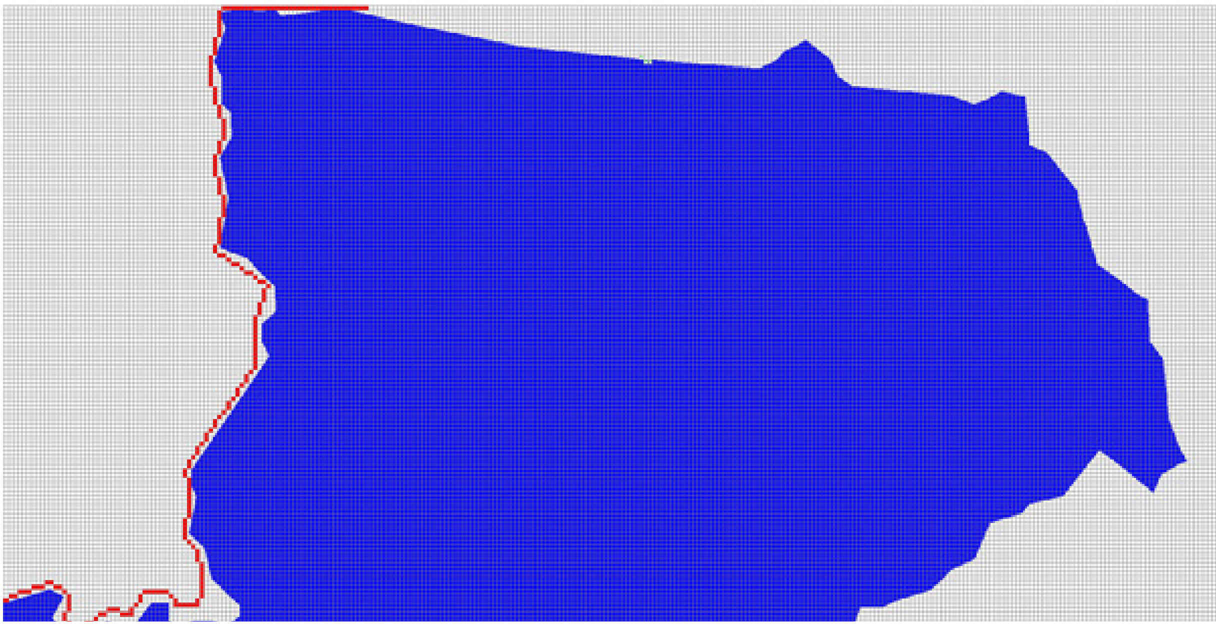


Figure 20. Screenshot showing how boundary grid elements are defined by line

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

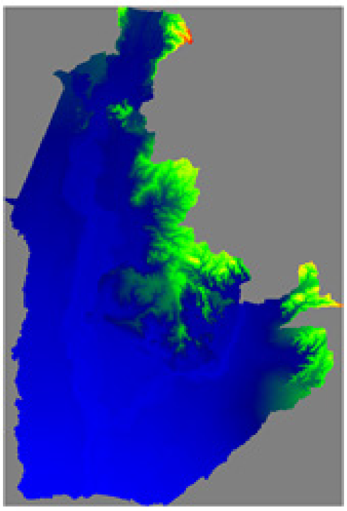


Figure 21. Screenshots of PTS files when loaded into the FLO-2D program

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

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

Figure 22. Areal image of Buayan floodplain

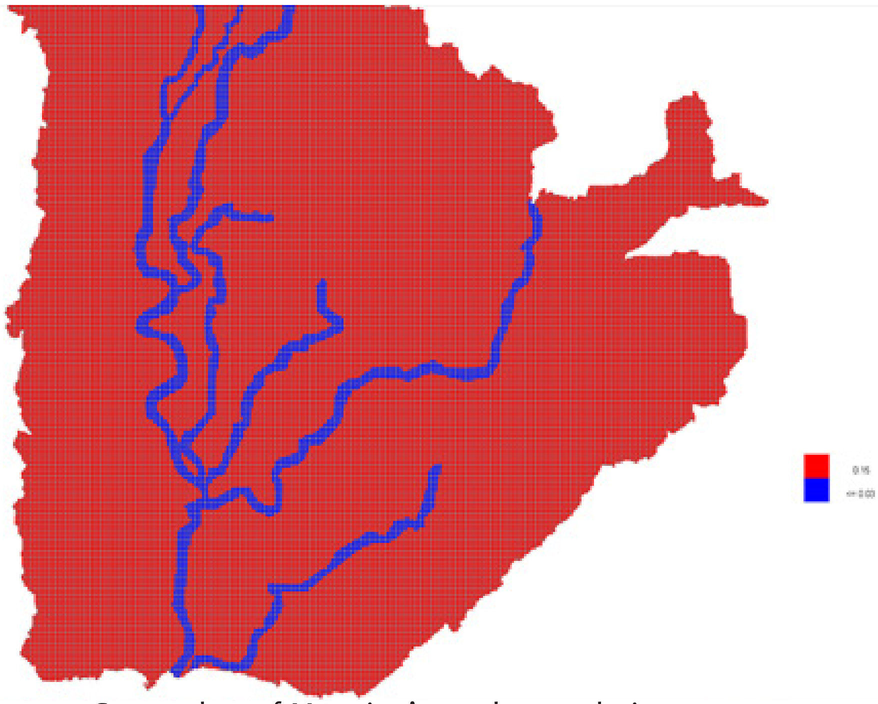


Figure 23. Screenshot of Manning's n-value rendering

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.

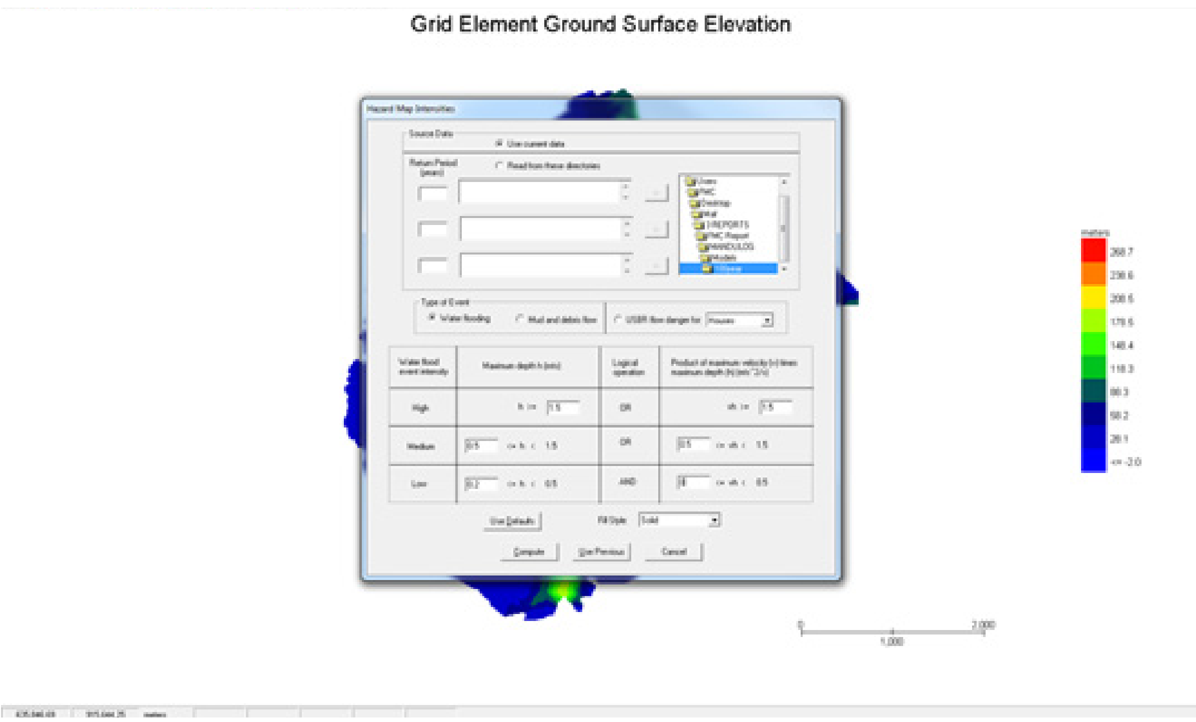


Figure 24. Flo-2D Mapper Pro General Procedure

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.

