

River Flood Hazard Modeling: Forecasting Flood Hazard for Disaster Risk Reduction Planning

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Abstract

The objective of the study is to create a flood hazard model of Tarlac River and to calibrate the model based on data gathered from the Philippine Atmospheric Geophysical and Astronomical Services Administration. The study employed analytical method wherein the 1D flood modeling was utilized. GIS, DEM data, rainfall data, river analysis system, HEC-GeoRAS, hydrologic modeling system, and HEC-GeoHMS were utilized. The different flood models revealed that Tarlac River is not expected to be overtopped by flood water as regards the different extreme rainfall events considered in the present study. The RAS model simulation was based on the concept that there is no base flow observed within the river reach before the occurrence of any extreme rainfall event. Henceforth, there is still no 100 percent assurance that the river reach will not be overtopped with the occurrence of initial base flow in combination with the occurrence of higher extreme rainfall events. Further studies or investigations should be delved into such combination of events. Possible levee breach of the Tarlac River as well as the possible incorporation of flood mitigating interventions in future modeling scenarios can be likewise considered.

Keywords: Flood Hazard Modeling; Flood Modeling; River Analysis.

1. Introduction

With the advent of global warming and higher recorded rainfall events, urban flooding as well as levee breach along waterways is experienced widespread among different countries. This causes significant damage to property, disruption of economic activity, and may result to loss of life. Flood modeling nowadays are commonly used to forecast probable flood events or scenarios based on different computed extreme rainfall data. The result of the flood models can serve as basis for policy makers to enhance the flood hazard preparedness of the community as well as to incorporate flood mitigating strategies in short term and/or long term project plans. In terms of preparedness, the communities which are vulnerable or which may encounter flood hazard should be made aware of risks they may be exposed to [1]. In this regard, it can be deduced that preparedness is the key to minimizing the harmful effect of flooding to the community.

Flood management or control is a public good and it can help bring riparian to negotiate around benefits versus allocating flows [2]. There are so many things which limit the management options as regards funding for flood hazard management, space or land utilization, and respect to cultural heritage [3]. These are the concerns that need to be addressed by the local government units in general.

Tarlac River is the primary waterway which passes through the City of Tarlac. The water flowing along the river originates from the mountain range along the boundary of the Provinces of Tarlac and Zambales. Tarlac River passes

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through several towns in the Province of Tarlac and is connected downstream to the Agno River of Pangasinan. The towns of Capas and San Jose in the Province of Tarlac are the main water sources of the Tarlac River. With the eruption of Mount Pinatubo in 1991, lahar flowed to Tarlac River which reduced its depth. More than 10 years after the eruption, the construction of bypass road along the Tarlac River reduced its width which may significantly affect the carrying capacity of the river.

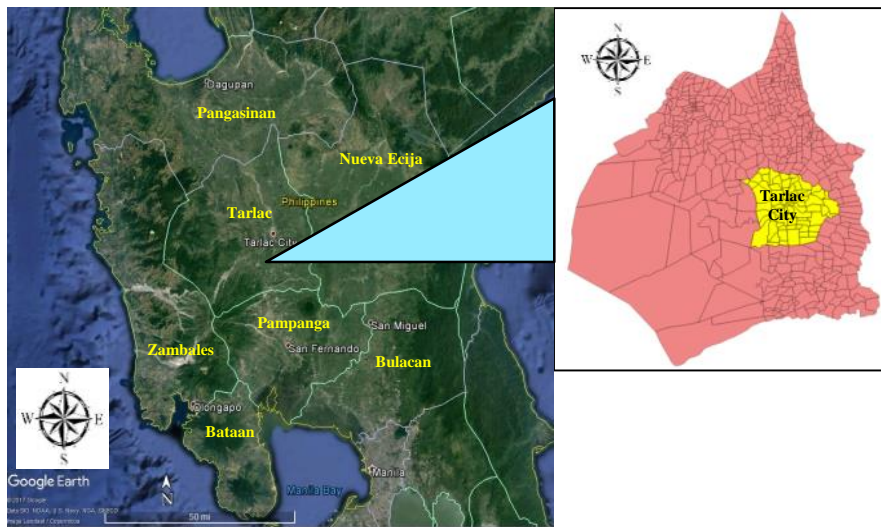


Figure 1. Location Map of Tarlac City

Tarlac City is composed of 76 barangays with a population 342,493 according to the 2015 report of the Philippine Statistical Authority [4]. Being a first class city, many businesses as well as residents will be affected if flood water will overtop the Tarlac River. The central business district and urban barangays, which are highly populated, are situated along the river system. This being said, the overtopping of the Tarlac River will pose high risk to the central business district as well as to the residents of the city which may result to a possible flooding disaster.

