FLOOD HAZARD MAPPING OF DONSOL RIVER BASIN USING LIDAR AND LEGAZPI RAINFALL INTENSITY DURATION FREQUENCY CURVES

Ferdinand E. Bien[1] and Emelina G. Regis[2]
[1]Ateneo de Naga University, Ateneo Ave., Bagumbayan Sur, Naga City, 4400, Philippines,
Email: freddie.bien@gmail.com
[2] Ateneo de Naga University, Ateneo Ave., Bagumbayan Sur, Naga City, 4400, Philippines,
Email: egregis@gmail.com

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ABSTRACT: This paper presents the methods and results of Flood Hazard mapping of Donsol river basin through the use of Light Detection and Ranging (LiDAR) and Legaspi Rainfall Intensity Duration Frequency (RIDF) Curves. Donsol River Basin is located in the province of Sorsogon, Philippines which is one of the river basins covered by the Ateneo de Naga University (ADNU) Phil-Lidar 1. This research project was funded by the Department of Science and Technology (DOST) through the Philippine Council for Industry, Energy and Emerging Technology Research and Development (PCIEERD). Its objectives are to simulate the hydrologic model of Donsol River basin using HEC-HMS software developed by the US Army Corps of Engineers Hydrologic Engineering Center and to develop a flood hazard map based on Legazpi RIDF Curves. Its basin covers an area of 138.3 sq.km and the hydrologic model was calibrated using the storm event typhoon Ruby. Its parameter had undergone a series of optimization processes of HEC-HMS software in order to produce an acceptable level of model efficiency. The Nash-Sutcliffe (E), Percent Bias and Standard Deviation Ratio were used to measure the model efficiency, giving values of 0.8336, 0.0075 and 0.4080 respectively which resulted to a "very good" performance rating of the model. The flood inundation model was simulated using HEC-RAS software developed by the US Army corps of Engineers and a detailed 2D flood hazard map of Donsol river basin was prepared using FLO-2D software to assess the impact of flooding in the area. This Flood Hazard maps will provide the Municipal Disaster Risk Reduction Management Office (MDRRMO), Local Government units (LGUs) and the community a tool for flood mitigation and preparedness.

1. INTRODUCTION

The Philippines is located in the Pacific region near the Equator which is prone to tropical cyclones and storms. Cyclones tend to develop over warm seas and approximately 80 typhoons form above tropical waters, 15 to 20 of which visit the Philippines per year. Filipinos have had to cope with much hardship due to these storms. These typhoons cause heavy rainfall which produces flooding that affects the residence of low-lying areas. With this natural disaster threat, the Philippine Government created a disaster risk reduction management system to establish safer, adaptive and resilient Filipino communities against these natural disasters. Four areas were institutionalized: disaster prevention and mitigation, disaster preparedness, disaster response, and disaster rehabilitation and recovery (NDRRMP, 2011). The Department of Science and Technology (DOST) being the responsible agency for disaster prevention and mitigation, initiated the Phil-LiDAR 1 program which is known as "Hazard mapping of the Philippines using LiDAR" program. It has commissioned the Higher Education Institutions (HEI's) and State Universities and Colleges (SUC's) to perform the hydrologic and flood models of their respective assigned watershed using LiDAR data. Ateneo de Naga University is one of the Higher Institutions commissioned by the DOST to perform flood models in the Bicol Region.

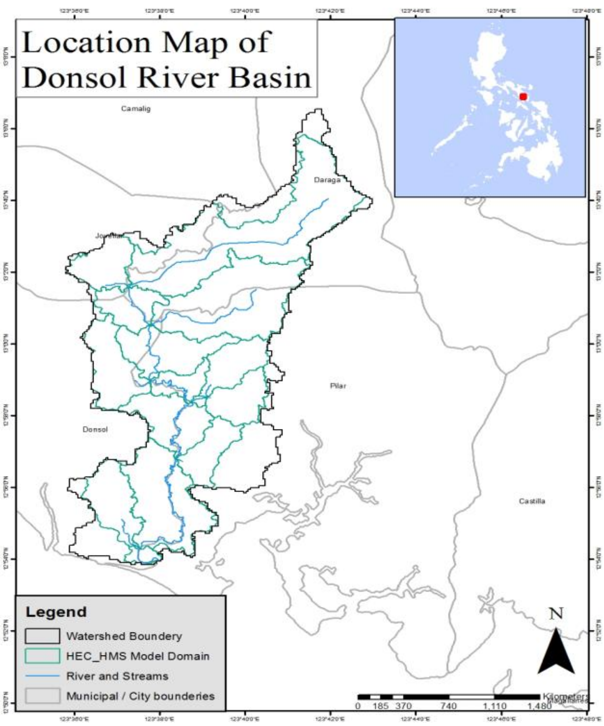

Figure 1. Map showing the location of Donsol River Basin

The objective of the program is to develop hydrologic and flood models to generate flood hazard maps of twenty four (24) river basins in the Bicol Region. Donsol River Basin was included in the first year of implementation. It covers a drainage area of 138.3 sq.km and is located in the provinces of Albay and Sorsogon which encompass the municipality of Daraga and Jovellar in Albay; Donsol and Pilar in Sorsogon. The watershed is traversed by Ogod River that serves as the main stream of base flow and direct runoff of water within the basin. The flood hazard map would contain the flooding extent categorized into low, medium and high hazards based on the Legaspi RIDF Curves as an input to the model. This flood hazard map will be tied up with the available rain gauge in the area and can be utilized by the local Government units in the area for disaster prevention and mitigation.

