REGION 4A

Lucena River Basin:

DREAM Flood Forecasting
and Flood Hazard Mapping

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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 re-search 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 ap-pended 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.
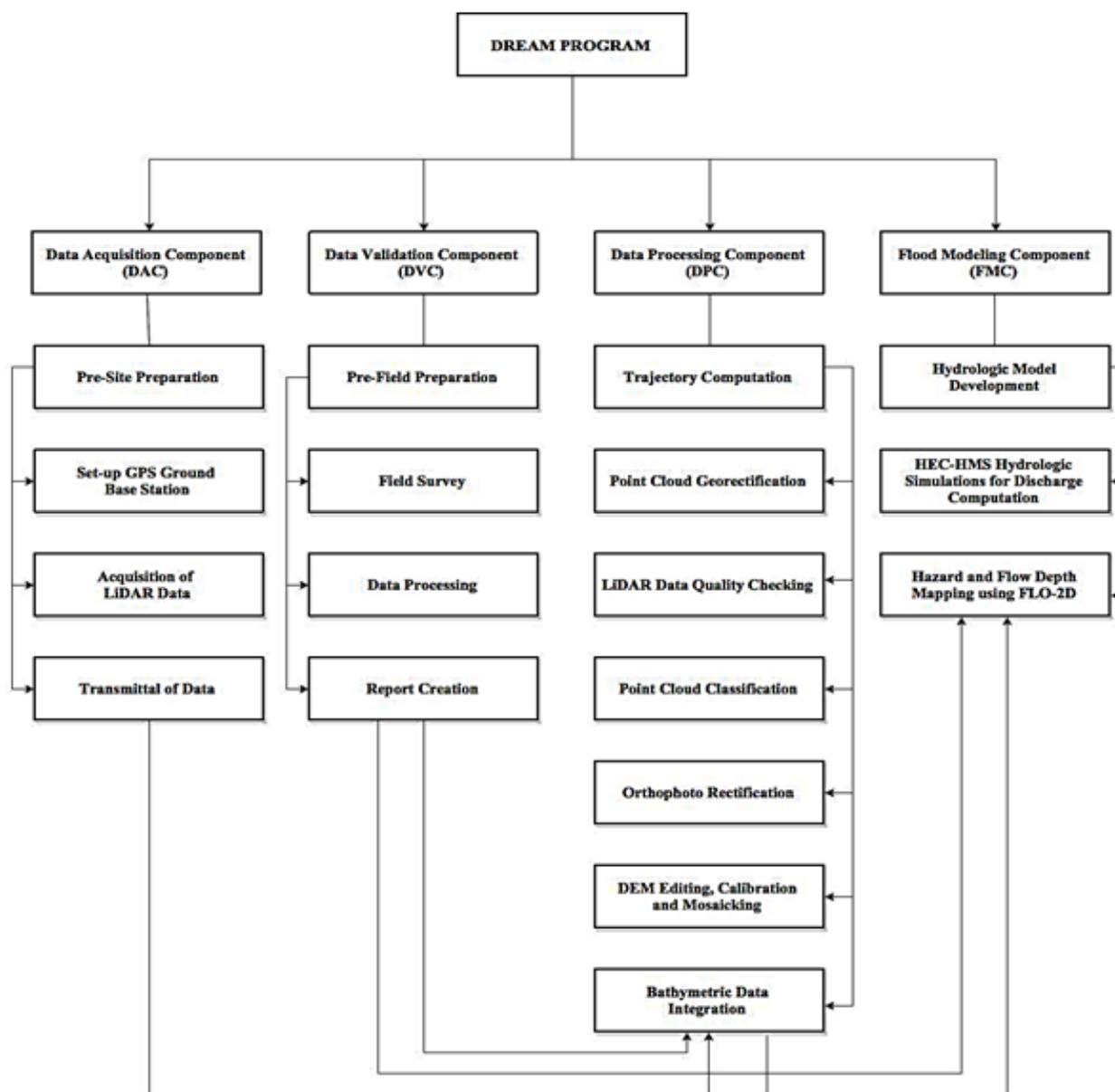
Figure 1. The general methodological framework of the program

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 Lucena 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 Lucena floodplain using FLO-2D GDS Pro; and

    d)   To prepare the static flood hazard and flow depth maps for the Lucena 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.
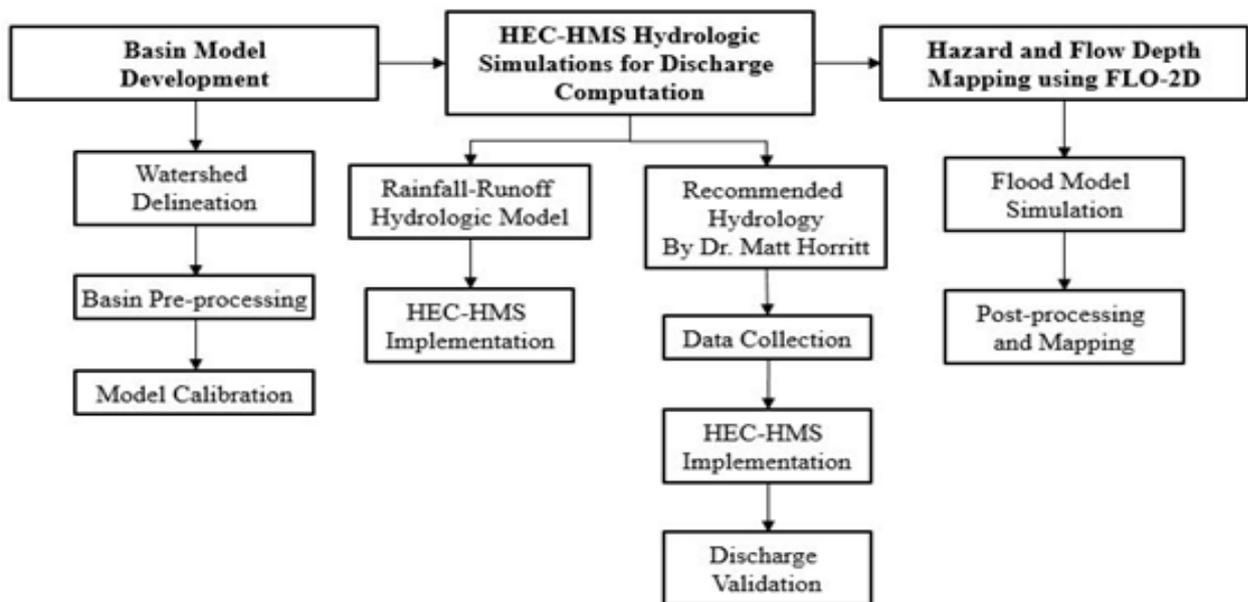
Figure 2. The operational framework and specific work flow of the Flood Modeling Component

The Lucena River Basin

The Lucena River Basin

Lucena River Basin is located in the province of Quezon. It comprises two major rivers, Dumacaa River on the east and Iyam River on the west. It traverses through Lucena, Tayabas, and Lucban City. The river basin covers an area of 253.0247 square kilometers. The location of the Lucena River Basin is as shown in Figure 3.
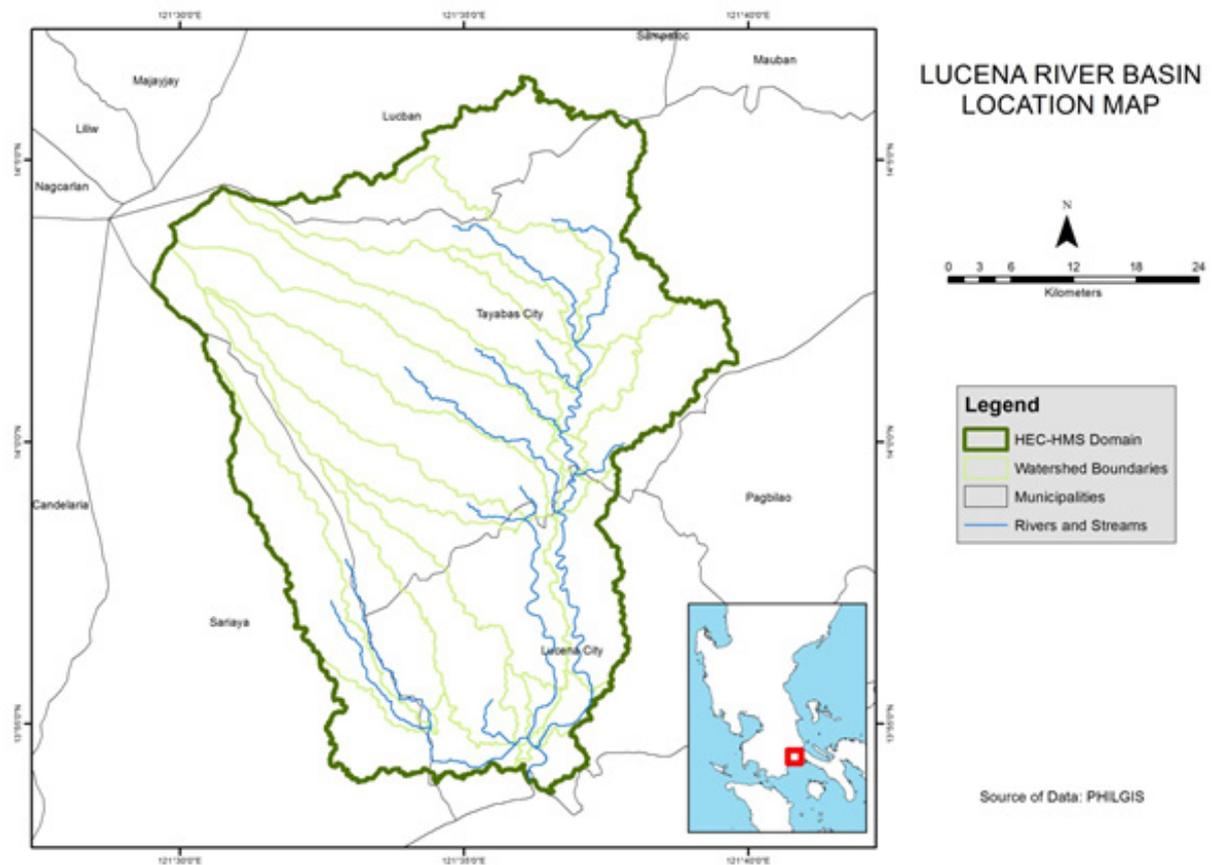
Figure 3. Lucena River Basin Location Map

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

The Lucena River Basin
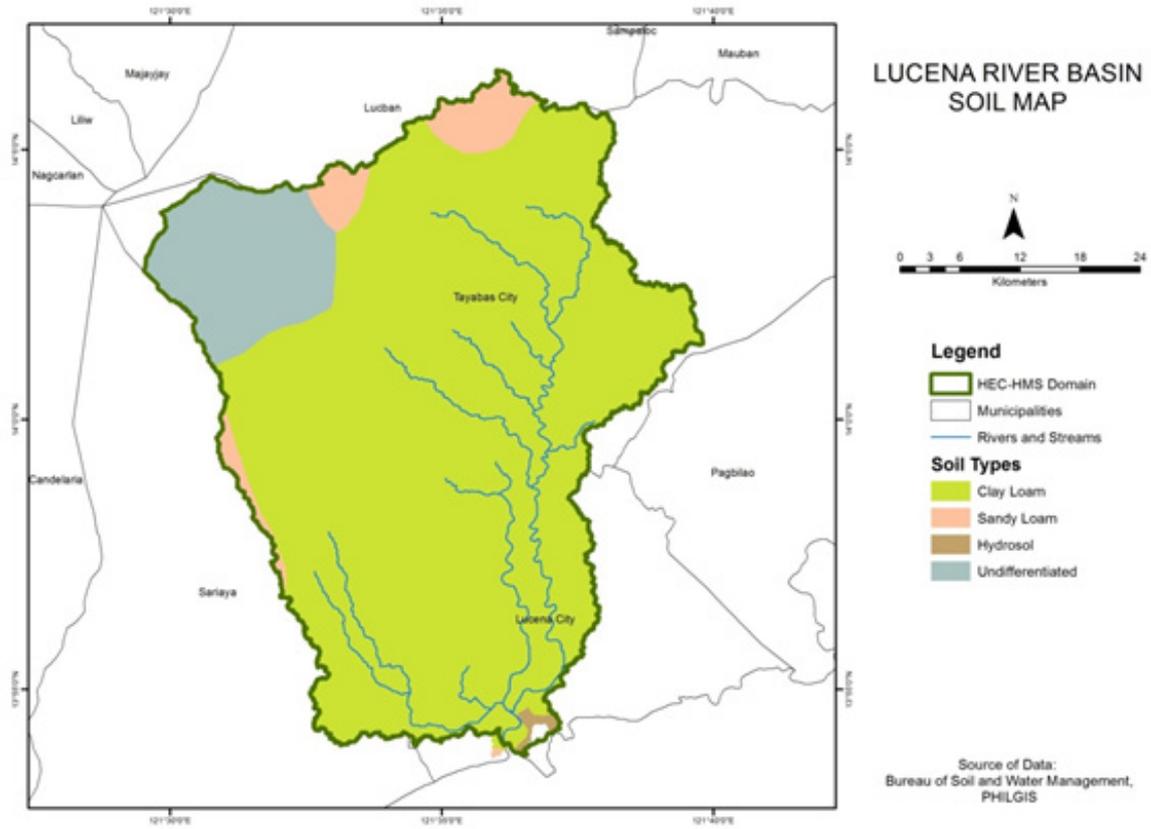
Figure 4. Lucena River Basin Soil Map
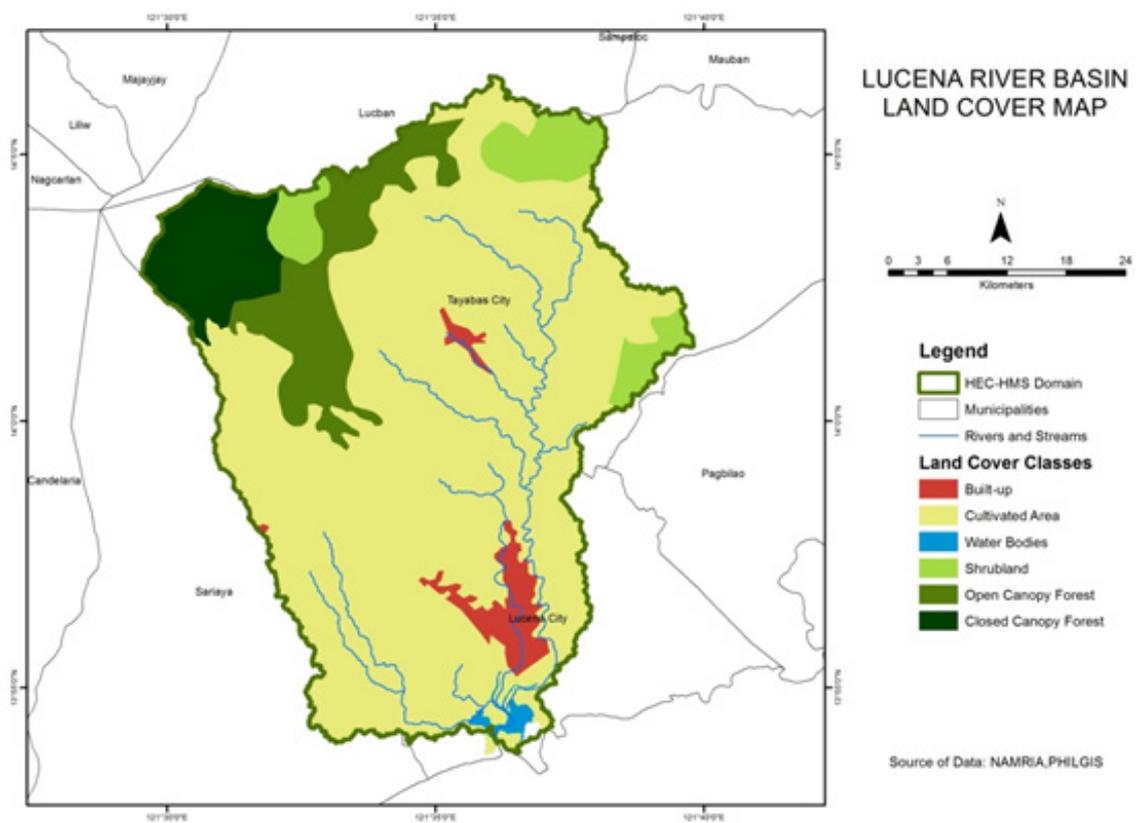
Figure 5. Lucena River Basin Land Cover Map