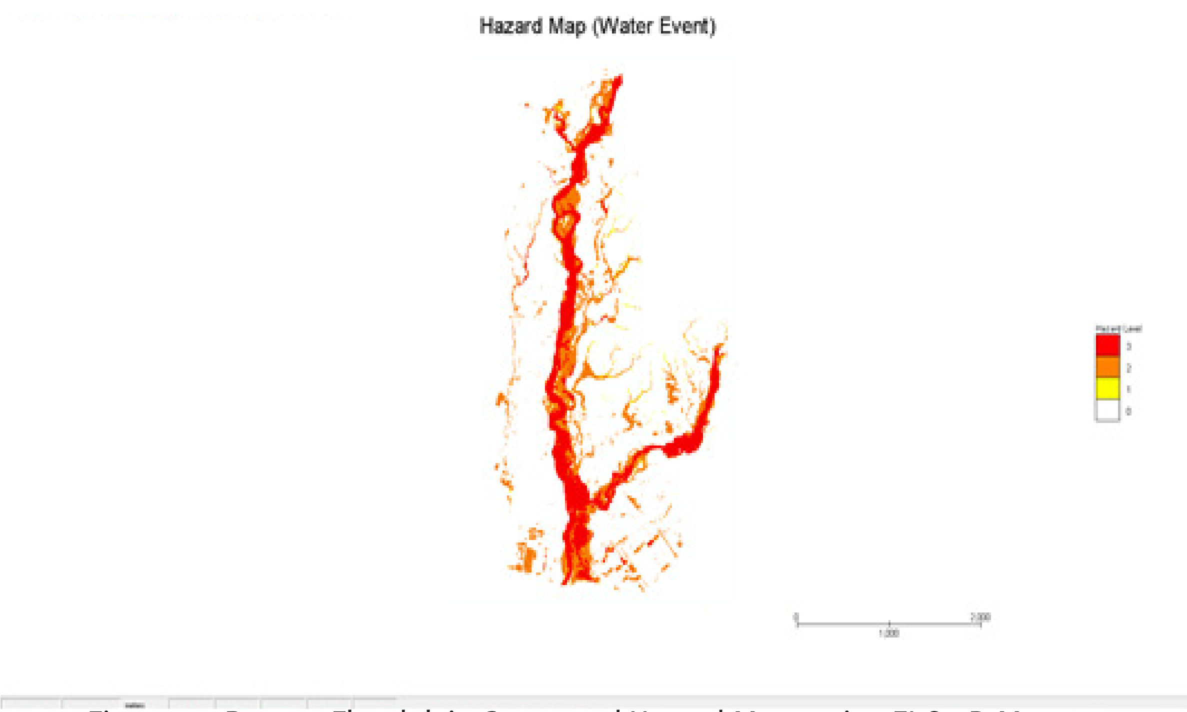


Figure 25. Buayan Floodplain Generated Hazard Maps using FLO-2D Mapper

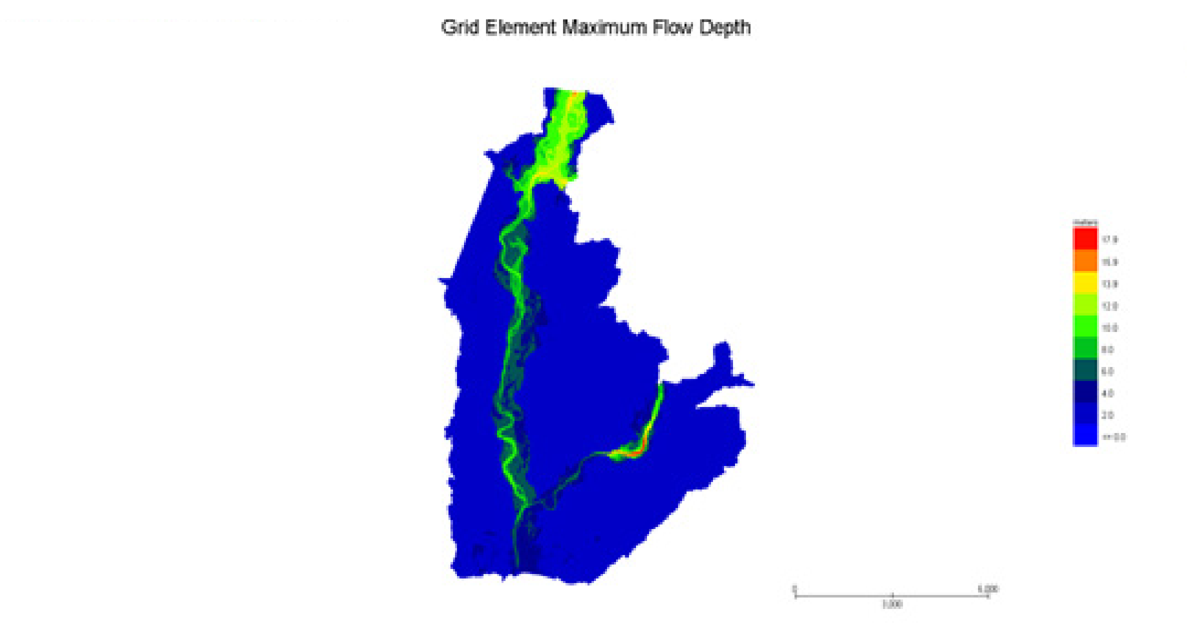
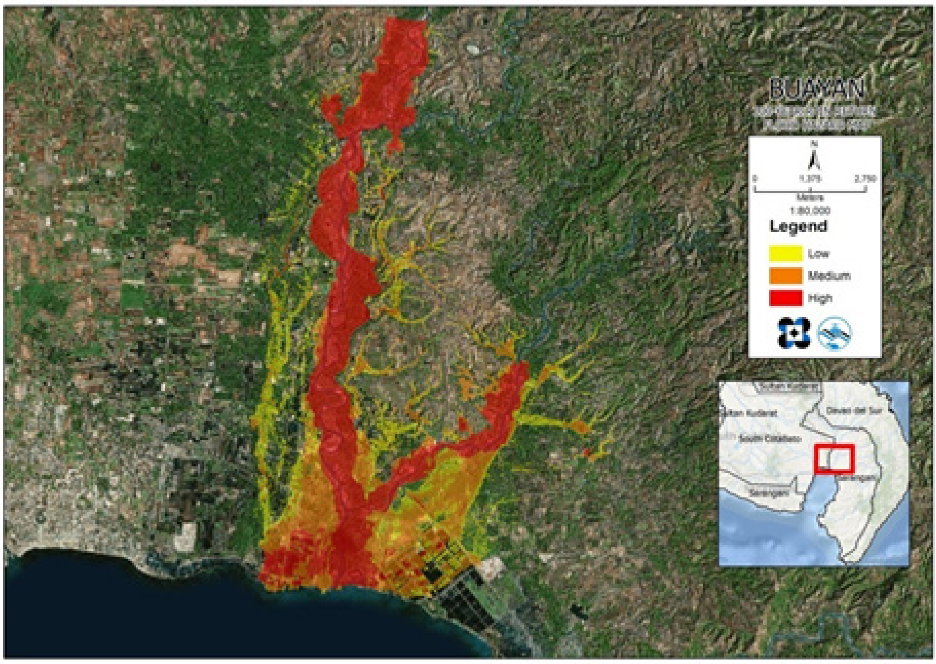


Figure 26. Buayan floodplain generated flow depth map using FLO-2D Mapper

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

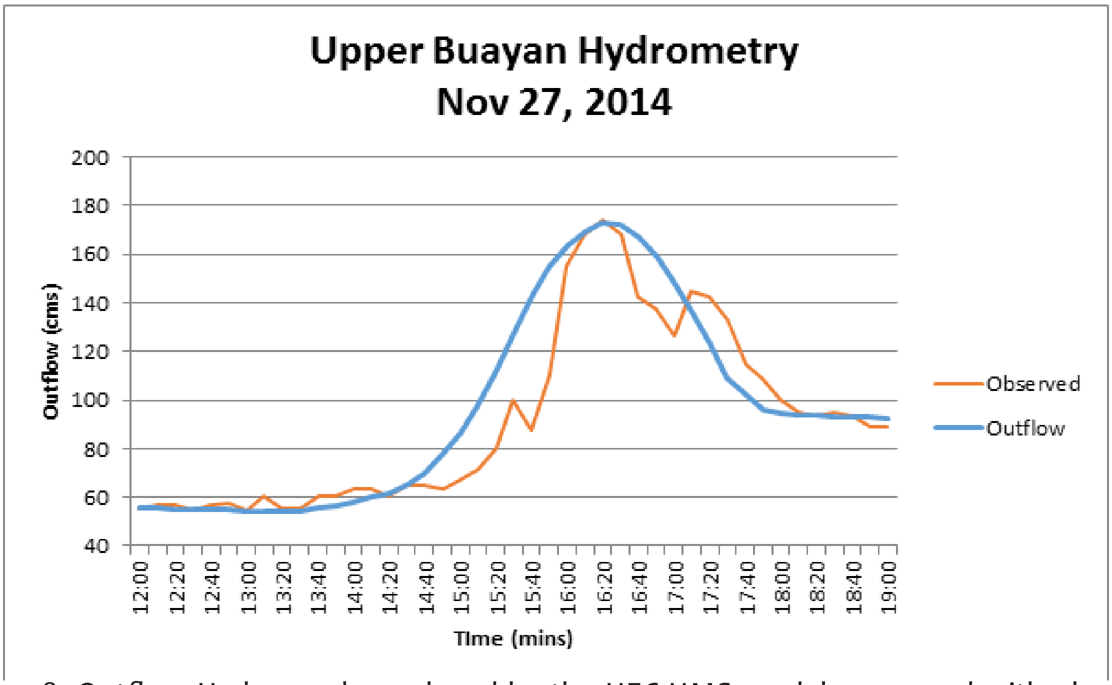


Figure 28. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow.

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

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 16.1 m3/s.

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 0.80.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is -4.66.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0. The model has an RSR value of 0.44.

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

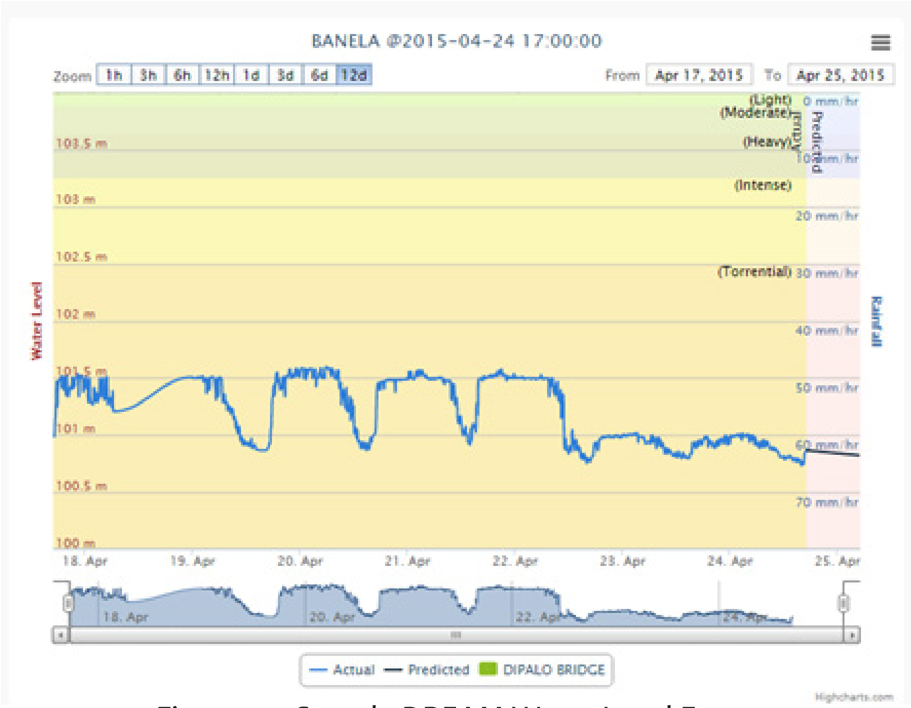


Figure 29. Sample DREAM Water Level Forecast

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

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

4.2.1 Hydrograph using the Rainfall-Runoff Model

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

In the 5-year return period graph, the peak outflow is 669.2 cms. This occurs 1 hour and 30 minutes after the peak precipitation of 12.7 mm, as shown on Figure 30.

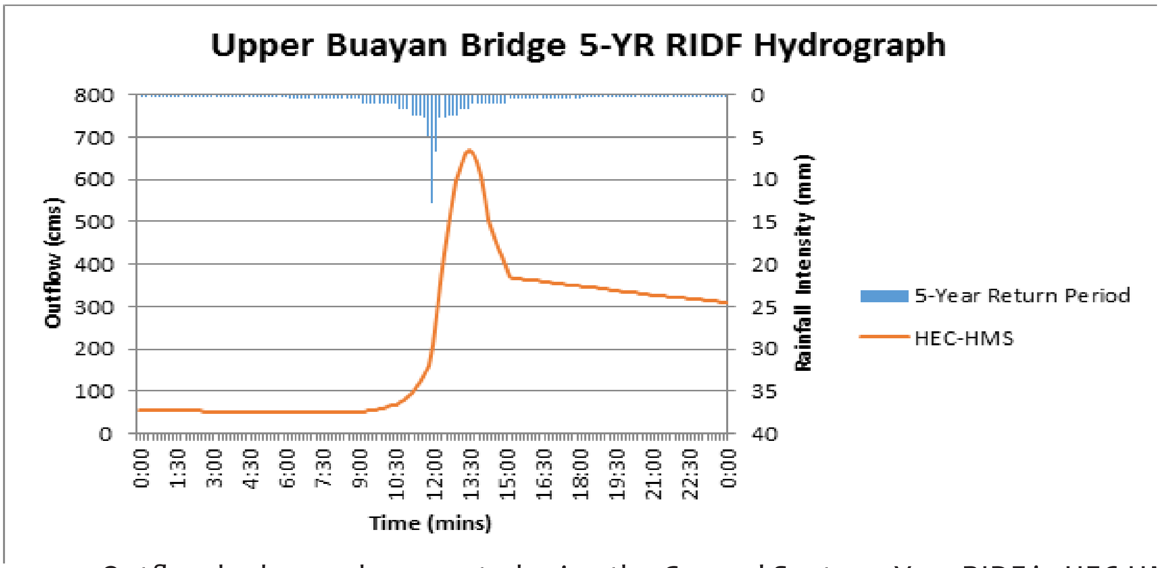


Figure 30. Outflow hydrograph generated using the General Santos 5-Year RIDF in HEC-HMS.

In the 10-year return period graph, the peak outflow is 911.9 cms. This occurs 1 hour and 30 minutes after the peak precipitation of 15.3 mm, as shown on Figure 31.

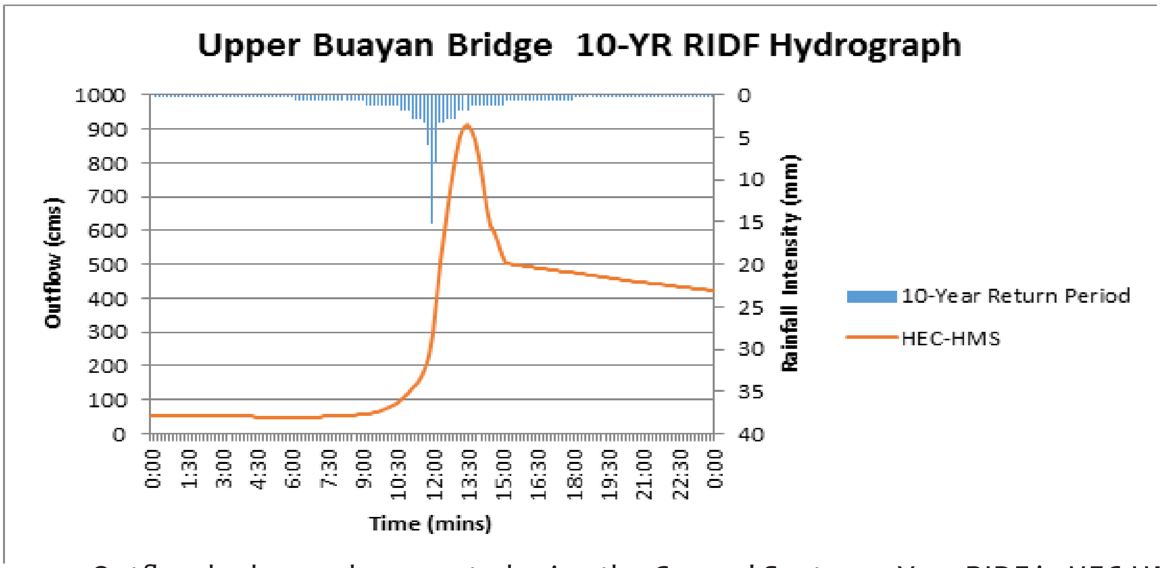


Figure 31. Outflow hydrograph generated using the General Santos 10-Year RIDF in HEC-HMS.

