REGION 6

Panay River Basin:

DREAM Flood Forecasting and Flood Hazard Mapping

TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY

2015

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

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

UP TCAGP (2015), DREAM Flood Forecasting and Flood Hazard Mapping for Panay River Basin, Disaster Risk Exposure and Assessment for Mitigation (DREAM), DOST Grants-in-Aid Program, 69 pp.

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Natioanal Library of the Philippines
ISBN: 978-971-9695-29-5

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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.

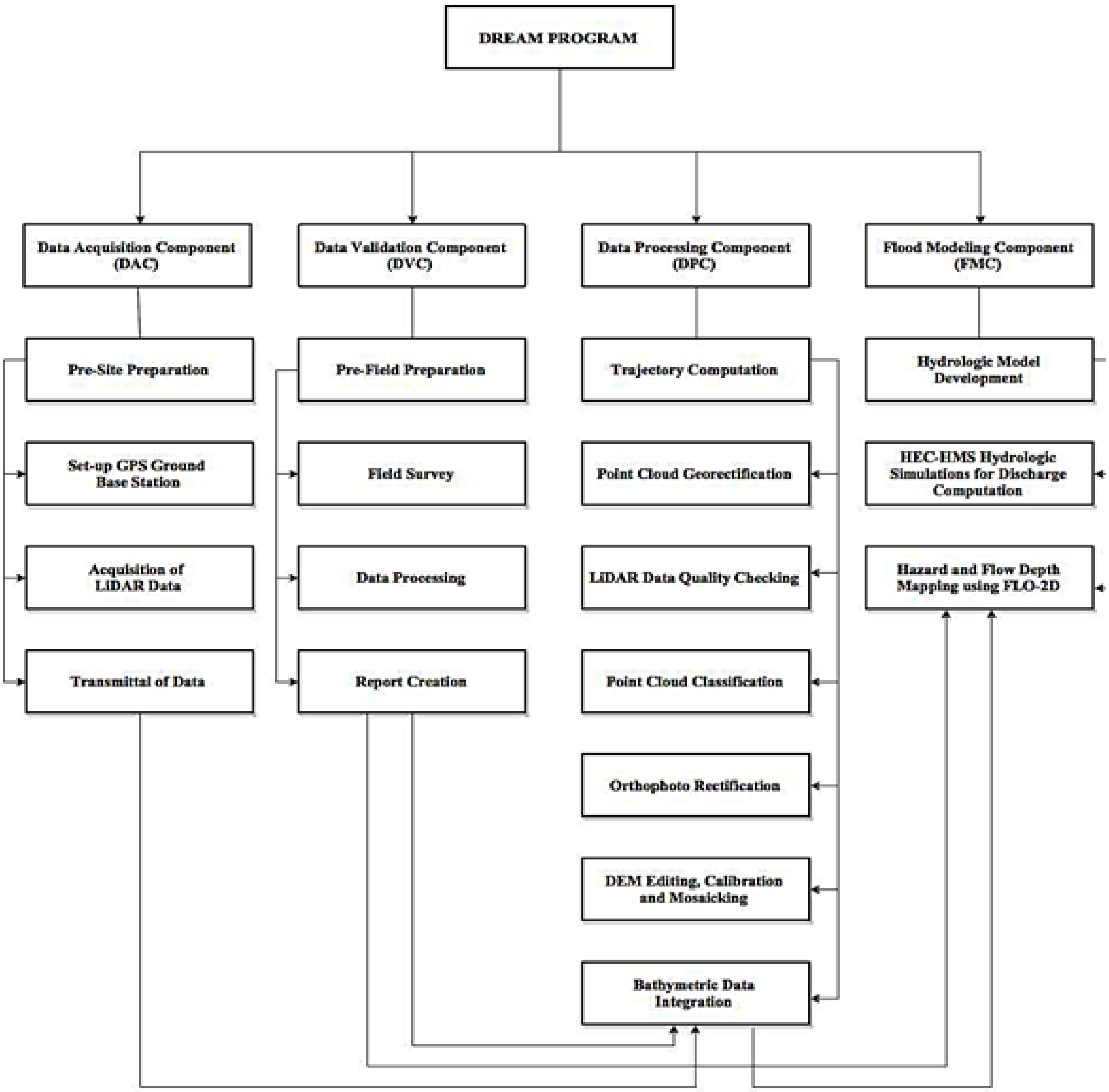


Figure 1. The general methodological framework of the program

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

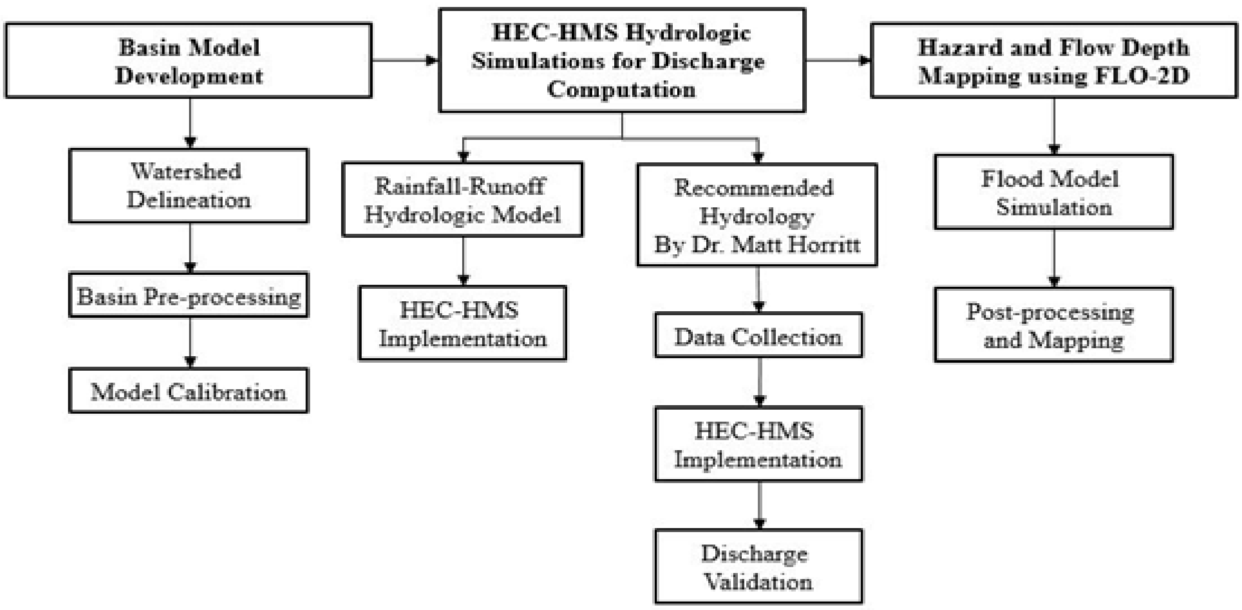


Figure 2. The operational framework and specific work flow of the Flood Modeling Component

The Panay River Basin

The Panay River Basin

The Panay River Basin located in the north eastern part island of Panay in Western Visayas. The Panay River Basin is considered as the 12th largest river basin in the Philippines. It covers an estimated basin area of 1,843 square kilometers. The location of Panay River Basin is as shown in Figure 3.

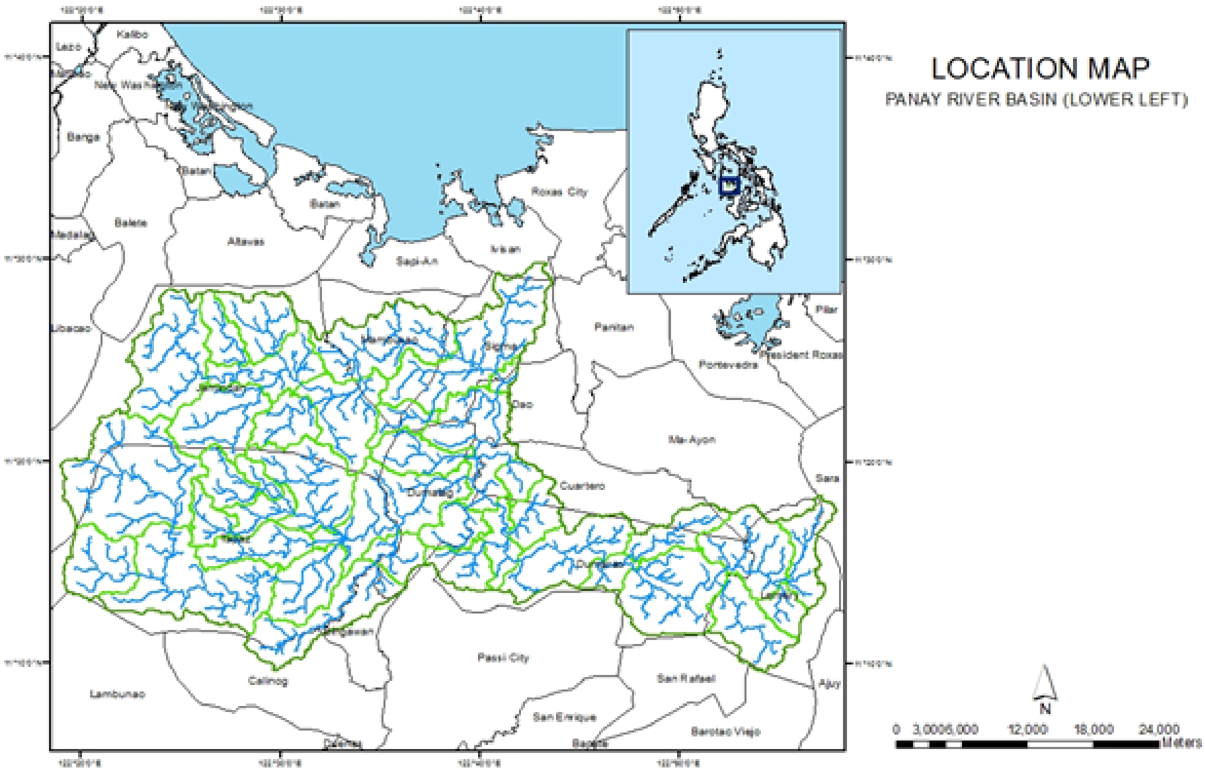


Figure 3. Panay River Basin Location Map

This area includes the whole province of Capiz and a part of Iloilo and Aklan.. The upper part of the Panay River Basin consists of the Upper Panay River mainstream basin and three major tributary basins, the Badbaran, Mambusao, and Maayon river basins. It traverses through the Roxas City and the towns of Capiz and Pontevedra and drains the northern portion of the island.

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 Panay River Basin

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

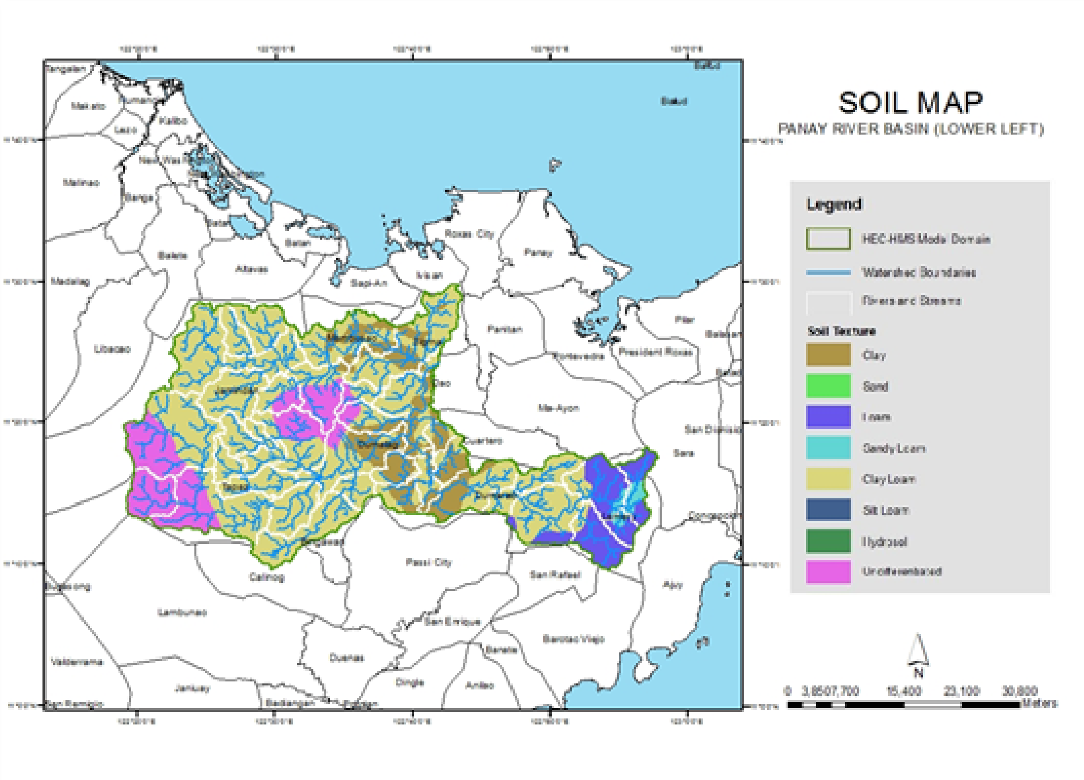


Figure 4. Panay River Basin Soil Map

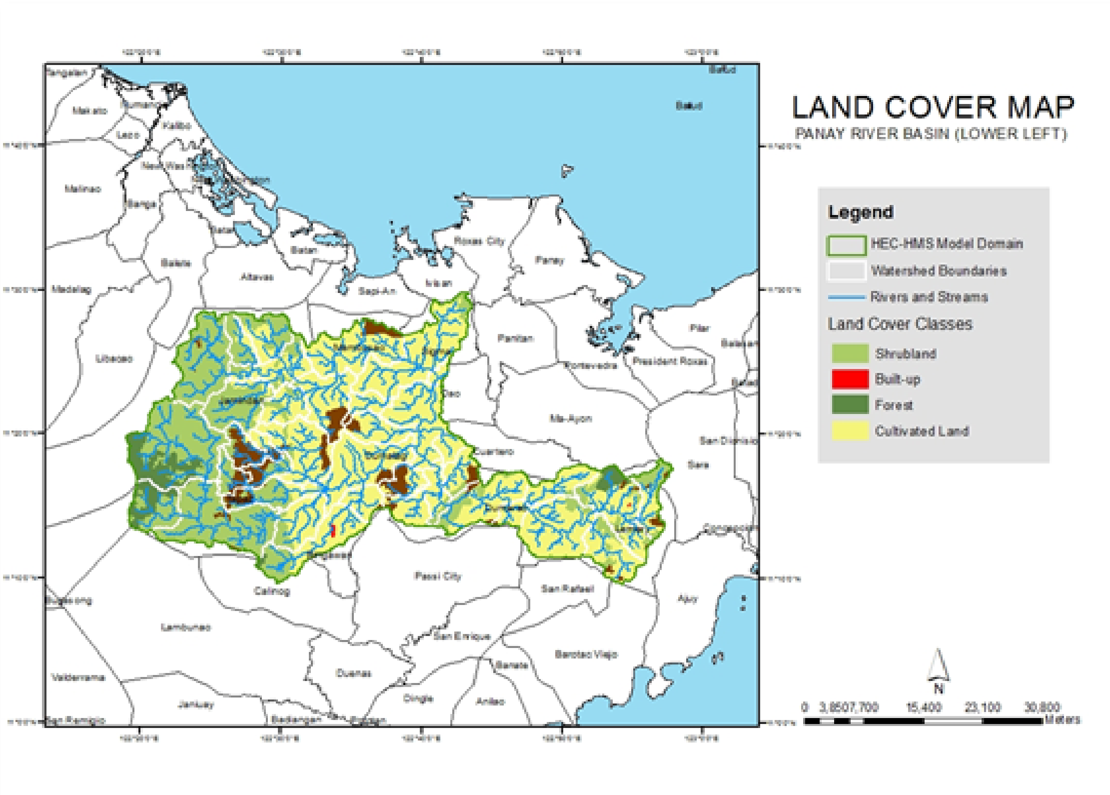


Figure 5. Panay River Basin Land Cover Map

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.

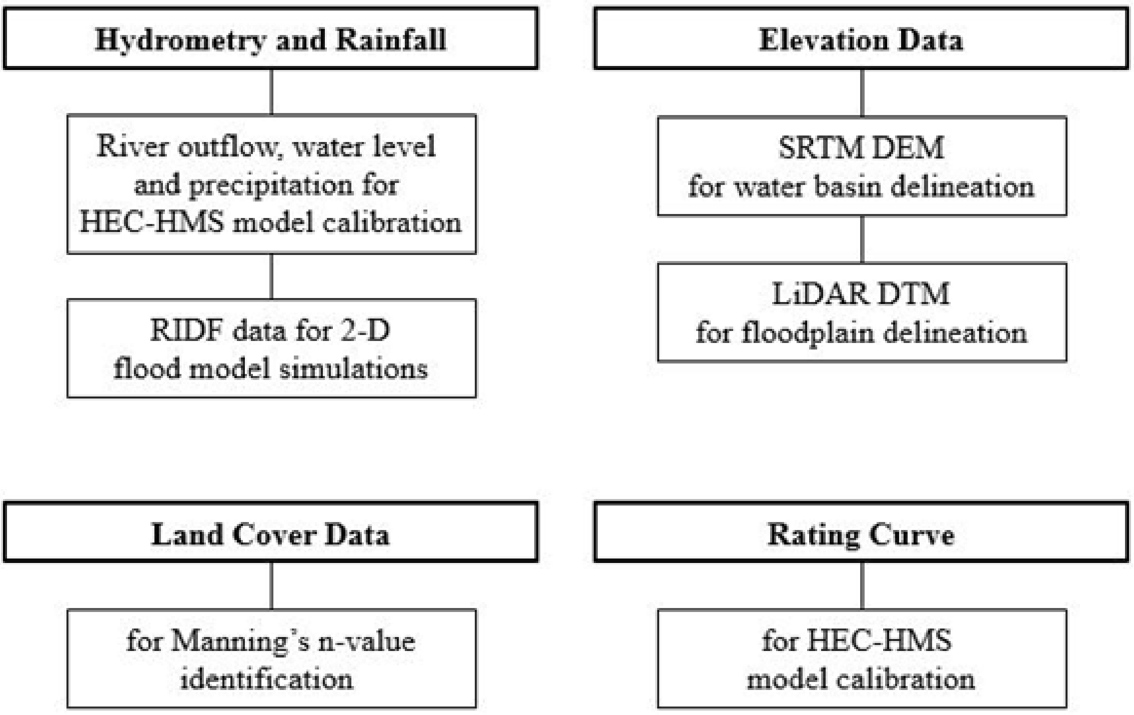


Figure 6. Summary of data needed for the purpose of flood modeling

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.