Methodology

Methodology

3.1   Pre-processing and Data Used

Flood modeling involved several data and parameters to achieve realistic simulations and outputs. Figure 6 shows a summary of the data needed to for the research.
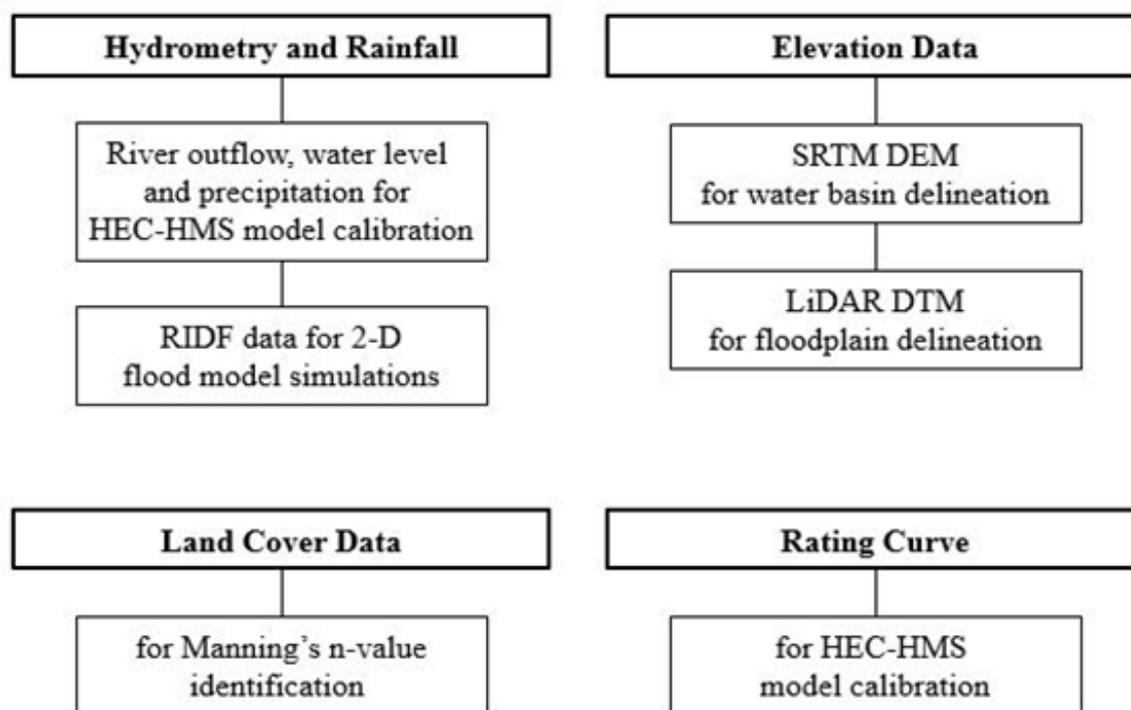
Figure 6. Summary of data needed for the purpose of flood modeling

3.1.1   Elevation Data

3.1.1.1   Hydro Corrected SRTM DEM

With the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) data as an input in determining the extent of the delineated water basin, the model was set-up. The Digital Elevation Model (DEM) is a set of elevation values for a range of points within a designated area. SRTM DEM has a 90 meter spatial mosaic of the entire country. Survey data of cross sections and profile points were integrated to the SRTM DEM for the hydro-correction.

3.1.1.2   LiDAR DEM

LiDAR was used to generate the Digital Elevation Model (DEM) of the different floodplains. DEMs used for flood modeling were already converted to digital terrain models (DTMs) which only show topography, and are thus cleared of land features such as trees and buildings. These terrain features would allow water to flow realistically in the models.

Figure 7 shows an image of the DEM generated through LiDAR.

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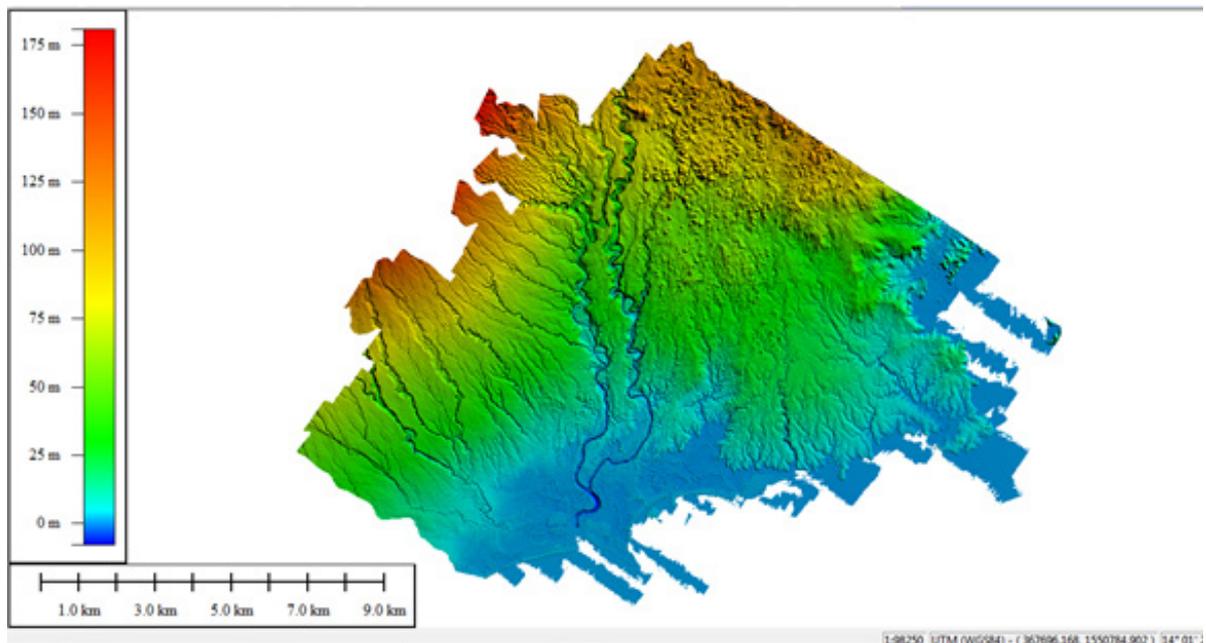
Figure 7. Digital Elevation Model (DEM) of the Lucena River Basin using Light Detection and Ranging (LiDAR) technology

Elevation points were created from LiDAR DTMs. Since DTMs were provided as 1-meter spatial resolution rasters (while flood models for Lucena 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.
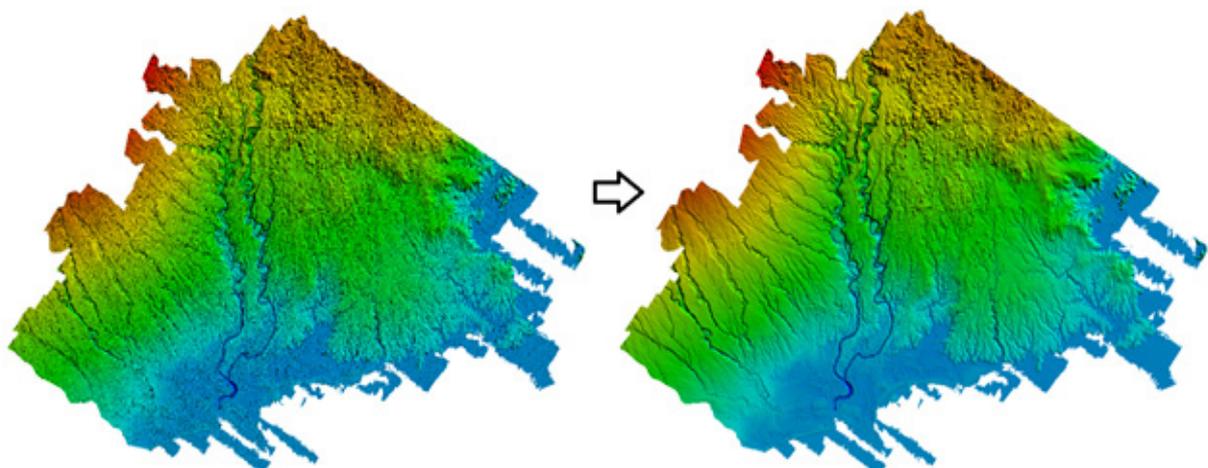
Figure 8. The 1-meter resolution LiDAR data resampled to a 10-meter raster grid in GIS software to ensure that values are properly adjusted.

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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 Lucena 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 Lucena floodplain.

3.1.3 Hydrometry and Rainfall Data

3.1.3.1   Hydrometry for Lucena

The river outflow from Iyam bridge, Lucena was used to calibrate the HEC-HMS model. This recorded peak discharge is around 10.60cms at 10:05 PM, June 18, 2014.
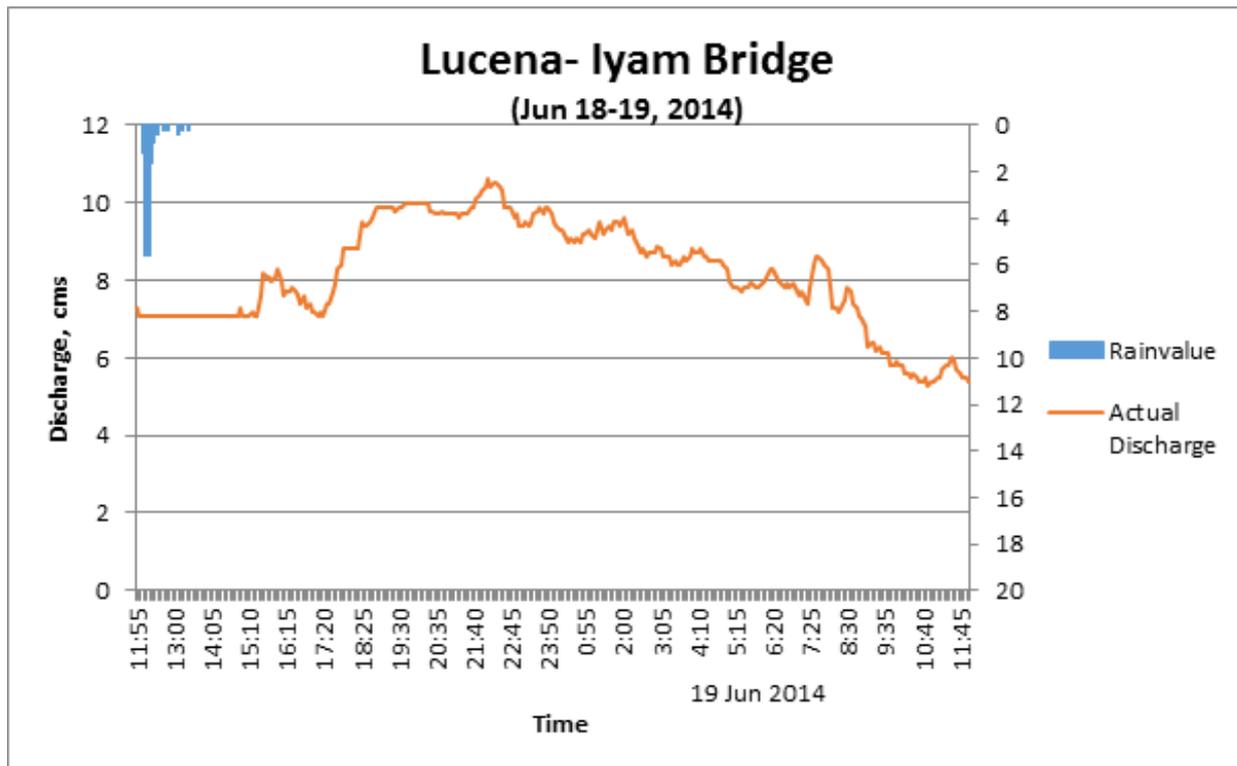
Figure 10. Asuncion Rainfall and outflow data used for modeling

Methodology

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 Lucena Rain Gauge. This station was chosen based on its proximity to the Lucena watershed. The extreme values for this watershed were computed based on a 26-year record.