2. METHODOLOGY

2.1 HEC-HMS model development

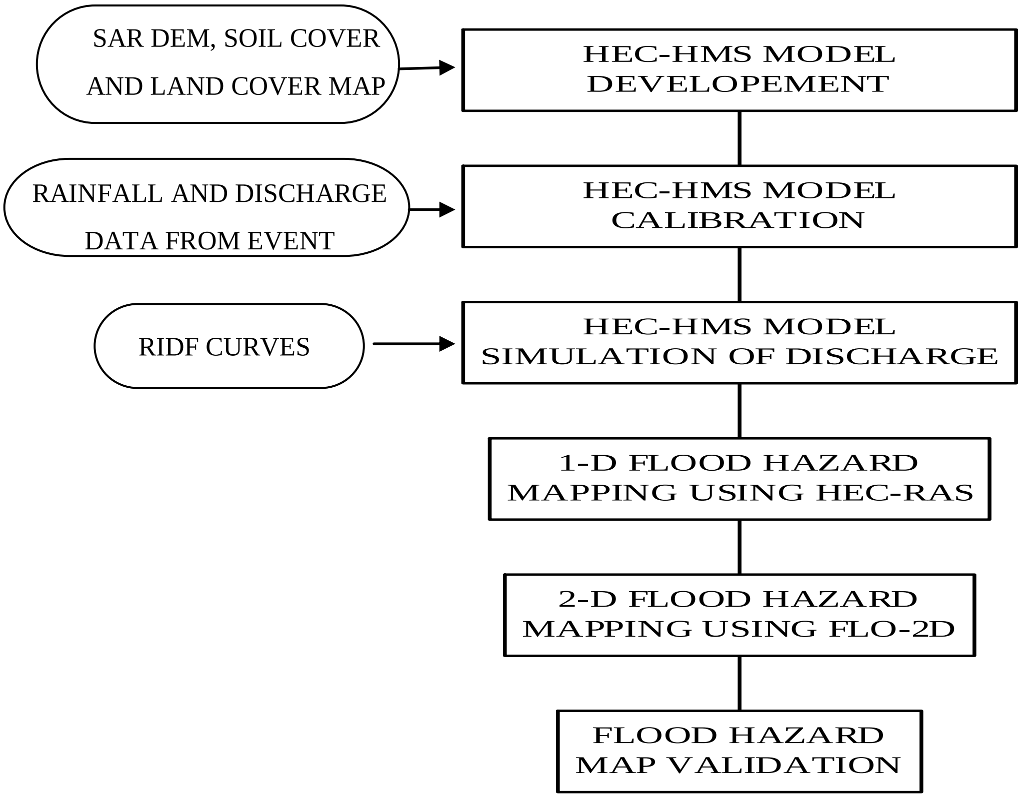

Figure 2. Framework for the Development of Flood Hazard Map

The process flow for the generation of flood hazard map is shown in Figure 2. The major input in the creation of HEC-HMS model includes the following: Synthetic Aperture Radar Digital Elevation Model (SAR DEM), soil map and land cover map. The soil map and land cover map are the important inputs in determining the Manning's coefficient. The soil and land cover were taken from the Department of Environment and Natural Resources Management and National Mapping and Resources Information Authority (NAMRIA). The soil and land cover map of Donsol river basin are shown in figure 3 and 4 respectively. The HEC-HMS model was generated using the GeoHMS toolbar in the ARC GIS software. With the advent of new knowledge and technology, these processes can be modeled by different modeling approaches (Lastoria, 2008), one of these is using HEC-HMS Model. HEC-HMS is the software developed by the US Army Corps of Engineers to simulate the rainfall-runoff processes. Rainfall-runoff models using HEC-HMS have been widely used to formulate a reliable relationship between the rainfall (input of the model) and runoff (output of the model) (Chatterjee, Rumpa De, Roy, Das and Mazumdar, 2014*)*. The HEC-HMS model of Donsol watershed consists of 19 sub-basins, 10 junctions and 9 reaches. The HEC-HMS model is shown in Figure 5. The Hydrologic process was organized by HEC-HMS into six components namely, meteorologic component, rainfall loss, direct runoff, river routing, base flow and reservoir component (HEC-HMS Technical Reference Manual, 2010). Each of the component uses several processes. In this study the following processes were used: The user hyetograph was used in modeling the meteorologic component, the SCS curve number method was used to model the rainfall loss component, the Clark Unit Hydrograph method was used for the runoff component, Muskingum-Cunge was used to model the river routing, and the Recession method was used in the base flow model.