Based on the aforesaid facts, there is a need to evaluate the flow capacity of the Tarlac River based on the present conditions as well as on the computed extreme rainfall events. The result of the study can be used by the local government units (LGUs) as basis for disaster preparedness and vulnerability assessment. Information dissemination, flood hazard warning systems, barangay official capacity building as community based responders, availability and access to evacuation routes and evacuation areas, and preparation of flood hazard maps can be some of the outputs of the LGUs based on the possible result of the present study.

The general objective of the present study is to develop a flood hazard model of the Tarlac River and to calibrate the model based on data gathered from recent typhoon and rainfall events. Specifically, the following objectives are wished to be attained in the present study. First, to delineate the watershed contributory to the Tarlac River. Second, to develop a model of the flood water along Tarlac River based on extreme rainfall events. Lastly, to identify the implication of the study towards disaster risk reduction planning.

2. Materials and Methods

The analytical method was employed in this study wherein the 1D flood modeling was utilized. The use of geographic information system (ArcGIS 10.2.1), LIDAR/SAR DEM data acquired from UP DREAM/PHIL-LiDAR 1 Program, rainfall data acquired from the Agno River Basin Flood Forecasting and Warning Center (ARBFFWC), river analysis system (HEC-RAS 5.0.3), HEC-GeoRAS, hydrologic modeling system (HEC-HMS 4.2), HEC-GeoHMS, FLO-2D Basic, and Global Mapper were the software's utilized in this study.

The cross-sections of the waterways along the delineated watershed in the Province of Tarlac contributory to the Tarlac River were generated using the Arc-GIS and Global Mapper software based on the 10m by 10m digital terrain model acquired from the UP DREAM/PHIL-LiDAR 1 Program. With the use of ArcGIS software, the locations of the cross-sections within Tarlac River were identified. The created cross-sections were then converted to shapefiles and inputted to the Global Mapper software. The processed or filled sinks 10m by 10m resolution DTM as well as the shapefiles of the cross-section based on their stationing and length were used for the creation of profile for each cross-section within the Tarlac River using the Global Mapper.

The source of the rainfall data was the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAG-ASA). The data collected from PAG-ASA focused on the reported months and years wherein flooding's were observed in Tarlac City. The researcher was able to gather data pertinent to the study area from the Agno River Basin Flood Forecasting and Warning Center (ARBFFWC) with office located in Rosales, Pangasinan. Data

acquired from the said office were rainfall and flow depth data for the Tarlac River. The rain gauge stations of ARBFFWC are located in barangays: Tibag, Tarlac City; O'Donnell, Capas, Tarlac; and Maasin, San Clemente, Tarlac. The Theissen method was used by the researcher for the distribution of rainfall for the sub-basins within the study area.

In computing for the runoff, the Soil Conservation Service (SCS) Curve Number (CN) model was utilized. The SCS approach relates accumulated rainfall excess or runoff to accumulated rainfall with CN [5]. It is popular because of its application to ungauged areas and its large empirical database. The SCS unit hydrograph was utilized for computing for the direct runoff. As to channel flow, the Muskingum-Cunge method was employed. The Muskingum-Cunge routing method belongs to the class of more accurate hydrologic-routing methods [6]. This is due to the equations that were added to the Muskingum method in order to determine the model input parameters in a physically based way. On the other hand, one of the problems of this model is the correct estimation of the time and distance step in the computation. When using HEC-HMS, this problem is irrelevant since the program automatically selects these parameters in a way that ensures accuracy and stability of the solution. Different model is created using the 2, 5, 10, 15, 25, 50, and 100-year return period storm event.

Based on the computed parameters using the HEC-HMS model its resulting hydrograph was utilized in the development of the HEC-RAS model for Tarlac River. The cross-sectional data of the creeks or waterways within the watershed were generated using the ArcGIS and Global Mapper software based on the 10 m by 10 m DTM acquired from the UP DREAM/PHIL-LiDAR 1 Program. The Manning's coefficient (n) is based on the book of Ven Te Chow in reference to the actual site configuration.