Results and Discussion

In the 25-year return period graph, the peak outflow is 1238.8 cms. This occurs 1 hour and 30 minutes after the peak precipitation of 18.5 mm, as shown on Figure 32.

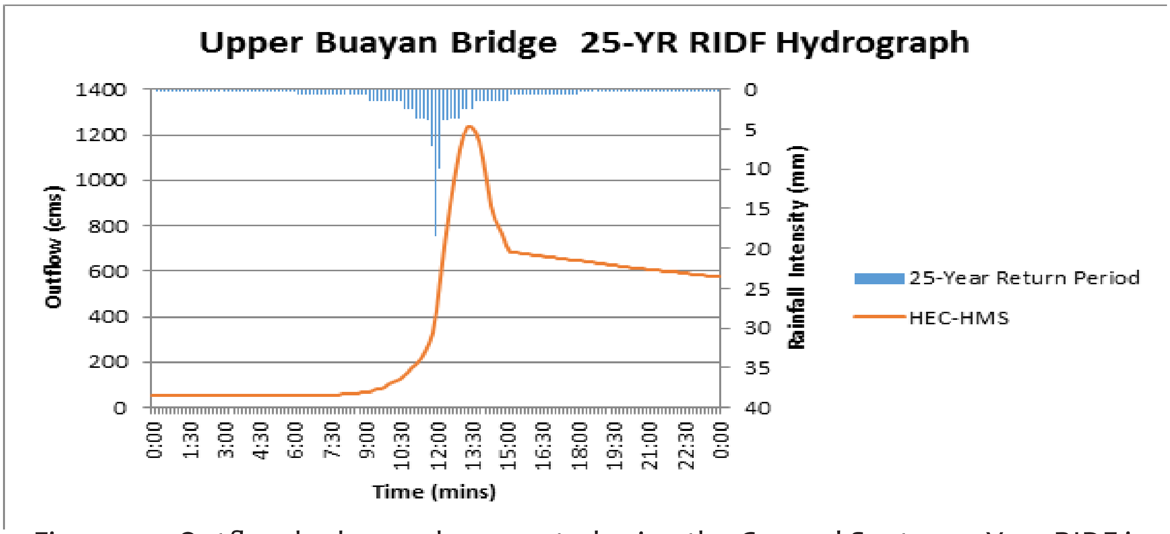


Figure 32. Outflow hydrograph generated using the General Santos 25-Year RIDF in HEC-HMS.

In the 50-year return period graph, the peak outflow is 1490.1 cms. This occurs 1 hour and 30 minutes after the peak precipitation of 20.9 mm, as shown on Figure 33.

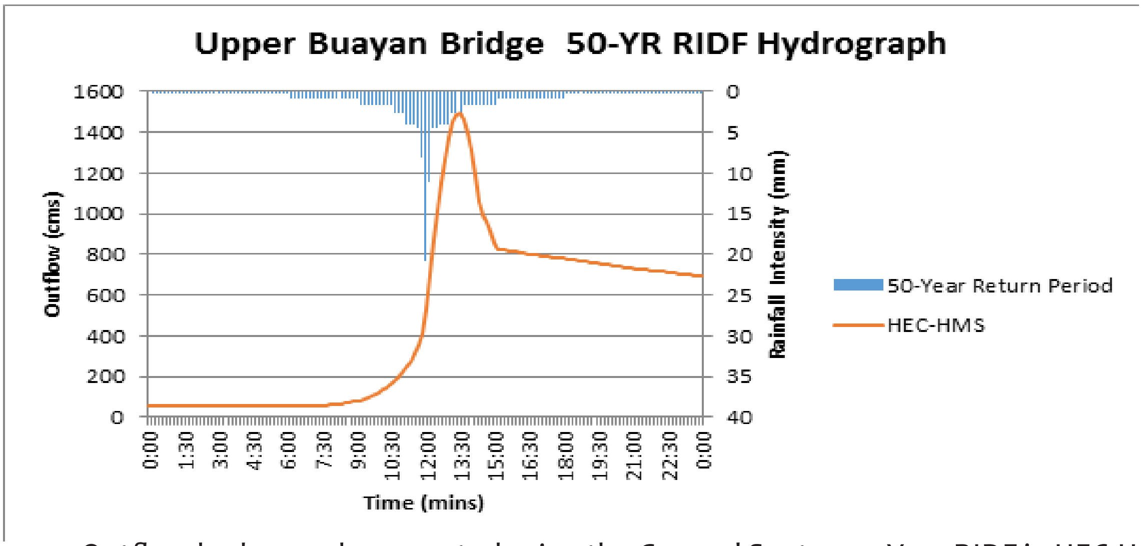


Figure 33. Outflow hydrograph generated using the General Santos 50-Year RIDF in HEC-HMS.

In the 100-year return period graph, the peak outflow is 1748.8 cms. This occurs 1 hour and 20 minutes after the peak precipitation of 23.3 mm, as shown on Figure 34.

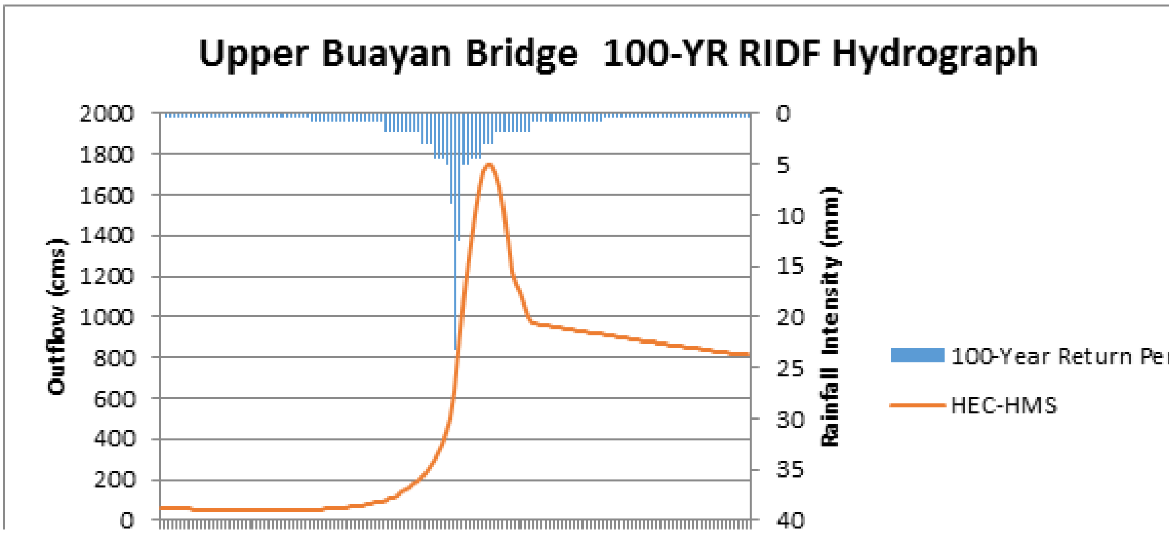


Figure 34. Outflow hydrograph generated using the General Santos 100-Year RIDF in HEC-HMS

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

Table 2. Summary of Buayan discharge using the General Santos Station Rainfall Intensity Duration Frequency (RIDF)

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	102.7	12.7	669.2	1 hour and 30 minutes
10-Year	125.1	15.3	911.9	1 hour and 30 minutes
25-Year	153.4	18.5	1238.8	1 hour and 30 minutes
50-Year	174.3	20.9	1490.1	1 hour and 30 minutes
100-Year	195.2	23.3	1748.8	1 hour and 20 minutes

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

The river discharge values using Dr. Horritt's recommended hydrological method are shown in Figures 35, 36 and 37. The peak discharge values are summarized in Tables 3, 4, and 5.

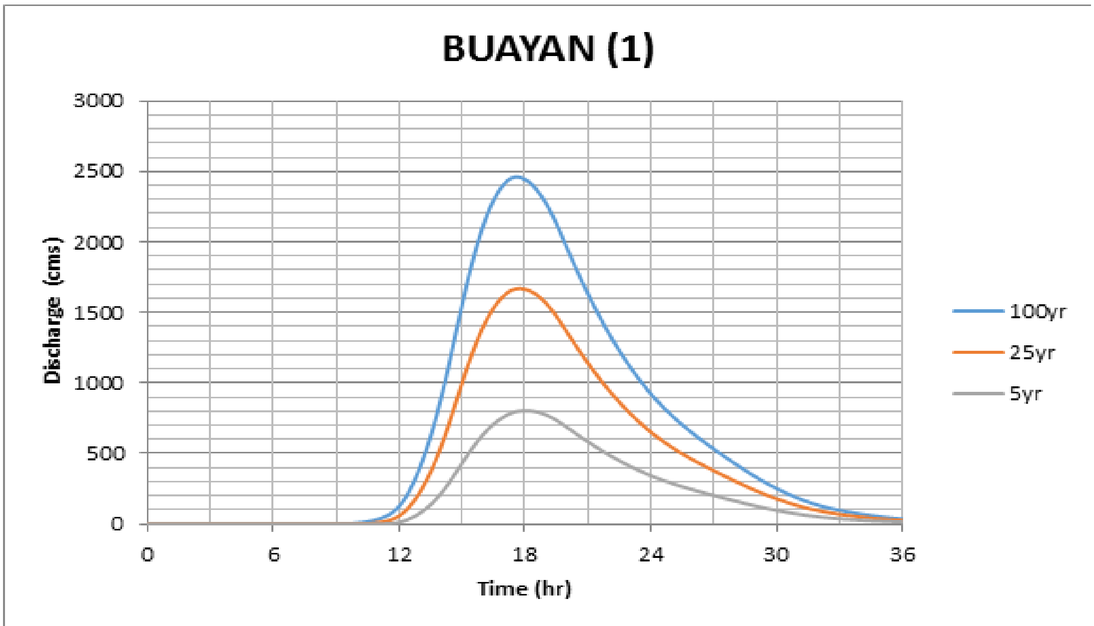


Figure 35. Outflow hydrograph generated for Buayan river (1) using the General Santos station 5-, 25-, 100-Year RIDF in HEC-HMS

Table 3. Summary of Buayan river (1) discharge using the recommended hydrological method by Dr. Horritt

RIDF Period	Peak Discharge	Time-to-peak
5-Year	803.1	17 hours, 50 minutes
25-Year	1,668.8	17 hours, 40 minutes
100-Year	2,459.4	17 hours, 40 minutes

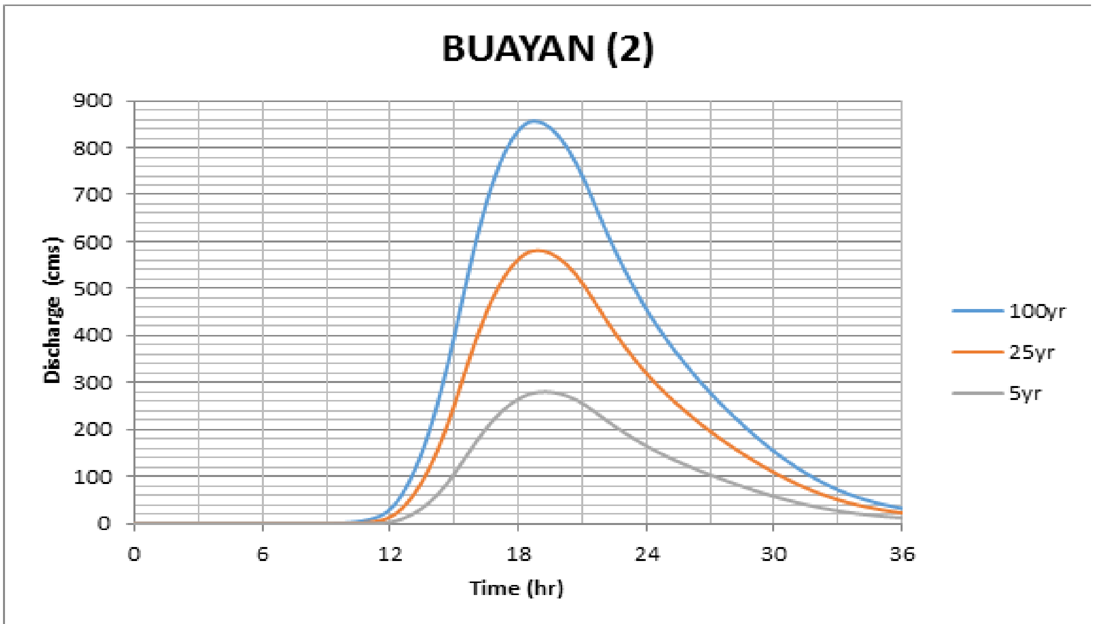


Figure 36. Outflow hydrograph generated for Buayan river (2) using the General Santos station 5-, 25-, 100-Year RIDF in HEC-HMS