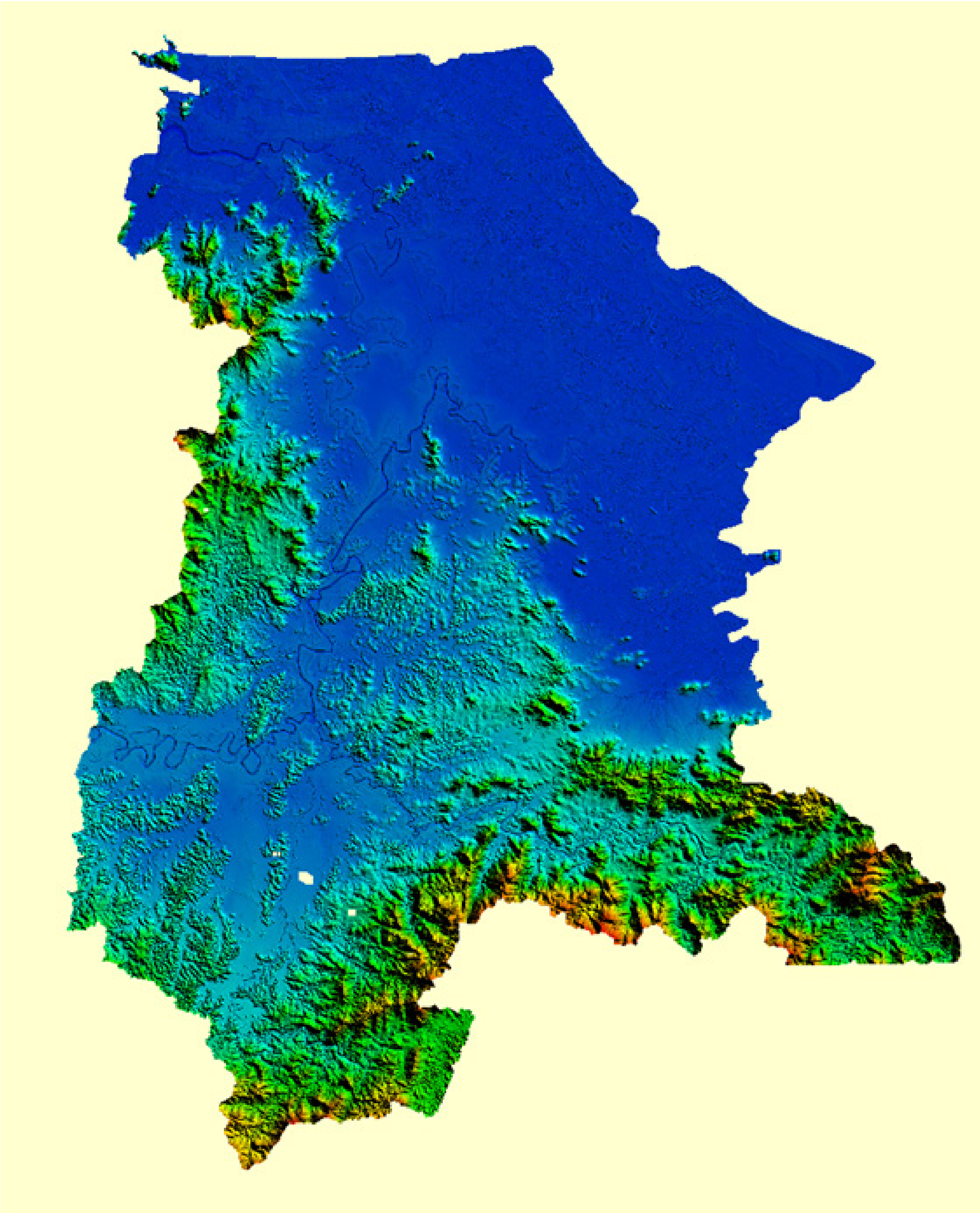


Figure 7. Digital Elevation Model (DEM) of the Panay River Basin using Light Detection and Ranging (LiDAR) technology

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

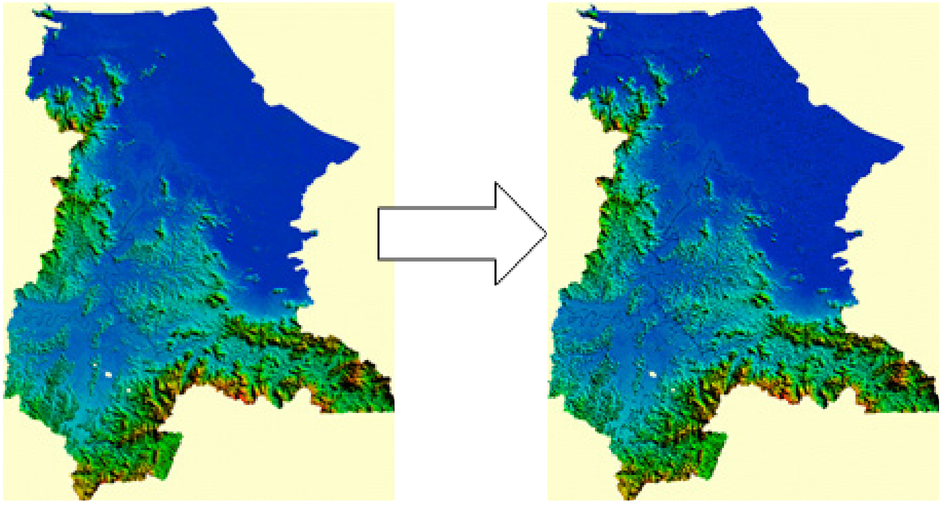


Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted.

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 Panay 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 Panay floodplain.

3.1.3 Hydrometry and Rainfall Data

3.1.3.1 Hydrometry for different discharge points

3.1.3.1.1 Dao, Capiz

This was taken from Dao Bridge located in the municipality of Dao, Capiz (11°23'31.95"N, 122°41'13.65"E). This was recorded during the typhoon Yolanda event on November 9, 2013. Peak discharge is 745.1 at 7:00 AM.

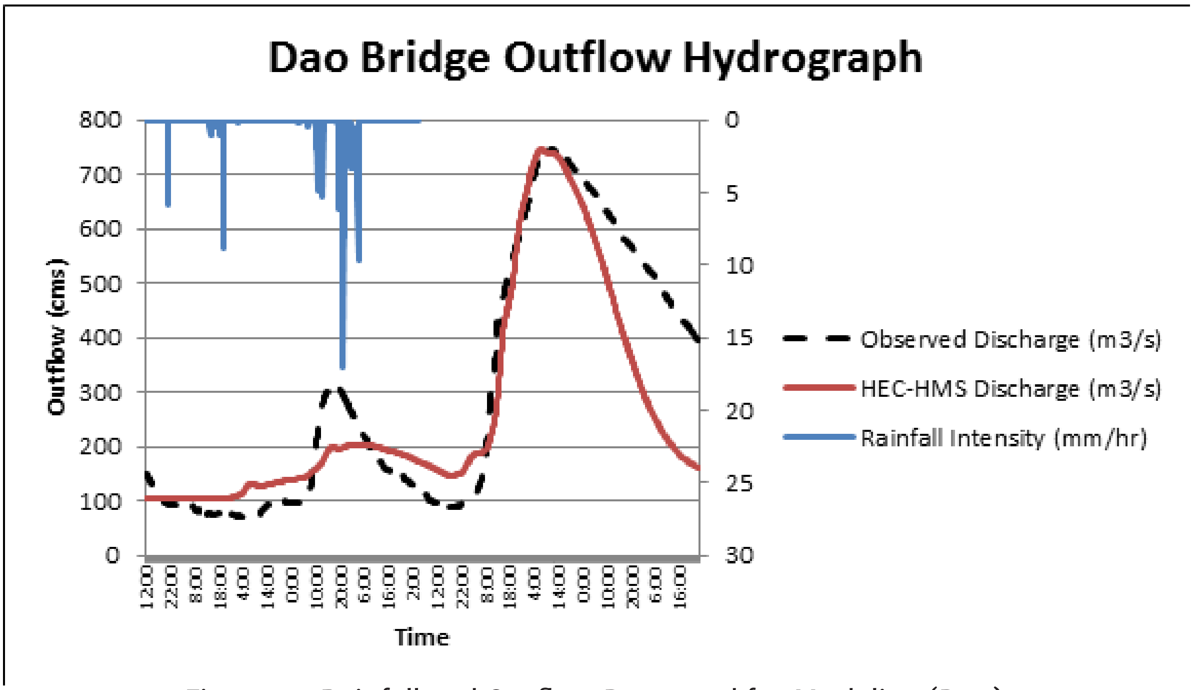


Figure 10. Rainfall and Outflow Data used for Modeling (Dao)

3.1.3.1.2 Panit-an Bridge, Panit-an

This was taken from Panit-An Bridge, Panit-An (11°27’49.17”N, 122°46’11.20”E). The recorded peak discharge is 5815 cms at 2:40 AM, February 2, 2014.

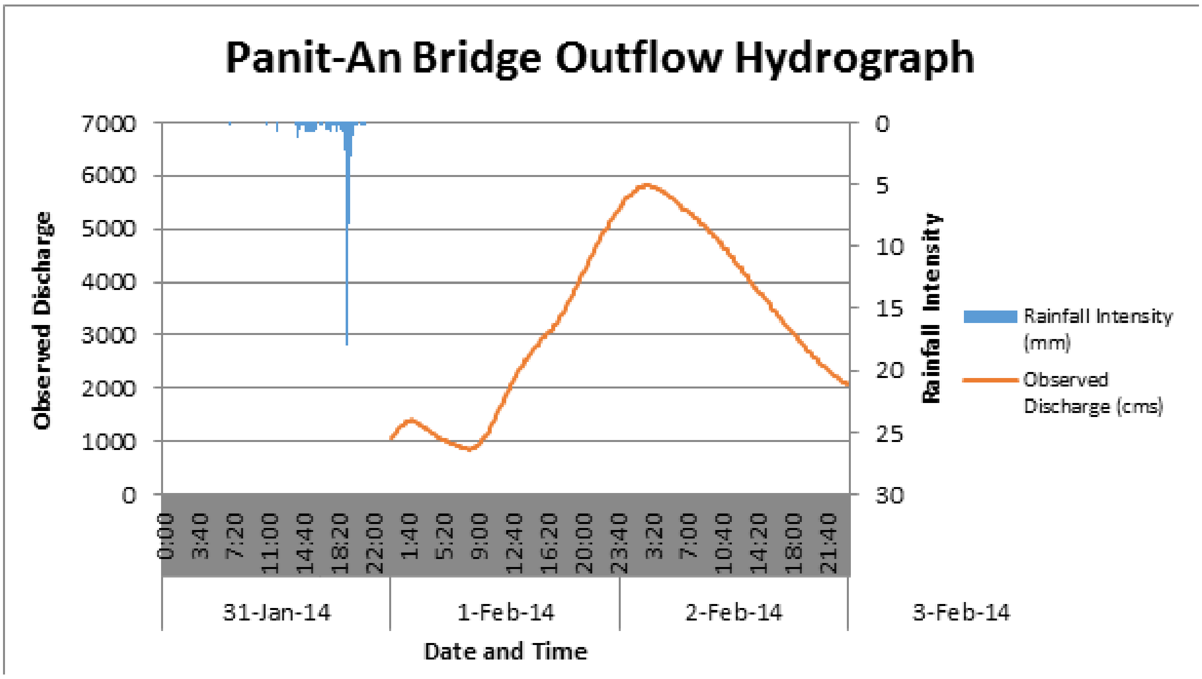


Figure 11. Rainfall and Outflow Data used for Modeling (Panit-an)

3.1.3.2 Rainfall Intensity Duration Frequency (RIDF)

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

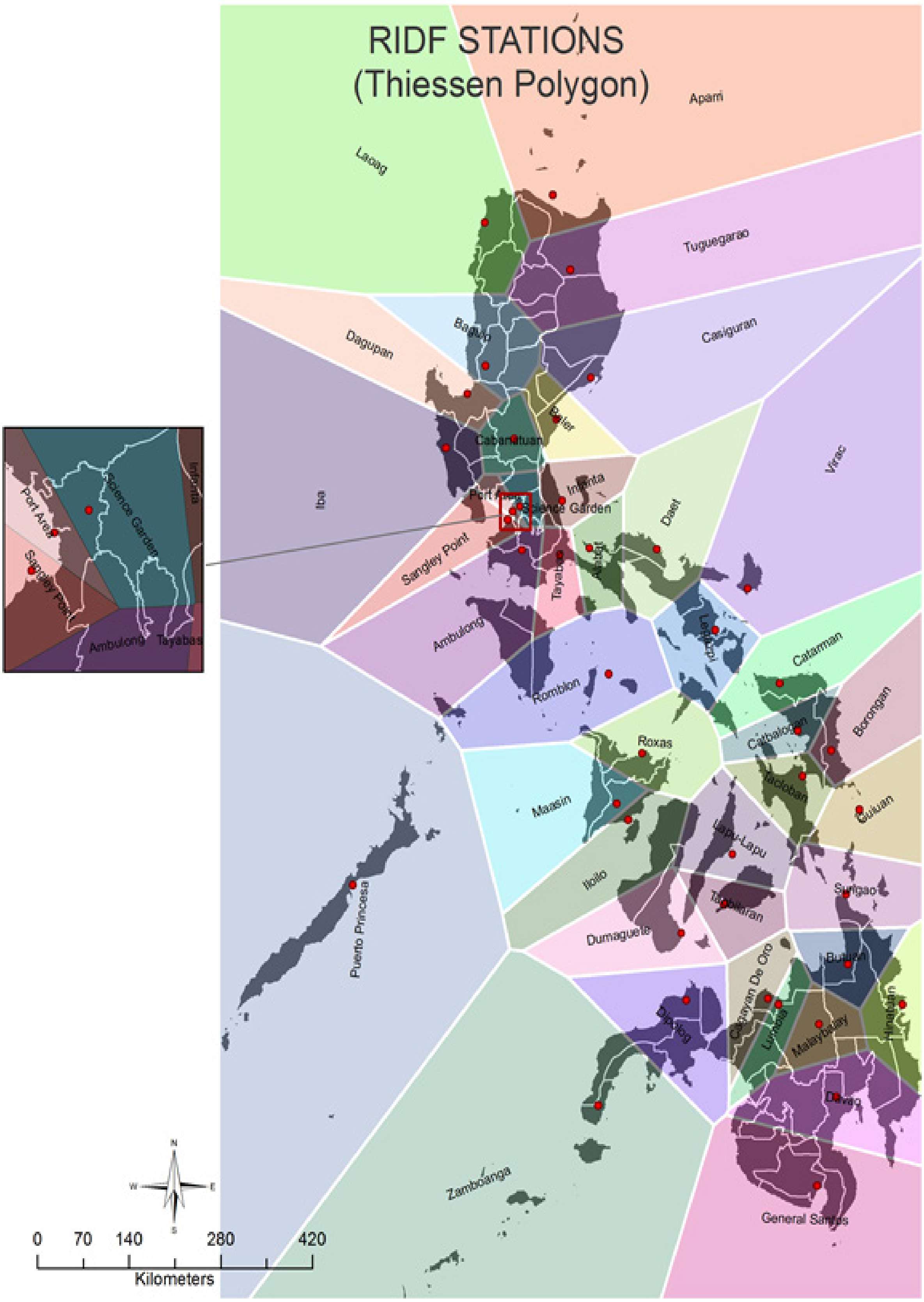


Figure 12. Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines.

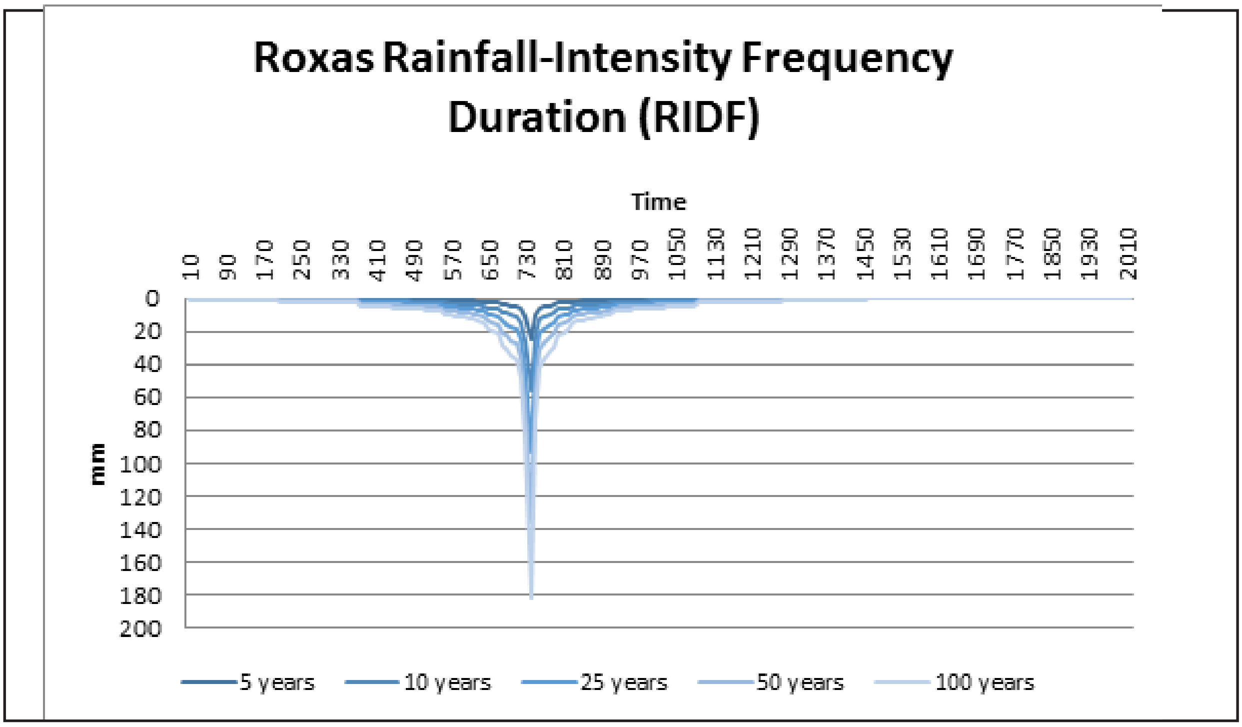


Figure 13. Roxas Rainfall Intensity Duration Frequency Curves

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

3.1.4 Rating Curves

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

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

$$Q = a^{nh}$$

Equation 1. Rating Curve

3.1.4.1 Dao Bridge Rating Curve

For Dao Bridge, the rating curve is expressed as $Q = 0.0018e^{1.5434x}$ as shown in Figure 14.

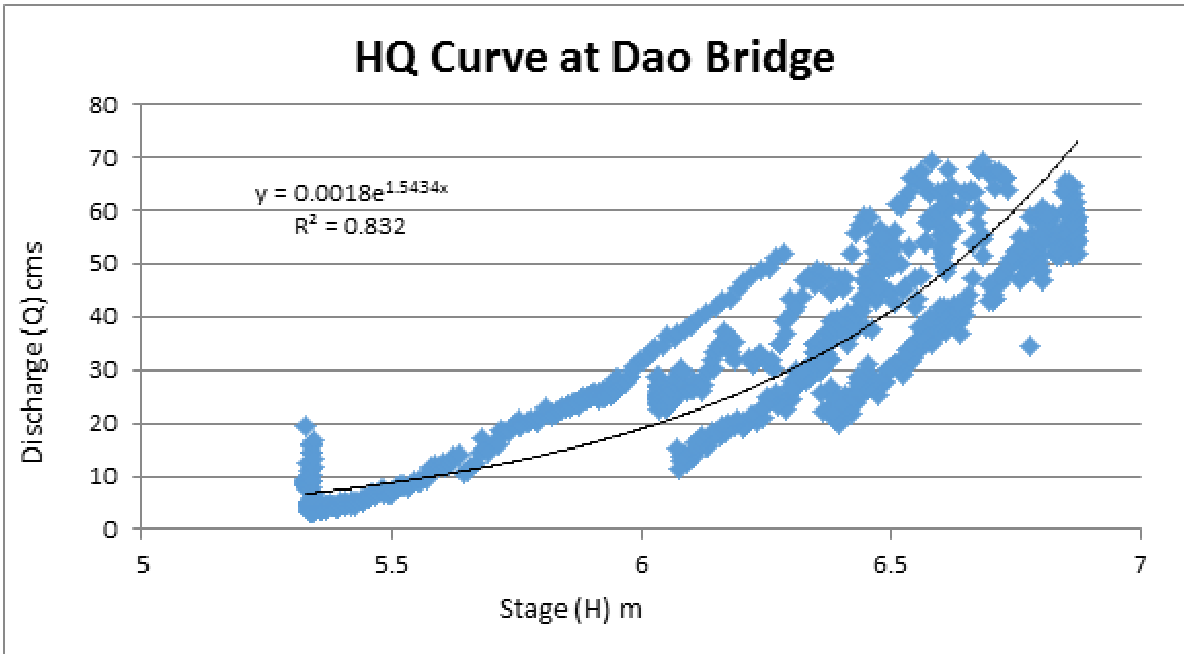


Figure 14. Water level vs. Discharge Curve for Dao Bridge

3.1.4.2 Panit-an Rating Curve

For Andanan Bridge, Panay, the rating curve is expressed as $Q = 3E^{-06e0.7368h}$ as shown in Figure 20.