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

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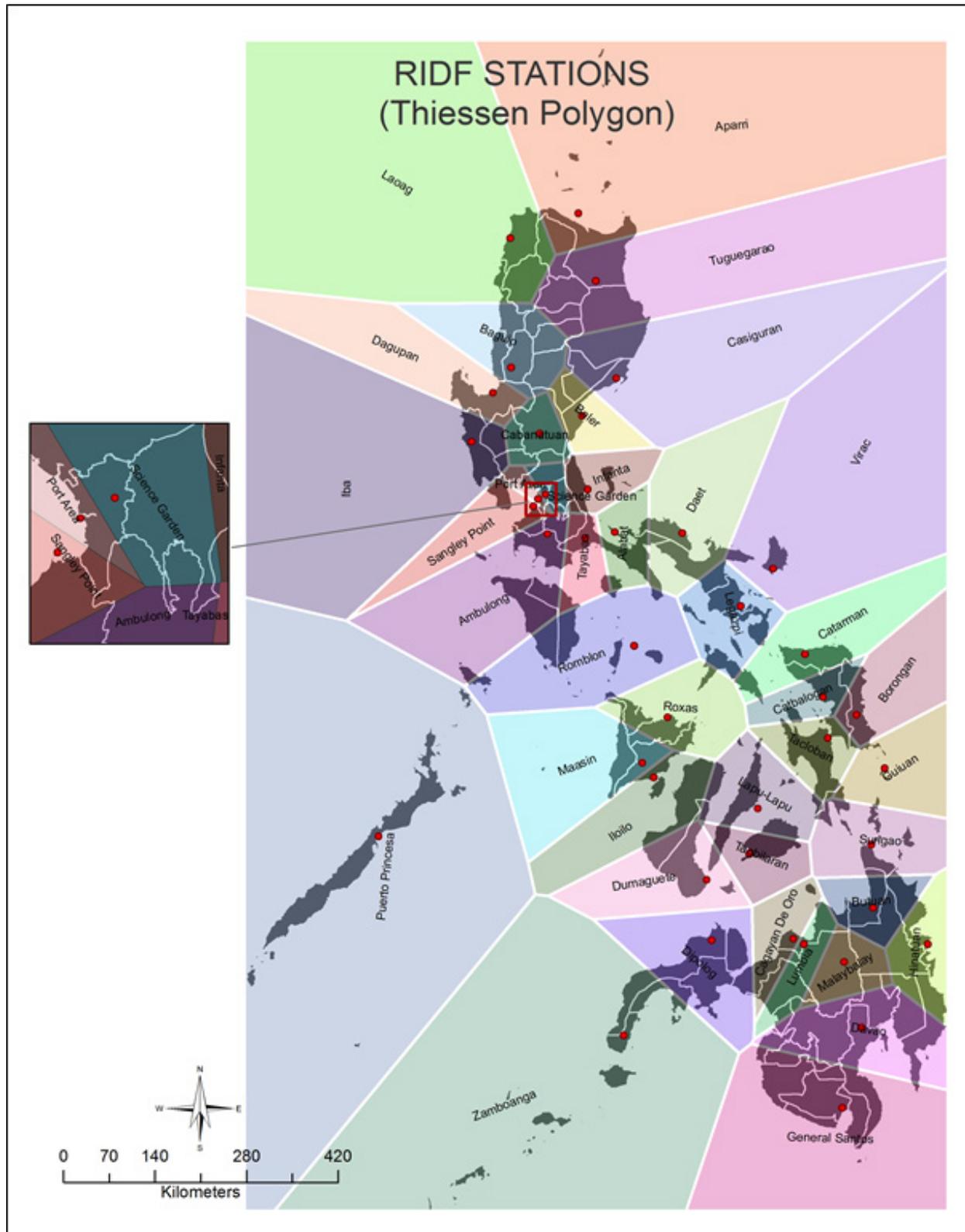
Figure 11. Thiessen Polygon of Rain Intensity Duration Frequency (RIDF) Stations for the whole Philippines.

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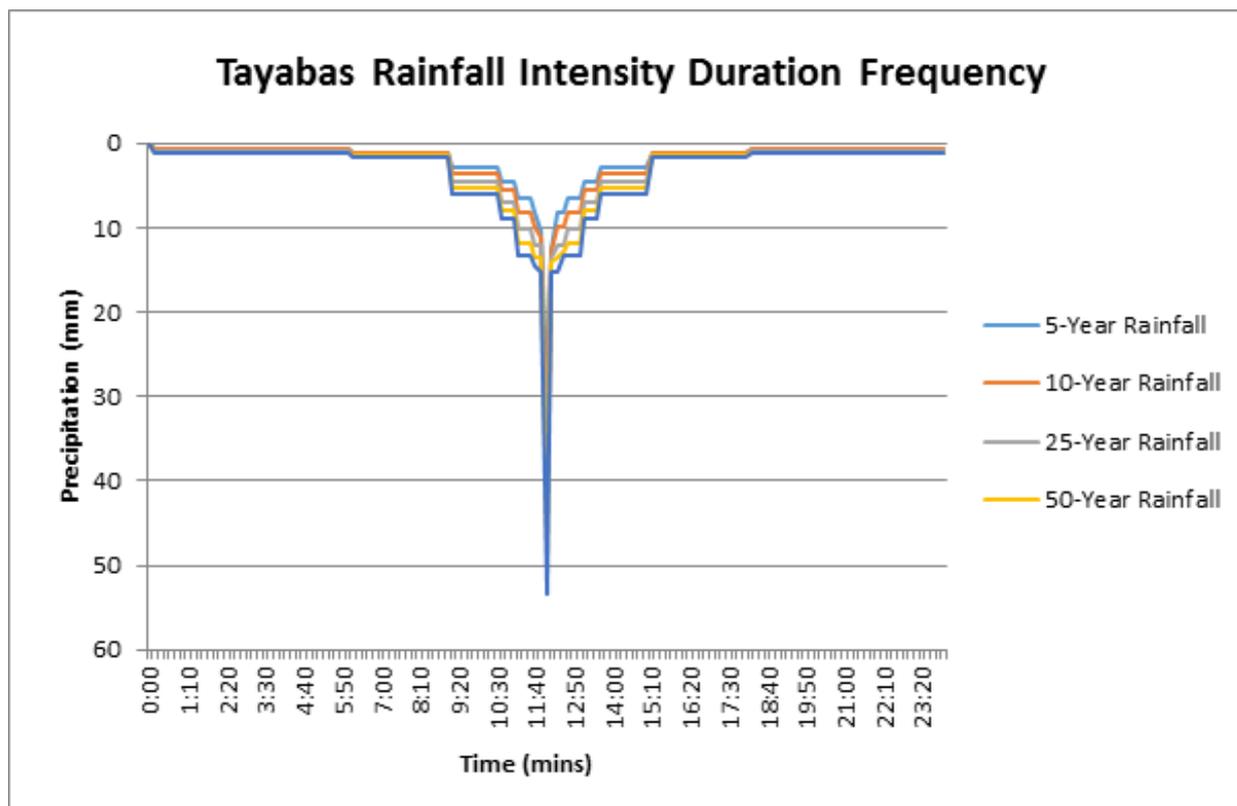
Figure 12. Tayabas Rainfall-Intensity Duration Frequency (RIDF) curves.

The outflow values at the discharge points in the Lucena river basin were computed for the five return periods, namely, 5-, 10-, 25-, 50-, and 100-year RIDFs.

3.1.5 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 Iyam Bridge, the rating curve is expressed as Q = 23.799.0004xh as shown in Figure 13.

Methodology
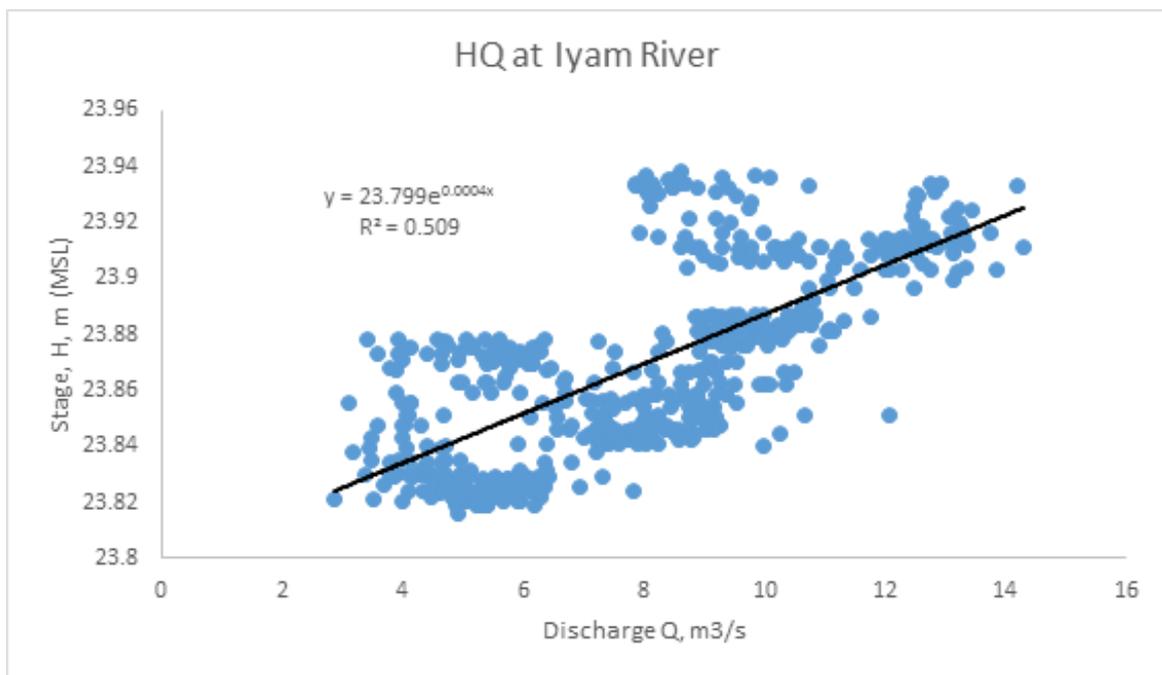
Figure 13. Water level vs. Discharge Curve for Iyam Bridge, Lucena

Methodology

3.2 Rainfall-Runoff Hydrologic Model Development

3.2.1 Watershed Delineation and Basin Model Pre-processing

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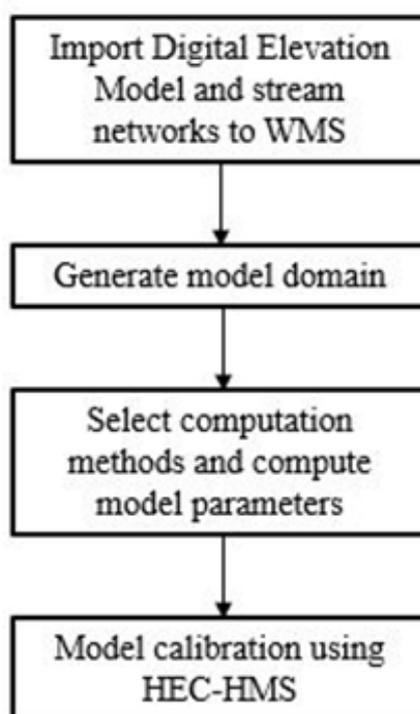
Figure 14. The Rainfall-Runoff Basin Model Development Scheme

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

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

Methodology
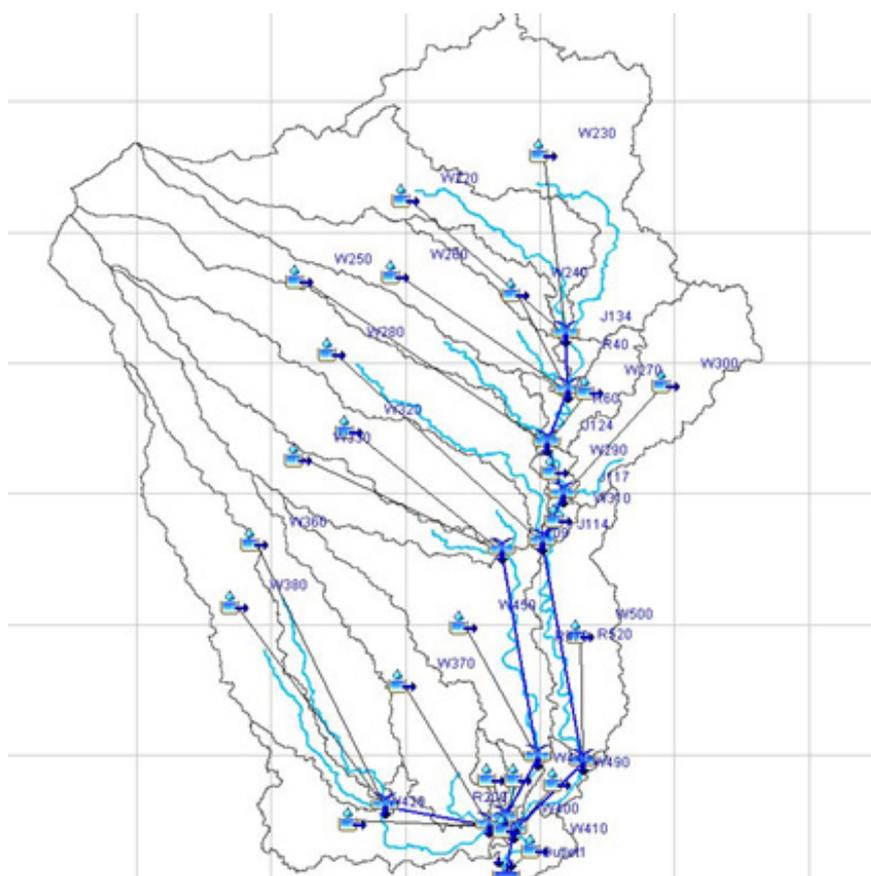
Figure 15. Lucena HEC-HMS Model domain generated by WMS

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

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

Methodology

3.2.2 Basin Model Calibration

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

Precipitation and waterlevel data were taken from the rain (ARG) and depth gauges deployed by the DREAM Program's Data Validation Component. These were placed on Iyam Bridge. At present, there are no ARGs and AWLS located in the watershed.

For the calibration of the downstream-most discharge point which is at Iyam Bridge, the total rain is 18 mm for one day. It peaked to 5.6 mm on 18 June 2014, 12:15 PM.

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 Lucena 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 Tayabas 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 Lucena discharge points .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.

Methodology

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 19.
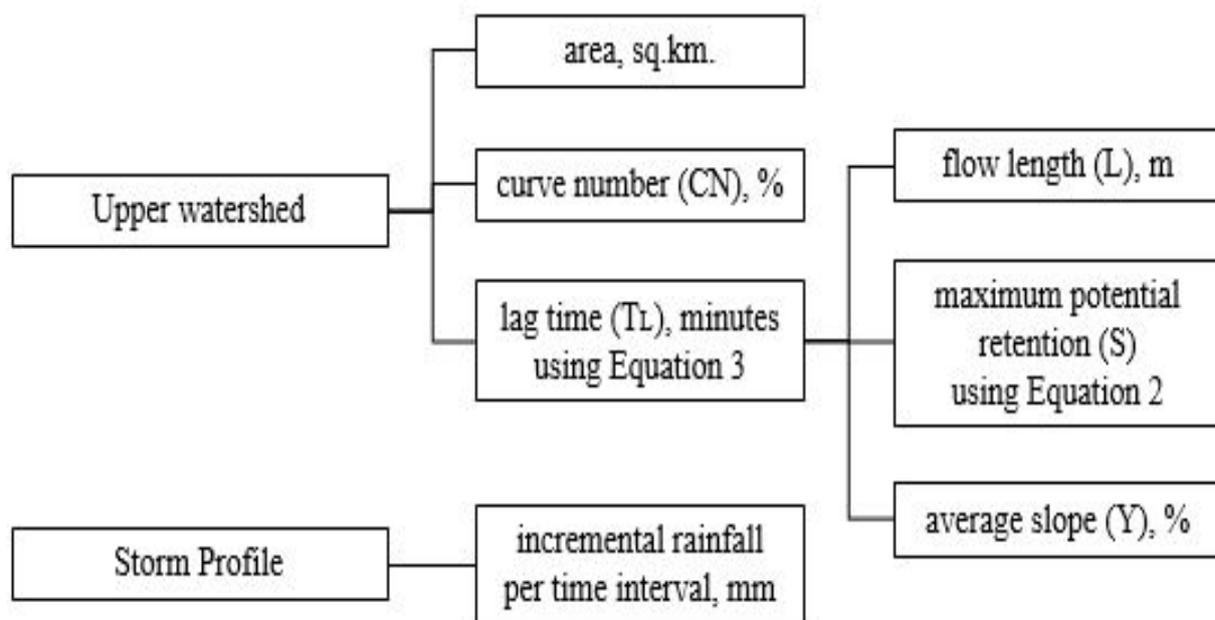
Figure 16. Different data needed as input for HEC-HMS discharge simulation using Dr. Horritt's recommended hydrology method.