Table 4. Summary of Buayan river (2) discharge using the recommended hydrological method by Dr. Horritt

RIDF Period	Peak Discharge	Time-to-peak
5-Year	280.3	19 hours, 10 minutes
25-Year	581.1	19 hours
100-Year	856.2	18 hours, 40 minutes

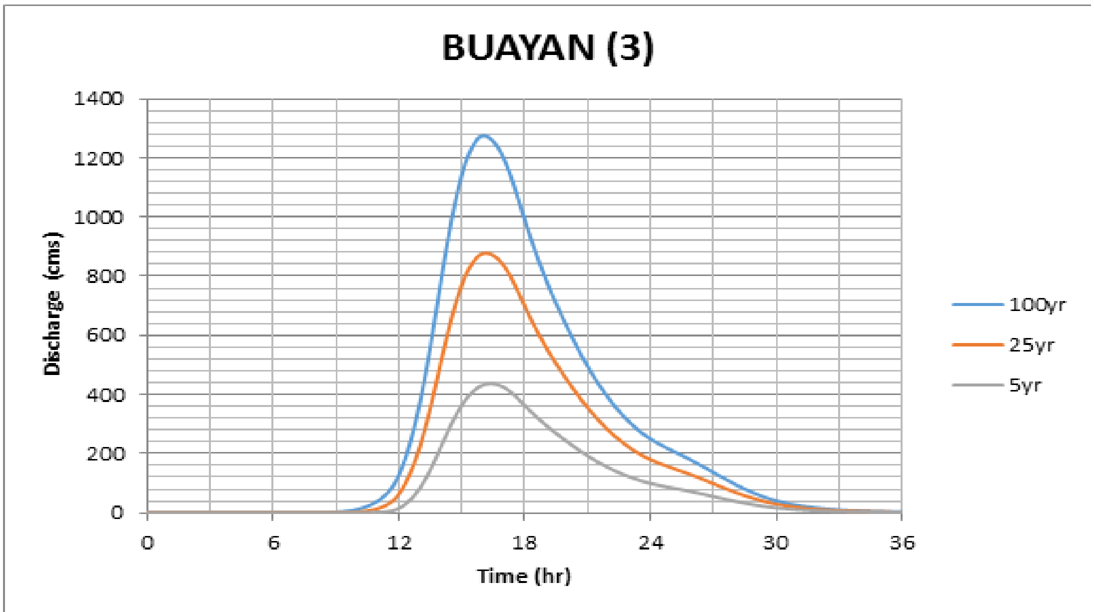


Figure 37. Outflow hydrograph generated for Buayan river (3) using the General Santos station 5-, 25-, 100-Year RIDF in HEC-HMS

Table 5. Summary of Buayan river (3) discharge using the recommended hydrological method by Dr. Horritt

RIDF Period	Peak Discharge	Time-to-peak
5-Year	436.3	16 hours, 20 minutes
25-Year	878.3	16 hours, 10 minutes
100-Year	1274.8	16 hours

The comparison of discharge values obtained from HEC-HMS, QMED, and from the bankful discharge method, Qbankful, are shown in Table 6. Using values from the DTM of Buayan, the bankful discharge for the river was computed.

Table 6. Validation of river discharge estimate

Discharge Point	Qbankful, cms	QMED, cms	Validation
Buayan river (1)	629.35	706.73	Pass
Buayan river (2)	58.44	246.66	Fail
Buayan river (3)	659.94	383.94	Pass

Two out of three values from the HEC-HMS discharge estimates were able to satisfy the conditions for validating the computed discharge using the bankful method. The computed values that passed the validation were used for the discharge points that did not have actual discharge data. The actual discharge data were also used for some areas in the floodplain that were modelled. 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 Buayan river basin.