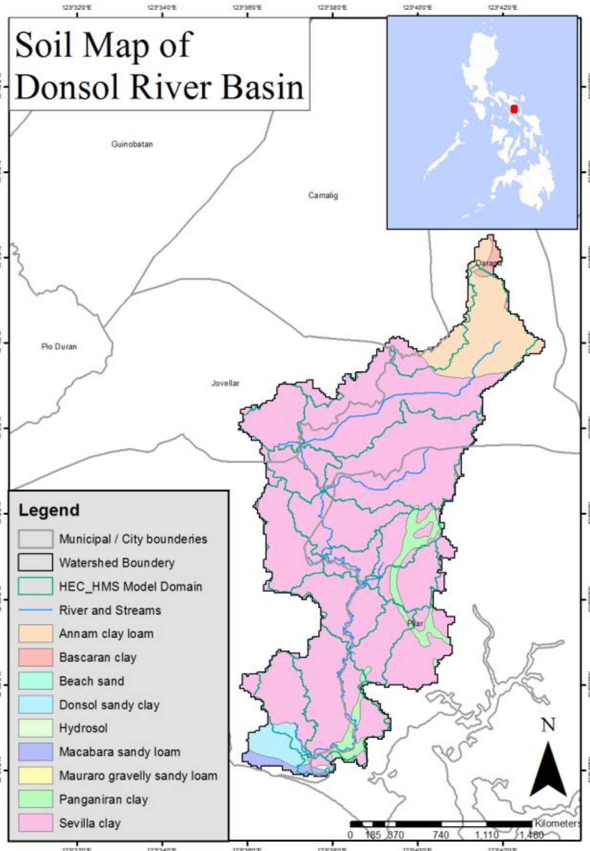

Figure 3. Donsol River Basin Soil Map

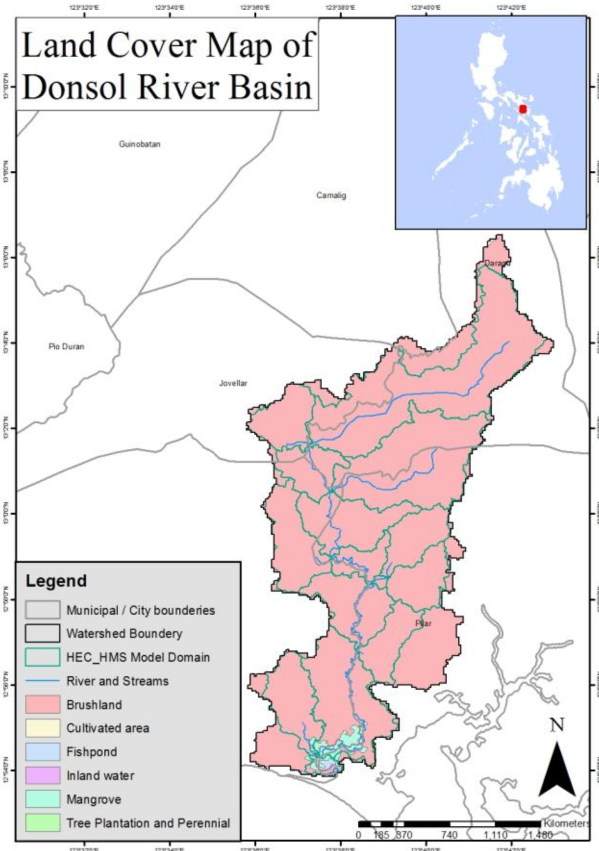

Figure 4. Donsol River Basin Land Cover Map

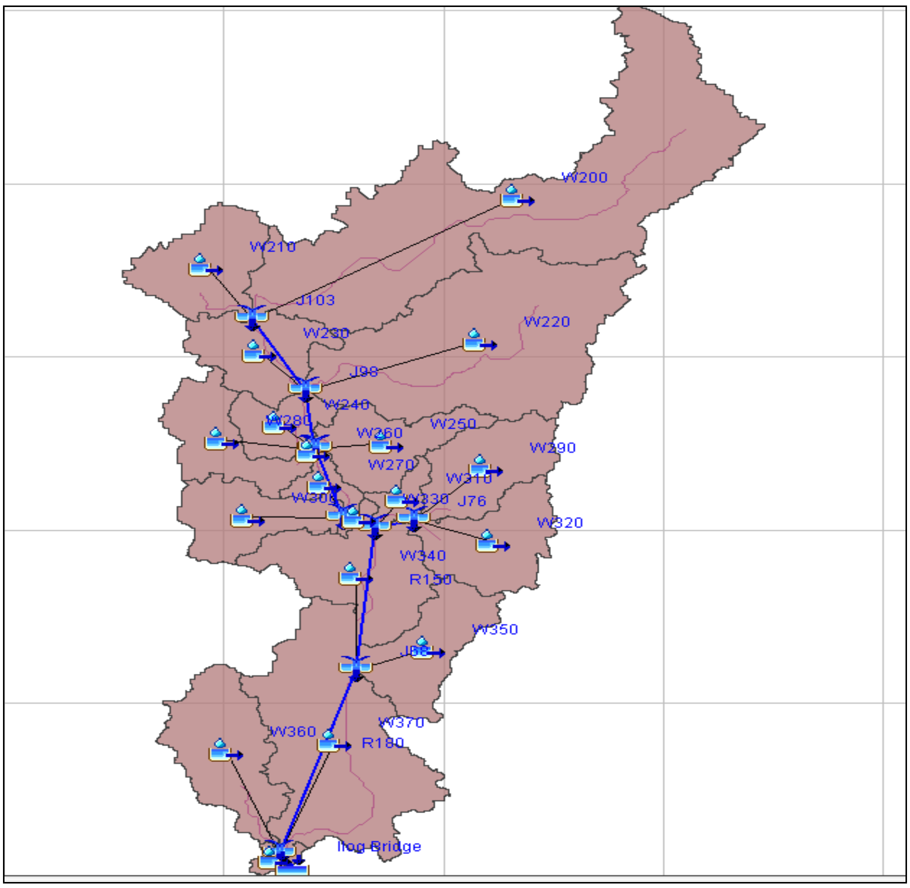

Figure 5. Donsol River Basin HEC-HMS Model

2.2 Model Calibration

The model calibration main inputs are the rainfall from an event and the corresponding discharge in the designated measuring station which is normally a bridge on the downstream side of the river. Figure 6 shows the rainfall and discharge data used in model calibration. For this study, the Ilog Bridge was the measuring station where the discharge was measured during typhoon Ruby (local name) last December 8-9, 2014 which hit the Sorsogon Area. The HEC-HMS version 3.5 was used to calibrate the hydrologic model that includes optimization manager which allows automated model calibration. A series of iteration process was performed to match the observed discharge with the simulated discharge. And a statistical evaluation tool was used to evaluate the performance of the model.