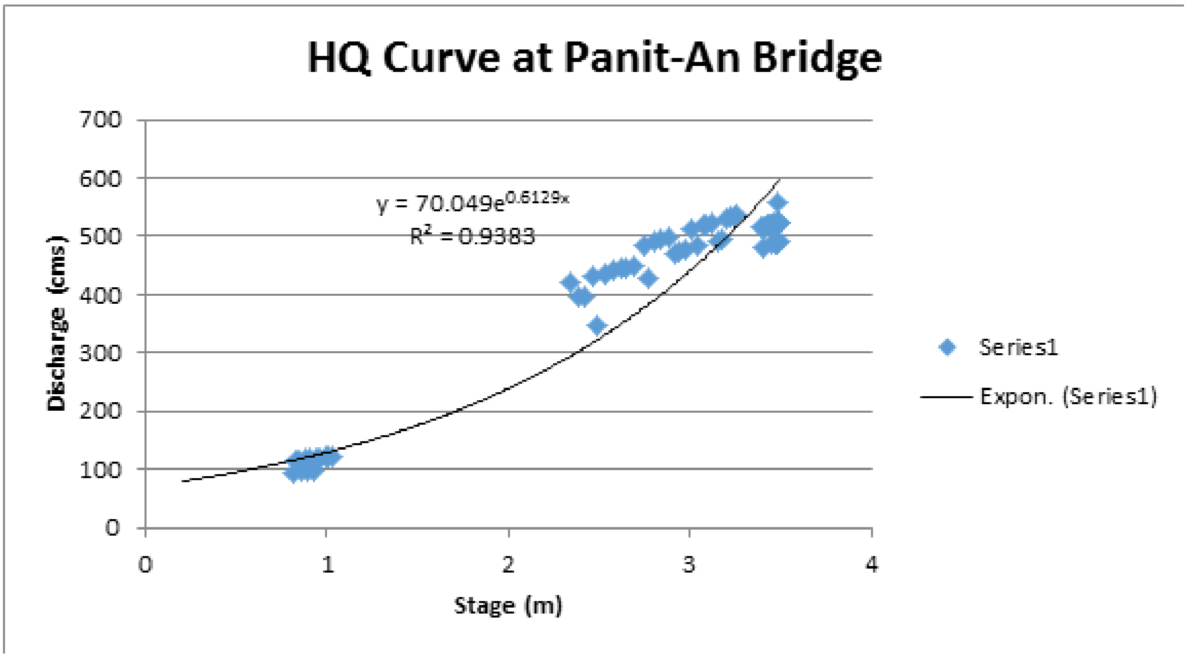


Figure 15. Water level vs. Discharge Curve for Panit-an

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

The hydrologic model of Panay 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 Figure 16.

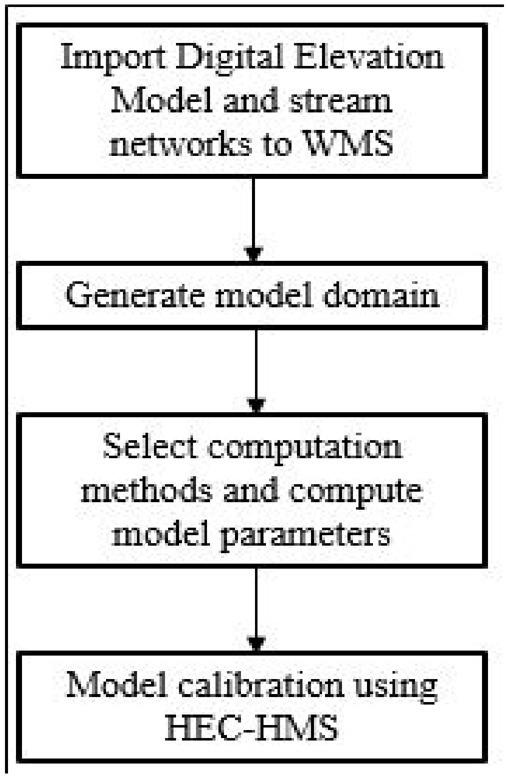


Figure 16. The Rainfall-Runoff Basin Model Development Scheme

Hydro-corrected SRTM DEM was used as the terrain for the basin model. The watershed delineation and its hydrologic elements, namely the subbasins, junctions and reaches, were generated using WMS after importing the elevation data and stream networks. An illustration of the Panay HEC-HMS domain is shown in Figure 17.

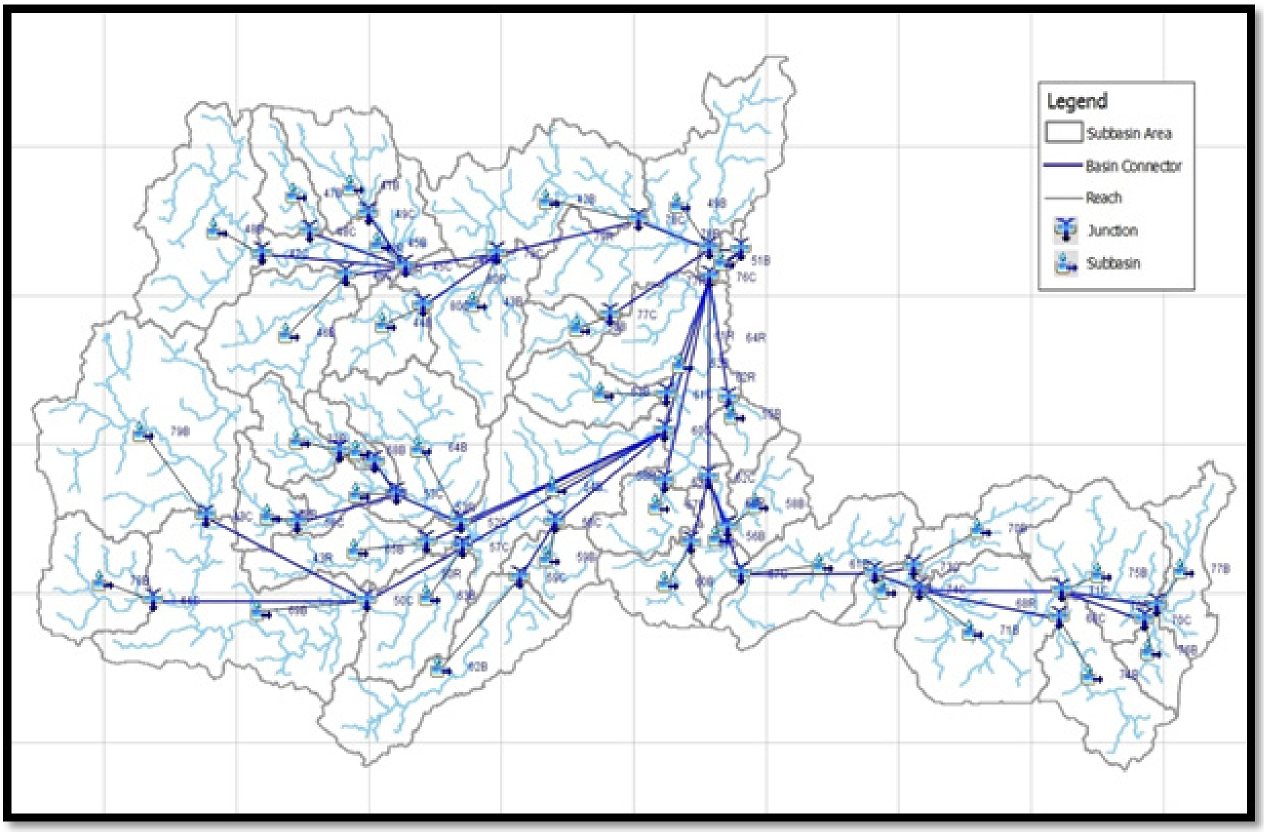


Figure 17. Panay HEC-HMS Model domain generated by WMS

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

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

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

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 the automatic rain gauge (ARG) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). This is the ARG located in Brgy. Codingle. The location of the rain gauge is seen in Figure 19.

The total rain based on the Codingle rain gauge is 153.67mm. It peaked to 17.018mm on 08 November, 2013 at 2:00. The lag time between the peak rainfall and discharge is twenty nine (29) hours.

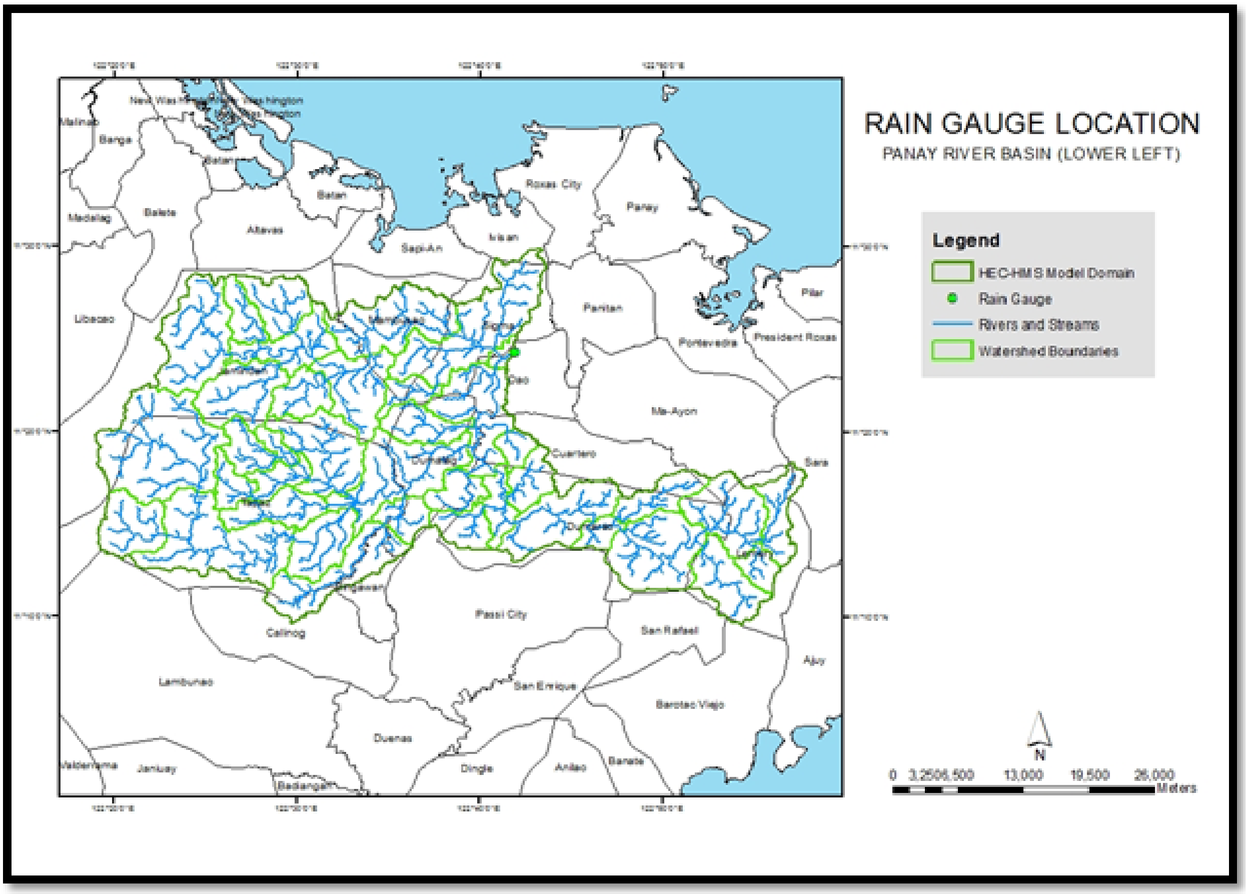


Figure 18. The location map of rain gauges used for the calibration of the Panay HEC-HMS

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

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

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 Panay River Basin using WMS and HEC-HMS was used to simulate the flow for for the five return periods, namely, 5-, 10-, 25-, 50-, and 100-year RIDFs. Time-series data of the precipitation data using the Roxas RIDF curves were encoded to HEC-HMS for the aforementioned return periods, wherein each return period corresponds to a scenario. This process was performed for Panay 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

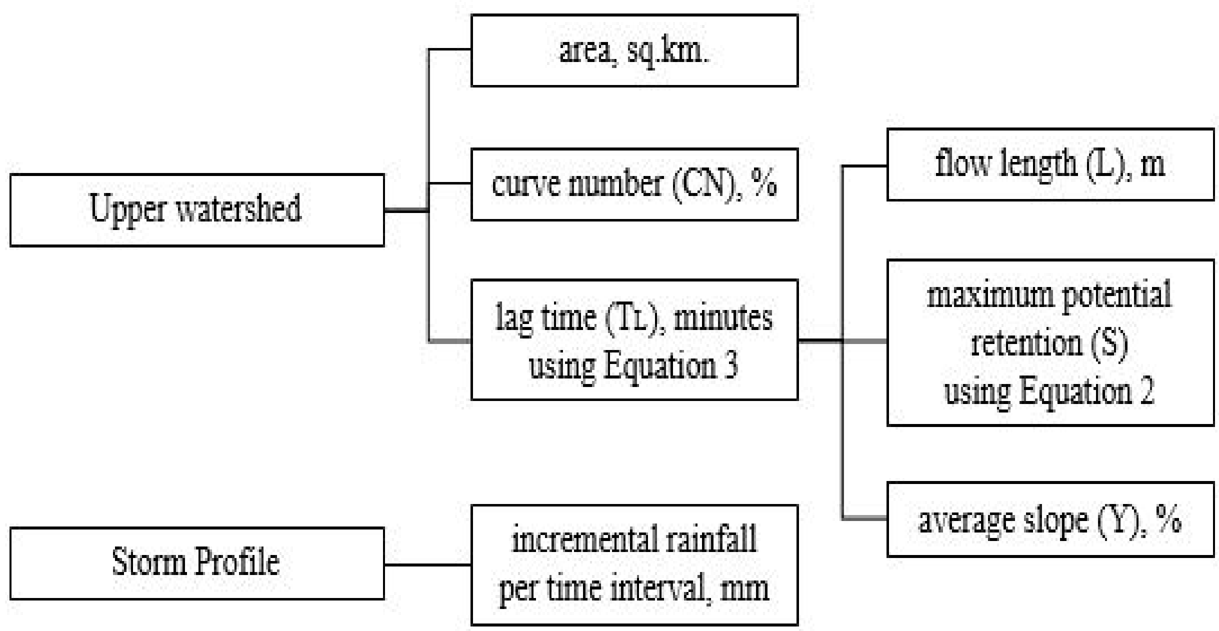


Figure 19. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method.

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. The method utilizes the SCS curve number and unit hydrograph method to have an accurate approximation of river discharge data from measurable catchment parameters.

3.3.2.1 Determination of Catchment Properties

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

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

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

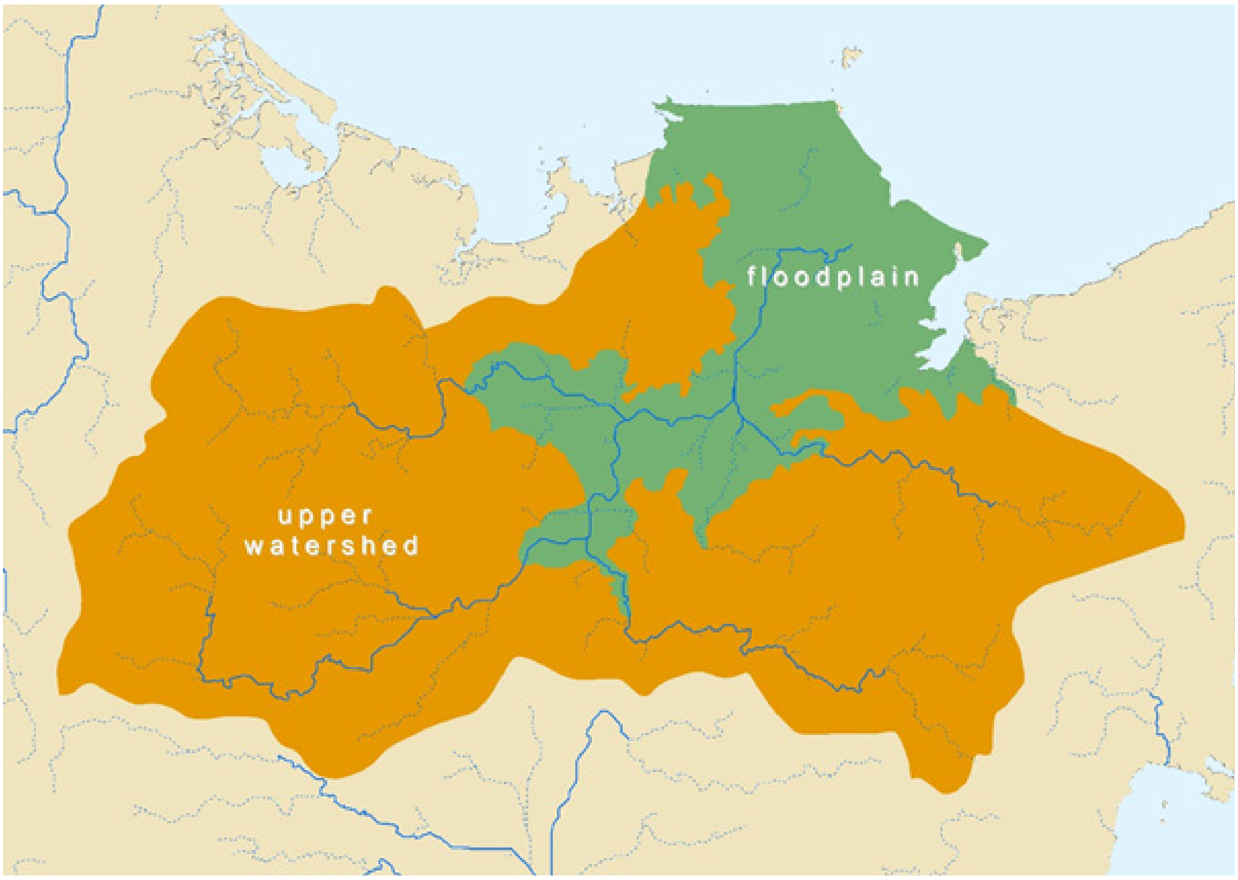


Figure 20. Delineation upper watershed for Panay floodplain discharge computation

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.

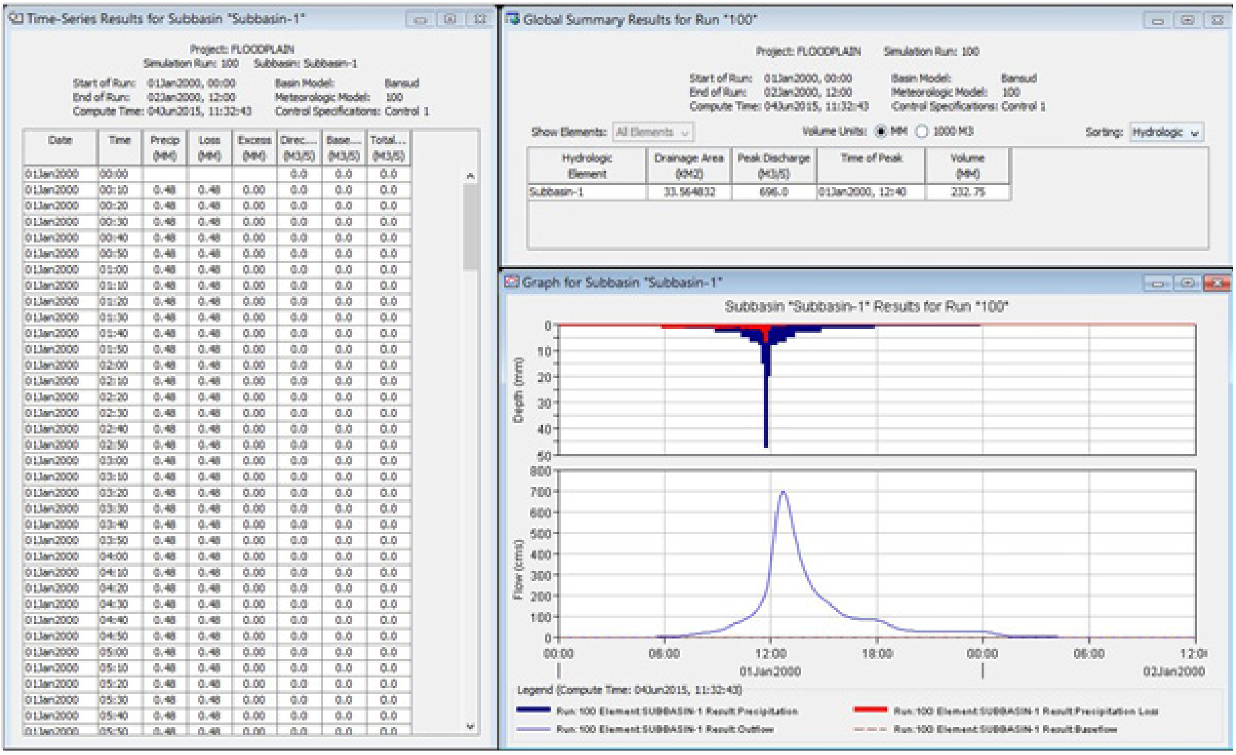


Figure 21. HEC-HMS simulation discharge results using Dr. Horritt's Method

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

he 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.

Methodology

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.