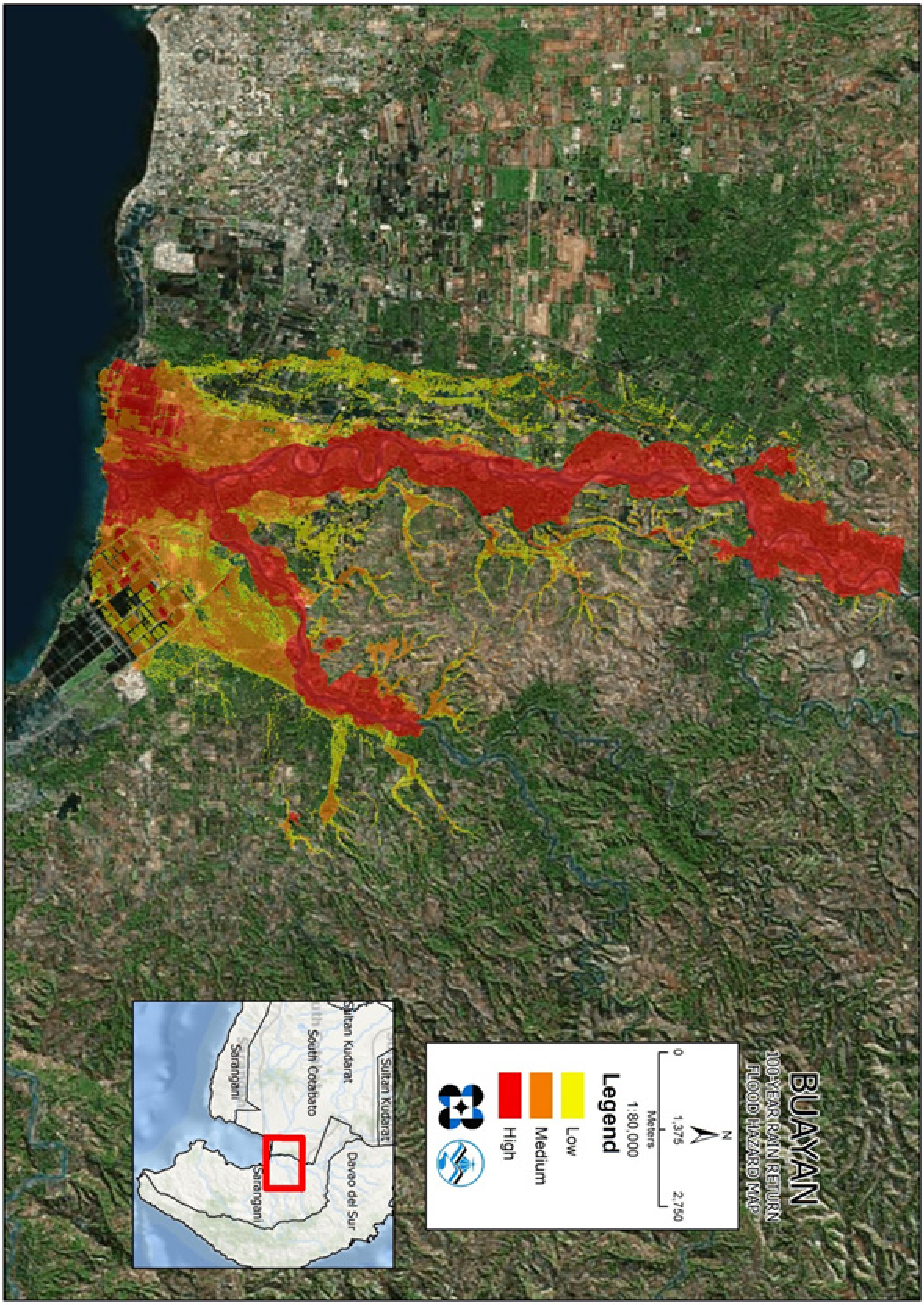


Figure 38. 100-year Flood Hazard Map for Buayan River Basin

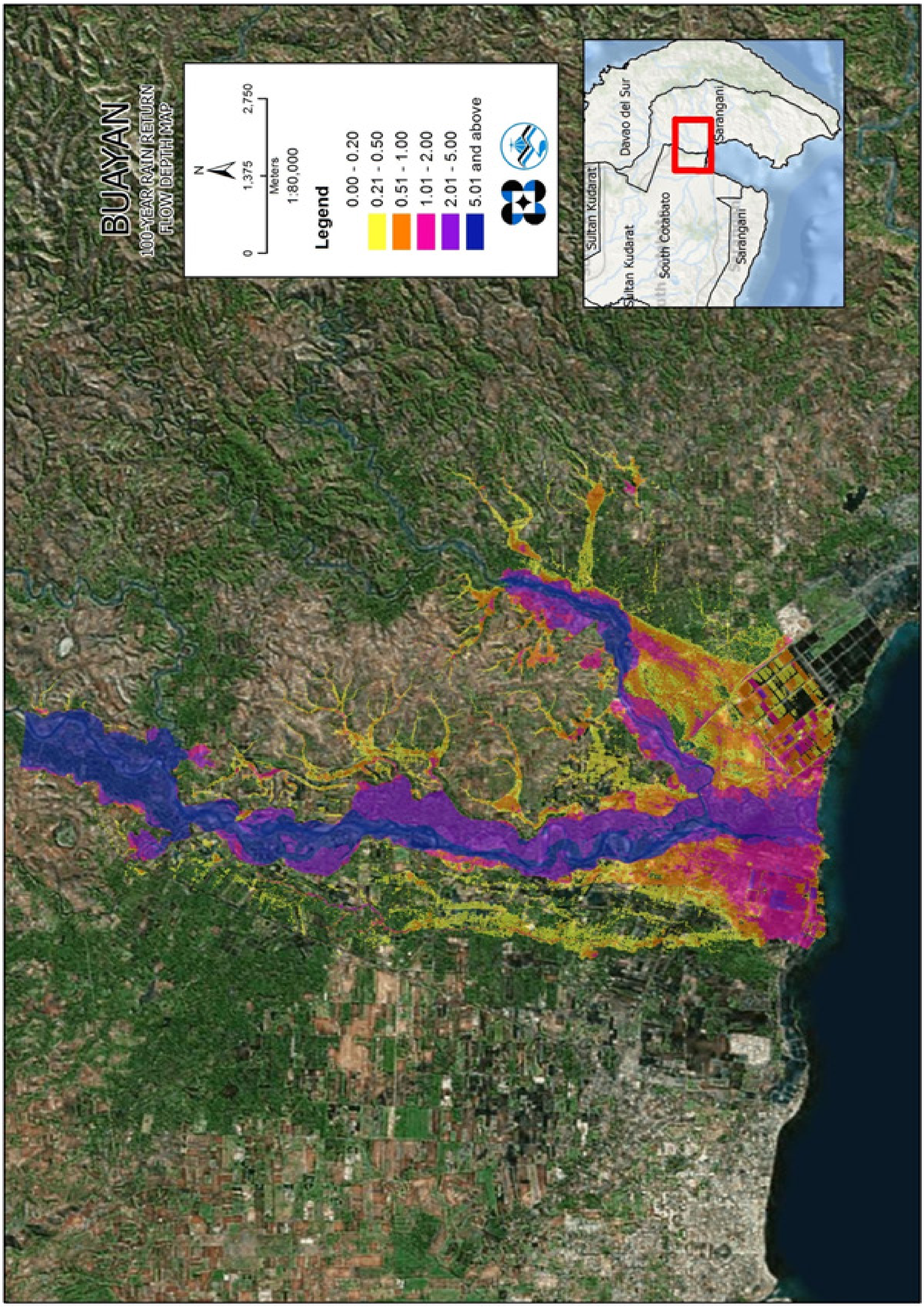


Figure 39. 100-year Flow Depth Map for Buayan River Basin

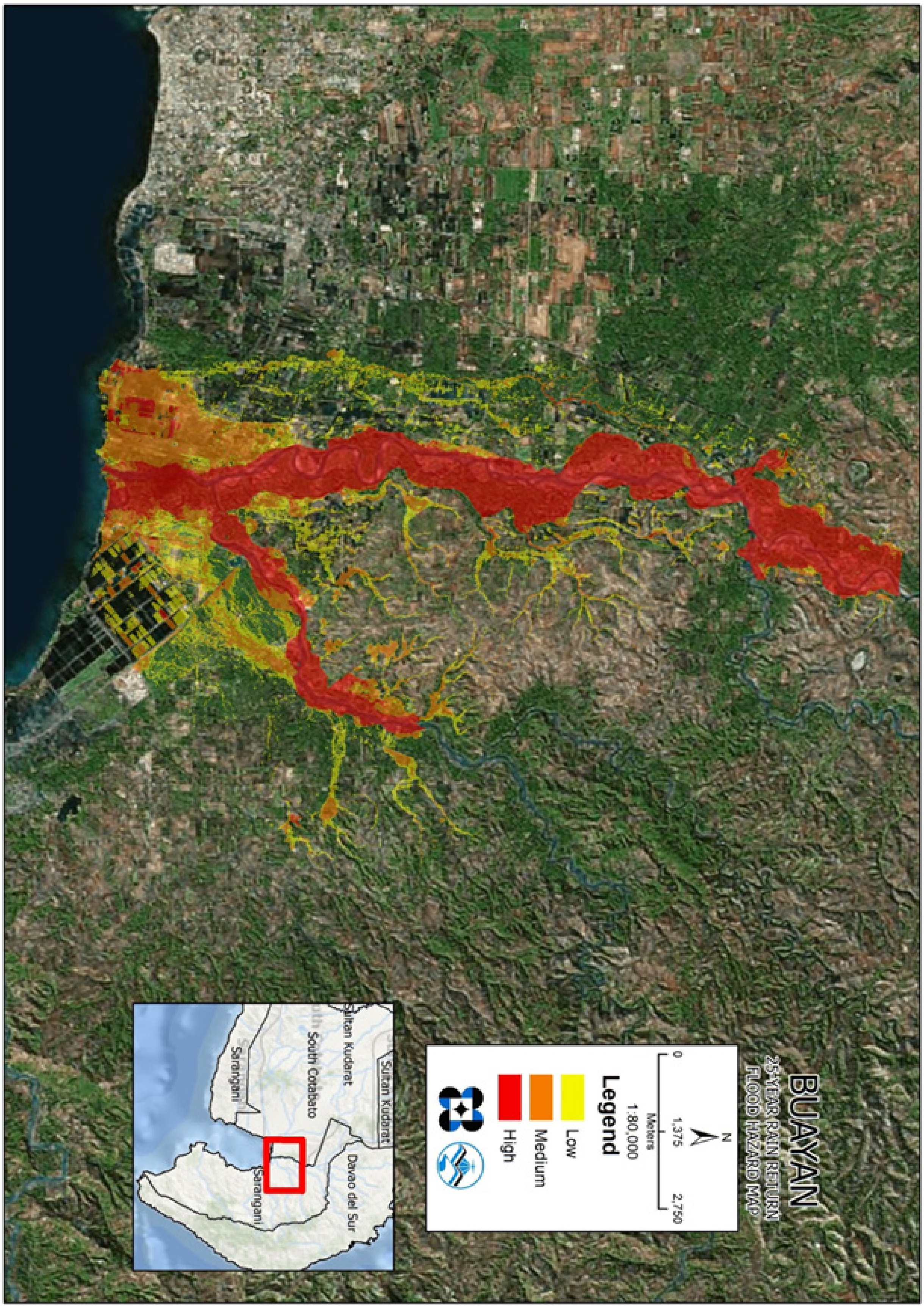


Figure 40. 25-year Flood Hazard Map for Buayan River Basin

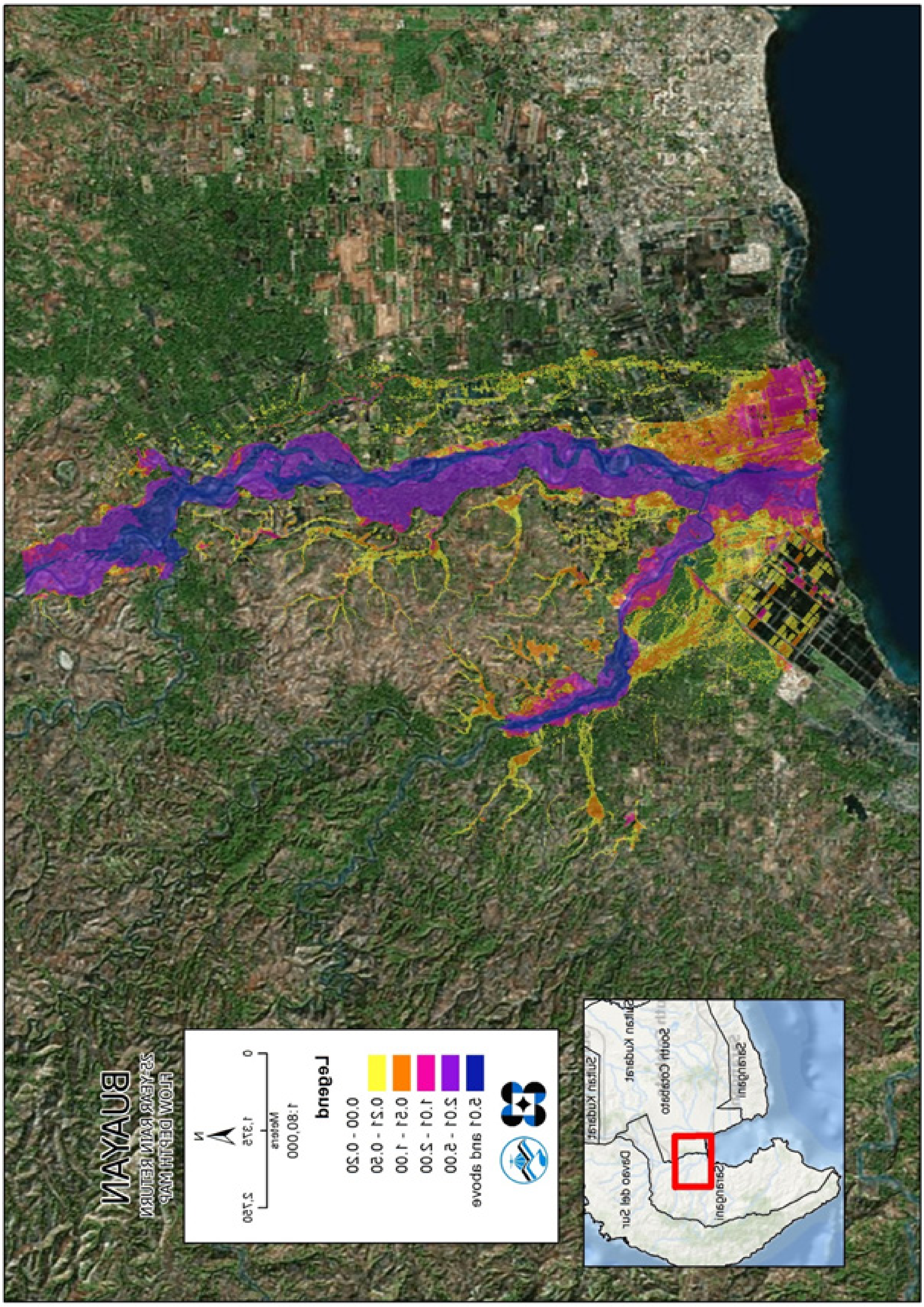


Figure 41. 25-year Flow Depth Map for Buayan River Basin

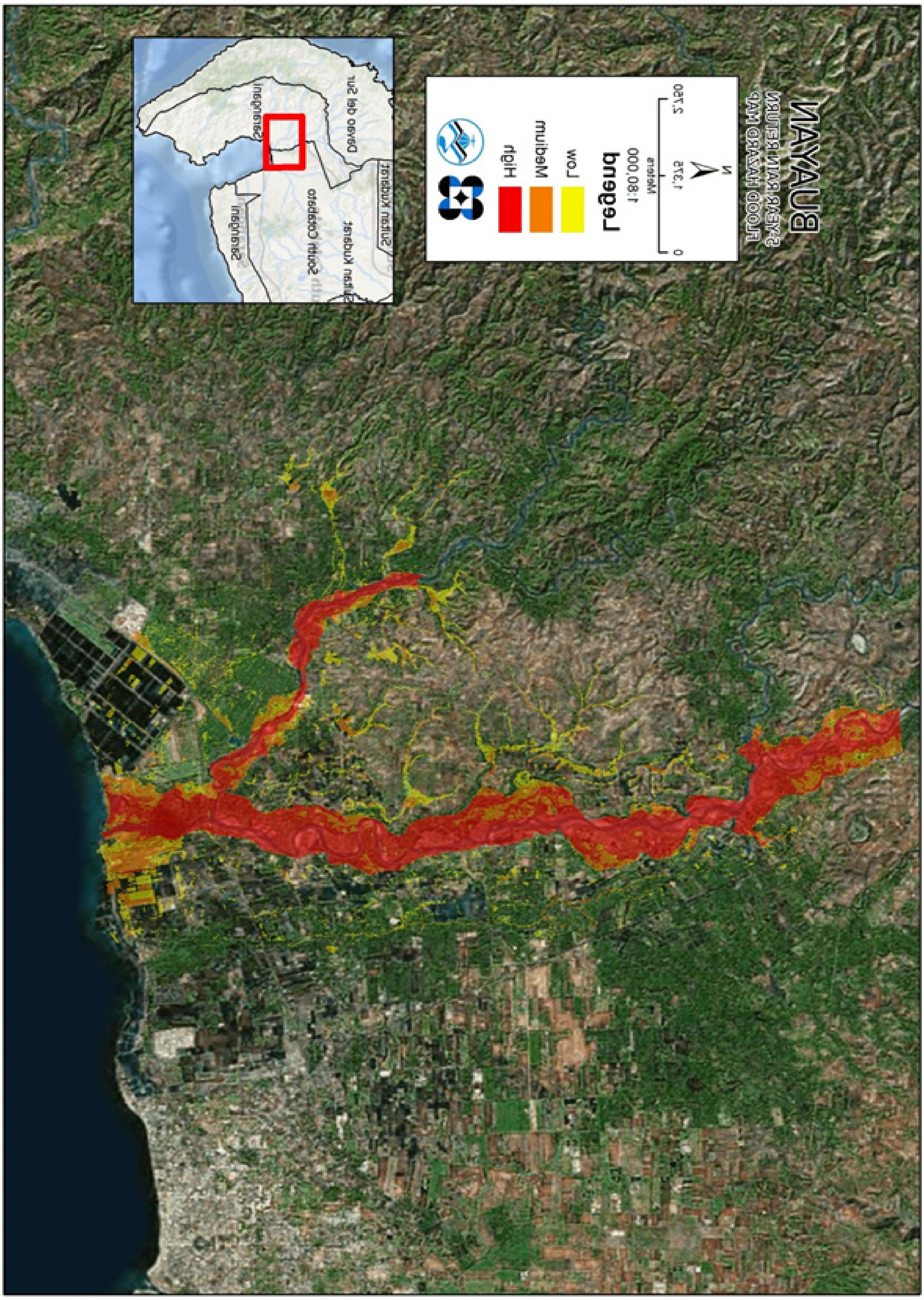


Figure 42. 5-year Flood Hazard Map for Buayan River Basin

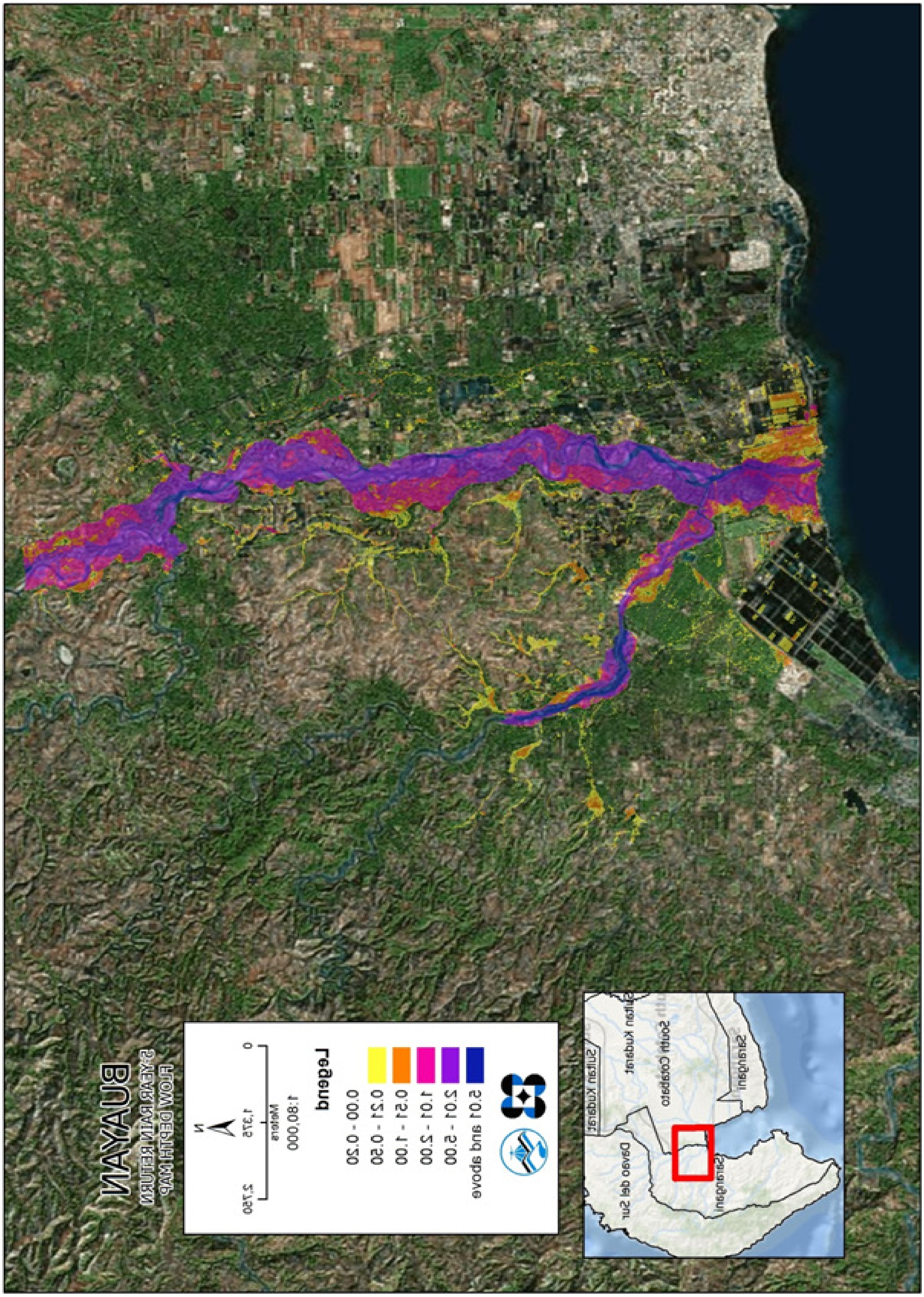


Figure 43. 5-year Flow Depth Map for Buayan River Basin

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Appendix

Appendix A. Buayan-Malungon 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
W1010	4.3814	74.35	0	0.13288	0.216855	Discharge	8.02E-05	1	Ratio to Peak	0.5
W1050	3.69	77.486	0	1.2314	2.009599	Discharge	0.0218333	1	Ratio to Peak	0.5
W1070	3.2446	79.651	0	1.6484	2.690187	Discharge	0.0435663	1	Ratio to Peak	0.5
W1090	4.5585	73.587	0	1.1319	1.847318	Discharge	0.0148016	1	Ratio to Peak	0.5
W1110	4.6973	73	0	0.12485	0.203759	Discharge	6.02E-05	1	Ratio to Peak	0.5
W1150	2.785	82.015	0	6.1151	9.979835	Discharge	0.52044	1	Ratio to Peak	0.5
W1170	3.2485	79.631	0	1.6823	2.745559	Discharge	0.0824462	1	Ratio to Peak	0.5
W1190	4.2042	75.129	0	0.4536	0.740269	Discharge	0.004532	1	Ratio to Peak	0.5
W1210	4.6973	73	0	0.15583	0.254314	Discharge	0.000164507	1	Ratio to Peak	0.5
W1250	4.6243	73.308	0	3.2896	5.368685	Discharge	0.25568	1	Ratio to Peak	0.5
W1270	5.7181	68.954	0	7.9057	12.902064	Discharge	1.7707	1	Ratio to Peak	0.5

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
20B	176.37	33.016	0	1.5041	2.703	Discharge	0.0214370	0.0361349	Ratio to Peak	0.01
21B	40.898	30.116	0	1.0347	2.7207	Discharge	0.0178965	0.0361349	Ratio to Peak	0.01
22B	27.412	49.098	0	0.93985	1.645	Discharge	0.0192448	0.0361349	Ratio to Peak	0.01
23B	50.051	47.611	0	3.5547	21.382	Discharge	0.0778584	0.18293	Ratio to Peak	0.01
24B	499.00	49.133	0	1.8488	5.0041	Discharge	0.0347289	0.0531184	Ratio to Peak	0.01
25B	244.42	49.089	0	1.8276	4.7867	Discharge	0.0237172	0.18293	Ratio to Peak	0.01
26B	32.000	49.082	0	2.6675	5.9384	Discharge	0.0248798	0.12691	Ratio to Peak	0.01
27B	51.219	49.138	0	0.7742	3.0636	Discharge	0.0183919	0.0361349	Ratio to Peak	0.01
28B	110.01	32.966	0	2.2861	6.1157	Discharge	0.0893548	0.18293	Ratio to Peak	0.01
29B	146.47	46.282	0	0.53045	1.3937	Discharge	0.0327274	0.18293	Ratio to Peak	0.01
2B	83.539	46.35	0	3.3269	2.5325	Discharge	0.0248253	0.1269	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
30B	499.00	37.48	0	2.164	5.6727	Discharge	0.0328998	0.0531184	Ratio to Peak	0.01
31B	1.2484	73.143	0	3.5553	9.3422	Discharge	0.0269480	0.0361349	Ratio to Peak	0.01
32B	499.00	24.081	0	1.4386	3.7711	Discharge	0.0488904	0.268905	Ratio to Peak	0.01
33B	499.00	37.507	0	2.6642	4.2565	Discharge	0.0543686	0.268905	Ratio to Peak	0.01
34B	499.00	27.034	0	1.2079	2.154	Discharge	0.0239689	0.403368	Ratio to Peak	0.01
35B	499.00	35.745	0	1.2824	3.3617	Discharge	0.0247704	0.274407	Ratio to Peak	0.01
36B	499.00	41.752	0	2.0422	5.3479	Discharge	0.0386023	0.9261	Ratio to Peak	0.01
37B	499.00	53.436	0	0.74525	1.9534	Discharge	0.0046294	0.9261	Ratio to Peak	0.01
38B	499.00	23.225	0	1.0714	2.8085	Discharge	0.0149046	0.245721	Ratio to Peak	0.01
39B	41.965	49.107	0	0.41346	2.8877	Discharge	0.0193250	0.552888	Ratio to Peak	0.01
3B	18.832	31.623	0	1.9961	28.474	Discharge	0.0217283	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
W1290	4.6973	73	0	0.017	0.1	Discharge	0.0123701	1	Ratio to Peak	0.5
W1310	4.6973	73	0	0.0259209	0.042303	Discharge	4.41E-05	1	Ratio to Peak	0.5
W310	4.3644	70.624268	0	3.0315	0.0824546	Discharge	21.905	0.6	Ratio to Peak	0.55
W340	3.7316	77.29	0	4.2922	7.004875	Discharge	1.0274	1	Ratio to Peak	0.5
W360	15.09	69.638218	0	2.26239	0.0615371	Discharge	33.795	0.6	Ratio to Peak	0.55
W380	4.0577	75.786	0	4.4707	7.29624	Discharge	0.7083	1	Ratio to Peak	0.5
W410	3.2754	79.497	0	5.0482	8.23871	Discharge	0.7382	1	Ratio to Peak	0.5
W420	2.6977	82.48	0	2.691	4.391712	Discharge	0.11573	1	Ratio to Peak	0.5
W430	6.7845	65.18	0	14.843	24.223867	Discharge	2.0557	1	Ratio to Peak	0.5
W460	4.176	75.255	0	12.568	20.511457	Discharge	0.94136	1	Ratio to Peak	0.5