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.

Methodology

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 17. Delineation of upper watershed for Lucena floodplain discharge computation

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

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

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

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

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

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

Equation 3. Lag Time Equation Calibrated for Philippine Setting

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

3.3.2.2   HEC-HMS Implementation

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

Methodology
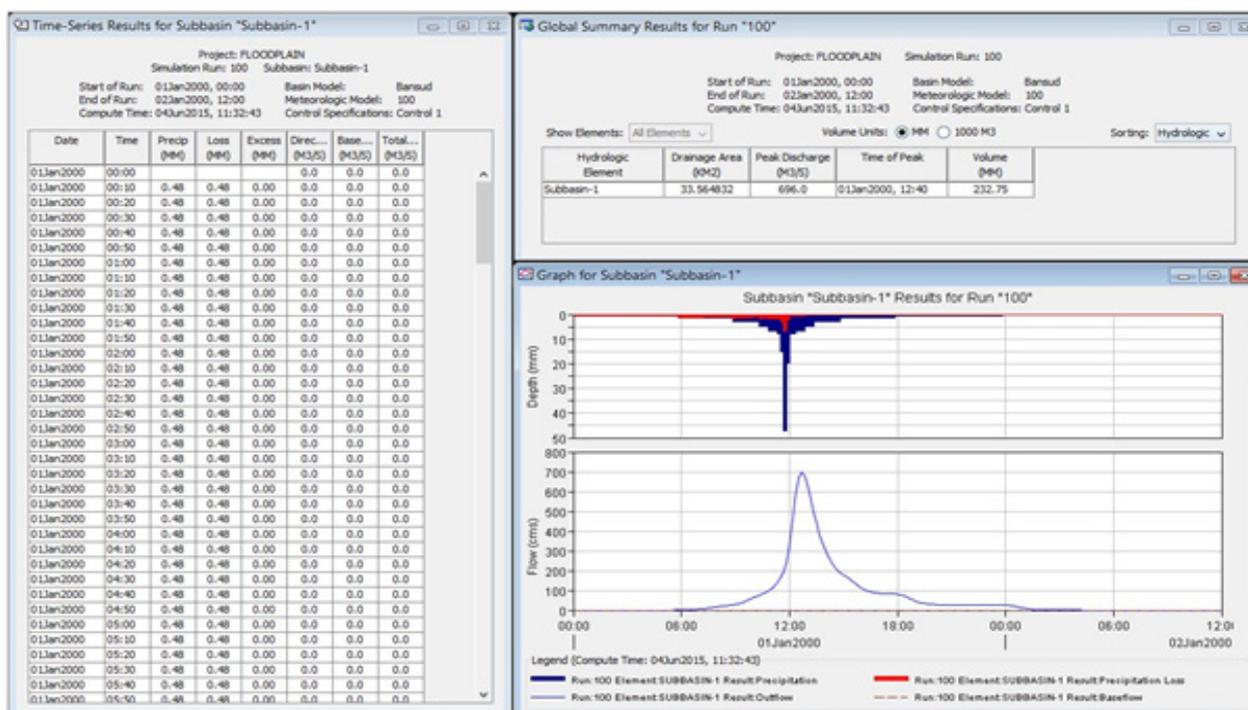
Figure 18. HEC-HMS simulation discharge results using Dr. Horritt's Method

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.

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

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.

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

Equation 6. Bankful discharge equation using measurable channel parameters

3.4 Hazard and Flow Depth Mapping using FLO-2D

3.4.1 Floodplain Delineation

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

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

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

3.4.2 Flood Model Generation

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

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

The boundary for the area was set by defining the boundary grid elements. This can either be

Methodology

done by defining each element individually, or by drawing a line that traces the boundaries of the subcatchment. The grid elements inside of the defined boundary were considered as the computational area in which the simulation will be run.
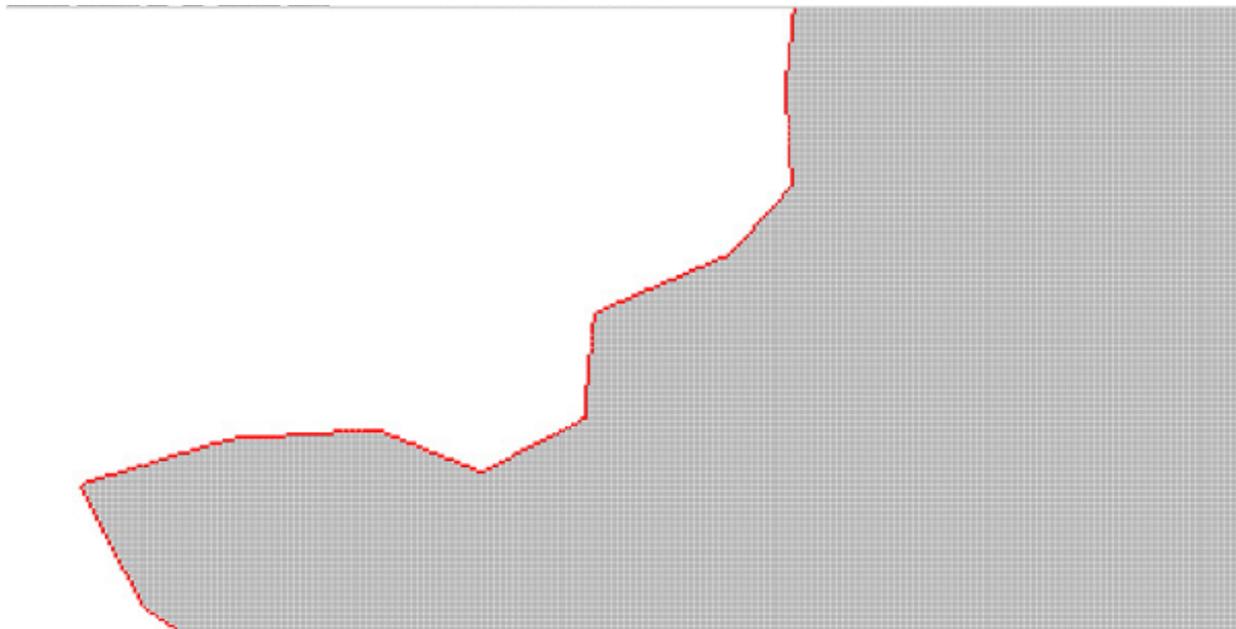
Figure 19. Screenshot showing how boundary grid elements are defined by line

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.
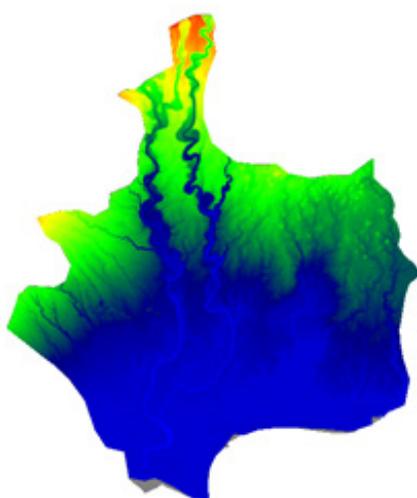
Figure 20. Screenshots of PTS files when loaded into the FLO-2D program

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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 21. Areal image of Lucena floodplain
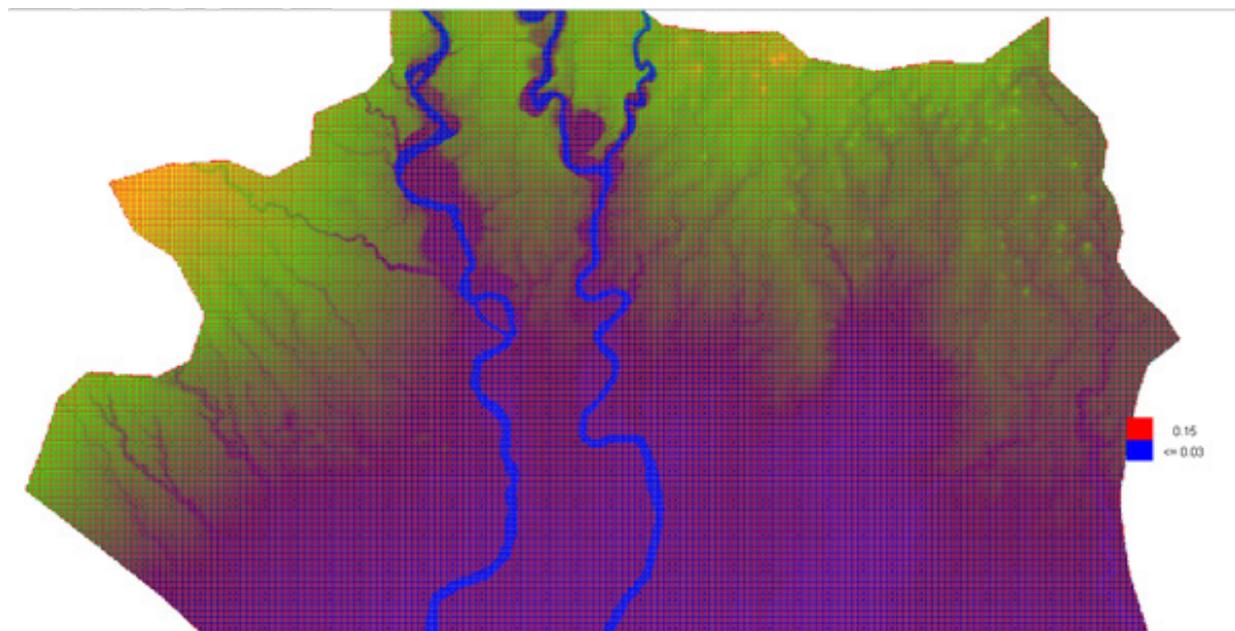
Figure 22. Screenshot of Manning's n-value rendering

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.
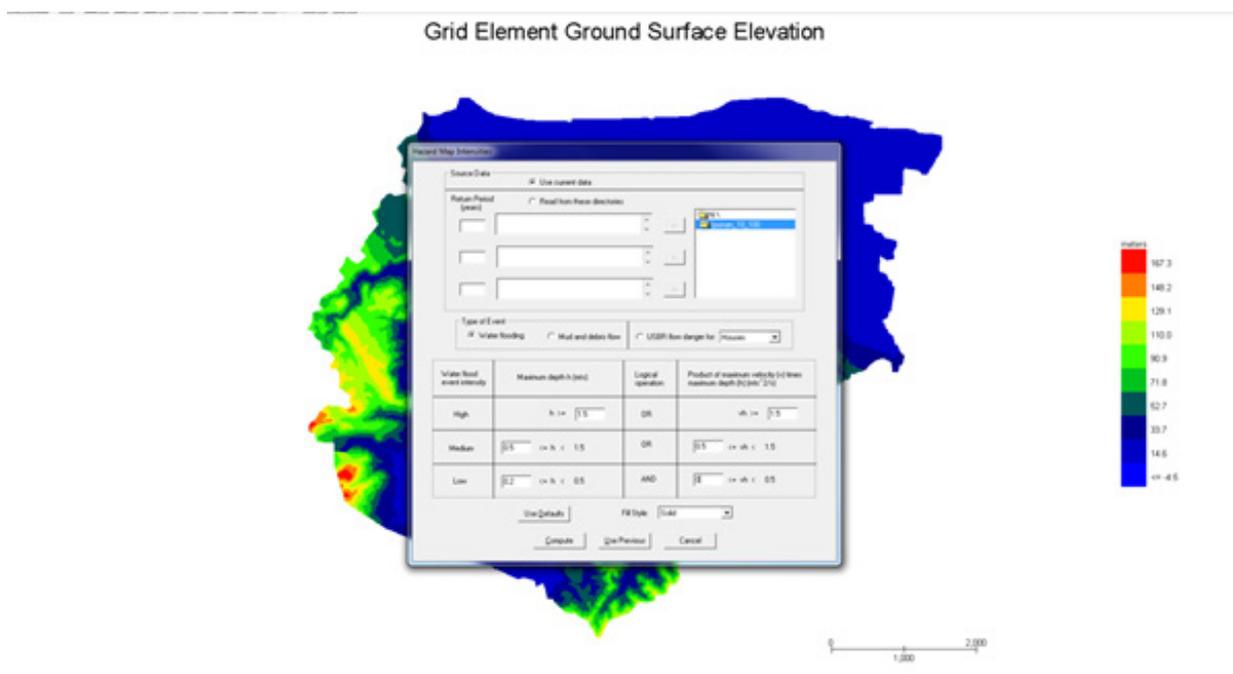
Figure 23. Flo-2D Mapper Pro General Procedure