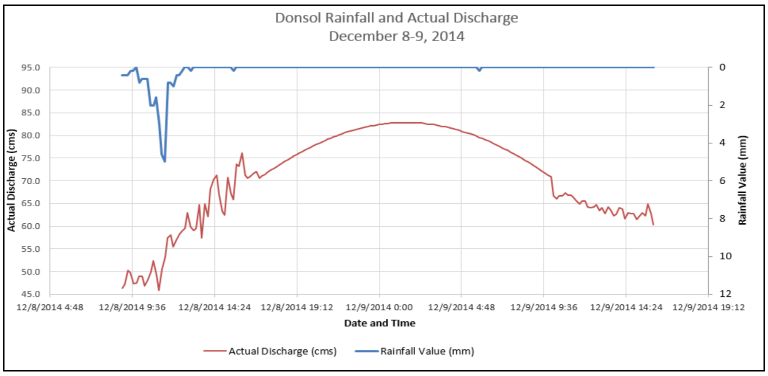

Figure 6. Donsol Rainfall and Discharge Data used in Model Calibration

2.3 Rainfall Intensity Duration Frequency (RIDF)

The RIDF values of Legaspi were used in this study because of its proximity in the area. The RIDF values were computed based on the extreme values on a 26-year record by the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). Figure 7 shows the Legaspi RIDF curve for the three selected return periods namely 5-, 25-, and 100-year RIDFs. Each RIDF return period is the input to the calibrated HEC-HMS model to simulate and compute the discharge corresponding to 5-, 25- and 100-yr return periods.

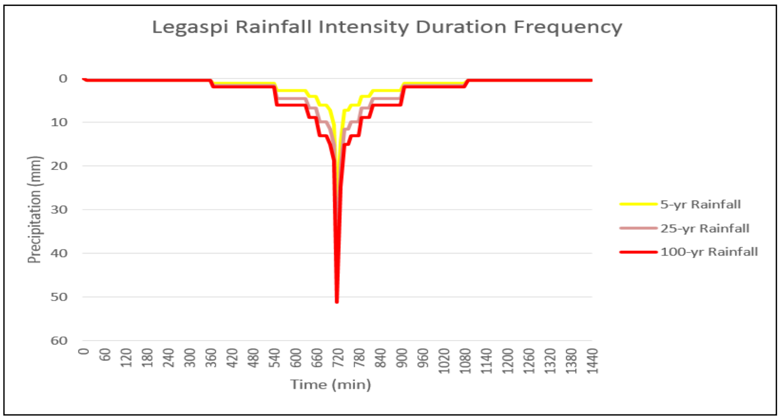

Figure 7. Legaspi RIDF curve for 5-, 25-, and 100-year return periods

3. RESULTS AND DISCUSSION

3.1 HEC-HMS Model Efficiency

HEC-HMS software has an automated calibration tool that allows a systematic optimization of all the parameters from a given initial parameters input. The main goal of this optimization process is to match the observed flow with the simulated flow to an acceptable level based on the statistical criteria. Figure 8 shows the observed flow and the simulated flow produced by the HEC-HMS.

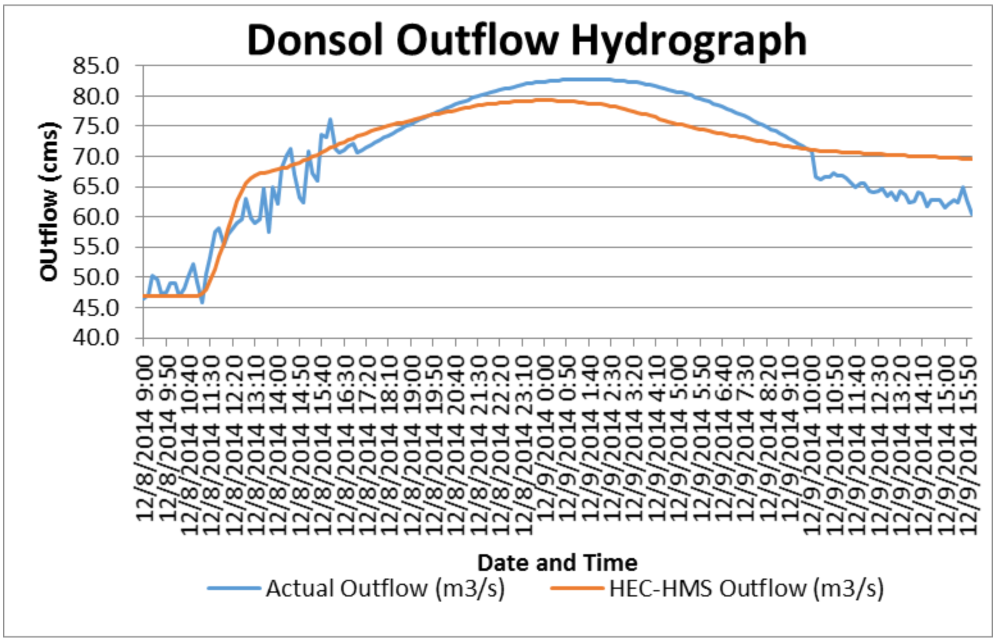

Figure 8. Outflow Hydrograph produced by the HEC-HMS model compared with observed outflow

Three statistical criteria were used to better evaluate the calibrated model performance such as: Nash and Sutcliffe Model Efficiency (NSE) [Nash and Sutcliffe, 1970], Percent Bias Ratio (PBR) and Standard Deviation Ratio (SDR). The three parameters were computed separately using the statistical equation given below.