W480	4.6971	73.001	0	3.2611	5.322035	Discharge	0.34843	1	Ratio to Peak	0.5

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W500	15.3207901	45.323	0	14.403	23.504907	Discharge	1.4078	1	Ratio to Peak	0.5
W510	7.7151	62.209	0	7.5443	12.312256	Discharge	0.69376	1	Ratio to Peak	0.5
W520	3.8323	76.819	0	6.8183	11.127473	Discharge	0.32288	1	Ratio to Peak	0.5
W530	2.2379	85.019	0	2.1361	3.486128	Discharge	0.0520605	1	Ratio to Peak	0.5
W540	9.1217	58.199	0	22.998	37.533242	Discharge	2.8851	1	Ratio to Peak	0.5
W550	6.0063	67.891	0	7.0257	11.465978	Discharge	0.84067	1	Ratio to Peak	0.5
W560	5.049	71.553	0	7.4865	12.217971	Discharge	0.72459	1	Ratio to Peak	0.5
W570	2.0778	85.94	0	5.0857	8.299856	Discharge	0.25649	1	Ratio to Peak	0.5
W580	0.12828	99	0	0.0753539	0.122977	Discharge	5.22E-05	1	Ratio to Peak	0.5
W600	5.0576	71.519	0	12.51	20.416969	Discharge	1.4963	1	Ratio to Peak	0.5
W620	13.758	48	0	0.12236	0.199689	Discharge	4.81E-05	1	Ratio to Peak	0.5

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W650	4.9179	72.086	0	6.0843	9.929526	Discharge	0.61144	1	Ratio to Peak	0.5
W670	3.3759	79	0	0.0645981	0.105424	Discharge	6.82E-05	1	Ratio to Peak	0.5
W700	4.565	73.559	0	5.3557	8.740583	Discharge	0.59016	1	Ratio to Peak	0.5
W720	4.6973	73	0	0.043105	0.070347	Discharge	2.61E-05	1	Ratio to Peak	0.5
W750	5.1059	71.325	0	16.989	27.726074	Discharge	1.9977	1	Ratio to Peak	0.5
W770	4.6973	73	0	0.26515	0.432721	Discharge	0.0013542	1	Ratio to Peak	0.5
W800	4.7795	72.657	0	16.049	26.191821	Discharge	2.6247	1	Ratio to Peak	0.5
W820	4.6973	73	0	0.1062	0.173324	Discharge	0.000154476	1	Ratio to Peak	0.5
W850	4.0582	75.784	0	5.5035	8.981634	Discharge	1.4495	1	Ratio to Peak	0.5
W870	3.3759	79	0	0.0435877	0.071135	Discharge	3.41E-05	1	Ratio to Peak	0.5
W900	3.9976	76.059	0	3.5043	5.719055	Discharge	0.58687	1	Ratio to Peak	0.5

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
W920	4.6973	73	0	0.0556809	0.090871	Discharge	3.61E-05	1	Ratio to Peak	0.5
W950	4.4419	74.087	0	4.1777	6.817946	Discharge	0.55658	1	Ratio to Peak	0.5
W970	4.4629	73.997	0	2.2593	3.687181	Discharge	0.0690188	1	Ratio to Peak	0.5
W990	4.3731	74.386	0	4.2157	6.879951	Discharge	0.17468	1	Ratio to Peak	0.5

Appendix B. Buayan-Malungon Model Reach

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R1000	Automatic Fixed Interval	4150.904037	0.01337	0.002	Trapezoid	60	1
R1060	Automatic Fixed Interval	1309.411254	0.0038096	0.002	Trapezoid	60	1
R1080	Automatic Fixed Interval	3662.898918	0.0061504	0.002	Trapezoid	60	1
R110	Automatic Fixed Interval	5560.9	0.0120094	0.002	Trapezoid	60	1
R1100	Automatic Fixed Interval	1314.680374	0.0409037	0.002	Trapezoid	60	1
R1160	Automatic Fixed Interval	12202.29581	0.002955	0.002	Trapezoid	60	1
R1180	Automatic Fixed Interval	2241.370849	0.0074337	0.002	Trapezoid	60	1
R120	Automatic Fixed Interval	11305	0.0013954	0.002	Trapezoid	60	1
R1200	Automatic Fixed Interval	532.842712	0.053069	0.002	Trapezoid	60	1
R1260	Automatic Fixed Interval	6472.619766	0.0074734	0.002	Trapezoid	60	1
R1300	Automatic Fixed Interval	1548.406204	0.1438	0.002	Trapezoid	60	1
R150	Automatic Fixed Interval	7809.8	0.010165	0.002	Trapezoid	60	1
R200	Automatic Fixed Interval	23322	0.0034786	0.002	Trapezoid	60	1
R220	Automatic Fixed Interval	1962.4	0.0028605	0.002	Trapezoid	60	1
R230	Automatic Fixed Interval	15590	0.0052203	0.002	Trapezoid	60	1
R250	Automatic Fixed Interval	5231	0.0018154	0.002	Trapezoid	60	1
R270	Automatic Fixed Interval	7.0711	0.0013056	0.002	Trapezoid	60	1
R280	Automatic Fixed Interval	6142.3	0.001503	0.002	Trapezoid	60	1
R290	Automatic Fixed Interval	10414	0.0025312	0.002	Trapezoid	60	1
R50	Automatic Fixed Interval	6163.2	0.0077701	0.002	Trapezoid	60	1
R610	Automatic Fixed Interval	33735	0.0064173	0.002	Trapezoid	60	1
R660	Automatic Fixed Interval	18700	0.022729	0.002	Trapezoid	60	1
R710	Automatic Fixed Interval	14059	0.0289194	0.002	Trapezoid	60	1
R760	Automatic Fixed Interval	43636	0.0079046	0.002	Trapezoid	60	1
R810	Automatic Fixed Interval	40810	0.0079229	0.002	Trapezoid	60	1
R860	Automatic Fixed Interval	15534	0.0331988	0.002	Trapezoid	60	1
R910	Automatic Fixed Interval	9732.6	0.0415619	0.002	Trapezoid	60	1
R960	Automatic Fixed Interval	6992.274887	0.0014438	0.002	Trapezoid	60	1
R980	Automatic Fixed Interval	2454.802307	0.0018071	0.002	Trapezoid	60	1