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.
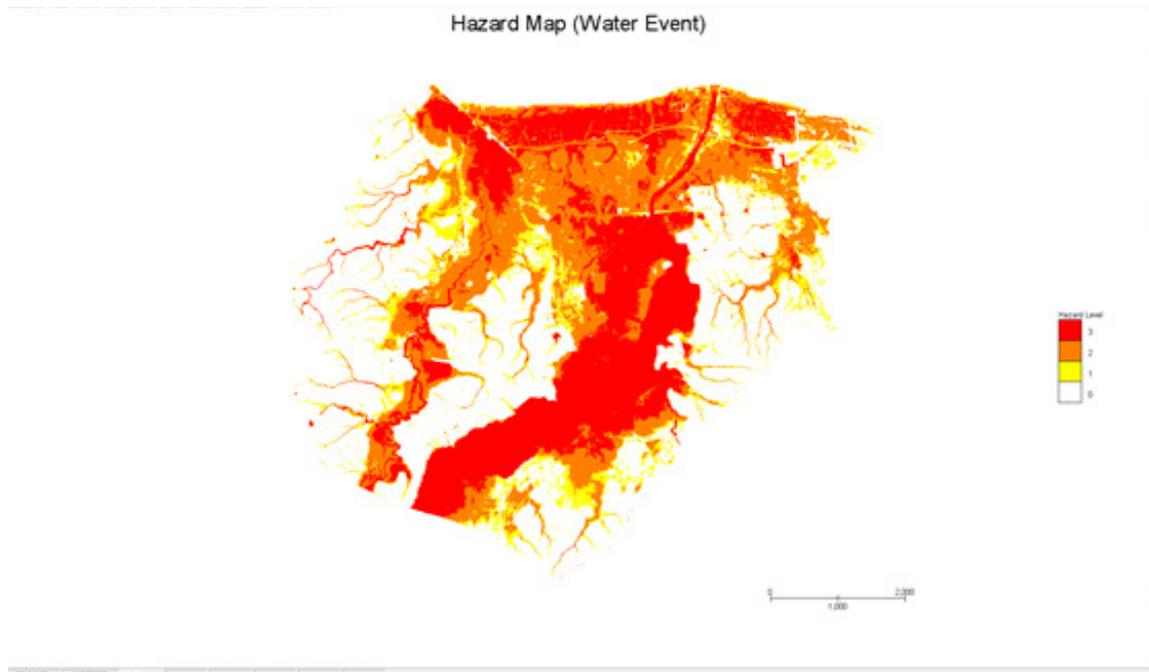
Figure 24. Lucena Floodplain Generated Hazard Maps using FLO-2D Mapper
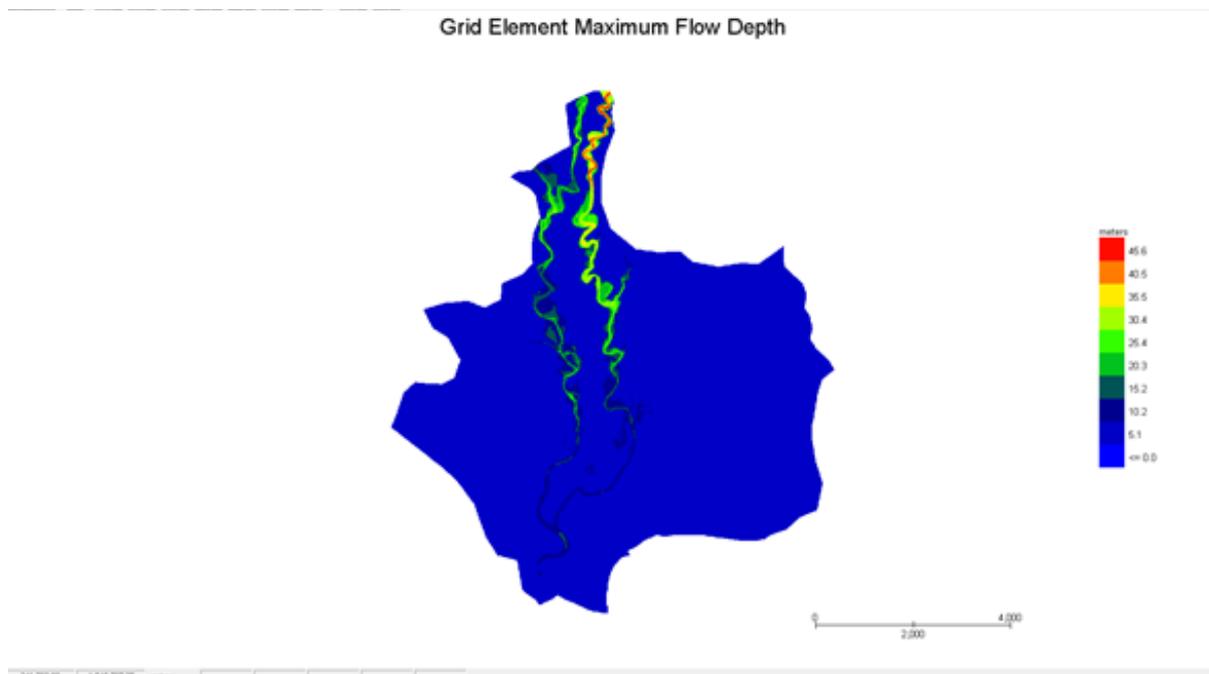
Figure 25. Lucena floodplain generated flow depth map using FLO-2D Mapper

Methodology

3.4.4 Hazard Map and Flow Depth Map Creation

The final procedure in creating the maps is to prepare them with the aid of ArcMap. The generated shapefiles from FLO-2D Mapper Pro were opened in ArcMap. The basic layout of a hazard map is shown in Figure 27. The same map elements are also found in a flow depth map.
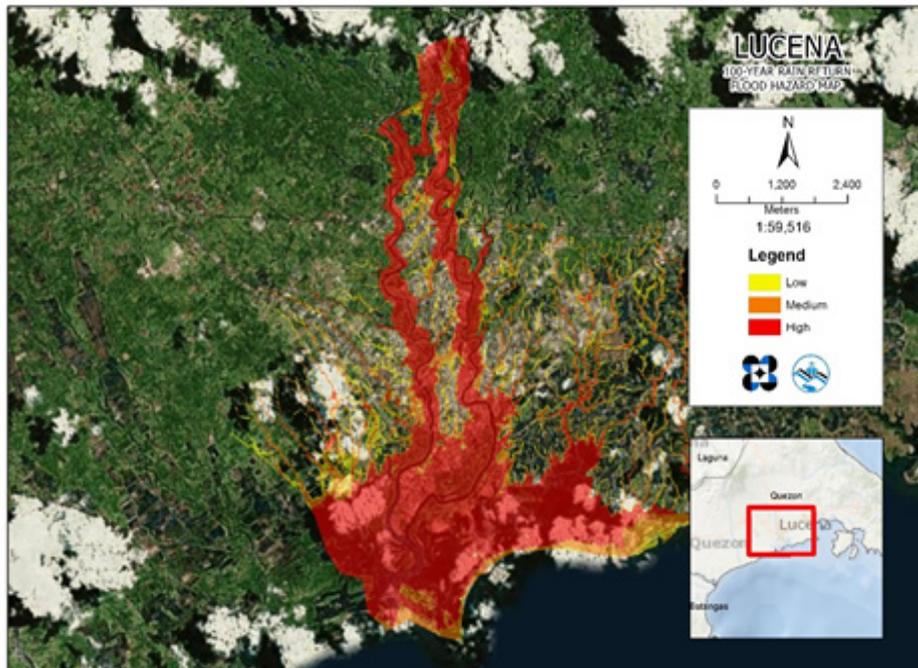
ELEMENTS:
1. River Basin Name
2. Hazard/Flow Depth Shapefile
3. Provincial Inset
4. Philippine Inset
5. Hi-Res image of the area
6. North Arrow
7. Scale Text and Bar

Figure 26. 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
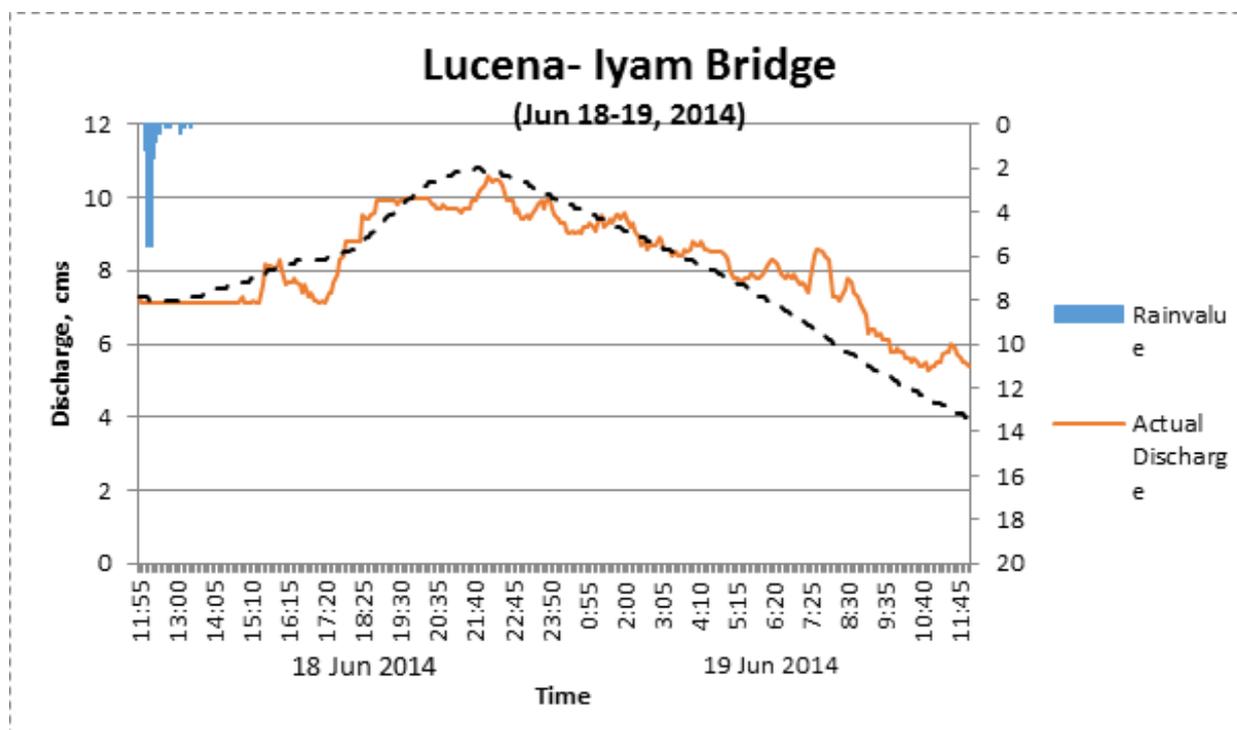
Figure 27. Iyam Bridge, Lucena Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow

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

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.5.

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 0.9956.

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 0.81.

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 -2.72.

Results and Discussion

After calibrating the Nanaga Bridge HEC-HMS river basin model, its accuracy was measured against the observed values and is shown in Figure 31.

For Talaingod, the RMSE is 4.7, the Pearson correlation coefficient, r2, is 0.866, it has a Nash-Sutcliffe E value of 0.6, PBIAS of -7.51 and RSR value of 0.63.

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.
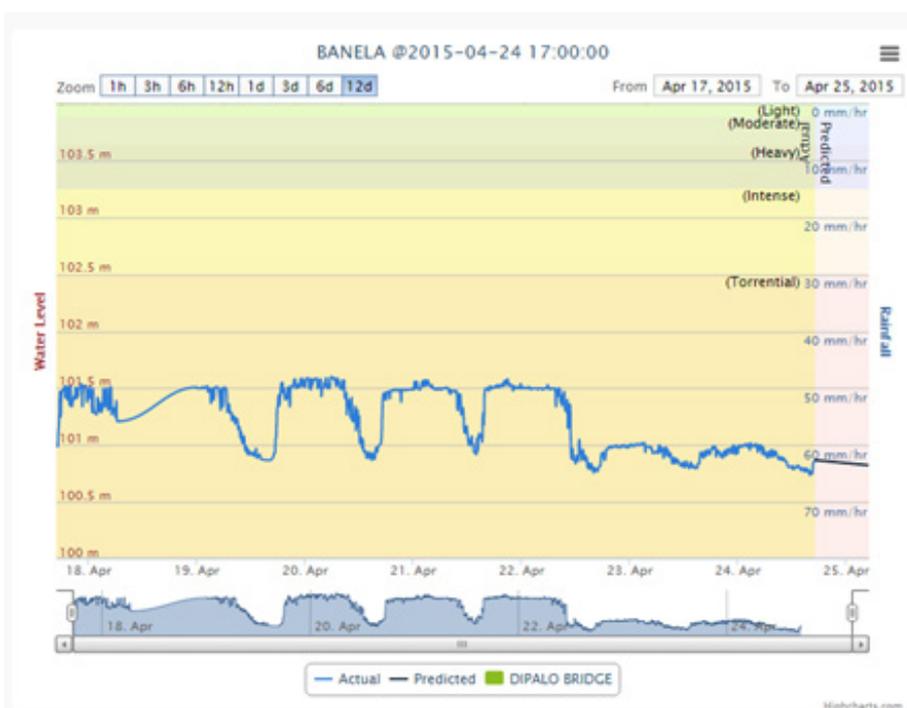
Figure 28. Sample DREAM Water Level Forecast

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.

Results and Discussion

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

In the 5-year return period graph, the peak outflow is 182.8 cms. This occurs after 1 hour and 40 minutes after the peak precipitation of 29.6 mm, as shown on Figure 30.
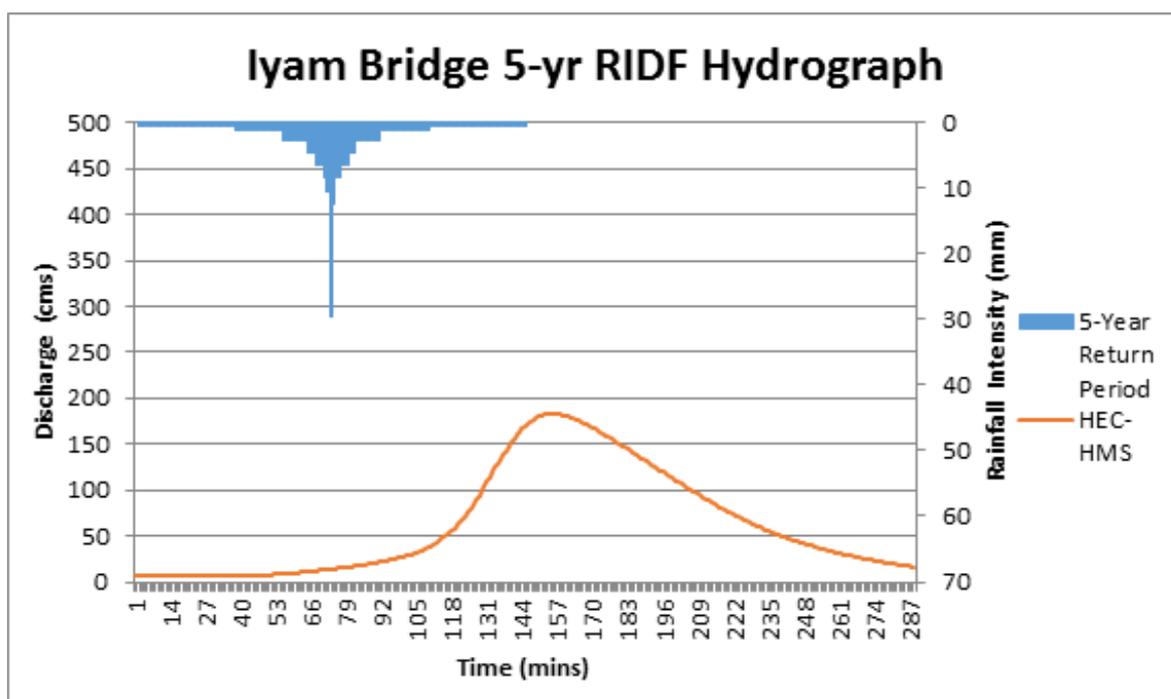
Figure 29. Lucena outflow hydrograph generated using the Tayabas 5-Year RIDF in HEC-HMS

In the 10-year return period graph, the peak outflow is 222.4 cms. This occurs after 1 hour and 40 minutes after the peak precipitation of 35.4 mm, as shown on Figure 31.