The Nash-Sutcliffe (E)

$$E = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{mean} \right)^2} \right] \qquad (1)$$

Percent Bias

$$PBIAS = \frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right) * 100}{\sum_{i=1}^{n} Y_i^{obs}} \qquad (2)$$

Standard Deviation Ratio

$$RSR = \frac{\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)}}{\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{mean} \right)^2}} \qquad (3)$$

Table 1. Criteria used for Model Validation and Performance Rating

Performance Rating	Statistic		
	Nash-Sutcliffe (E)	Percent Bias (PBIAS)	Standard deviation Ratio (RSR)
Very Good	$0.75 < E \leq 1.00$	$PBIAS < \pm 10$	$0.00 < RSR \leq 0.50$
Good	$0.75 < E \leq 1.00$	$\pm 10 \leq PBIAS < \pm 10$	$0.50 < RSR \leq 0.60$
Satisfactory	$0.5 < E \leq 0.65$	$\pm 15 \leq PBIAS < \pm 25$	$0.60 < RSR \leq 0.70$
Unsatisfactory	$E \leq 0.50$	$PBIAS \geq \pm 25$	$RSR > 0.70$

Table 2. Result of the model validation and performance rating

Statistics Parameter	Computed Value	Remarks
Nash-Sutcliffe (E)	0.8336	Very Good
Percent Bias (PBIAS)	0.0075	Very Good
Standard deviation Ratio (RSR)	0.4080	Very Good

The result of the calibration shows that the model exhibits a very good performance rating based on the criteria shown in Table 1.

3.2 Calculated Discharge and Outflow Hydrograph Based on the 5-, 25- and 100-yr RIDF of Legaspi

The 5-, 25-, and 100-year RIDFs of Legaspi were inputted into the calibrated HEC-HMS model. A simulation run for each RIDF was performed to generate the discharge for each return period. Figure 9 show the corresponding graph of each return period.

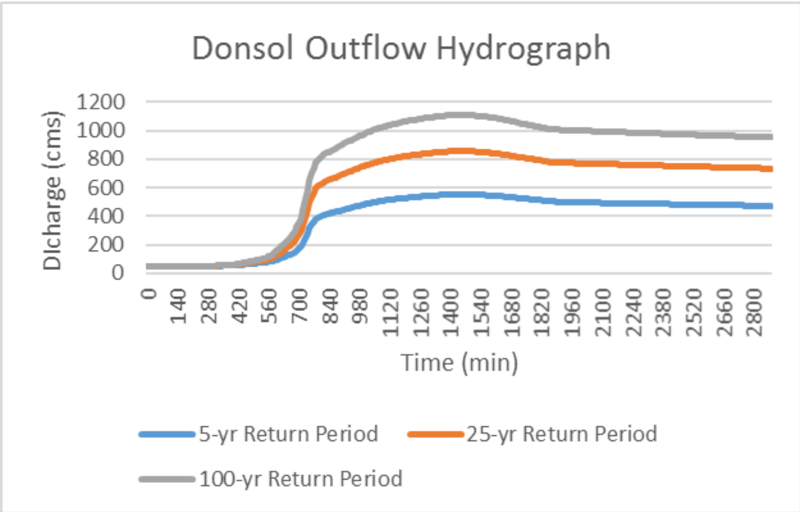

Figure 9. Donsol outflow hydrograph generated using Legaspi 5-, 25- and 100-year RIDFs in utilizing HEC-HMS model

3.3 Hazard mapping (1-D) using HEC-RAS

The calculated values of discharge for 5-, 25- and 100-year return periods are the input to HEC-RAS model to simulate the flood inundation of the river system. Figure 10 shows the HEC-RAS model of Donsol River Basin.