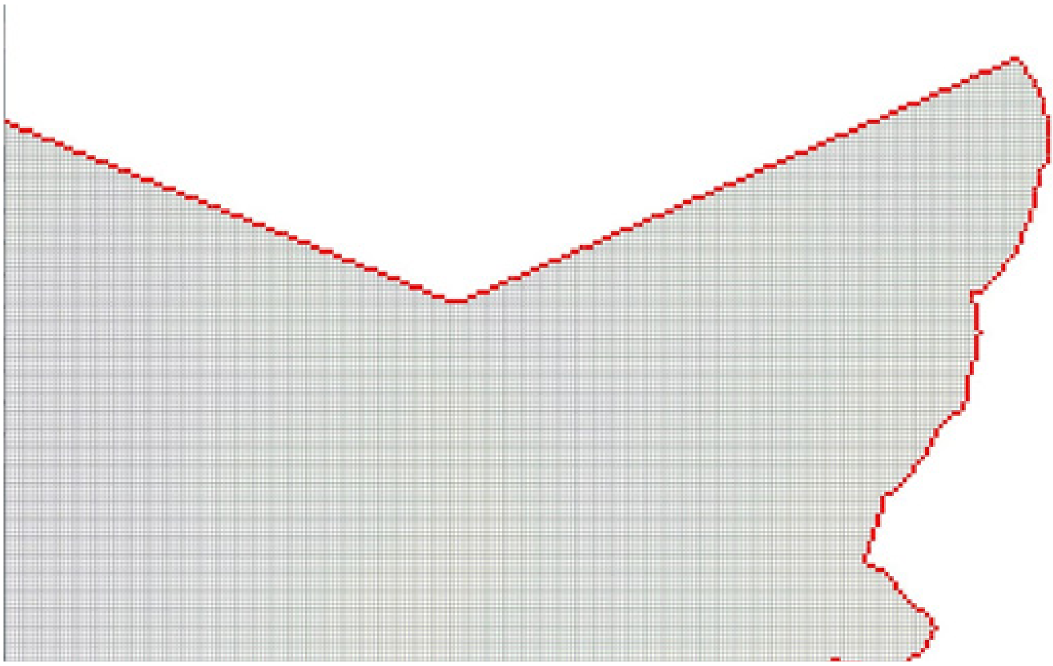


Figure 22. Screenshot showing how boundary grid elements are defined by line

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.

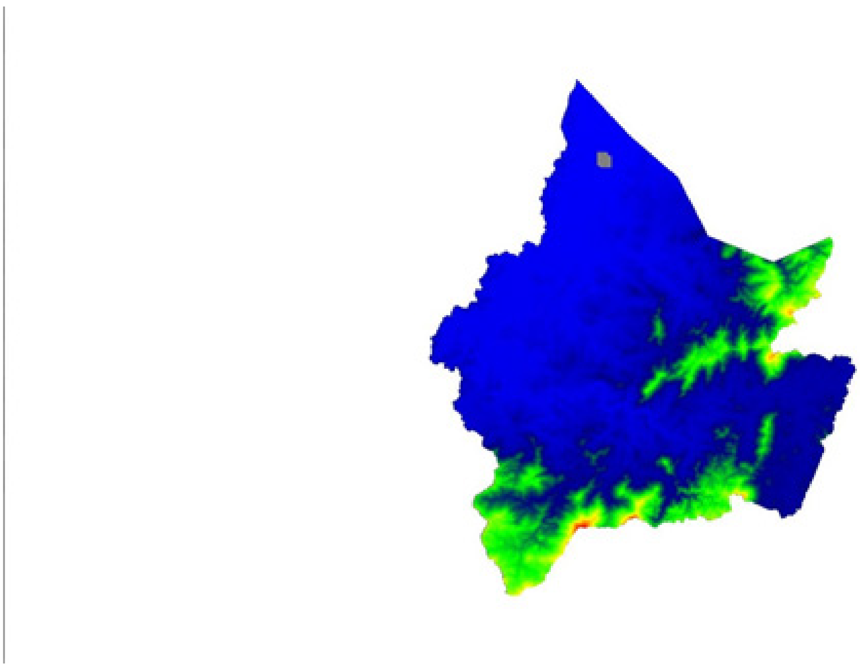


Figure 23. Screenshots of PTS files when loaded into the FLO-2D program

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 24. Aerial Image of Panay floodplain

Figure 25. 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 in Figure 26.

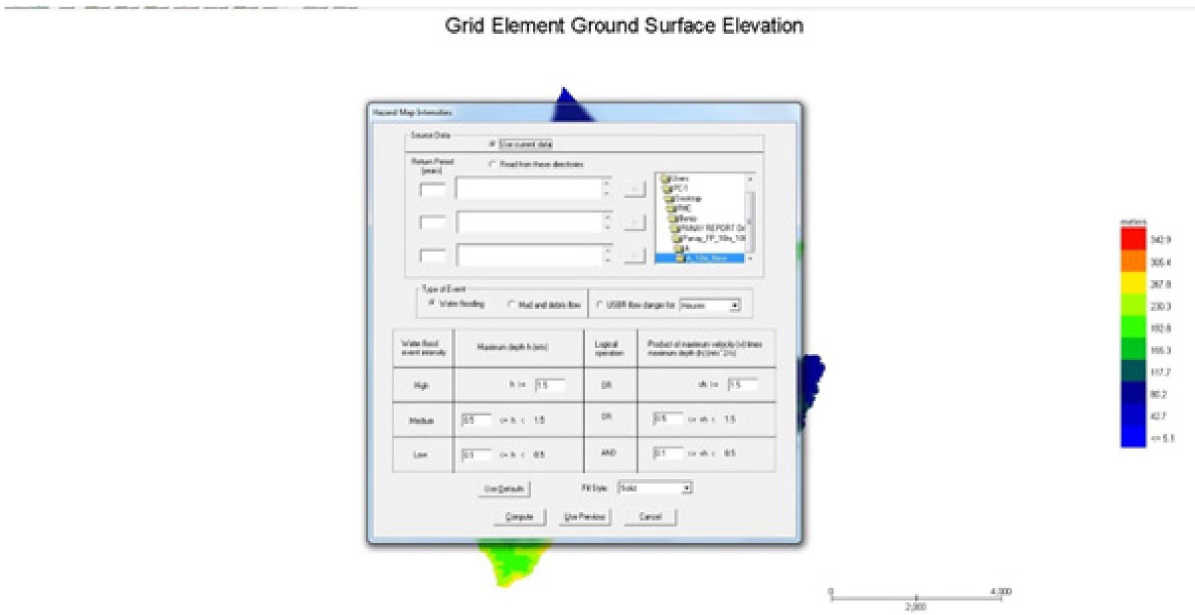


Figure 26. Flo-2D Mapper Pro General Procedure

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.

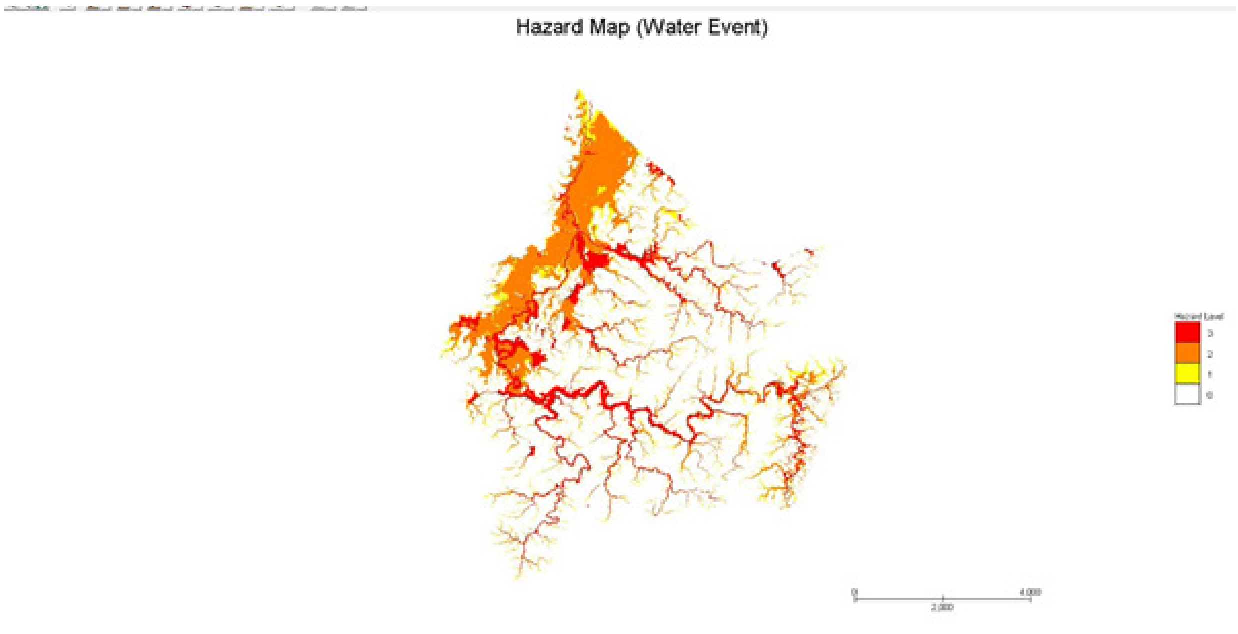


Figure 27. Panay Floodplain Generated Hazard Maps using Flo-2D Mapper

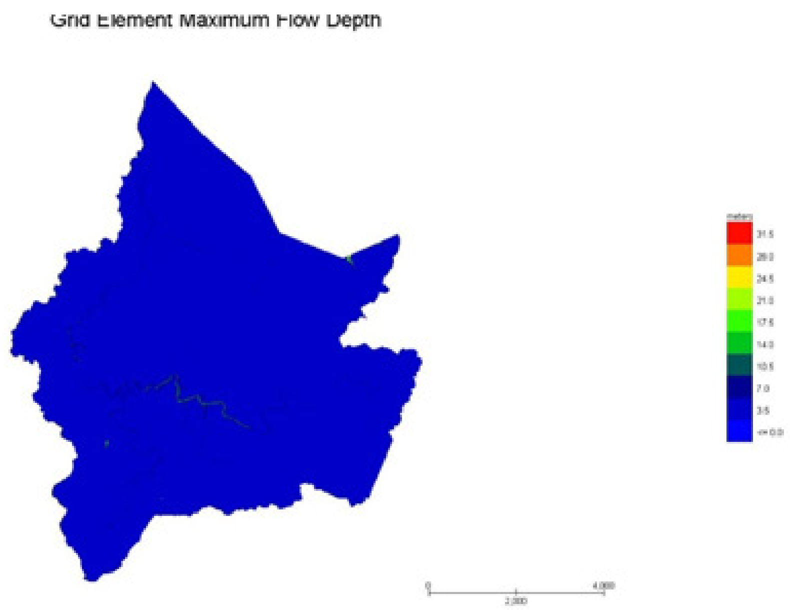
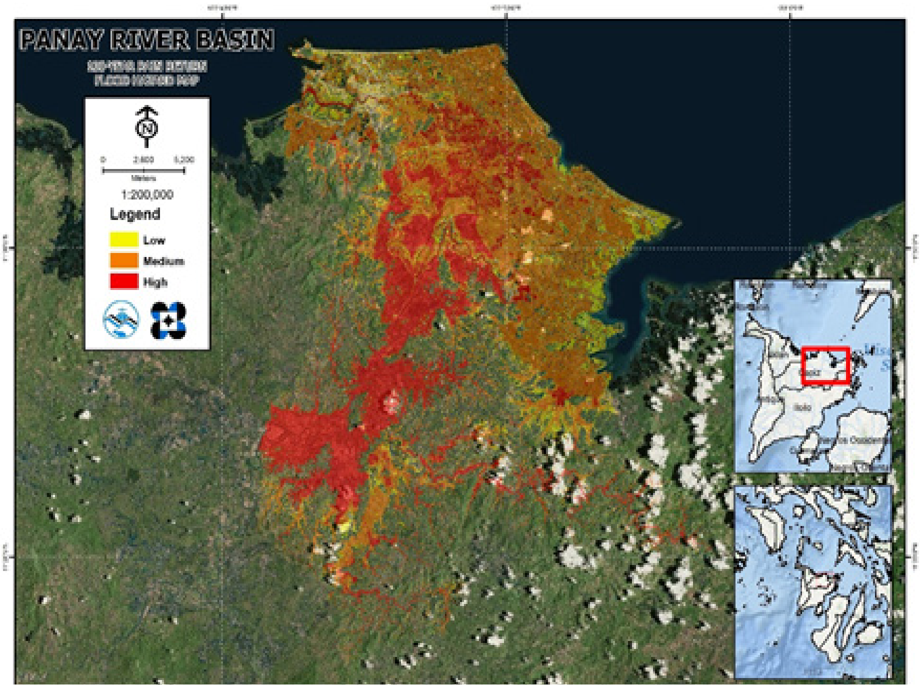


Figure 28. Panay floodplain generated flow depth map using Flo-2D Mapper

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 29. 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 29. 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

4.1.1 Dao Bridge

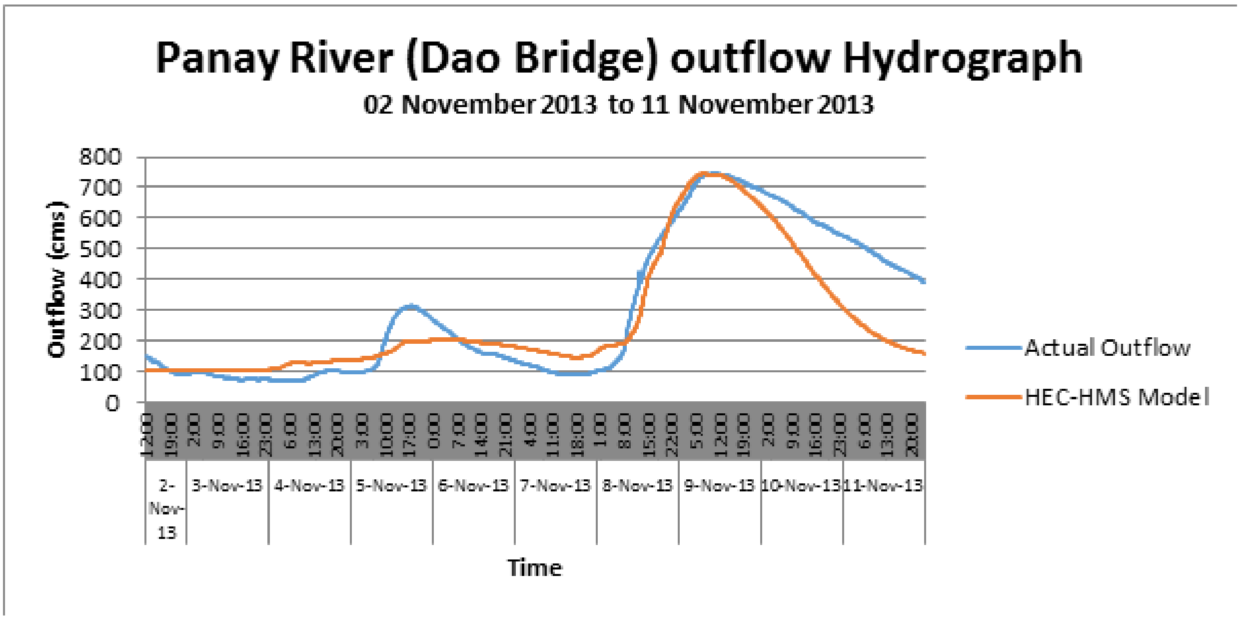


Figure 30. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow at Dao Bridge

After calibrating the Panay (Dao Bridge) HEC-HMS river basin model, its accuracy was measured against the observed values and is shown in Figure 30.

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 37.1319.

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 0.269914812.

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 11.35555497

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.519533263.

4.1.2 Panit-an Bridge

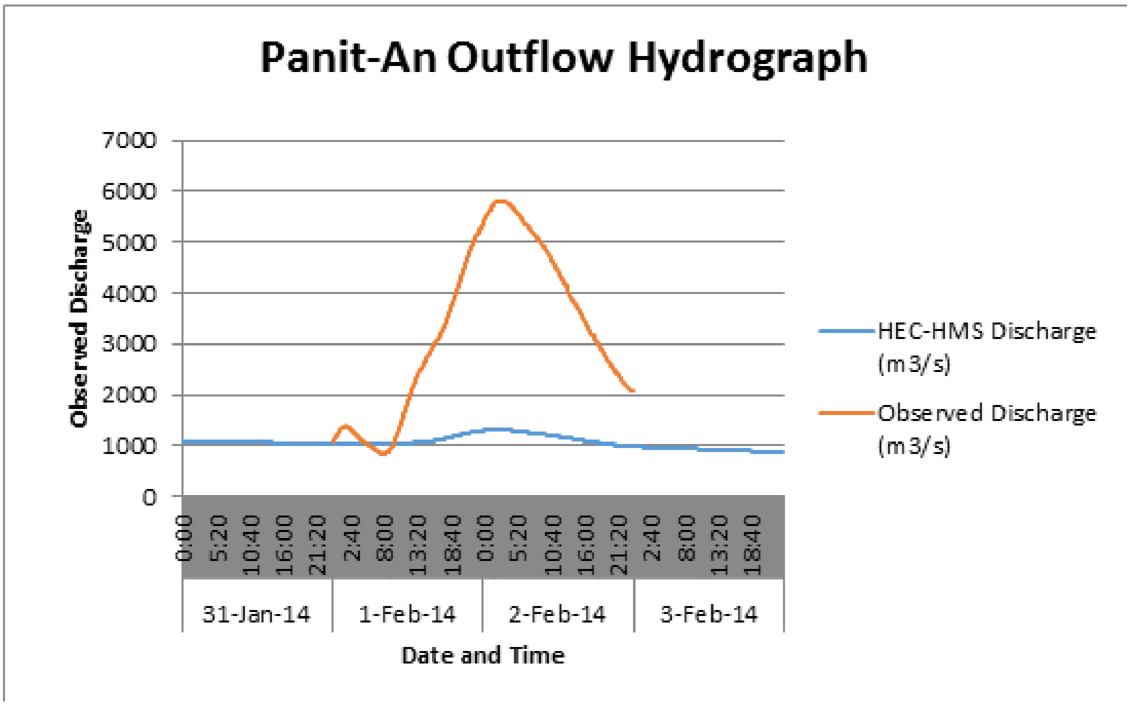


Figure 31. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow at Panit-an Bridge

After calibrating the Andanan HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 38 shows the comparison between the two discharge data.

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 1.9.

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 0.9615.

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 0.87.

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 -11.29.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.36.

Results and Discussion

After calibrating the Panit-An HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 32 shows the comparison between the two discharge data. The RMSE was identified at 2016.68. The Pearson correlation coefficient (r2) measured 0.84. The Nash-Sutcliffe (E) method attained an efficiency coefficient of -1.65. The PBIAS is 191.09. Finally, the model has an RSR value of 1.63.

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.

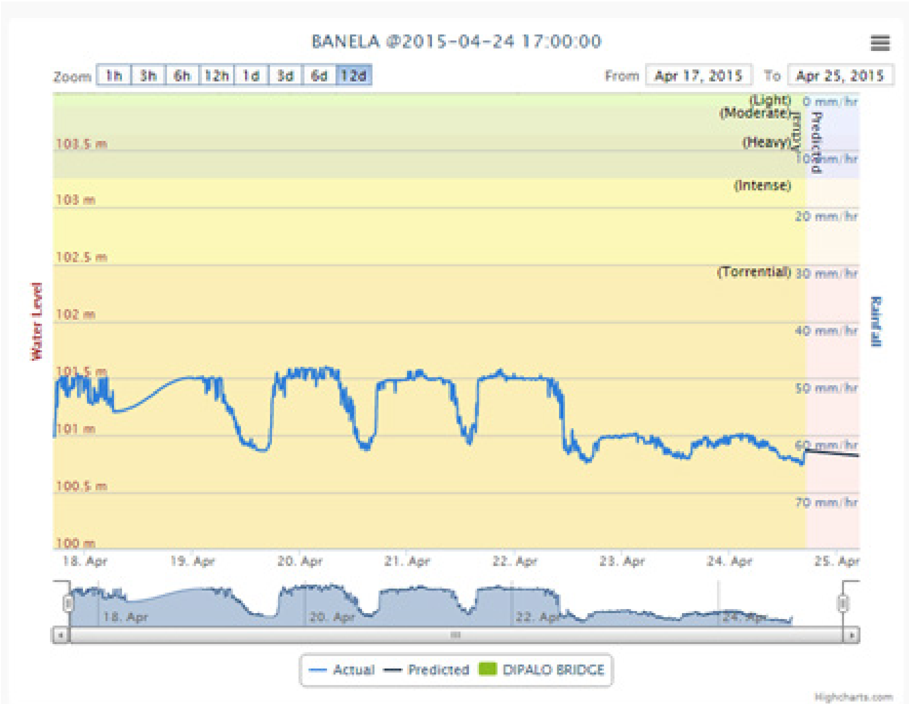


Figure 32. Sample DREAM Water Level Forecast

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

4.2.1.1 Dao Bridge

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

In the 5-year return period graph shown in Figure 30, the peak outflow is 949.5 cms. This occurs after 8 hours and 10 minutes after the peak precipitation of 25.05 mm.