Results and Discussion
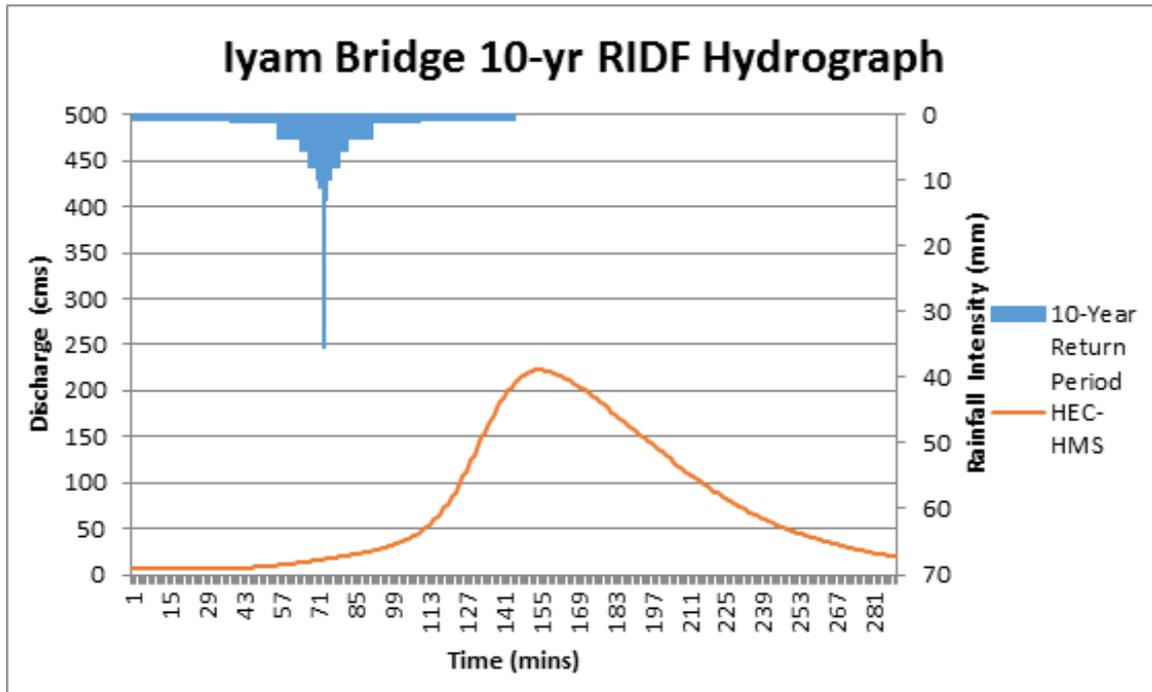
Figure 30. Lucena outflow hydrograph generated using the Tayabas 10-Year RIDF in HEC-HMS

In the 25-year return period graph, the peak outflow is 272.7 cms. This occurs after 1 hour and 30 minutes after the peak precipitation 42.6 mm, as shown on Figure 32.
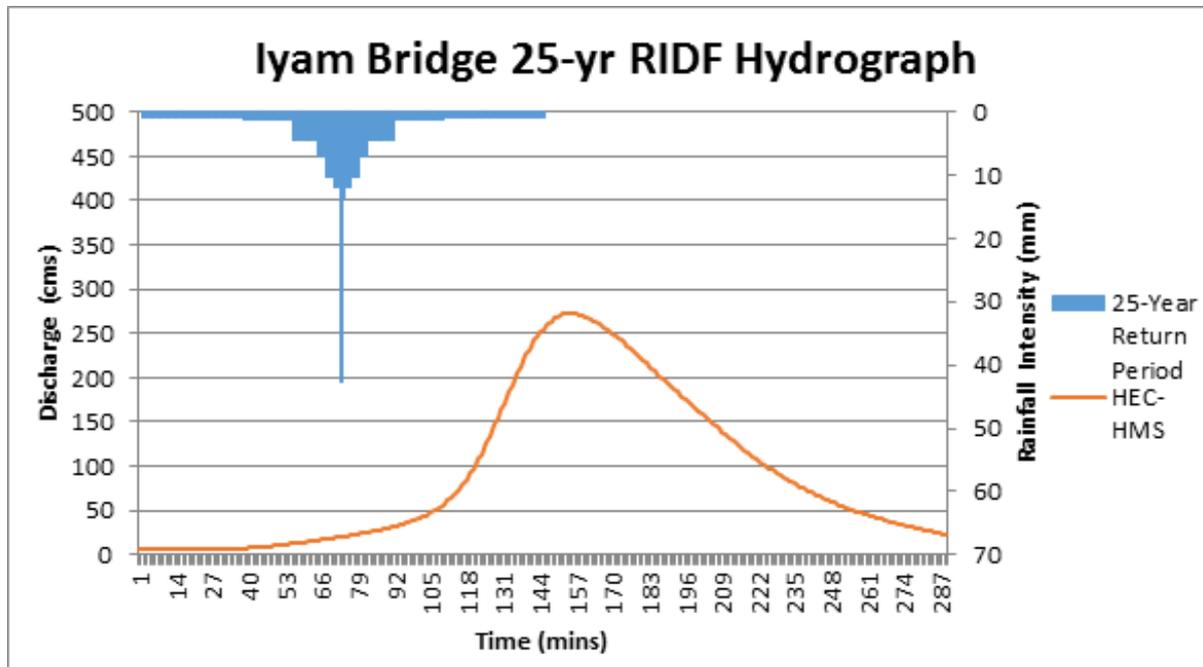
Figure 31. Lucena outflow hydrograph generated using the Tayabas 25-Year RIDF in HEC-HMS

Results and Discussion

In the 50-year return period graph, the peak outflow is 310.1 cms. This occurs after 1 hour and 30 minutes after the peak precipitation of 48 mm, as shown on Figure 33.
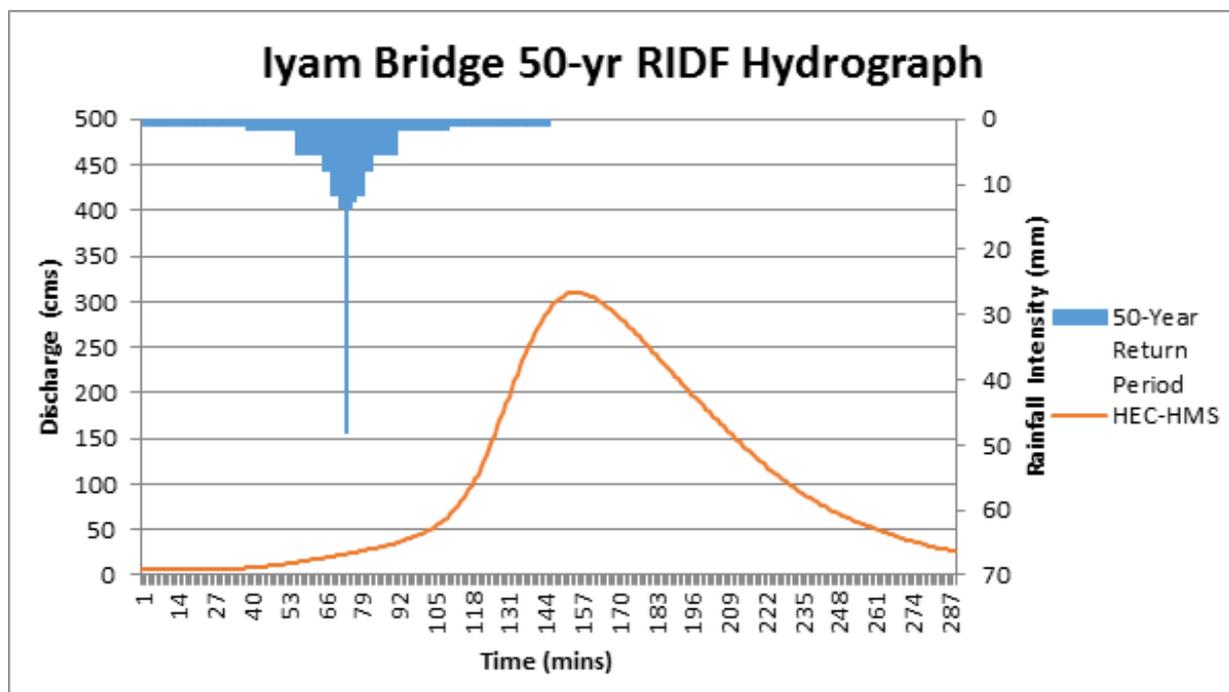
Figure 32. Lucena outflow hydrograph generated using the Tayabas 50-Year RIDF in HEC-HMS

In the 100-year return period graph, the peak outflow is 347.1 cms. This occurs after 1 hour and 30 minutes after the peak precipitation of 53.4 mm, as shown on Figure 34.
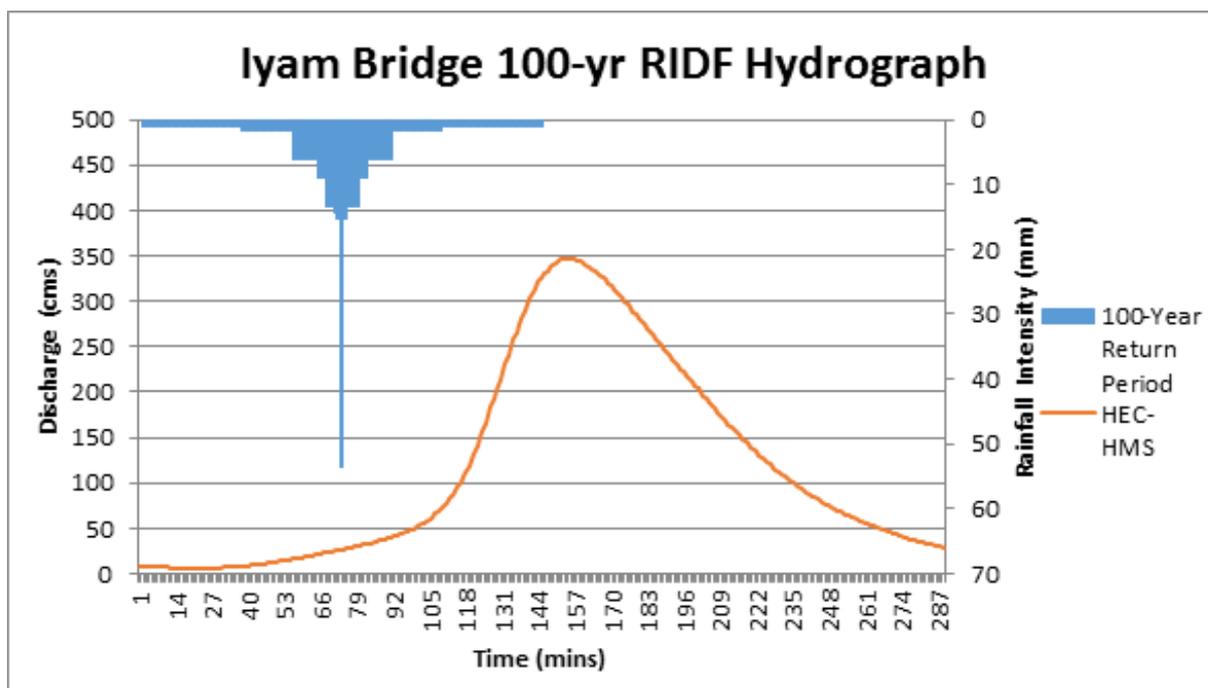
Figure 33. Lucena outflow hydrograph generated using the Tayabas 100-Year RIDF in HEC-HMS

Results and Discussion

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

Table 2. Summary of Lucena discharge using Tayabas Station Rainfaill Intensity Duration Frequency (RIDF)

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	279.5	29.6	182.8	1 hour and 40 minutes
10-Year	334.9	35.4	222.4	1 hour and 40 minutes
25-Year	404.8	42.6	272.7	1 hour and 30 minutes
50-Year	456.7	48	310.1	1 hour and 30 minutes
100-Year	508.3	53.4	347.1	1 hour and 30 minutes

Results and Discussion

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

The river discharge values using Dr. Horritt's recommended hydrological method are shown in Figure 35 and the peak discharge values are summarized in Table 3.
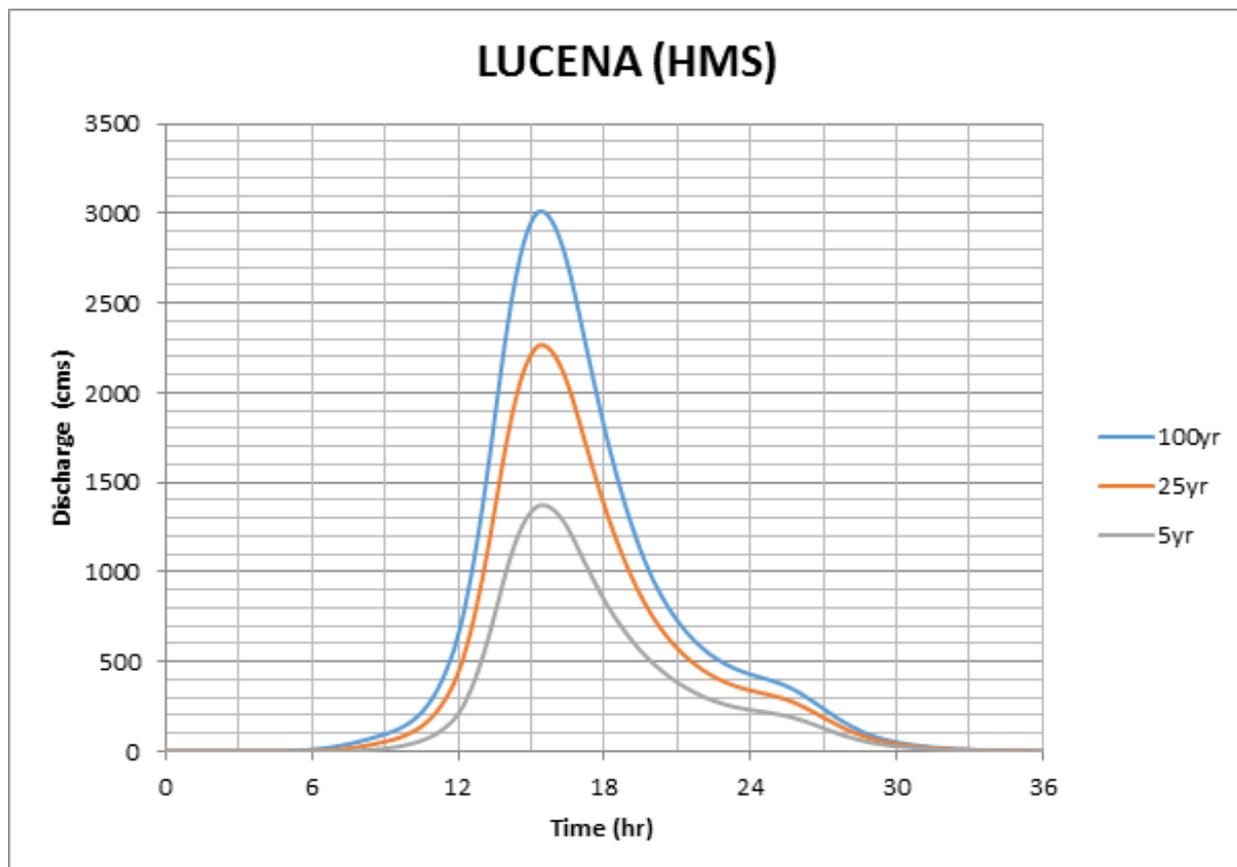
Figure 34. Outflow hydrograph generated using the Lucena 5-,25-, 100-Year RIDF in HEC-HMS.