Appendix C. Buayan River (1) HEC-HMS Discharge Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	5.6666667	0	0	0
0.1666667	0	0	0	5.8333333	0	0	0
0.3333333	0	0	0	6	0	0	0
0.5	0	0	0	6.1666667	0	0	0
0.6666667	0	0	0	6.3333333	0	0	0
0.8333333	0	0	0	6.5	0	0	0
1	0	0	0	6.6666667	0	0	0
1.1666667	0	0	0	6.8333333	0	0	0
1.3333333	0	0	0	7	0	0	0
1.5	0	0	0	7.1666667	0	0	0
1.6666667	0	0	0	7.3333333	0	0	0
1.8333333	0	0	0	7.5	0	0	0
2	0	0	0	7.6666667	0	0	0
2.1666667	0	0	0	7.8333333	0	0	0
2.3333333	0	0	0	8	0	0	0
2.5	0	0	0	8.1666667	0.1	0	0
2.6666667	0	0	0	8.3333333	0.2	0	0
2.8333333	0	0	0	8.5	0.3	0	0
3	0	0	0	8.6666667	0.4	0	0
3.1666667	0	0	0	8.8333333	0.7	0	0
3.3333333	0	0	0	9	1	0	0
3.5	0	0	0	9.1666667	1.5	0.1	0
3.6666667	0	0	0	9.3333333	2.2	0.2	0
3.8333333	0	0	0	9.5	3.1	0.3	0
4	0	0	0	9.6666667	4.4	0.6	0
4.1666667	0	0	0	9.8333333	6	0.9	0
4.3333333	0	0	0	10	8	1.5	0
4.5	0	0	0	10.166667	10.5	2.2	0
4.6666667	0	0	0	10.333333	13.5	3.1	0
4.8333333	0	0	0	10.5	17.2	4.3	0.1
5	0	0	0	10.666667	21.8	6	0.2
5.1666667	0	0	0	10.833333	27.3	8	0.3
5.3333333	0	0	0	11	34.1	10.8	0.7
5.5	0	0	0	11.166667	42.5	14.3	1.2

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
11.333333	52.5	18.8	1.9	17.666667	2459.4	1668.8	798.5
11.5	64.6	24.5	3	17.833333	2454.1	1668.6	801.8
11.666667	79.8	32.1	4.7	18	2443	1664.4	803.1
11.833333	101.2	43.7	8.2	18.166667	2427	1656.7	802.7
12	127.2	58.4	12.9	18.333333	2406.1	1645.4	800.4
12.166667	157.4	75.8	18.8	18.5	2379.8	1630.4	796.2
12.333333	195.5	98.5	27.1	18.666667	2349.2	1612.3	790.5
12.5	239.8	125.5	37.3	18.833333	2314.2	1591	783
12.666667	288.6	155.7	49	19	2273.4	1565.6	773.4
12.833333	343.7	190.3	62.8	19.166667	2228.8	1537.4	762.3
13	404.3	228.7	78.4	19.333333	2180.9	1506.8	749.8
13.166667	469.8	270.6	95.7	19.5	2128	1472.5	735.3
13.333333	542.8	317.8	115.6	19.666667	2072.1	1435.9	719.5
13.5	621.8	369.2	137.7	19.833333	2014.8	1398.1	702.7
13.666667	705.7	424.3	161.7	20	1957.9	1360.4	685.8
13.833333	797.4	485.1	188.6	20.166667	1901	1322.5	668.5
14	895.3	550.4	218	20.333333	1843.8	1284.1	650.8
14.166667	997.3	618.8	249.3	20.5	1789	1247.2	633.6
14.333333	1105	691.6	283.1	20.666667	1736.1	1211.5	616.9
14.5	1217.1	767.9	319	20.833333	1683.6	1175.9	600.1
14.666667	1330.9	845.9	356.2	21	1632.4	1141.2	583.6
14.833333	1443.6	923.6	393.8	21.166667	1582.4	1107.1	567.3
15	1553.8	1000	431.2	21.333333	1533.2	1073.5	551.2
15.166667	1662	1075.5	468.6	21.5	1485.7	1041.1	535.5
15.333333	1765.1	1147.9	505	21.666667	1439.4	1009.3	520.1
15.5	1861.6	1216.1	539.7	21.833333	1394.1	978.2	504.9
15.666667	1953	1281.1	573.2	22	1350.7	948.3	490.2
15.833333	2037.3	1341.6	604.8	22.166667	1309	919.6	476.1
16	2113.1	1396.4	633.8	22.333333	1268.3	891.4	462.3
16.166667	2182.4	1447	661.1	22.5	1228.4	863.9	448.7
16.333333	2243.6	1492.2	685.9	22.666667	1189.6	837	435.4
16.5	2295.3	1531.1	707.8	22.833333	1151.9	810.9	422.5
16.666667	2340.2	1565.3	727.6	23	1115.8	785.9	410
16.833333	2378.5	1595.2	745.3	23.166667	1081.1	761.8	398
17	2409.7	1620.1	760.8	23.333333	1047.4	738.5	386.4
17.166667	2434.7	1641	774.4	23.5	1014.8	715.7	375
17.333333	2452	1656.6	785.5	23.666667	983	693.6	364
17.5	2459.1	1665.1	793.2	23.833333	952.1	672.1	353.2

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
24	922.7	651.6	342.8	30.333333	227.4	161.7	87.4
24.166667	895	632.3	333.1	30.5	216	153.6	83
24.333333	868.4	613.7	323.7	30.666667	205	145.7	78.8
24.5	842.5	595.6	314.5	30.833333	194.3	138.2	74.7
24.666667	817.3	577.9	305.6	31	184.1	130.9	70.8
24.833333	792.7	560.7	296.8	31.166667	174.4	124	67
25	769.1	544.1	288.4	31.333333	165.2	117.4	63.5
25.166667	746.5	528.3	280.3	31.5	156.4	111.2	60.1
25.333333	724.7	513	272.5	31.666667	148.1	105.3	56.9
25.5	703.3	498	264.8	31.833333	140.3	99.7	53.9
25.666667	682.5	483.4	257.4	32	133	94.5	51
25.833333	662.2	469.2	250.1	32.166667	126.1	89.6	48.4
26	642.5	455.3	242.9	32.333333	119.7	85.1	45.9
26.166667	623.5	442	236.1	32.5	113.7	80.8	43.6
26.333333	605	429	229.3	32.666667	107.9	76.7	41.4
26.5	586.7	416.1	222.7	32.833333	102.5	72.9	39.3
26.666667	568.4	403.2	216	33	97.4	69.2	37.3
26.833333	550.2	390.4	209.3	33.166667	92.5	65.7	35.5
27	532.2	377.7	202.7	33.333333	87.8	62.4	33.7
27.166667	514.6	365.3	196.1	33.5	83.4	59.3	32
27.333333	497.3	353	189.7	33.666667	79.1	56.3	30.4
27.5	480	340.8	183.2	33.833333	75.1	53.4	28.9
27.666667	462.8	328.7	176.8	34	71.2	50.7	27.4
27.833333	445.7	316.6	170.4	34.166667	67.5	48.1	26
28	428.9	304.7	164.1	34.333333	64	45.6	24.6
28.166667	412.4	293	157.9	34.5	60.5	43.1	23.4
28.333333	396.3	281.6	151.8	34.666667	57.3	40.8	22.1
28.5	380.3	270.2	145.7	34.833333	54.1	38.6	20.9
28.666667	364.6	259.1	139.8	35	51.2	36.5	19.8
28.833333	349.1	248.1	133.9	35.166667	48.3	34.5	18.7
29	334	237.4	128.2	35.333333	45.6	32.6	17.7
29.166667	319.3	227	122.6	35.5	43	30.7	16.7
29.333333	305	216.8	117.1	35.666667	40.5	28.9	15.8
29.5	291	206.9	111.8	35.833333	38.1	27.2	14.9
29.666667	277.4	197.2	106.6	36	35.8	25.6	14
29.833333	264.2	187.9	101.5				
30	251.5	178.8	96.6				
30.166667	239.2	170.1	91.9				

Appendix D. Buayan River (2) HEC-HMS Discharge Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	5.6666667	0	0	0
0.1666667	0	0	0	5.8333333	0	0	0
0.3333333	0	0	0	6	0	0	0
0.5	0	0	0	6.1666667	0	0	0
0.6666667	0	0	0	6.3333333	0	0	0
0.8333333	0	0	0	6.5	0	0	0
1	0	0	0	6.6666667	0	0	0
1.1666667	0	0	0	6.8333333	0	0	0
1.3333333	0	0	0	7	0	0	0
1.5	0	0	0	7.1666667	0	0	0
1.6666667	0	0	0	7.3333333	0	0	0
1.8333333	0	0	0	7.5	0	0	0
2	0	0	0	7.6666667	0	0	0
2.1666667	0	0	0	7.8333333	0	0	0
2.3333333	0	0	0	8	0	0	0
2.5	0	0	0	8.1666667	0	0	0
2.6666667	0	0	0	8.3333333	0	0	0
2.8333333	0	0	0	8.5	0.1	0	0
3	0	0	0	8.6666667	0.1	0	0
3.1666667	0	0	0	8.8333333	0.2	0	0
3.3333333	0	0	0	9	0.3	0	0
3.5	0	0	0	9.1666667	0.4	0	0
3.6666667	0	0	0	9.3333333	0.6	0	0
3.8333333	0	0	0	9.5	0.8	0.1	0
4	0	0	0	9.6666667	1.1	0.1	0
4.1666667	0	0	0	9.8333333	1.5	0.2	0
4.3333333	0	0	0	10	2	0.4	0
4.5	0	0	0	10.166667	2.6	0.5	0
4.6666667	0	0	0	10.333333	3.3	0.8	0
4.8333333	0	0	0	10.5	4.2	1.1	0
5	0	0	0	10.666667	5.4	1.5	0
5.1666667	0	0	0	10.833333	6.7	2	0.1
5.3333333	0	0	0	11	8.4	2.7	0.2
5.5	0	0	0	11.166667	10.4	3.6	0.3