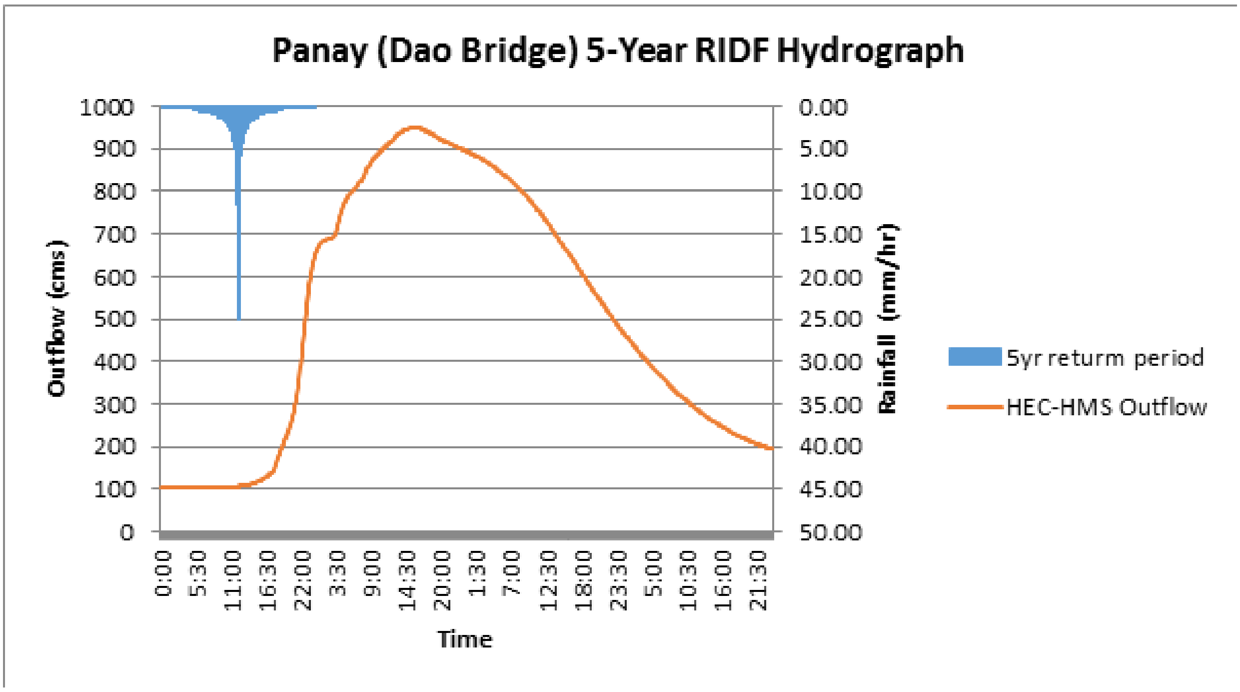


Figure 33 . Outflow hydrograph generated using the Roxas 5-Year RIDF inputted in HEC-HMS

In the 10-year return period graph shown in Figure 31, the peak outflow is 1299.5 cms. This occurs after 7 hours and 10 minutes after the peak precipitation of 30.80 mm.

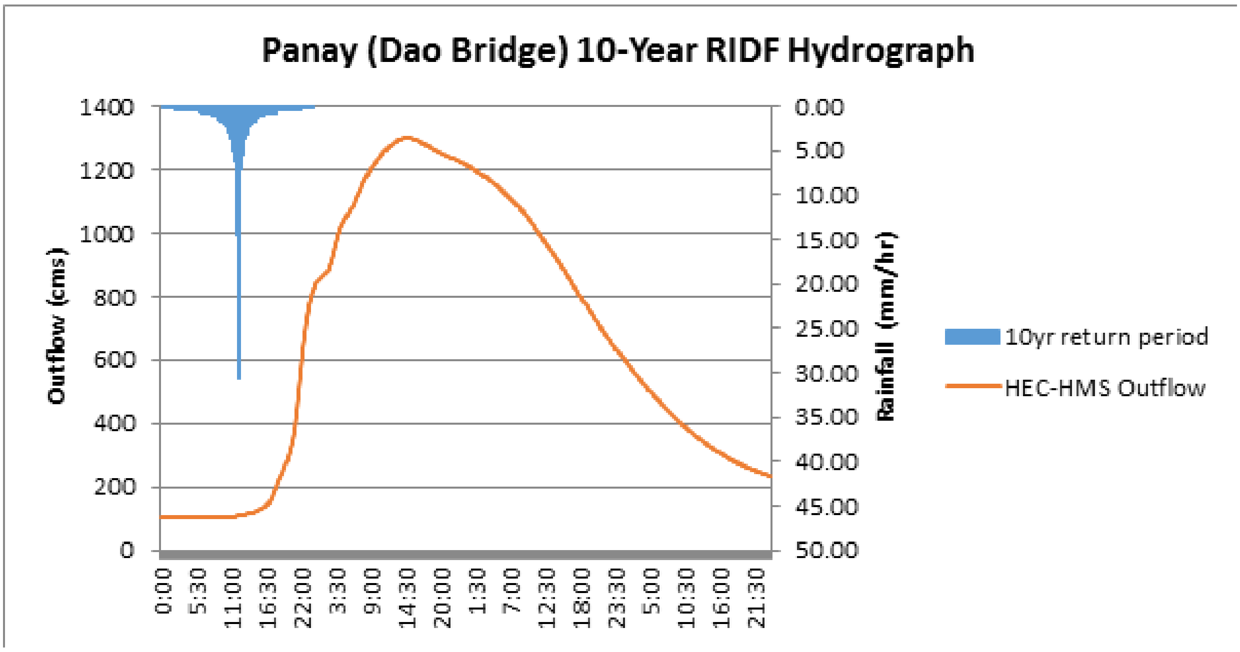


Figure 34. Outflow hydrograph generated using the Roxas 10-Year RIDF inputted in HEC-HMS

In the 25-year return period graph showin in Figure 32, the peak outflow is 1448.8 cms. This occurs after 6 hours and 50 minutes after the peak precipitation of 37.46 mm.

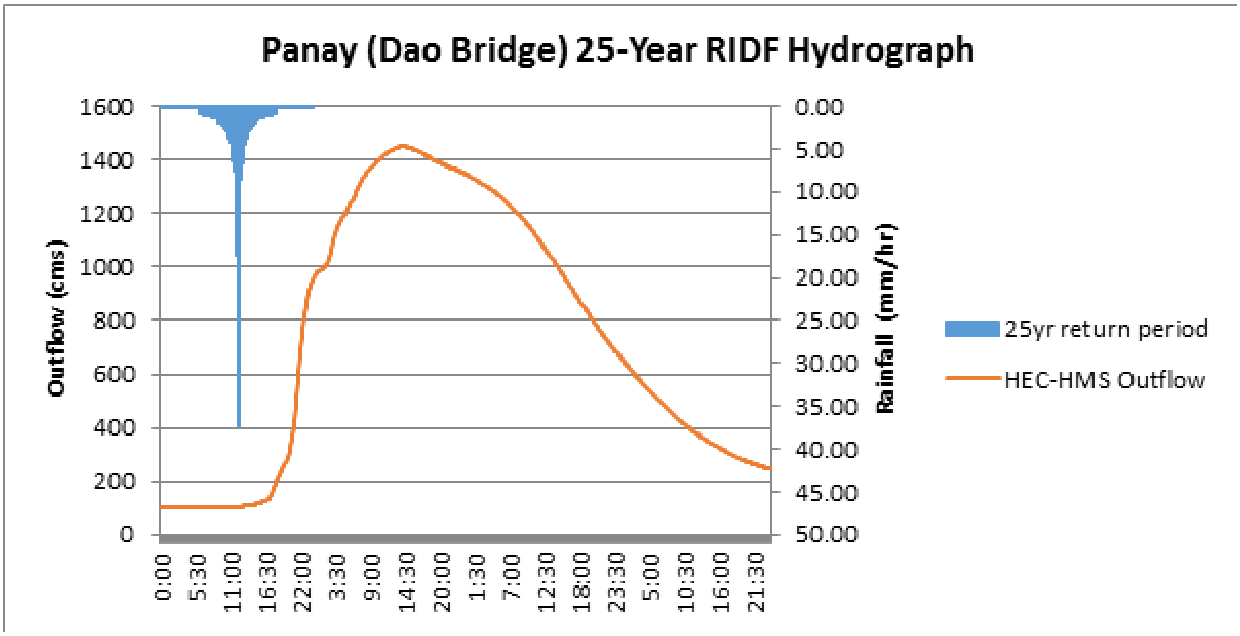


Figure 35. Outflow hydrograph generated using the Roxas 25-Year RIDF inputted in HEC-HMS

In the 50-year return period graph shown in Figure 33, the peak outflow is 1801 cms. This occurs after 6 hours after the peak precipitation of 42.09 mm.

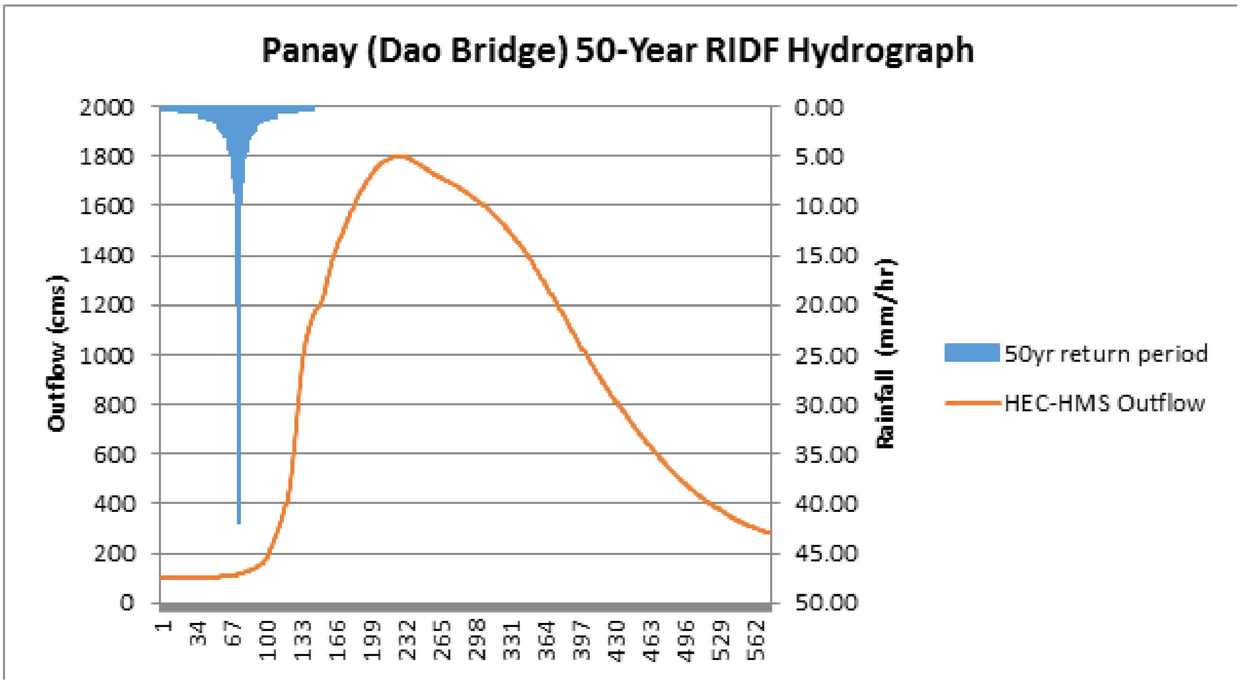


Figure 36. Outflow hydrograph generated using the Roxas 50-Year RIDF inputted in HEC-HMS

In the 100-year return period graph shown in Figure 34, the peak outflow is 2007.8 cms. This occurs after 5 hours and 50 minutes after the peak precipitation of 46.75 mm.

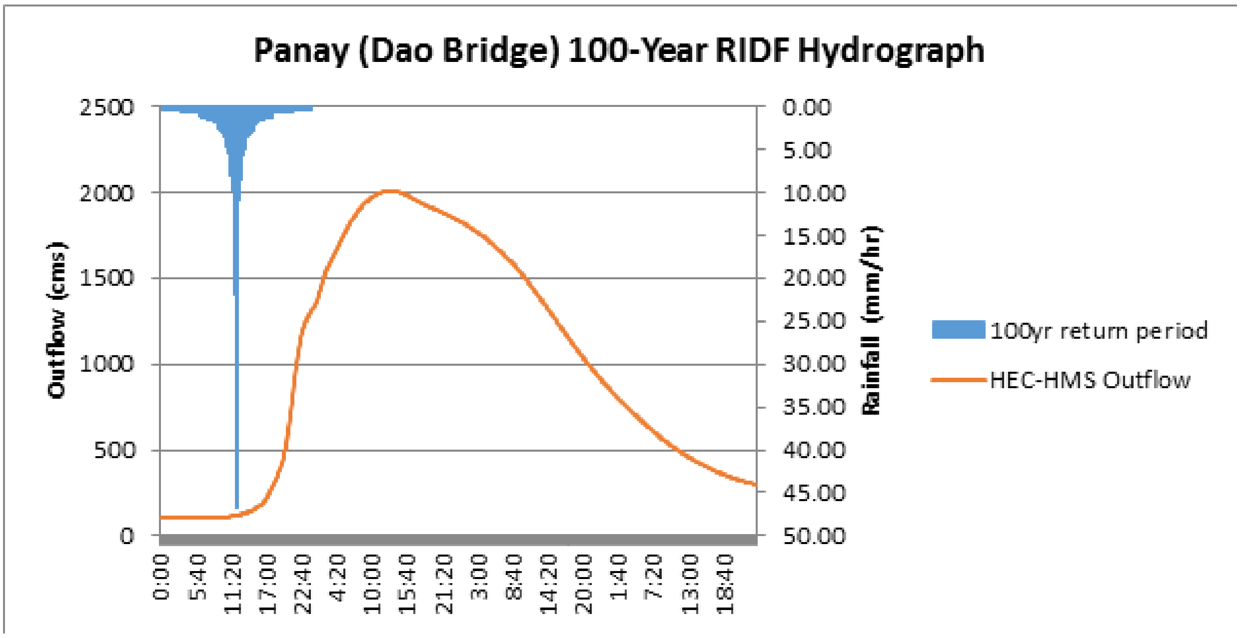


Figure 37. Outflow hydrograph generated using the Roxas 100-Year RIDF inputted in HEC-HMS

Results and Discussion

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

Table 2. Summary of peak values of the Panay outflow using the Roxas RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	183.07	25.05	949.5	3 hours, 30 minutes
10-Year	229.04	30.80	1299.5	2 hours, 30 minutes
25-Year	256.08	37.46	1448.8	1 hour, 50 minutes
50-Year	320.97	42.09	1801.0	1 hour, 20 minutes
100-Year	358.85	46.75	2007.8	50minutes

4.2.1.2 Panit-an Bridge

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

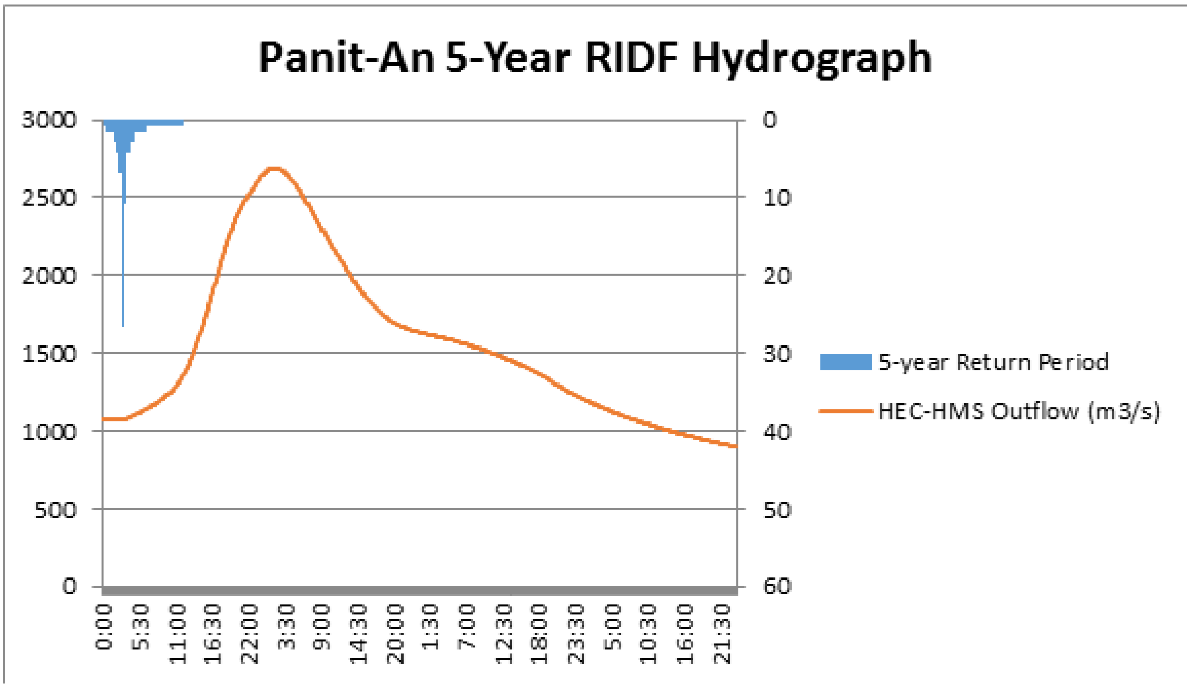


Figure 38. Outflow hydrograph generated using the Roxas 5-Year RIDF inputted in HEC-HMS

In the 10-year return period graph shown in Figure 36, the peak outflow is 3135.3 cms. This occurs after 23 hours and 30 minutes after the peak precipitation of 8.50 mm.

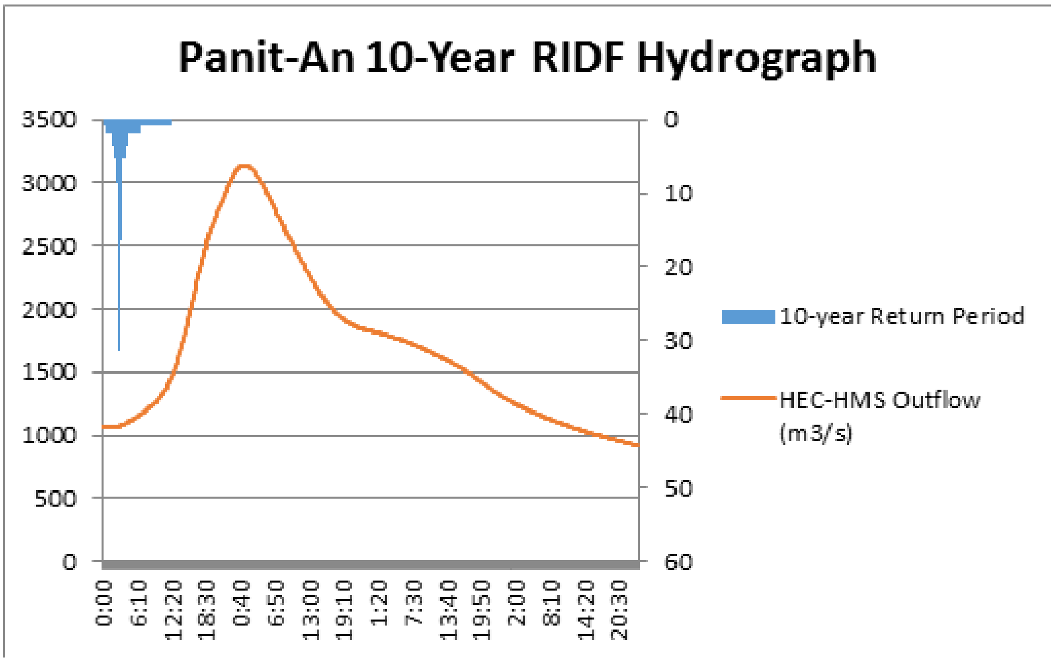


Figure 39. Outflow hydrograph generated using the Roxas 10-Year RIDF inputted in HEC-HMS

In the 25-year return period graph showin in Figure 37, the peak outflow is 3735.6 cms. This occurs after 6 hours and 50 minutes after the peak precipitation of 10.5 mm.