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

RIDF Period	Peak discharge (cms)	Time-to-peak
5-Year	1374.7	15 hours, 30 minutes
25-Year	2266	15 hours, 30 minutes
100-Year	3012	15 hours, 20 minutes

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 Lucena, the bankful discharge for the river was computed.

Results and Discussion

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

Discharge Point	Qbankful, cms	QMED, cms	Validation
Lucena (1)	2212.2	1209.74	Pass

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

4.3 Flood Hazard and Flow Depth Maps

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

Results and Discussion

Flood Hazard Maps and Flow Depth Maps

Figure 35. 100-year Flood Hazard Map for Lucena River Basin
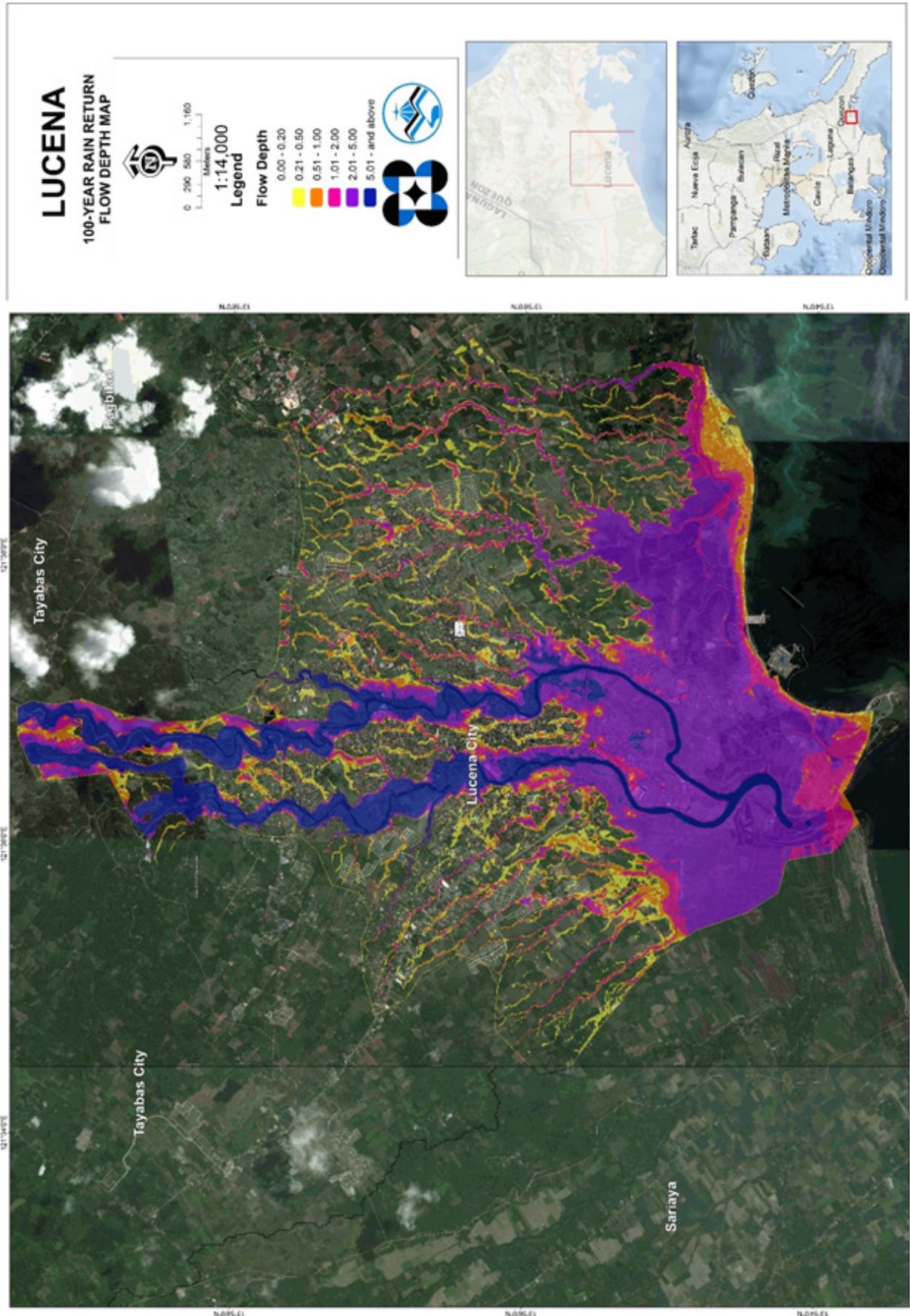
Figure 36. 100-year Flow Depth Map for Lucena River Basin

Results and Discussion
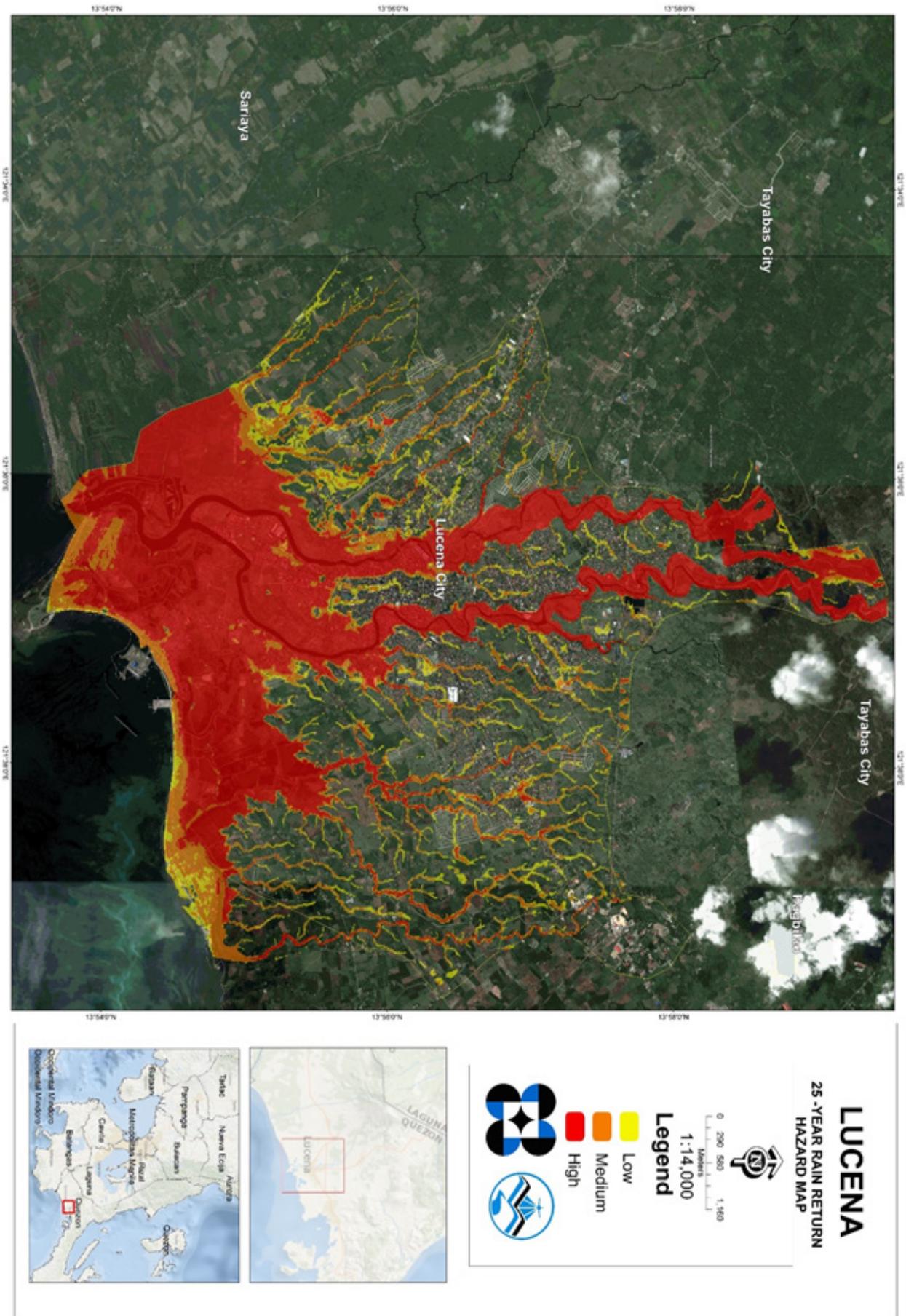
Figure 37. 25-year Flood Hazard Map for Lucena River Basin
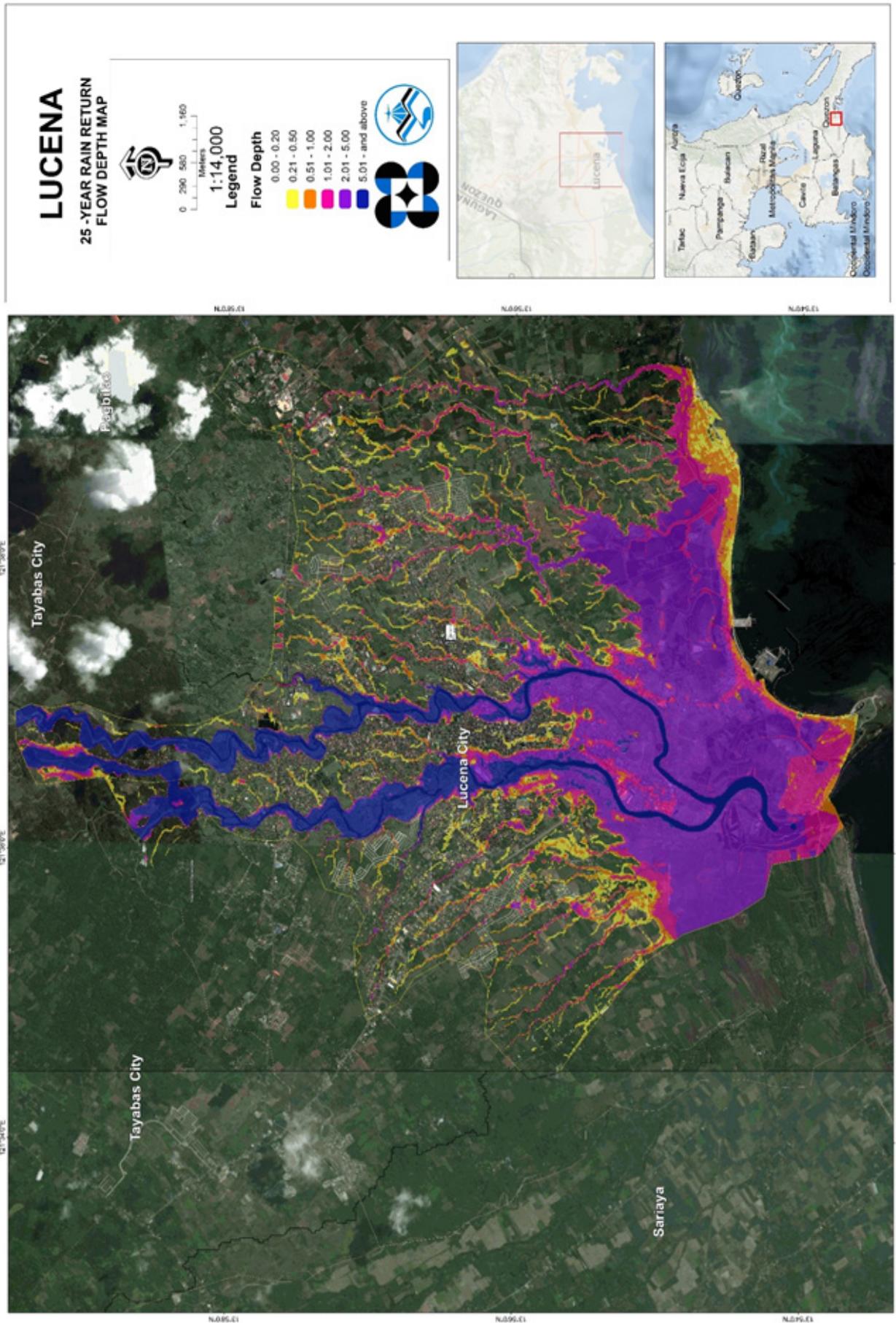
Figure 38. 25-year Flow Depth Map for Lucena River Basin
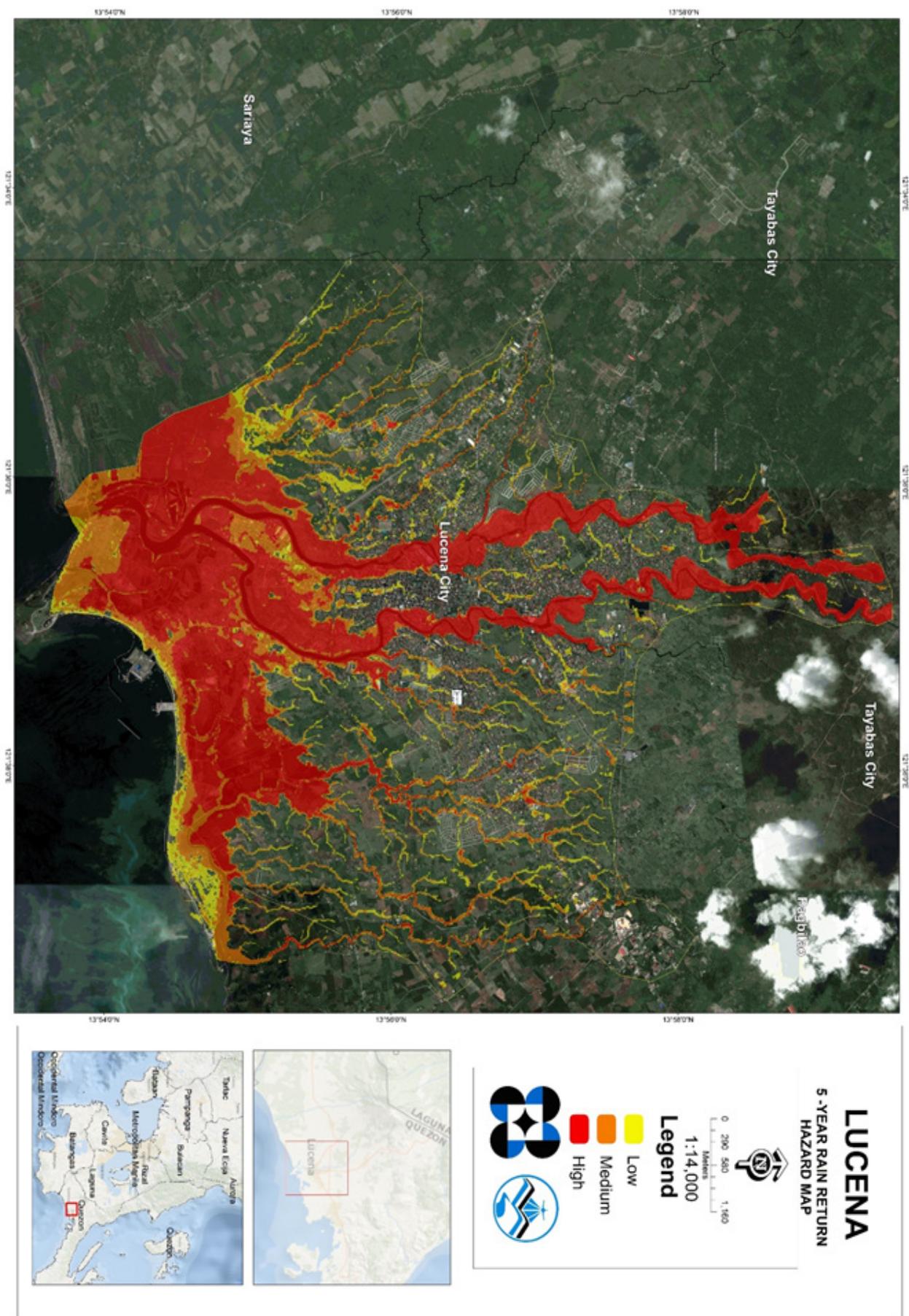
Figure 39. 5-year Flood Hazard Map for Lucena River Basin