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
11.333333	12.9	4.7	0.5	17.666667	814.8	545.8	255.2
11.5	15.8	6	0.8	17.833333	826.5	554.7	260.4
11.666667	19.6	7.9	1.2	18	836.2	562.3	265
11.833333	25	10.8	2.1	18.166667	844.2	568.9	269.1
12	31.6	14.5	3.3	18.333333	850.6	574.3	272.7
12.166667	39.1	18.8	4.8	18.5	854.7	578.1	275.5
12.333333	48.1	24.1	6.7	18.666667	856.2	580.2	277.5
12.5	59.2	30.8	9.2	18.833333	856.1	581.1	278.9
12.666667	71.6	38.4	12.2	19	854.7	581.1	279.9
12.833333	85.3	46.8	15.5	19.166667	851.7	580	280.3
13	100.5	56.3	19.3	19.333333	847.4	578	280.2
13.166667	117.2	66.8	23.6	19.5	841.9	575.2	279.7
13.333333	135.1	78.1	28.3	19.666667	835.2	571.4	278.8
13.5	154.4	90.4	33.5	19.833333	827.2	566.8	277.4
13.666667	175.7	104.1	39.3	20	818.1	561.4	275.6
13.833333	198.5	119	45.6	20.166667	808	555.2	273.5
14	222.6	134.7	52.5	20.333333	796.6	548.2	270.8
14.166667	248.2	151.5	59.9	20.5	783.9	540.2	267.7
14.333333	276.1	169.9	68.1	20.666667	770.3	531.5	264.2
14.5	305.3	189.4	76.9	20.833333	755.7	522.1	260.3
14.666667	335.6	209.7	86.1	21	739.9	511.8	255.9
14.833333	367.4	231	96	21.166667	723	500.7	251
15	400.5	253.4	106.5	21.333333	705.5	489.1	245.8
15.166667	434.4	276.5	117.4	21.5	687.6	477.2	240.4
15.333333	468.4	299.8	128.6	21.666667	670	465.4	235
15.5	501.7	322.7	139.6	21.833333	652.3	453.6	229.5
15.666667	534.4	345.3	150.7	22	634.6	441.6	224
15.833333	566.9	367.8	161.8	22.166667	617.4	430	218.4
16	598.2	389.7	172.7	22.333333	601	418.8	213.2
16.166667	627.4	410.2	183	22.5	584.9	407.9	208
16.333333	655.4	429.9	193.1	22.666667	569	397.1	202.8
16.5	682.2	449	202.8	22.833333	553.6	386.6	197.7
16.666667	707	466.7	212.1	23	538.6	376.3	192.8
16.833333	729.6	482.9	220.6	23.166667	523.9	366.3	187.9
17	750.6	498.1	228.7	23.333333	509.5	356.4	183.1
17.166667	770.1	512.3	236.4	23.5	495.7	346.9	178.5
17.333333	787	524.8	243.3	23.666667	482.3	337.7	174
17.5	801.7	535.8	249.4	23.833333	469.1	328.6	169.5

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
24	456.5	319.9	165.2	30.333333	142.2	100.6	53.6
24.166667	444.4	311.6	161.1	30.5	136.7	96.7	51.6
24.333333	432.8	303.5	157.2	30.666667	131.4	93	49.6
24.5	421.4	295.7	153.3	30.833333	126.2	89.3	47.6
24.666667	410.3	288	149.5	31	121.1	85.7	45.7
24.833333	399.4	280.5	145.8	31.166667	116.2	82.2	43.9
25	388.8	273.1	142.1	31.333333	111.4	78.9	42.1
25.166667	378.4	265.9	138.6	31.5	106.9	75.6	40.4
25.333333	368.4	259	135.1	31.666667	102.4	72.5	38.7
25.5	358.7	252.3	131.8	31.833333	98.1	69.4	37.1
25.666667	349.1	245.6	128.4	32	93.9	66.5	35.5
25.833333	339.7	239.1	125.1	32.166667	89.9	63.6	33.9
26	330.3	232.6	121.9	32.333333	85.9	60.8	32.5
26.166667	321.1	226.2	118.7	32.5	82.2	58.1	31
26.333333	312.1	219.9	115.5	32.666667	78.6	55.6	29.7
26.5	303.4	213.8	112.4	32.833333	75.1	53.1	28.4
26.666667	295	208	109.4	33	71.8	50.8	27.1
26.833333	286.8	202.2	106.5	33.166667	68.6	48.5	25.9
27	278.7	196.6	103.6	33.333333	65.6	46.4	24.8
27.166667	270.7	191	100.7	33.5	62.7	44.3	23.7
27.333333	262.8	185.4	97.9	33.666667	59.9	42.4	22.6
27.5	255	180	95.1	33.833333	57.3	40.5	21.6
27.666667	247.4	174.6	92.3	34	54.8	38.8	20.7
27.833333	240	169.4	89.6	34.166667	52.4	37.1	19.8
28	232.7	164.3	87	34.333333	50.2	35.5	18.9
28.166667	225.5	159.2	84.4	34.5	48	34	18.1
28.333333	218.4	154.3	81.8	34.666667	45.9	32.5	17.3
28.5	211.3	149.3	79.2	34.833333	43.9	31.1	16.6
28.666667	204.4	144.4	76.7	35	42	29.7	15.9
28.833333	197.5	139.6	74.1	35.166667	40.2	28.4	15.2
29	190.8	134.9	71.7	35.333333	38.5	27.2	14.5
29.166667	184.4	130.3	69.3	35.5	36.9	26.1	13.9
29.333333	178	125.8	66.9	35.666667	35.3	25	13.3
29.5	171.7	121.4	64.6	35.833333	33.8	23.9	12.7
29.666667	165.5	117.1	62.3	36	32.4	22.9	12.2
29.833333	159.5	112.8	60.1				
30	153.5	108.6	57.9				
30.166667	147.8	104.5	55.7				

Appendix E. Buayan River (3) HEC-HMS Discharge Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	5.6666667	0	0	0
0.1666667	0	0	0	5.8333333	0	0	0
0.3333333	0	0	0	6	0	0	0
0.5	0	0	0	6.1666667	0	0	0
0.6666667	0	0	0	6.3333333	0	0	0
0.8333333	0	0	0	6.5	0	0	0
1	0	0	0	6.6666667	0	0	0
1.1666667	0	0	0	6.8333333	0	0	0
1.3333333	0	0	0	7	0	0	0
1.5	0	0	0	7.1666667	0	0	0
1.6666667	0	0	0	7.3333333	0	0	0
1.8333333	0	0	0	7.5	0	0	0
2	0	0	0	7.6666667	0.1	0	0
2.1666667	0	0	0	7.8333333	0.1	0	0
2.3333333	0	0	0	8	0.2	0	0
2.5	0	0	0	8.1666667	0.3	0	0
2.6666667	0	0	0	8.3333333	0.5	0	0
2.8333333	0	0	0	8.5	0.8	0	0
3	0	0	0	8.6666667	1.1	0	0
3.1666667	0	0	0	8.8333333	1.5	0.1	0
3.3333333	0	0	0	9	2.1	0.1	0
3.5	0	0	0	9.1666667	2.9	0.3	0
3.6666667	0	0	0	9.3333333	3.9	0.4	0
3.8333333	0	0	0	9.5	5.3	0.7	0
4	0	0	0	9.6666667	7	1.2	0
4.1666667	0	0	0	9.8333333	9.1	1.8	0
4.3333333	0	0	0	10	11.6	2.5	0
4.5	0	0	0	10.166667	14.6	3.5	0.1
4.6666667	0	0	0	10.333333	18.2	4.8	0.1
4.8333333	0	0	0	10.5	22.4	6.5	0.3
5	0	0	0	10.666667	27.5	8.6	0.5
5.1666667	0	0	0	10.833333	33.5	11.2	0.8
5.3333333	0	0	0	11	40.7	14.6	1.3
5.5	0	0	0	11.166667	49.2	18.7	2

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
11.333333	59.3	23.9	3	17.666667	1065.4	748.9	386.5
11.5	71.1	30.2	4.4	17.833333	1027.4	723.4	374.7
11.666667	85.4	38.2	6.5	18	989.9	698	362.8
11.833333	104.6	49.5	10.2	18.166667	953.3	673.1	351
12	127.9	63.7	15.2	18.333333	918.6	649.5	339.6
12.166667	156.7	81.8	22.1	18.5	884.9	626.4	328.5
12.333333	190.6	103.6	30.9	18.666667	852.2	604.1	317.7
12.5	229.1	128.7	41.4	18.833333	820.6	582.3	307.1
12.666667	272.3	157.2	53.7	19	790.1	561.3	296.8
12.833333	320	189	67.9	19.166667	760.9	541.2	286.9
13	373.3	224.9	84.2	19.333333	733.3	522.2	277.5
13.166667	431.2	264.3	102.5	19.5	707	504	268.5
13.333333	495	308	123.2	19.666667	681.4	486.2	259.6
13.5	563	355.1	146	19.833333	656.1	468.6	250.8
13.666667	634.8	405.1	170.6	20	631	451.1	241.9
13.833333	709.3	457.4	196.8	20.166667	606.7	434.1	233.3
14	783.5	509.8	223.4	20.333333	583.1	417.5	224.8
14.166667	855.2	560.9	249.8	20.5	559.7	401.1	216.4
14.333333	924.3	610.4	275.8	20.666667	536.9	385	208.1
14.5	987.5	656.2	300.3	20.833333	515.2	369.7	200.2
14.666667	1046	698.9	323.5	21	494.8	355.2	192.6
14.833333	1098	737.2	344.8	21.166667	475.2	341.3	185.3
15	1143.5	771.2	364	21.333333	456.1	327.7	178.3
15.166667	1181.9	800.4	381	21.5	437.6	314.6	171.4
15.333333	1212.9	824.4	395.5	21.666667	420.2	302.1	164.8
15.5	1237.8	844.2	407.9	21.833333	403.5	290.2	158.5
15.666667	1256.9	859.9	418.3	22	387.4	278.7	152.4
15.833333	1270.1	871.5	426.7	22.166667	371.9	267.7	146.5
16	1274.8	877.1	432	22.333333	357.3	257.2	141
16.166667	1273.1	878.3	435	22.5	343.5	247.3	135.7
16.333333	1266.8	876.1	436.3	22.666667	330.4	237.9	130.7
16.5	1256.1	870.7	435.8	22.833333	317.8	228.9	125.9
16.666667	1241.1	862.2	433.7	23	305.9	220.3	121.3
16.833333	1221.7	850.7	429.9	23.166667	294.8	212.3	117
17	1198.2	836	424.4	23.333333	284.5	204.9	113
17.166667	1170.2	818.1	417.2	23.5	274.8	198	109.3
17.333333	1138.7	797.6	408.4	23.666667	265.8	191.5	105.8
17.5	1103.2	774.1	398	23.833333	257.4	185.5	102.6

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
24	249.8	180	99.7	30.333333	34.8	25.3	14.3
24.166667	242.6	174.9	97	30.5	32.2	23.3	13.2
24.333333	235.8	170	94.3	30.666667	29.7	21.5	12.2
24.5	229.3	165.3	91.8	30.833333	27.5	19.9	11.3
24.666667	223.1	160.8	89.5	31	25.5	18.5	10.5
24.833333	217.1	156.6	87.1	31.166667	23.6	17.1	9.7
25	211.3	152.4	84.9	31.333333	21.9	15.9	9
25.166667	205.5	148.2	82.6	31.5	20.3	14.7	8.4
25.333333	199.7	144.1	80.4	31.666667	18.8	13.6	7.7
25.5	194	139.9	78.2	31.833333	17.4	12.6	7.2
25.666667	188.2	135.7	75.9	32	16.1	11.7	6.6
25.833333	182.1	131.4	73.5	32.166667	14.9	10.8	6.2
26	175.9	127	71.1	32.333333	13.8	10	5.7
26.166667	169.6	122.4	68.6	32.5	12.8	9.3	5.3
26.333333	163.2	117.8	66	32.666667	11.9	8.6	4.9
26.5	156.6	113.1	63.4	32.833333	11	8	4.5
26.666667	150	108.3	60.7	33	10.2	7.4	4.2
26.833333	143.3	103.4	58	33.166667	9.4	6.8	3.9
27	136.6	98.6	55.4	33.333333	8.7	6.3	3.6
27.166667	130	93.9	52.7	33.5	8.1	5.9	3.3
27.333333	123.4	89.1	50	33.666667	7.5	5.4	3.1
27.5	116.9	84.4	47.4	33.833333	6.9	5	2.9
27.666667	110.5	79.8	44.8	34	6.4	4.6	2.6
27.833333	104.2	75.3	42.3	34.166667	5.9	4.3	2.4
28	98	70.8	39.8	34.333333	5.5	4	2.3
28.166667	92	66.5	37.4	34.5	5.1	3.7	2.1
28.333333	86.2	62.3	35	34.666667	4.7	3.4	1.9
28.5	80.6	58.2	32.8	34.833333	4.3	3.1	1.8
28.666667	75.2	54.3	30.6	35	4	2.9	1.6
28.833333	70	50.6	28.5	35.166667	3.7	2.7	1.5
29	65.1	47.1	26.5	35.333333	3.4	2.5	1.4
29.166667	60.4	43.7	24.6	35.5	3.1	2.3	1.3
29.333333	55.9	40.4	22.8	35.666667	2.9	2.1	1.2
29.5	51.7	37.4	21.1	35.833333	2.7	1.9	1.1
29.666667	47.8	34.6	19.5	36	2.5	1.8	1
29.833333	44.2	32	18.1				
30	40.8	29.6	16.7				
30.166667	37.7	27.3	15.5				

DREAM

Disaster RIsk and Exposure Assessment for Mitigation