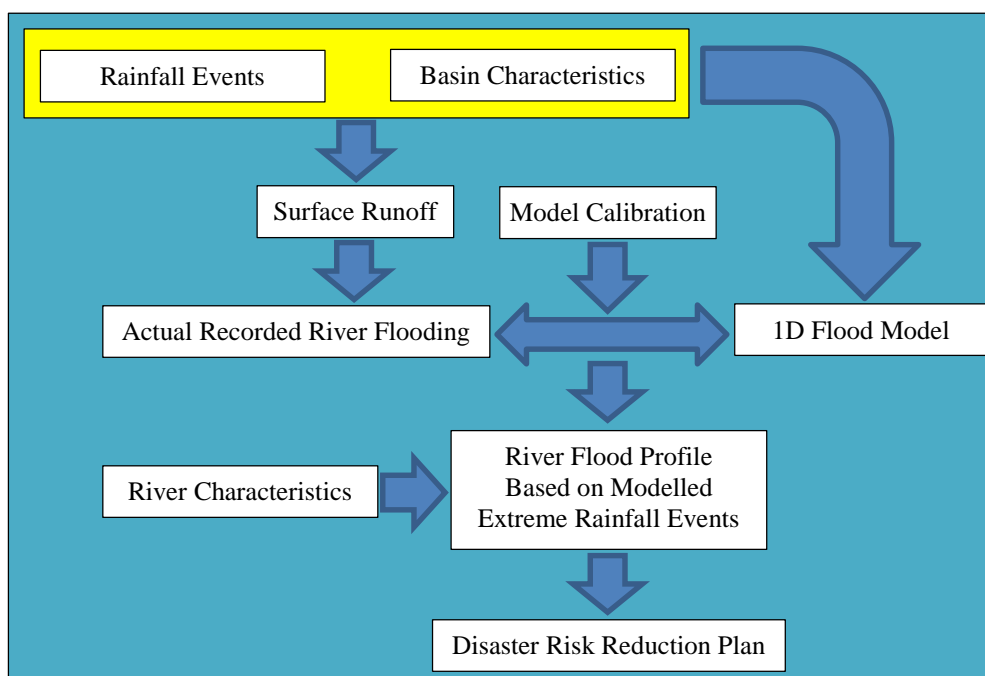


Figure 2. Research Methodology Flowchart

The Typhoon Lando incident on October 18, 2015 served as the basis of the researcher in the calibration of different flood models in the study. Rainfall data and flow depth at the Agana Bridge monitoring station of the ARBFFWC were acquired and were used to calibrate the HMS, and RAS model.

The 1D flood model was calibrated using the data from the Typhoon Lando of 2015. The rainfall as well as the flow depth data by the ARBFFWC were utilized for model calibration. The calibration cycle of the HMS model, for this study, is presented in Figure 2. Based on the initial parameters set in the HMS model the resulting hydrograph was inputted to the RAS model wherein the observed water level at the Agana Bridge was compared with the RAS model flow depth. If the modelled depth and the observed depth at the Agana Bridge were not comparable the process was repeated. The calibration cycle was repeated until such time the best possible parameters for the HMS model would result to a flow hydrograph acceptable or comparable to the observed flow depth at the observation station.

Calibration of model and sensitivity analysis were undertaken to acquire the best set of parameters that should be taken into account for the study area wherein the roughness coefficients and the considered infiltration value are the primary parameters to be used in the model [7]. In developing a flood model, this can be calibrated or verified using the data or records of previous flood events [8]. Proper calibration and validation of hydrological model are imperative to assure the reliability of the developed flood model [9, 10].