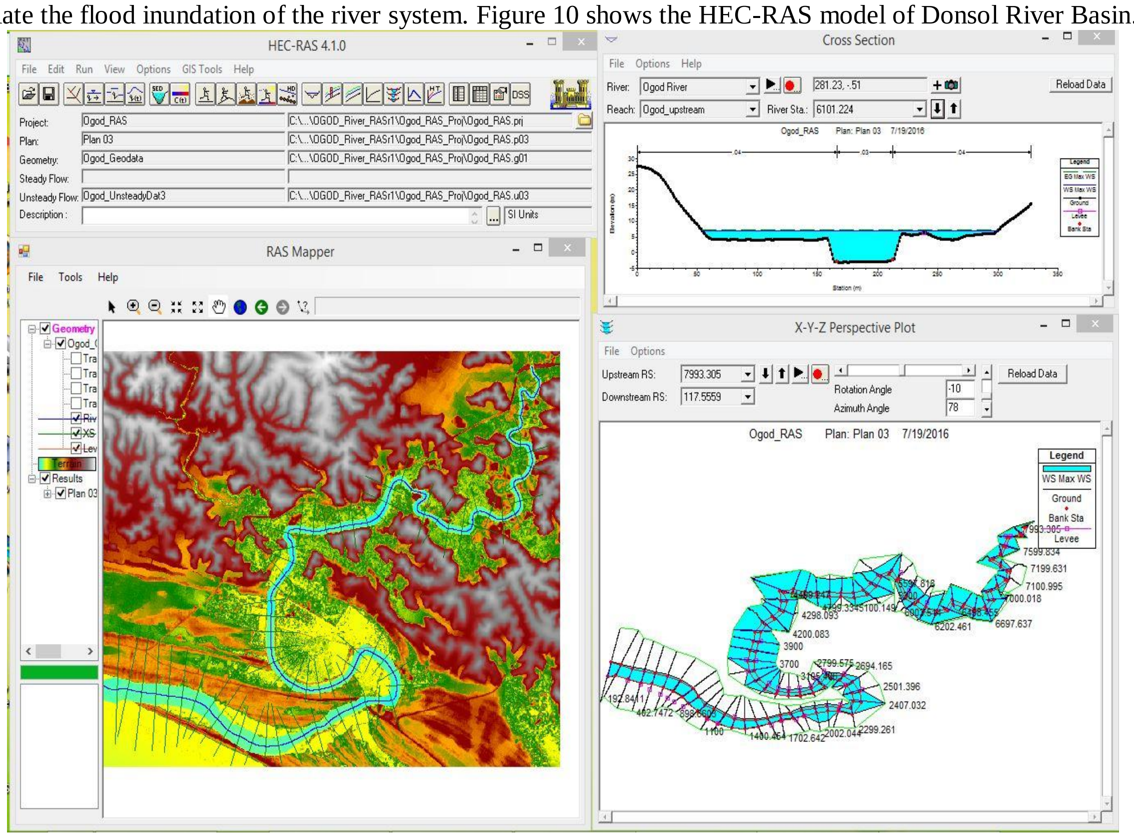

Figure 10. 1-D HEC-RAS Model of Donsol River Basin

3.4 Hazard Mapping using FLO-2D

The 2D flood Hazard map was generated by the University of the Philippines Disaster Risk and Exposure for Mitigation (UP DREAM) Phil-LiDAR 1 program using the FLO-2D software. FLO-2D Software is the most widely used and affordable 2-D hydraulic model commercially available for flood routing. Model development and flood mapping are done with GIS compatible data files and post processor programs.