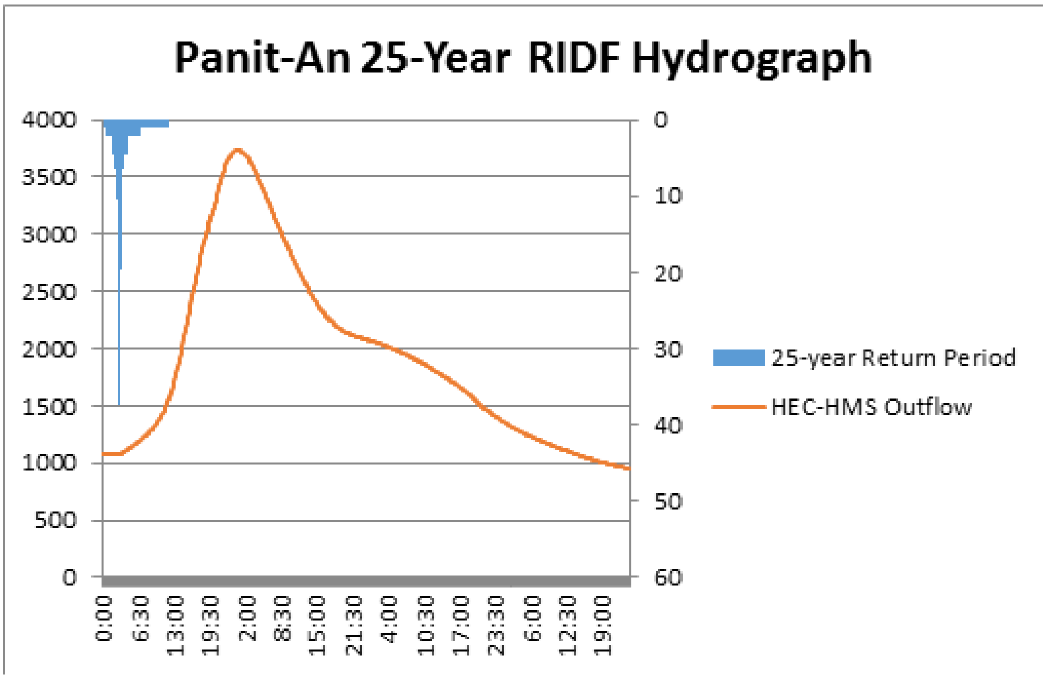


Figure 40. Outflow hydrograph generated using the Roxas 25-Year RIDF inputted in HEC-HMS

In the 50-year return period graph shown in Figure 38, the peak outflow is 4162.3 cms. This occurs after 22 hours and 40 minutes after the peak precipitation of 11.97 mm.

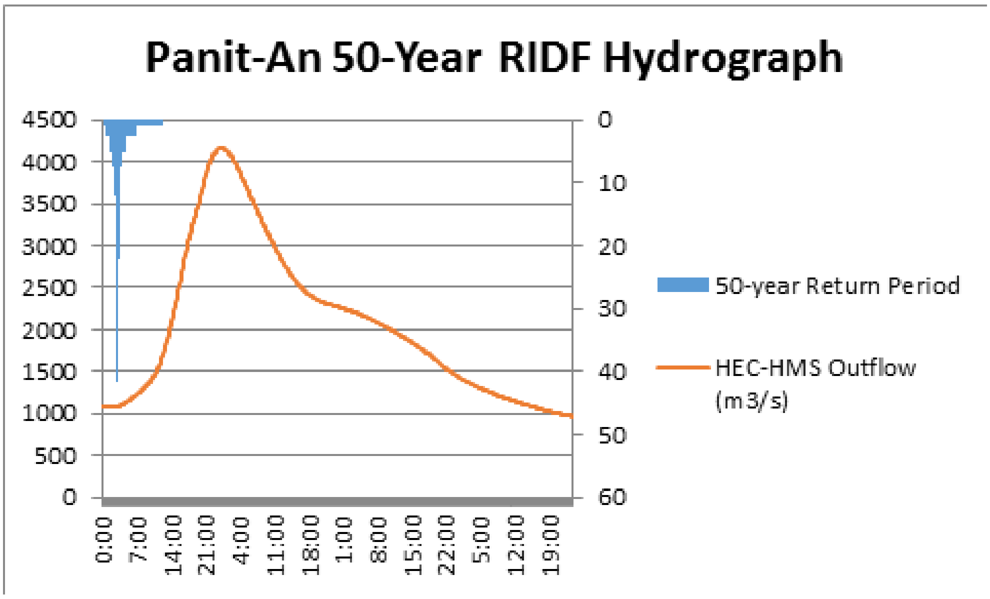


Figure 41.Outflow hydrograph generated using the Roxas 50-Year RIDF inputted in HEC-HMS

In the 100-year return period graph shown in Figure 39, the peak outflow is 4596.7 cms. This occurs after 22 hours after the peak precipitation of 11.97 mm.

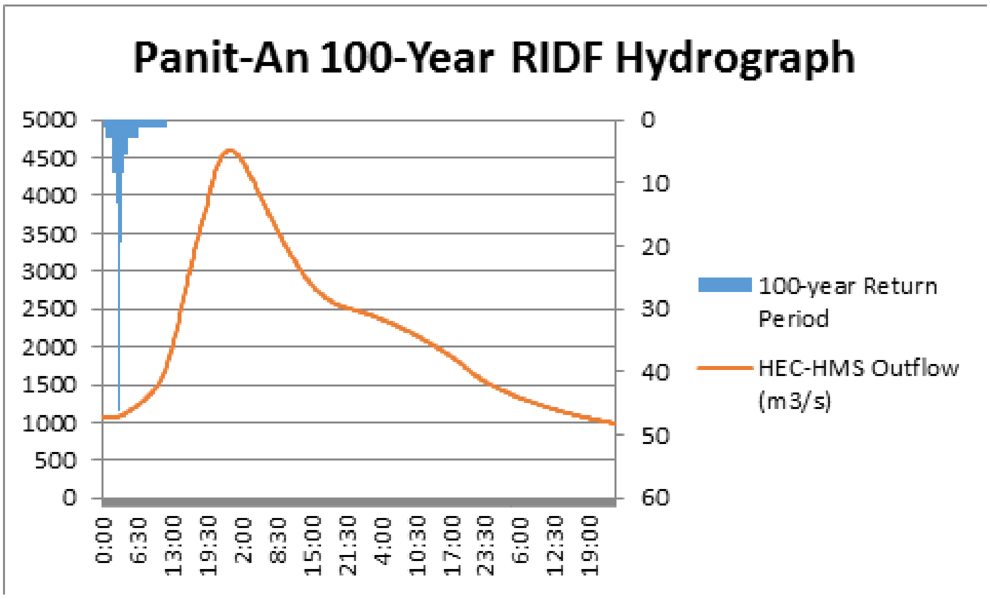


Figure 42. Outflow hydrograph generated using the Roxas 100-Year RIDF inputted in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of Panit-an Bridge discharge using the Roxas Rainfall Intensity Duration Frequency curves (RIDF) in five different return periods is shown in Table 3.

Table 3. Summary of peak values of the Panay outflow using the Roxas RIDF

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	165.9	6.93	2690.8	23 hours, 50 minutes
10-Year	200.1	8.5	3135.3	22 hours, 50 minutes
25-Year	243.4	10.5	3735.6	22 hours, 20 minutes
50-Year	275.4	11.97	4162.3	22 hours
100-Year	307.2	13.4	4596.7	21 hours, 40 minutes

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

The river discharge values using Dr. Horritt's recommended hydrological method are shown in Figure 40 and the peak discharge values are summarized in Table 4.

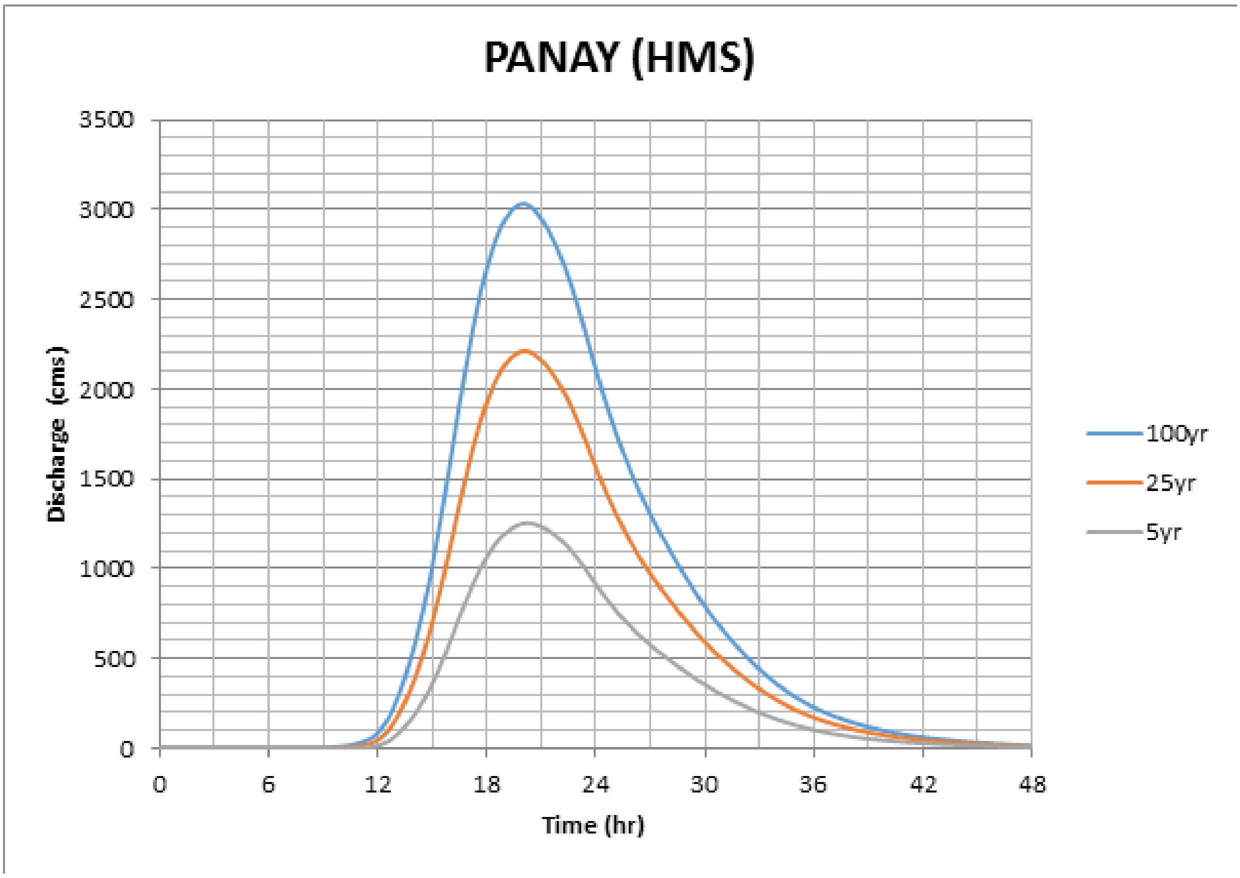


Figure 43. Outflow hydrograph generated for Tara, Panay using the Roxas 5-, 25-, and 100-year Rainfall Intensity Duration Frequency (RIDF) in HEC-HMS

Table 4. Summary of Tara river discharge using the recommended hydrological method by Dr. Horritt

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	1,254.4	20 hours, 10 minutes
25-Year	2,212.9	20 hours
100-Year	3,033.2	20 hours

The comparison of discharge values obtained from HEC-HMS, QMED, and from the bankful discharge method, Qbankful, are shown in Table 5. Using values from the DTM of Panay, the bankful discharge for the river was computed.

Table 5. Validation of river discharge estimate using the bankful method

Discharge Point	Qbankful, cms	QMED, cms	Validation
Panay (1)	1,852.99	1,103.87	Pass

The value from the HEC-HMS discharge estimate was able to satisfy the condition for validating the computed discharge using the bankful method. The computed value was used for the discharge point that did not have actual discharge data. The calibrated discharge data were also used for areas in the floodplain that were modeled. It is recommended, therefore, to use the actual value of the river discharge for higher-accuracy modeling.