Results and Discussion
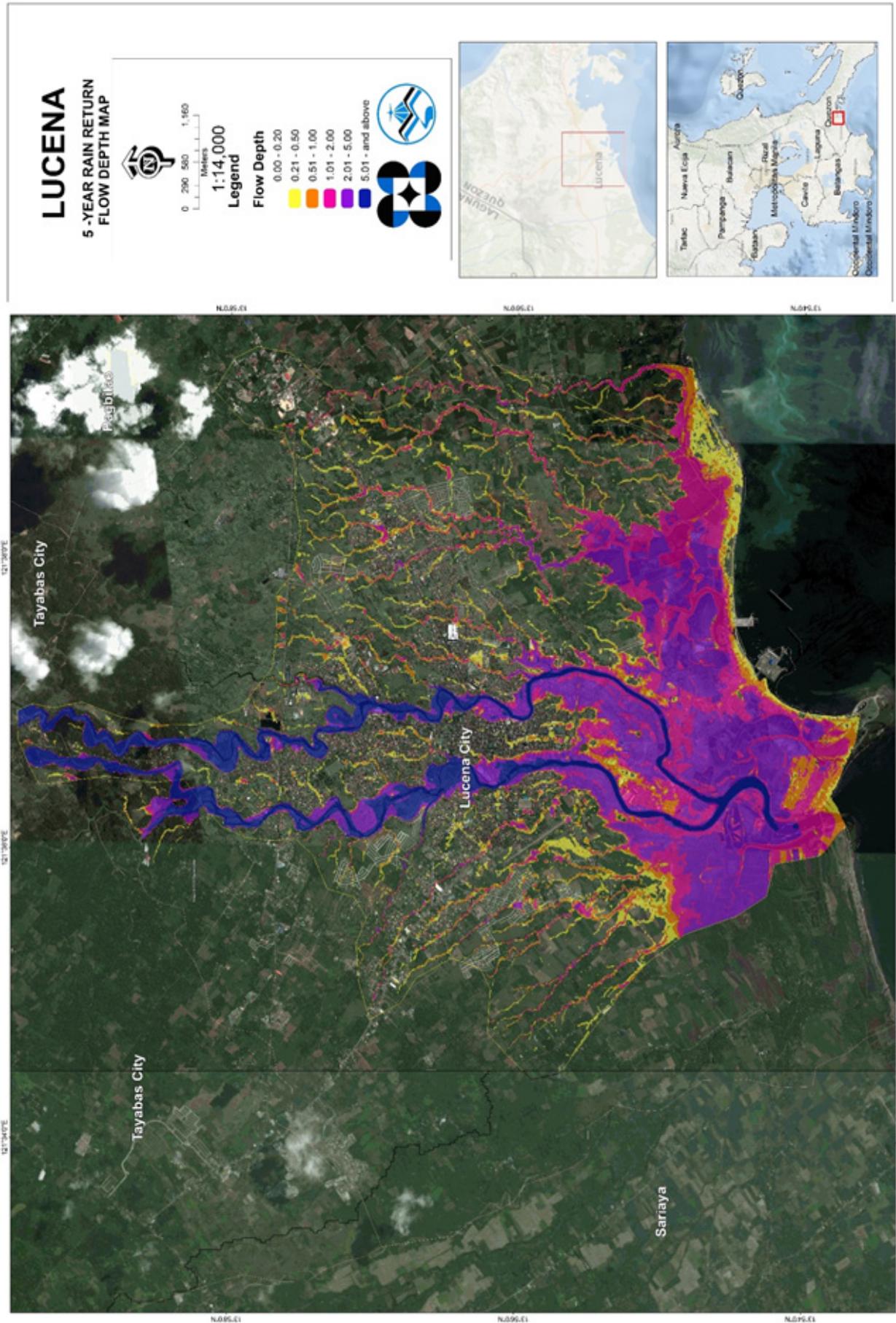
Figure 40. 5-year Flow Depth Map for Lucena River Basin

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Appendix

Appendix

Appendix A. Lucena 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
W320	0.472905	99.000	0.0	14.54165	7.5557	Discharge	2.8825	0.1	Ratio to Peak	0.01
W330	0.32173	93.990	0.0	6.412025	4.9132	Discharge	1.7724	0.1	Ratio to Peak	0.01
W450	0.48433	88.923	0.0	7.16319	6.6135	Discharge	2.6632	0.1	Ratio to Peak	0.01

Appendix

Appendix B. Lucena Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R470	Automatic Fixed Interval	7497.7	0.0054710	0.14595	Trapezoid	50	1

Appendix

Appendix C. Lucena 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	5.833333	8.9	1.9	0
0.166667	0	0	0	6	10.9	2.5	0
0.333333	0	0	0	6.166667	13.2	3.3	0
0.5	0	0	0	6.333333	15.7	4.3	0.1
0.666667	0	0	0	6.5	18.5	5.5	0.2
0.833333	0	0	0	6.666667	21.6	6.9	0.3
1	0	0	0	6.833333	24.9	8.5	0.5
1.166667	0	0	0	7	28.6	10.3	0.8
1.333333	0	0	0	7.166667	32.6	12.5	1.1
1.5	0	0	0	7.333333	36.9	14.9	1.6
1.666667	0	0	0	7.5	41.6	17.5	2.3
1.833333	0	0	0	7.666667	46.6	20.5	3
2	0	0	0	7.833333	51.9	23.8	4
2.166667	0	0	0	8	57.6	27.5	5.2
2.333333	0	0	0	8.166667	63.6	31.4	6.6
2.5	0	0	0	8.333333	69.8	35.6	8.2
2.666667	0	0	0	8.5	76.3	40.1	10
2.833333	0	0	0	8.666667	83	44.8	12.1
3	0	0	0	8.833333	89.8	49.7	14.3
3.166667	0	0	0	9	96.8	54.8	16.8
3.333333	0	0	0	9.166667	104.3	60.4	19.6
3.5	0	0	0	9.333333	112.6	66.4	22.7
3.666667	0	0	0	9.5	122	73.3	26.3
3.833333	0.1	0	0	9.666667	132.8	81.1	30.3
4	0.2	0	0	9.833333	145.3	90	35
4.166667	0.3	0	0	10	159.6	100.2	40.2
4.333333	0.5	0	0	10.16667	176.2	111.8	46.1
4.5	0.8	0	0	10.33333	195.4	125.1	52.8
4.666667	1.2	0.1	0	10.5	217.6	140.4	60.4
4.833333	1.8	0.2	0	10.66667	243.8	158.2	69.2
5	2.5	0.3	0	10.83333	274.2	178.9	79.2
5.166667	3.3	0.4	0	11	309.3	202.7	90.8
5.333333	4.4	0.7	0	11.16667	349.8	230.3	104.2
5.5	5.7	1	0	11.33333	395.6	261.4	119.4
5.666667	7.2	1.4	0	11.5	447.5	297	136.8

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
11.66667	505.6	337.1	156.9	18	1807.1	1371.8	844.2
11.83333	570.6	382.3	180	18.16667	1714.2	1303.5	805.6
12	649.5	438.3	209.9	18.33333	1627	1239.7	769.7
12.16667	737.3	501.3	244.9	18.5	1542.7	1178.1	735.3
12.33333	841.6	577.2	288.2	18.66667	1462.2	1119.3	702.5
12.5	955.4	661.1	337.4	18.83333	1385.9	1063.6	671.3
12.66667	1080.9	754.3	392.8	19	1313.9	1010.9	641.8
12.83333	1216.2	856	454.3	19.16667	1245	960.4	613.4
13	1363.2	967.1	522.4	19.33333	1179.3	912.2	586.1
13.16667	1519.5	1086.1	596.7	19.5	1118.2	867.3	560.6
13.33333	1684.8	1213.1	677	19.66667	1061.3	825.2	536.5
13.5	1855.4	1345	761.8	19.83333	1008	785.7	513.6
13.66667	2028.2	1479.6	849.2	20	958.4	748.7	491.9
13.83333	2193.7	1609.5	934.6	20.16667	913	714.7	471.6
14	2351.1	1733.6	1016.4	20.33333	871.1	683	452.5
14.16667	2492	1845.6	1090.9	20.5	831.7	653.2	434.2
14.33333	2621.1	1948.4	1159	20.66667	794.9	625.1	416.9
14.5	2729.8	2035.4	1217.2	20.83333	761	599.2	400.6
14.66667	2824.9	2111.6	1267.7	21	729.3	574.8	385.2
14.83333	2895.6	2169	1306.6	21.16667	699.7	551.9	370.6
15	2952.3	2215.2	1337.6	21.33333	672	530.5	356.9
15.16667	2990.4	2246.9	1359.6	21.5	646.4	510.6	344
15.33333	3012	2265.5	1372.8	21.66667	622.5	491.9	331.9
15.5	3009.8	2266	1374.7	21.83333	600.1	474.4	320.5
15.66667	2993.4	2255.1	1368.8	22	579.5	458.3	309.8
15.83333	2962.1	2232.9	1356	22.16667	560.5	443.3	300
16	2918.4	2200.7	1337	22.33333	542.8	429.5	290.8
16.16667	2862.5	2159.4	1312.2	22.5	526.6	416.6	282.3
16.33333	2793.8	2108.2	1281.3	22.66667	511.7	404.9	274.5
16.5	2713.7	2048.2	1244.8	22.83333	498.1	394.2	267.3
16.66667	2622.4	1979.6	1202.9	23	485.6	384.3	260.8
16.83333	2522	1904	1156.7	23.16667	474.1	375.3	254.8
17	2418.8	1826.4	1109.5	23.33333	463.7	367.1	249.4
17.16667	2312.5	1746.6	1061.6	23.5	454.1	359.6	244.4
17.33333	2209.3	1669.3	1015.8	23.66667	445.3	352.7	239.9
17.5	2105.4	1592.1	970.7	23.83333	437.2	346.3	235.7
17.66667	2003.9	1516.8	927.1	24	429.9	340.6	232
17.83333	1903.2	1442.5	884.5	24.16667	423	335.2	228.4

Appendix

DIRECT FLOW (cms)							
Time (hr)	100-yr	25-yr	5-year	Time (hr)	100-yr	25-yr	5-year
24.33333	416.3	330	225	30.66667	36.3	28.9	20
24.5	409.7	324.8	221.5	30.83333	33.3	26.5	18.3
24.66667	403	319.6	218.1	31	30.4	24.2	16.7
24.83333	396.1	314.1	214.5	31.16667	27.9	22.2	15.3
25	388.8	308.4	210.7	31.33333	25.5	20.3	14
25.16667	381	302.2	206.5	31.5	23.3	18.6	12.8
25.33333	372.4	295.5	202	31.66667	21.4	17	11.7
25.5	362.9	288	197	31.83333	19.6	15.6	10.7
25.66667	352.4	279.7	191.4	32	17.9	14.2	9.8
25.83333	340.7	270.5	185.1	32.16667	16.4	13	9
26	328	260.4	178.3	32.33333	15	11.9	8.2
26.16667	314.3	249.5	170.9	32.5	13.7	10.9	7.5
26.33333	299.9	238.1	163.1	32.66667	12.5	9.9	6.8
26.5	284.8	226.2	155	32.83333	11.4	9.1	6.2
26.66667	269.4	214	146.7	33	10.4	8.3	5.7
26.83333	253.7	201.5	138.2	33.16667	9.5	7.6	5.2
27	238.1	189.1	129.7	33.33333	8.7	6.9	4.8
27.16667	222.5	176.8	121.2	33.5	8	6.3	4.3
27.33333	207.2	164.6	112.9	33.66667	7.3	5.8	4
27.5	192.1	152.6	104.7	33.83333	6.6	5.3	3.6
27.66667	177.7	141.2	96.9	34	6.1	4.8	3.3
27.83333	164	130.3	89.4	34.16667	5.5	4.4	3
28	150.9	119.9	82.3	34.33333	5	4	2.8
28.16667	138.4	110	75.5	34.5	4.6	3.7	2.5
28.33333	126.6	100.6	69.1	34.66667	4.2	3.3	2.3
28.5	115.6	91.9	63.2	34.83333	3.8	3	2.1
28.66667	105.3	83.8	57.6	35	3.5	2.8	1.9
28.83333	96	76.4	52.5	35.16667	3.1	2.5	1.7
29	87.6	69.7	48	35.33333	2.9	2.3	1.6
29.16667	80.1	63.7	43.9	35.5	2.6	2.1	1.4
29.33333	73.3	58.3	40.2	35.66667	2.3	1.9	1.3
29.5	67.1	53.4	36.8	35.83333	2.1	1.7	1.2
29.66667	61.5	48.9	33.7	36	1.9	1.5	1
29.83333	56.3	44.8	30.9				
30	51.6	41.1	28.3				
30.16667	47.2	37.6	26				
30.33333	43.3	34.5	23.8				
30.5	39.7	31.6	21.8				

DREAM

Disaster RIsk and Exposure Assessment for Mitigation