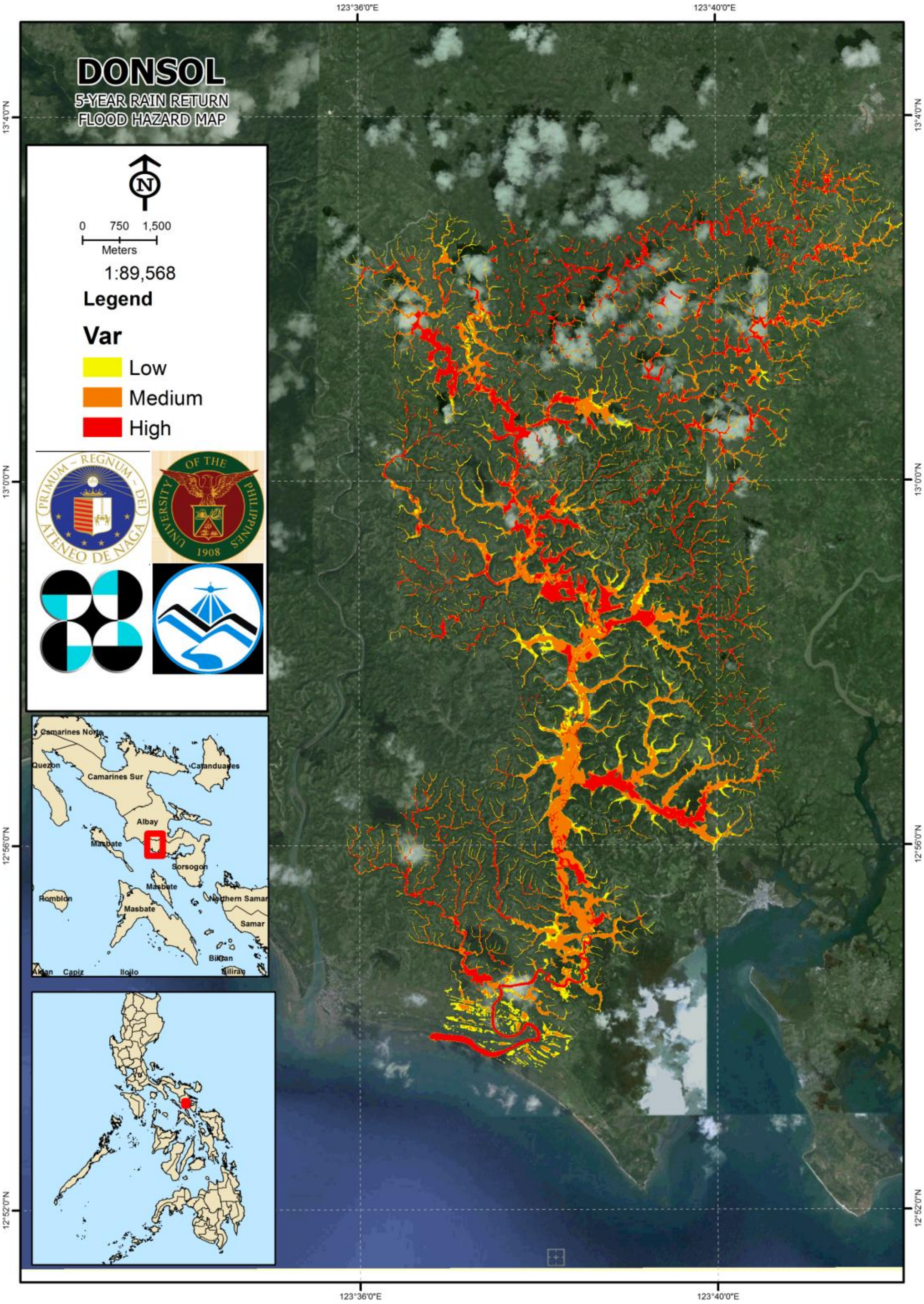

Figure 11. 5-year Flood Hazard Map for Donsol River Basin

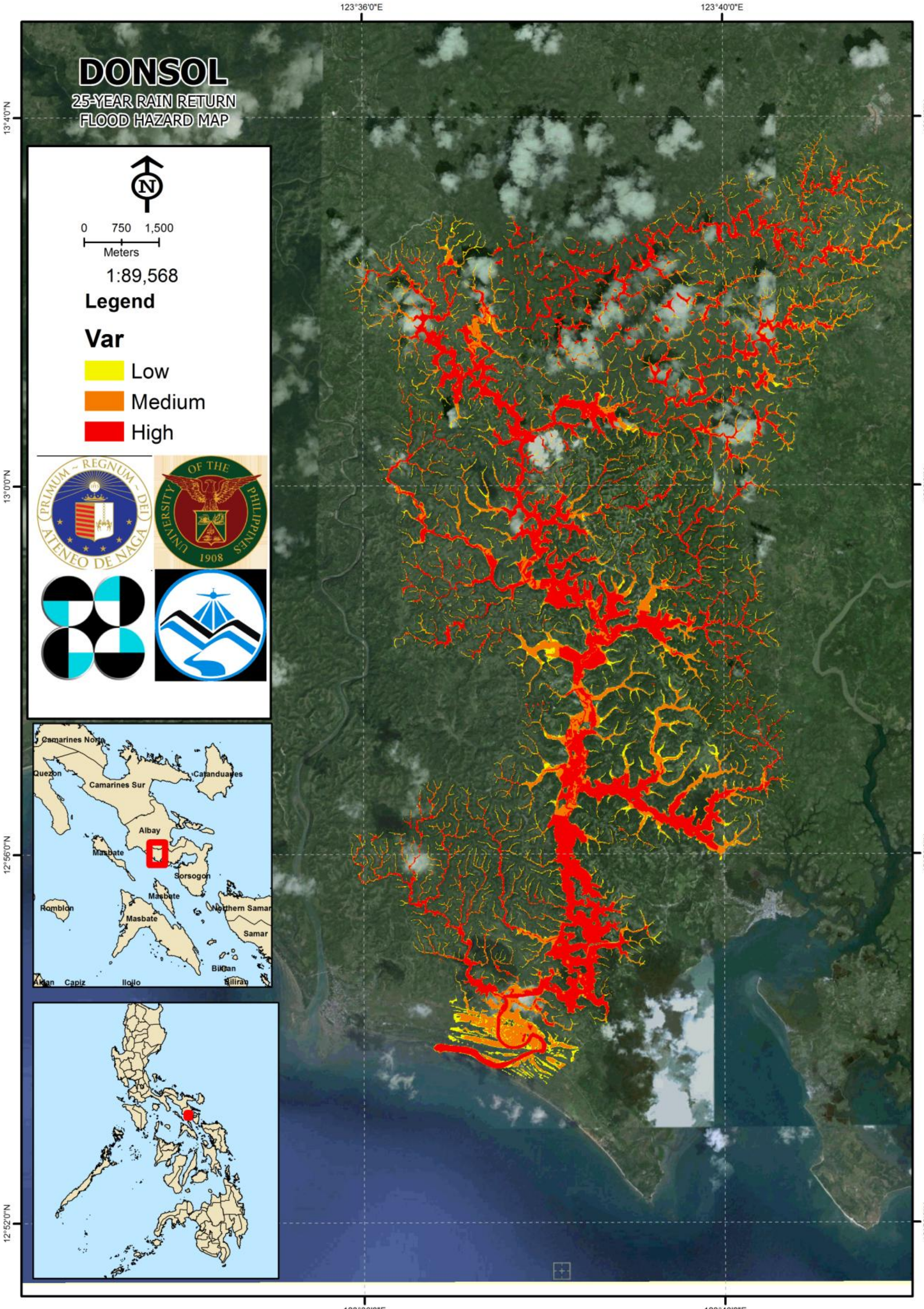

Figure 12. 25-year Flood Hazard Map for Donsol River Basin

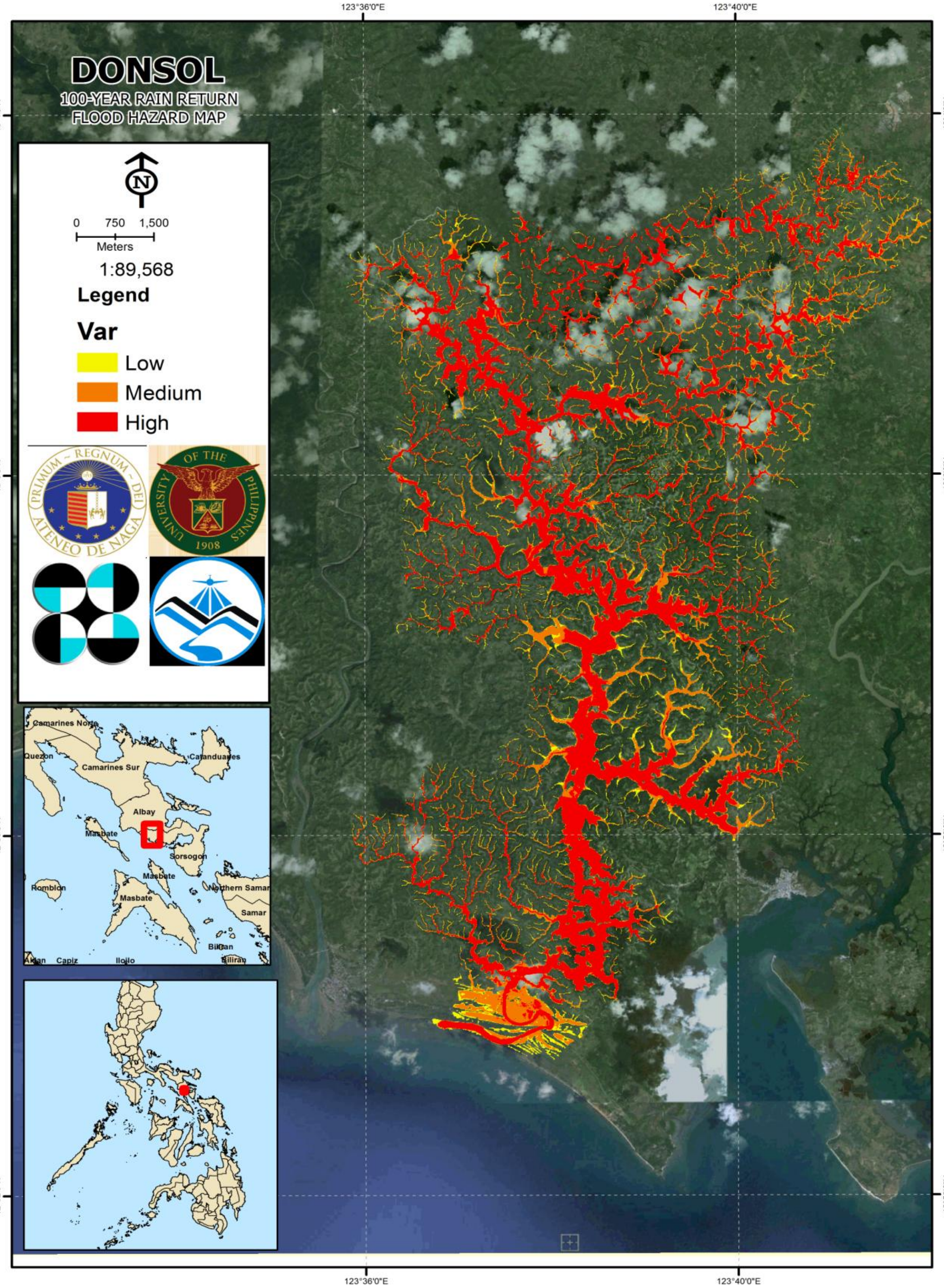

Figure 13. 100-year Flood Hazard Map for Donsol River Basin

4. CONCLUSION

The main objective of the study is to produce flood hazard maps generated from a simulation of calibrated event-based rainfall and runoff model and Legaspi RIDF curves. The HEC-HMS software was used for the simulation of rainfall and runoff hydrograph of Donsol river basin based on the RIDF of Legaspi. The shape and surface characteristics of the River Basin were generated using the Light Detection and Ranging (LiDAR) technology. And the field data collection for the flow measurement was conducted at the Ilog Bridge which was used to calibrate the HEC-HMS model and the rainfall data from Tagaytay Bridge located on the upper portion of the River Basin. The stage-discharge model can be used to predict the discharge based on the recorded water level elevation of the Automatic Water level Sensor installed at the Ilog Bridge. The statistical criteria used to evaluate the model showing the values of Nash-Sutcliffe model efficiency (E), percent bias (PBIAS) and Standard deviation ratio (SDR) were used on observed and simulated discharge to assess the performance of the model, and had been found with values 0.8336, 0.0075 and 0.4080 respectively, indicating a "very good performance" of the model. The flood hazard map generated from this extensive study could be extremely valuable for susceptibility, hazard and risk mitigation as indicated by the calibrated model. Thus, it will provide the Municipal Disaster Risk Reduction Management Office (MDRRMO), Local Government units (LGUs) of Donsol River Basin a tool for flood mitigation and preparedness. LGUs of Donsol could identify flood adaptation strategies that includes Land use planning with integrated flood hazard map and relocation sites of affected communities identified in the flood hazard map.

5. RECOMMENDATIONS

It is thus recommended that the rainfall-runoff simulation model must be further tested and calibrated using the future rainfall events to increase the confidence level of the Hydrologic model. The Bathymetric data of Ogod River must be updated in the future since the data utilized were gathered by the University of the Philippines Data Validation and Bathymetric Component last October 2014. The 2D flood hazard map must likewise be updated using the future RIDF curves.

ACKNOWLEDGMENTS

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