4.3 Flood Hazard and Flow Depth Maps

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

Results and Discussion

Flood Hazard Maps and Flow Depth Maps

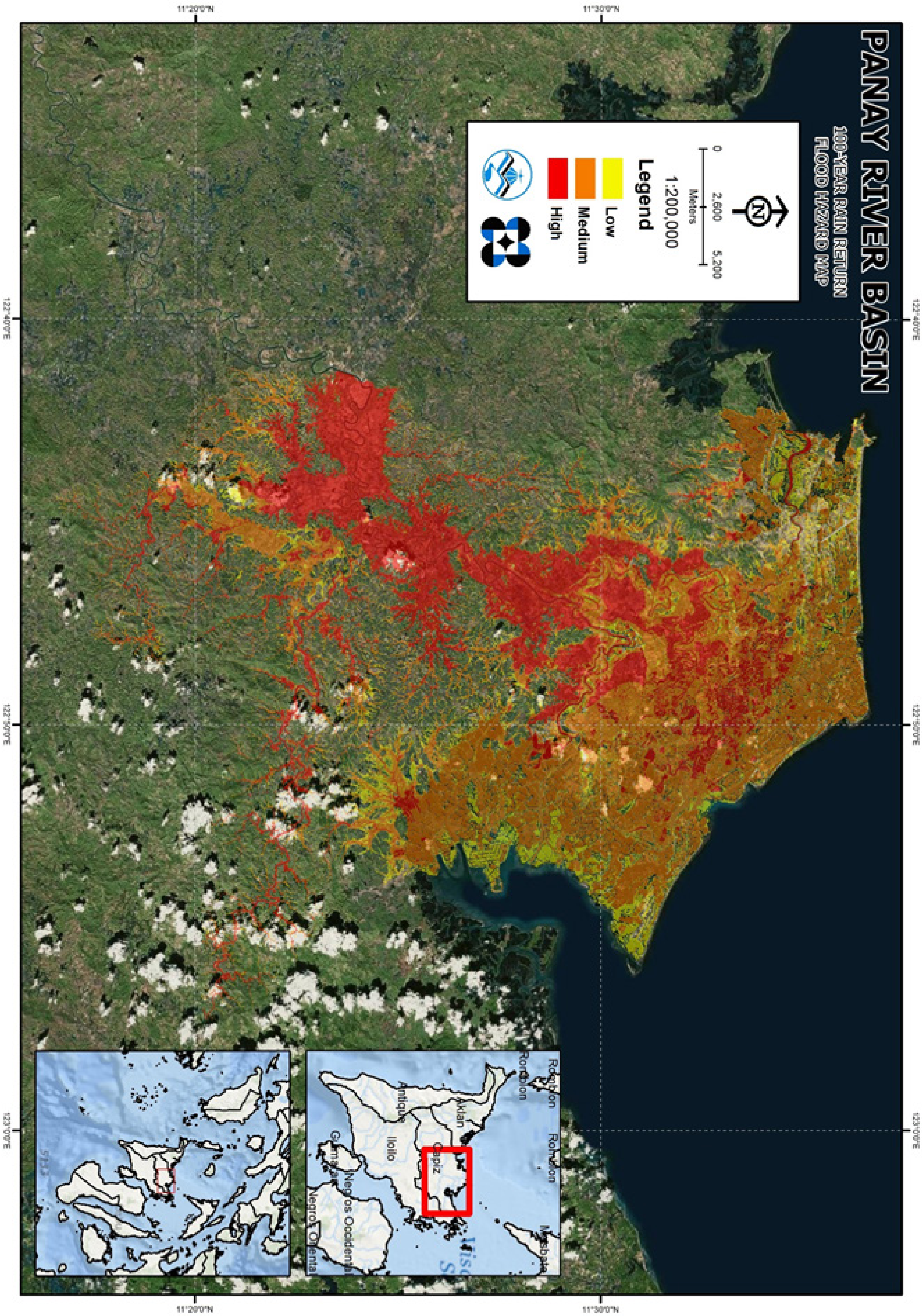


Figure 44. 100-year Flood Hazard Map for Panay River Basin

Results and Discussion

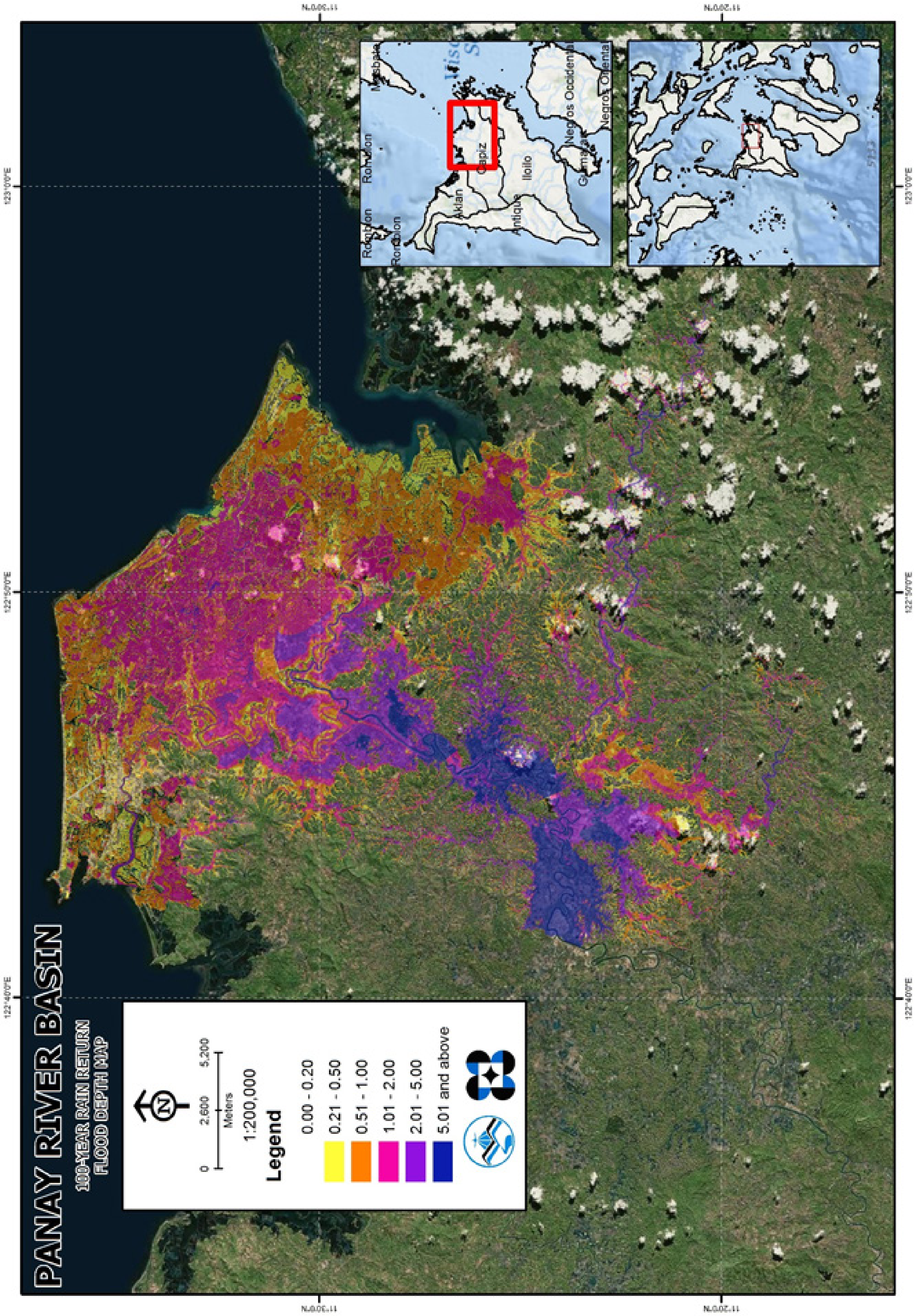


Figure 45. 100-year Flow Depth Map forPanay River Basin

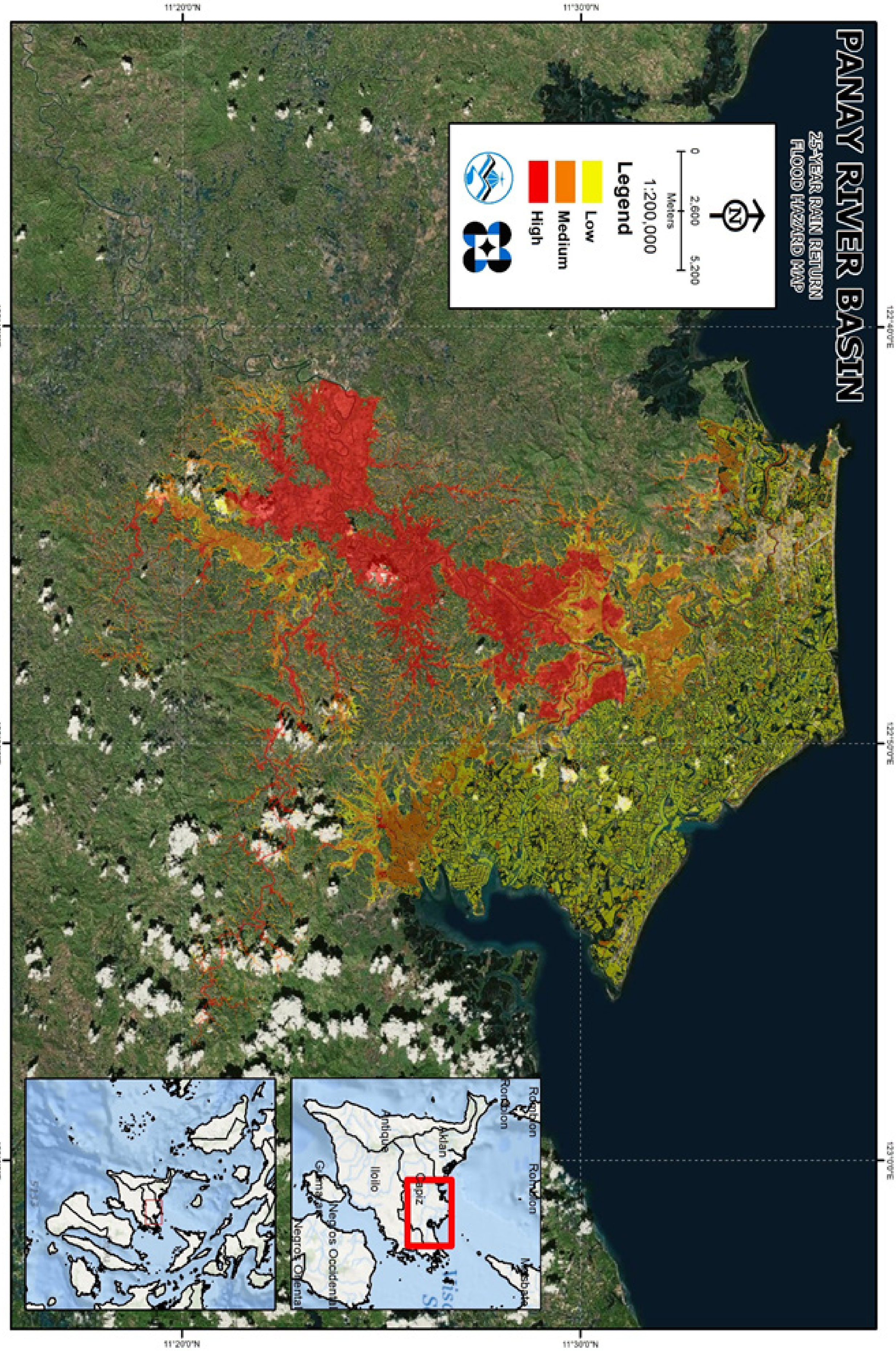


Figure46. 25-year Flood Hazard Map for Panay River Basin

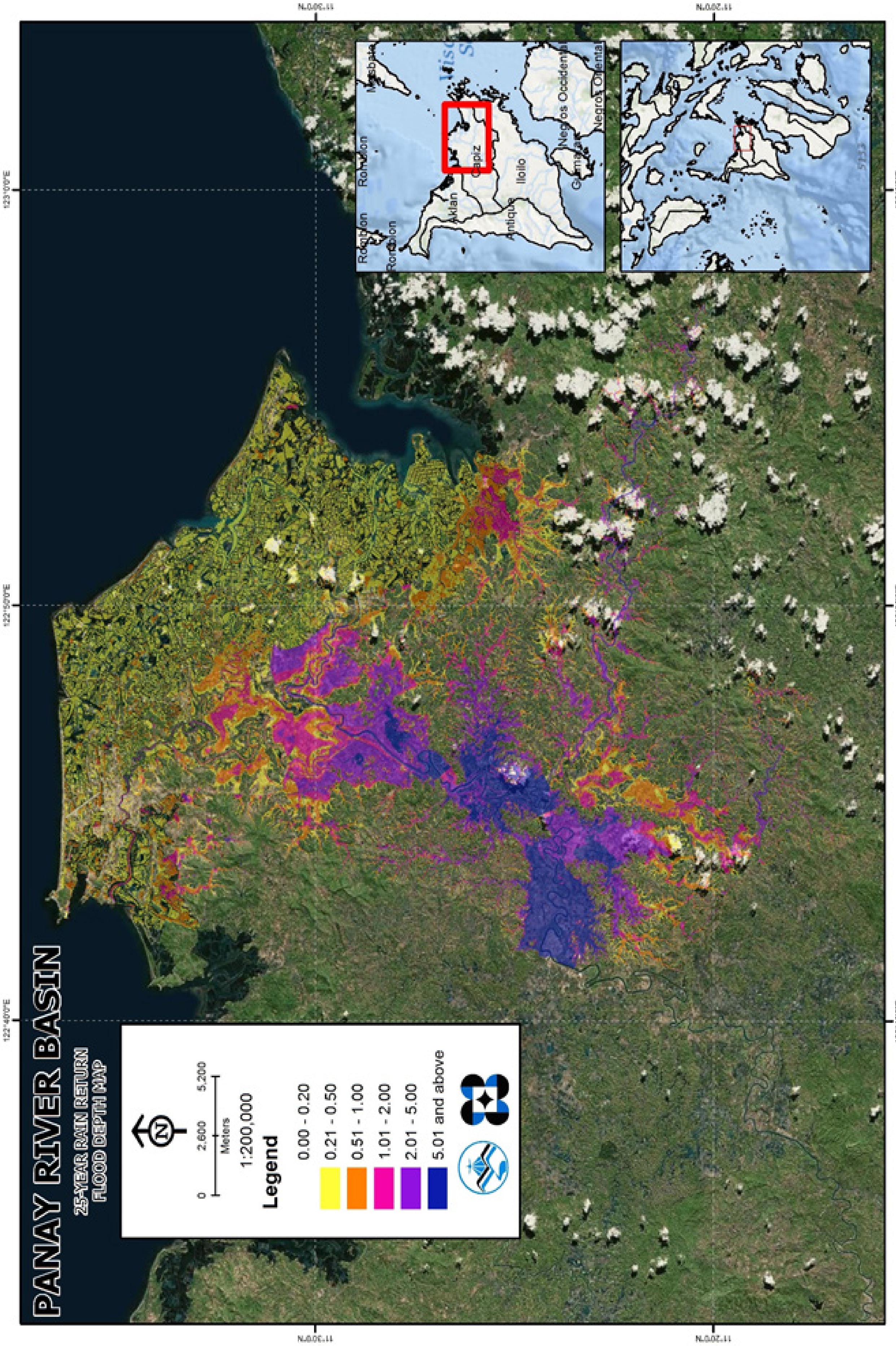


Figure 47. 25-year Flow Depth Map forPanay River Basin

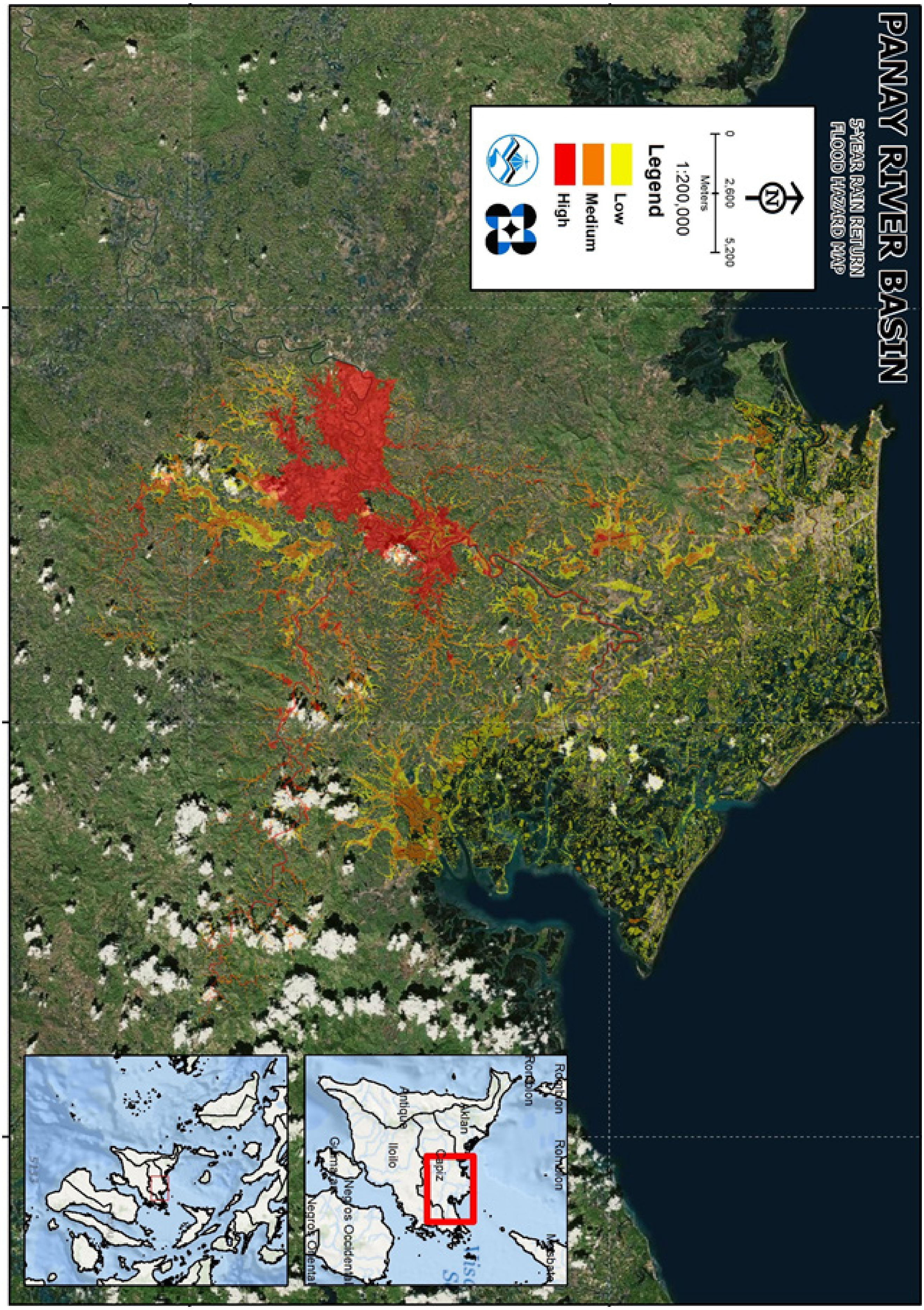


Figure 48. 5-year Flood Hazard Map for Panay River Basin

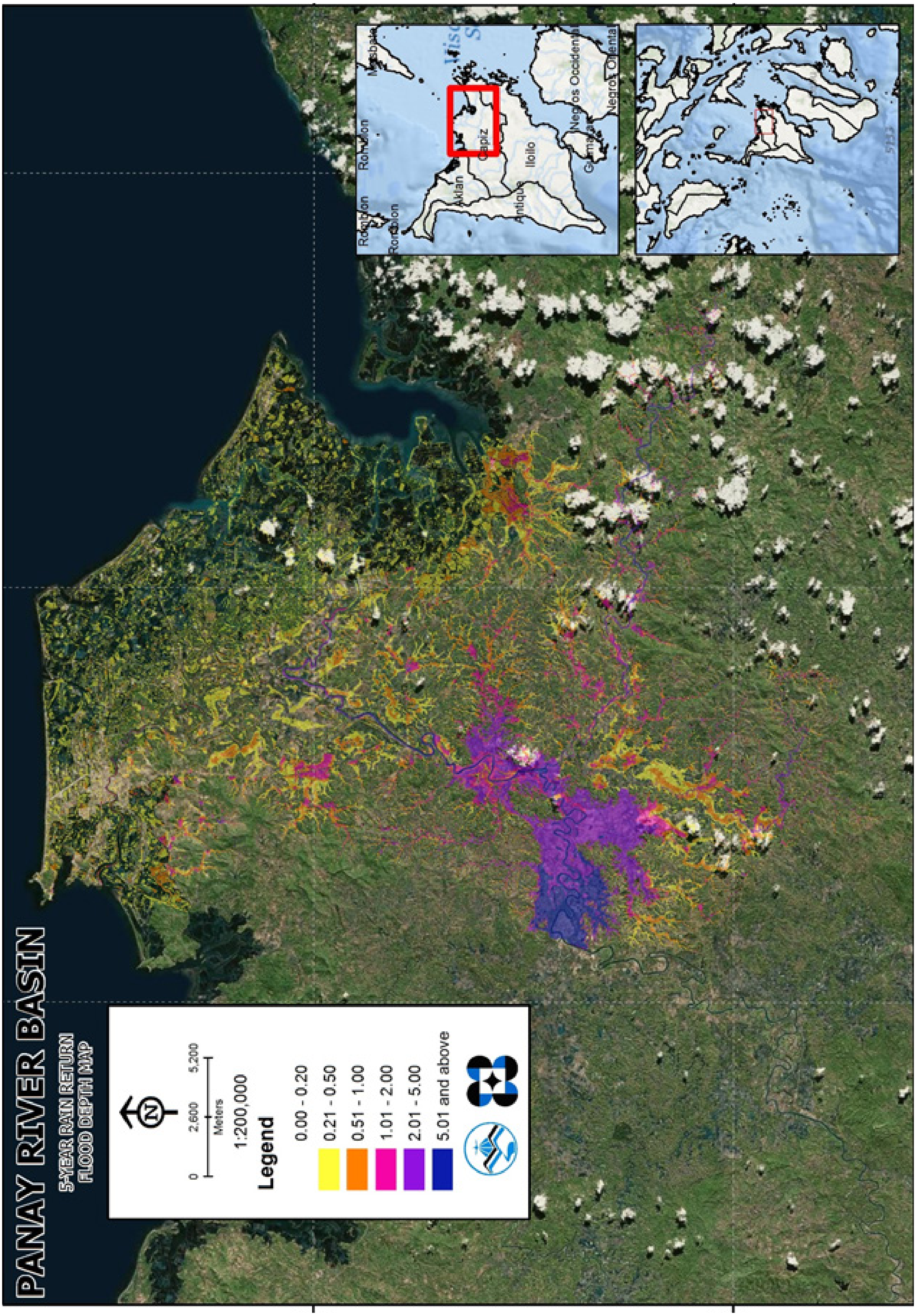


Figure 49. 5-year Flood Hazard Map for Panay River Basin

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Appendix

Appendix A. Dao Bridge Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
41B	1	86.4432	0	26.94	3.33106	Discharge	3.1683	1	Ratio to Peak	0.01
42B	1	84.3048	0	48.18	5.9605	Discharge	6.6052	1	Ratio to Peak	0.01
43B	1	89.1108	0	25.2	3.12085	Discharge	4.7258	1	Ratio to Peak	0.01
44B	1	88.722	0	27.6	3.41614	Discharge	2.4498	1	Ratio to Peak	0.01
45B	1	88.0632	0	38.7	4.78615	Discharge	3.6304	1	Ratio to Peak	0.01
46B	1	84.24	0	25.86	3.19865	Discharge	4.6847	1	Ratio to Peak	0.01
47B	1	84.7692	0	24.66	3.05396	Discharge	1.901	1	Ratio to Peak	0.01
48B	1	83.2032	0	34.56	4.27427	Discharge	6.803	1	Ratio to Peak	0.01
49B	1	86.3244	0	29.82	3.69187	Discharge	8.93842	1	Ratio to Peak	0.01
50B	1	90.234	0	15	1.85276	Discharge	1.4584	1	Ratio to Peak	0.01
51B	1	85.0284	0	19.56	2.42242	Discharge	0.54399	1	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
52B	1	84.7584	0	64.23	13.4199	Discharge	5.8527	1	Ratio to Peak	0.01
53B	1	85.6008	0	14.1906	0.78137	Discharge	2.6242	1	Ratio to Peak	0.01
54B	1	84.2724	0	43.1028	8.45325	Discharge	7.0159	1	Ratio to Peak	0.01
55B	1	80.4276	0	53.055	4.44561	Discharge	1.1456	1	Ratio to Peak	0.01
56B	1	80.4708	0	16.9344	1.3702	Discharge	1.9006	1	Ratio to Peak	0.01
57B	1	74.0448	0	12.2694	1.04215	Discharge	1.9747	1	Ratio to Peak	0.01
58B	1	77.1876	0	8.5068	1.03591	Discharge	2.1627	1	Ratio to Peak	0.01
59B	1	90.4932	0	5.22666	1.34128	Discharge	1.8119	1	Ratio to Peak	0.01
60B	1	81.1188	0	11.0154	7.0642	Discharge	2.0976	1	Ratio to Peak	0.01
61B	1	79.4772	0	22.0302	9.4861	Discharge	5.3604	1	Ratio to Peak	0.01
62B	1	88.4736	0	56.5848	7.0707	Discharge	5.3693	1	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
63B	1	88.8516	0	18.9336	8.1458	Discharge	3.5933	1	Ratio to Peak	0.01
64B	1	89.8236	0	63.474	5.31421	Discharge	5.5899	1	Ratio to Peak	0.01
65B	1	84.7368	0	33.9102	13.7774	Discharge	2.9947	1	Ratio to Peak	0.01
66B	1	90.3852	0	11.5734	2.12095	Discharge	1.202	1	Ratio to Peak	0.01
67B	1	84.7152	0	7.1202	1.99609	Discharge	1.6548	1	Ratio to Peak	0.01
68B	1	88.4412	0	11.4516	4.73714	Discharge	0.86738	1	Ratio to Peak	0.01
69B	1	83.2032	0	150.252	5.44564	Discharge	9.1551	1	Ratio to Peak	0.01
70B	1	90.3312	0	38.448	4.81241	Discharge	2.6194	1	Ratio to Peak	0.01
71B	1	90.0828	0	88.29	3.20249	Discharge	6.4003	1	Ratio to Peak	0.01
72B	1	85.158	0	40.77	5.07618	Discharge	2.0561	1	Ratio to Peak	0.01
73B	1	84.0024	0	16.4898	6.9082	Discharge	1.5723	1	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
74B	1	89.0892	0	46.53	3.87309	Discharge	3.8234	1	Ratio to Peak	0.01
75B	1	87.534	0	35.811	4.45322	Discharge	4.8616	1	Ratio to Peak	0.01
76B	1	88.8624	0	17.904	3.31975	Discharge	1.3351	1	Ratio to Peak	0.01
77B	1	86.616	0	47.34	3.93816	Discharge	2.7553	1	Ratio to Peak	0.01
78B	1	83.4408	0	13.56	2.52863	Discharge	3.6824	1	Ratio to Peak	0.01
79B	1	83.2788	0	38.5224	7.14025	Discharge	11.314	1	Ratio to Peak	0.01

Appendix B. Panit-an Bridge Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow				
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Type	Initial Discharge (M3/S)	Recession Constant	Threshold Type	Ratio to Peak
141B	5.551011	87.88422	0.0	147.1785	1.2394	29.773	0.09	0	Ratio to Peak	0.01
142B	7.531056	99	0.0	78.79159	0.66355	15.950	0.09	0	Ratio to Peak	0.01
143B	10.05615	78.81744	0.0	42.24039	1.7458	16.875	0.09	0	Ratio to Peak	0.01
144B	11.54817	77.9688	0.0	37.24135	1.1418	24.952	0.09	0	Ratio to Peak	0.01
145B	8.019162	90.22818	0.0	11.8663	0.21588	6.4023	0.09	0	Ratio to Peak	0.01
146B	7.539966	76.84068	0.0	57.10697	0.46603	8.8139	0.09	0	Ratio to Peak	0.01
147B	8.9181	80.21994	0.0	40.93499	0.50715	4.6198	0.09	0	Ratio to Peak	0.01
148B	12.14838	51.33966	0.0	47.7006	1.2958	48.762	0.09	0	Ratio to Peak	0.01
149B	11.22012	84.609	0.0	39.44127	1.602	10.125	0.09	0	Ratio to Peak	0.01
150B	8.048565	90.03948	0.0	89.36212	0.73779	13.951	0.09	0	Ratio to Peak	0.01
151B	5.45616	85.0782	0.0	62.72233	1.1261	34.089	0.09	0	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
152B	7.358121	77.24256	0.0	28.92317	0.5344	10.9511874	0.09	0	Ratio to Peak	0.01
153B	11.03706	77.00898	0.0	36.90109	1.3183	36.234	0.09	0	Ratio to Peak	0.01
154B	7.836669	77.44452	0.0	38.46222	0.68592	8.3742	0.09	0	Ratio to Peak	0.01
155B	8.73423	84.1398	0.0	48.44746	0.61128	20.364	0.09	0	Ratio to Peak	0.01
156B	9.62037	55.11366	0.0	37.99891	1.0491	25.893	0.09	0	Ratio to Peak	0.01
157B	8.8614	83.9256	0.0	18.64368	0.50645	7.1109	0.09	0	Ratio to Peak	0.01
158B	10.15902	81.804	0.0	33.01913	1.3448	14.675	0.09	0	Ratio to Peak	0.01
159B	18.16668	52.5963	0.0	14.45677	0.26712	19.613	0.09	0	Ratio to Peak	0.01
160B	12.25368	81.906	0.0	0.0784667	1.6527	60.261	0.09	0	Ratio to Peak	0.01

Appendix C. Dao Bridge Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
43R	Automatic Fixed Interval	89000.403	0.0053	0.01193	Trapezoid	30	45
44R	Automatic Fixed Interval	75952.565	0.00727	0.01193	Trapezoid	30	45
45R	Automatic Fixed Interval	27343.034	0.00104	0.01193	Trapezoid	30	45
46R	Automatic Fixed Interval	18544.425	0.00109	0.01193	Trapezoid	30	45
47R	Automatic Fixed Interval	48036.657	0.00178	0.01193	Trapezoid	30	45
48R	Automatic Fixed Interval	32027.824	0.00202	0.01193	Trapezoid	30	45
49R	Automatic Fixed Interval	13226.696	0.00033	0.01193	Trapezoid	30	45
50R	Automatic Fixed Interval	27573.381	0.00253	0.01193	Trapezoid	30	45
51R	Automatic Fixed Interval	65097.507	0.00095	0.01193	Trapezoid	30	45
52R	Automatic Fixed Interval	58640.395	0.00104	0.01193	Trapezoid	30	45
53R	Automatic Fixed Interval	16913.327	0.00059	0.01193	Trapezoid	30	45
54R	Automatic Fixed Interval	8671.081	0.00924	0.01193	Trapezoid	30	45
55R	Automatic Fixed Interval	10322.766	0.00508	0.01193	Trapezoid	30	45
56R	Automatic Fixed Interval	26971.705	0.00823	0.01193	Trapezoid	30	45
57R	Automatic Fixed Interval	58140.39	0.00082	0.01193	Trapezoid	30	45
58R	Automatic Fixed Interval	33950.999	0.00077	0.01193	Trapezoid	30	45
59R	Automatic Fixed Interval	15337.155	0.00377	0.01193	Trapezoid	30	45
60R	Automatic Fixed Interval	40376.404	0.00069	0.01193	Trapezoid	30	45
61R	Automatic Fixed Interval	32630.468	0.00091	0.01193	Trapezoid	30	45
62R	Automatic Fixed Interval	51325.34	0.00083	0.01193	Trapezoid	30	45
63R	Automatic Fixed Interval	52612.595	0.00081	0.01193	Trapezoid	30	45
64R	Automatic Fixed Interval	45044.656	0.00058	0.01193	Trapezoid	30	45
65R	Automatic Fixed Interval	25377.822	0.0004	0.01193	Trapezoid	30	45
66R	Automatic Fixed Interval	14331.202	0.00046	0.01193	Trapezoid	30	45
67R	Automatic Fixed Interval	26520.034	0.00149	0.01193	Trapezoid	30	45
68R	Automatic Fixed Interval	41172.963	0.00157	0.01193	Trapezoid	30	45
69R	Automatic Fixed Interval	26030.404	0.00173	0.01193	Trapezoid	30	45
70R	Automatic Fixed Interval	23201.28	0.00226	0.01193	Trapezoid	30	45
71R	Automatic Fixed Interval	43245.968	0.00122	0.01193	Trapezoid	30	45
72R	Automatic Fixed Interval	36058.999	0.00094	0.01193	Trapezoid	30	45
73R	Automatic Fixed Interval	17271.767	0.00204	0.01193	Trapezoid	30	45
74R	Automatic Fixed Interval	18647.503	0.00151	0.01193	Trapezoid	30	45
75R	Automatic Fixed Interval	8679.479	0.0004	0.01193	Trapezoid	30	45
76R	Automatic Fixed Interval	8709.994	0.0004	0.01193	Trapezoid	30	45
77R	Automatic Fixed Interval	34257.408	0.00161	0.01193	Trapezoid	30	45

Appendix

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
78R	Automatic Fixed Interval	16755.871	0.0004	0.01193	Trapezoid	30	45
79R	Automatic Fixed Interval	50939.238	0.00082	0.01193	Trapezoid	30	45
80R	Automatic Fixed Interval	21182.253	0.00179	0.01193	Trapezoid	30	45

Appendix D. Panit-an Bridge Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
100R	Automatic Fixed Interval	15337.155	0.003770	0.0506727	Trapezoid	0.3	0.45
101R	Automatic Fixed Interval	40376.404	0.000690	0.0097604	Trapezoid	0.3	0.45
102R	Automatic Fixed Interval	32630.468	0.000910	0.0181033	Trapezoid	0.3	0.45
103R	Automatic Fixed Interval	51325.340	0.000830	0.0150554	Trapezoid	0.3	0.45
104R	Automatic Fixed Interval	52612.595	0.000810	0.0097605	Trapezoid	0.3	0.45
105R	Automatic Fixed Interval	45044.656	0.000580	0.0069733	Trapezoid	0.3	0.45
106R	Automatic Fixed Interval	25377.822	0.000580	0.0097605	Trapezoid	0.3	0.45
107R	Automatic Fixed Interval	14331.202	0.000460	0.0150277	Trapezoid	0.3	0.45
108R	Automatic Fixed Interval	26520.034	0.001490	0.0153187	Trapezoid	0.3	0.45
109R	Automatic Fixed Interval	41172.963	0.001570	0.0316506	Trapezoid	0.3	0.45
110R	Automatic Fixed Interval	26030.404	0.001730	0.05145	Trapezoid	0.3	0.45
111R	Automatic Fixed Interval	23201.280	0.002260	0.021	Trapezoid	0.3	0.45
112R	Automatic Fixed Interval	43245.968	0.001220	0.0269671	Trapezoid	0.3	0.45
113R	Automatic Fixed Interval	36058.999	0.000940	0.0342999	Trapezoid	0.3	0.45
114R	Automatic Fixed Interval	17271.767	0.002040	0.0342999	Trapezoid	0.3	0.45
115R	Automatic Fixed Interval	18647.503	0.001510	0.0348249	Trapezoid	0.3	0.45
116R	Automatic Fixed Interval	8679.479	0.000380	0.0345328	Trapezoid	0.3	0.45
117R	Automatic Fixed Interval	8709.994	0.000910	0.0252764	Trapezoid	0.3	0.45
118R	Automatic Fixed Interval	34257.408	0.001610	0.022971	Trapezoid	0.3	0.45
119R	Automatic Fixed Interval	16755.871	0.000820	0.0152444	Trapezoid	0.3	0.45
120R	Automatic Fixed Interval	50939.238	0.000820	0.0103703	Trapezoid	0.3	0.45
121R	Automatic Fixed Interval	21182.253	0.001790	0.0103703	Trapezoid	0.3	0.45
123R	Automatic Fixed Interval	35400.507	0.000030	0.0791168	Trapezoid	0.3	0.45
124R	Automatic Fixed Interval	27760.085	0.000120	.000351733	Trapezoid	0.3	0.45
83R	Automatic Fixed Interval	25681.629	0.000130	0.0224093	Trapezoid	0.3	0.45
84R	Automatic Fixed Interval	89000.403	0.005300	0.0344434	Trapezoid	0.3	0.45
85R	Automatic Fixed Interval	75952.565	0.007270	0.0342999	Trapezoid	0.3	0.45
86R	Automatic Fixed Interval	27366.264	0.001040	0.0226129	Trapezoid	0.3	0.45
87R	Automatic Fixed Interval	18544.425	0.001090	0.07875	Trapezoid	0.3	0.45
88R	Automatic Fixed Interval	48036.657	0.001780	0.035175	Trapezoid	0.3	0.45
89R	Automatic Fixed Interval	32027.824	0.002020	0.0517026	Trapezoid	0.3	0.45
90R	Automatic Fixed Interval	13251.647	0.000330	0.0156241	Trapezoid	0.3	0.45
91R	Automatic Fixed Interval	27573.381	0.002530	0.0156163	Trapezoid	0.3	0.45
92R	Automatic Fixed Interval	65097.507	0.000950	0.0103703	Trapezoid	0.3	0.45
93R	Automatic Fixed Interval	58640.395	0.001040	0.0233331	Trapezoid	0.3	0.45
94R	Automatic Fixed Interval	16913.327	0.000590	0.0348222	Trapezoid	0.3	0.45

Appendix

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
95R	Automatic Fixed Interval	8671.081	0.009240	0.0156323	Trapezoid	0.3	0.45
96R	Automatic Fixed Interval	10379.696	0.005050	0.0342999	Trapezoid	0.3	0.45
97R	Automatic Fixed Interval	26971.705	0.008230	0.02345	Trapezoid	0.3	0.45
98R	Automatic Fixed Interval	58140.390	0.000820	0.0155556	Trapezoid	0.3	0.45
99R	Automatic Fixed Interval	33950.999	0.000770	0.0233994	Trapezoid	0.3	0.45

Appendix E. Panay River Discharge from HEC-HMS Simulation

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
0	0	0	0	6	0	0	0
0.1667	0	0	0	6.1667	0	0	0
0.3333	0	0	0	6.3333	0	0	0
0.5	0	0	0	6.5	0	0	0
0.6667	0	0	0	6.6667	0	0	0
0.8333	0	0	0	6.8333	0	0	0
1	0	0	0	7	0.1	0	0
1.1667	0	0	0	7.1667	0.1	0	0
1.3333	0	0	0	7.3333	0.2	0	0
1.5	0	0	0	7.5	0.3	0	0
1.6667	0	0	0	7.6667	0.4	0	0
1.8333	0	0	0	7.8333	0.5	0	0
2	0	0	0	8	0.7	0.1	0
2.1667	0	0	0	8.1667	1	0.1	0
2.3333	0	0	0	8.3333	1.3	0.2	0
2.5	0	0	0	8.5	1.7	0.3	0
2.6667	0	0	0	8.6667	2.1	0.4	0
2.8333	0	0	0	8.8333	2.6	0.6	0
3	0	0	0	9	3.2	0.7	0
3.1667	0	0	0	9.1667	4	1	0
3.3333	0	0	0	9.3333	4.9	1.3	0
3.5	0	0	0	9.5	6	1.7	0.1
3.6667	0	0	0	9.6667	7.2	2.2	0.1
3.8333	0	0	0	9.8333	8.8	2.8	0.2
4	0	0	0	10	10.6	3.6	0.3
4.1667	0	0	0	10.167	12.7	4.6	0.5
4.3333	0	0	0	10.333	15.2	5.7	0.7
4.5	0	0	0	10.5	18	7.1	0.9
4.6667	0	0	0	10.667	21.5	8.8	1.3
4.8333	0	0	0	10.833	25.5	10.8	1.8
5	0	0	0	11	30.2	13.2	2.5
5.1667	0	0	0	11.167	35.7	16.2	3.3
5.3333	0	0	0	11.333	42.3	19.8	4.4
5.5	0	0	0	11.5	50	24.2	5.9
5.6667	0	0	0	11.667	59.3	29.7	7.8

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
12	87.2	47.2	15.1	18.333	2786.1	2012.9	1118.9
12.167	106.7	59.9	20.9	18.5	2835.2	2050.8	1142.5
12.333	128.8	74.5	27.8	18.667	2877	2083.3	1162.9
12.5	154.1	91.5	35.8	18.833	2912.4	2111	1180.6
12.667	184.3	111.9	45.9	19	2943.1	2135.4	1196.4
12.833	219.7	136.3	58.1	19.167	2969.5	2156.6	1210.4
13	258.8	163.4	72	19.333	2991.3	2174.5	1222.6
13.167	301.1	192.8	87.1	19.5	3007.8	2188.5	1232.6
13.333	346.8	224.7	103.5	19.667	3020.3	2199.5	1240.9
13.5	397.2	260	122	19.833	3029	2207.8	1247.6
13.667	450.9	297.9	141.9	20	3033.2	2212.9	1252.6
13.833	507.7	338	163	20.167	3030.1	2212.4	1254.4
14	567.7	380.5	185.5	20.333	3021.2	2207.7	1253.5
14.167	632.5	426.5	210.1	20.5	3008.5	2200	1251.1
14.333	701.9	476	236.7	20.667	2992.2	2189.8	1247.1
14.5	774.7	528	264.8	20.833	2972.6	2177.1	1241.6
14.667	850.8	582.5	294.4	21	2949.4	2161.7	1234.5
14.833	930.9	640.1	325.8	21.167	2923.3	2144.1	1226.2
15	1017.5	702.6	360.1	21.333	2894.8	2124.7	1216.8
15.167	1107.9	768	396.3	21.5	2863.7	2103.4	1206.3
15.333	1201	835.6	433.9	21.667	2829.4	2079.7	1194.4
15.5	1297.2	905.5	472.9	21.833	2792.7	2054.1	1181.3
15.667	1397.3	978.5	513.9	22	2753.8	2027	1167.3
15.833	1500.6	1054.1	556.7	22.167	2712.8	1998.2	1152.3
16	1605.4	1131.1	600.5	22.333	2668.8	1967.1	1136
16.167	1710.8	1208.6	644.8	22.5	2621.4	1933.5	1118.1
16.333	1815.3	1285.7	689.1	22.667	2571.7	1898.1	1099.1
16.5	1917	1360.9	732.4	22.833	2520	1861.1	1079.1
16.667	2016.7	1434.7	775.2	23	2466.1	1822.5	1058.1
16.833	2114.5	1507.4	817.4	23.167	2409	1781.4	1035.6
17	2209.5	1578.1	858.8	23.333	2349.9	1738.7	1012
17.167	2299	1644.9	898.1	23.5	2289.8	1695.2	987.8
17.333	2383.1	1707.8	935.1	23.667	2229.2	1651.1	963.2
17.5	2463.2	1767.9	970.8	23.833	2169.3	1607.5	938.7
17.667	2539.4	1825.3	1005	24	2110.8	1564.9	914.7
17.833	2610.4	1879	1037.3	24.167	2053	1522.7	891
18	2673.9	1927.2	1066.5	24.333	1996	1481.1	867.4
18.167	2732.1	1971.6	1093.5	24.5	1940.4	1440.4	844.3

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
24.667	1888	1402.1	822.5	31	658.5	493.6	296.4
24.833	1837.9	1365.4	801.7	31.167	637.8	478.1	287.2
25	1789.1	1329.7	781.4	31.333	617.8	463.2	278.3
25.167	1741.6	1294.8	761.6	31.5	598.5	448.8	269.7
25.333	1695.5	1261	742.3	31.667	579.6	434.6	261.2
25.5	1651	1228.4	723.7	31.833	561	420.7	252.9
25.667	1607.7	1196.5	705.5	32	542.7	407.1	244.8
25.833	1565.2	1165.3	687.6	32.167	524.8	393.7	236.8
26	1523.8	1134.9	670.2	32.333	507.3	380.5	228.9
26.167	1484.2	1105.7	653.4	32.5	490.1	367.7	221.2
26.333	1445.7	1077.3	637.1	32.667	473.4	355.2	213.7
26.5	1408.1	1049.6	621.1	32.833	457.4	343.2	206.5
26.667	1371.6	1022.7	605.6	33	441.9	331.6	199.6
26.833	1336.6	996.9	590.7	33.167	426.8	320.3	192.8
27	1303.3	972.3	576.5	33.333	412.1	309.2	186.2
27.167	1270.9	948.4	562.8	33.5	397.7	298.4	179.7
27.333	1239.1	924.9	549.2	33.667	383.6	287.9	173.3
27.5	1208	901.9	535.9	33.833	369.9	277.6	167.1
27.667	1177.3	879.3	522.9	34	356.5	267.5	161.1
27.833	1147	856.9	509.9	34.167	343.5	257.8	155.2
28	1116.9	834.6	496.9	34.333	331.2	248.5	149.6
28.167	1087.2	812.6	484.1	34.5	319.3	239.6	144.3
28.333	1058.1	791	471.6	34.667	307.8	231	139.1
28.5	1029.6	769.9	459.3	34.833	296.7	222.7	134
28.667	1001.6	749.1	447.1	35	286	214.6	129.2
28.833	973.8	728.5	435.1	35.167	275.5	206.7	124.4
29	946.3	708.1	423.1	35.333	265.4	199.1	119.9
29.167	919.1	687.9	411.2	35.5	255.7	191.8	115.5
29.333	892.3	667.9	399.5	35.667	246.3	184.8	111.2
29.5	865.9	648.2	387.9	35.833	237.5	178.2	107.2
29.667	840	628.9	376.5	36	229	171.8	103.4
29.833	815.2	610.4	365.6	36.167	220.9	165.7	99.7
30	791.4	592.7	355.1	36.333	213.1	159.8	96.2
30.167	768.1	575.4	344.9	36.5	205.5	154.2	92.8
30.333	745.4	558.5	334.9	36.667	198.2	148.7	89.5
30.5	723.1	541.8	325	36.833	191.1	143.4	86.3
30.667	701.2	525.5	315.3	37	184.2	138.2	83.2

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
37.333	171.4	128.5	77.4	43.667	44.6	33.5	20.1
37.5	165.4	124	74.6	43.833	43	32.3	19.4
37.667	159.5	119.7	72	44	41.5	31.2	18.7
37.833	153.9	115.5	69.5	44.167	40	30	18.1
38	148.5	111.4	67	44.333	38.6	29	17.4
38.167	143.2	107.4	64.7	44.5	37.1	27.9	16.8
38.333	138.1	103.6	62.4	44.667	35.8	26.9	16.2
38.5	133.2	99.9	60.1	44.833	34.4	25.9	15.6
38.667	128.4	96.3	58	45	33.1	24.9	15
38.833	123.9	92.9	55.9	45.167	31.8	23.9	14.4
39	119.5	89.7	54	45.333	30.5	22.9	13.9
39.167	115.3	86.5	52	45.5	29.3	22	13.3
39.333	111.2	83.4	50.2	45.667	28.1	21.1	12.8
39.5	107.2	80.4	48.4	45.833	26.9	20.3	12.3
39.667	103.3	77.5	46.6	46	25.8	19.4	11.8
39.833	99.6	74.7	45	46.167	24.6	18.6	11.3
40	96	72	43.3	46.333	23.5	17.8	10.8
40.167	92.5	69.4	41.7	46.5	22.5	17	10.3
40.333	89.2	66.9	40.3	46.667	21.4	16.2	9.9
40.5	86.1	64.6	38.8	46.833	20.4	15.4	9.4
40.667	83.1	62.3	37.5	47	19.4	14.7	9
40.833	80.2	60.1	36.2	47.167	18.4	13.9	8.5
41	77.3	58	34.9	47.333	17.4	13.2	8.1
41.167	74.6	56	33.6	47.5	16.5	12.5	7.7
41.333	72	54	32.5	47.667	15.5	11.8	7.3
41.5	69.5	52.1	31.3	47.833	14.6	11.1	6.8
41.667	67	50.3	30.2	48	13.7	10.4	6.4
41.833	64.8	48.6	29.2				
42	62.6	47	28.2				
42.167	60.6	45.4	27.3				
42.333	58.6	43.9	26.4				
42.5	56.6	42.5	25.5				
42.667	54.8	41	24.7				
42.833	52.9	39.7	23.8				
43	51.2	38.4	23				
43.167	49.5	37.1	22.3				
43.333	47.8	35.8	21.5				
43.5	46.2	34.6	20.8				

DREAM

Disaster RIsk and Exposure Assessment for Mitigation