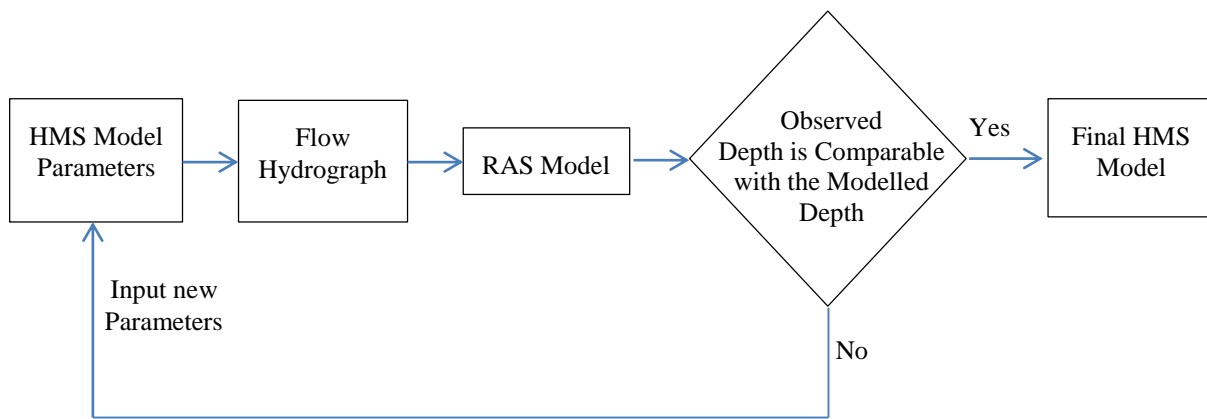


Figure 3. HMS Calibration Cycle

3. Results and Discussion

3.1. Delineated Watershed

The area of the delineated watershed in this study is equal to 855.80 square kilometers. The delineated watershed is shown in Figure 4.

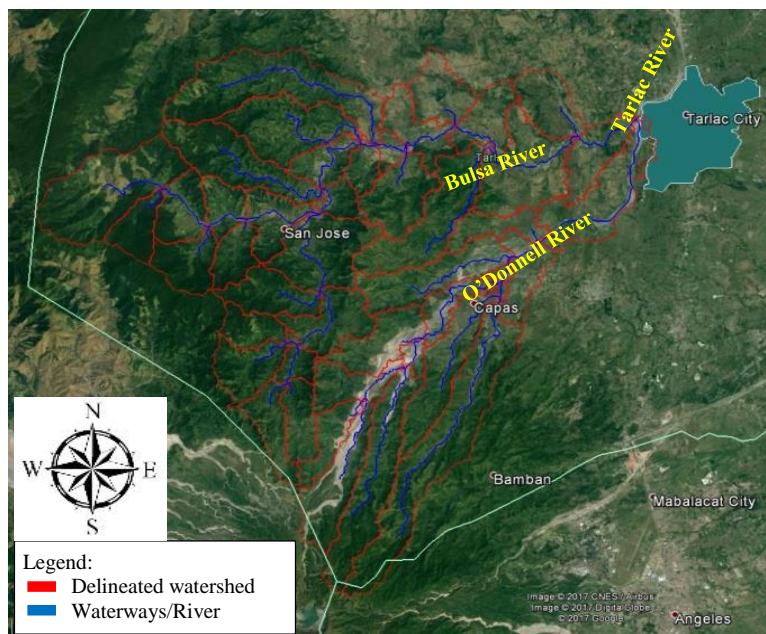


Figure 4. Delineated Watershed

In reference to the average precipitation depth versus area as cited by Chow, the distributed rainfall to the sub-basins of this study was reduced to 90 percent. Frequency analysis of precipitation over an area has not been well developed as has analysis of point precipitation. Point estimates are usually extended to develop an average depth over area [11].

For the 1D modeling, the river reach was modeled based on the concept of unsteady flow for open-channel. The Saint-Venant equation was used for the river flow routing which is governed by the principle of conservation of mass and momentum. These principles were utilized towards the development of the HMS and RAS models on the identified watershed river reach contributory to the Tarlac River.

For the development of HMS model the following parameters were considered for the basin model: SCS Curve Number Method; SCS Unit Hydrograph; and Muskingum-Cunge. The curve number (CN) method was used for the soil infiltration wherein the curve number methodology is implemented. The SCS Unit Hydrograph makes use of the lag time method which is approximated to be 60 percent of the time of concentration. The combination of conservation of mass as well as the conservation of momentum, wherein the Muskingum-Cunge was based, was used for the river reach routing.

The development of the RAS model was based on the unsteady flow simulation wherein the 1D Saint-Venant equations were used. The open-channel flow was modelled based on the continuity and momentum equations. To draw the rating curve, required parameters for each reaches are estimated from hydraulic properties, floodplain geometry and

hydrologic structures [12]. As regards hydrologic, modeling of poorly gauged catchments can be best modeled with the use of flood data gathered through remote sensing [13]. The accuracy of the developed flood model can then be estimated using the actual flood scenarios. Furthermore, past flood events can be used for the calibration of model parameters to ensure the reliability and robustness of the model outcomes [14]. Other factors which can influence the accuracy of the developed flood model are the quality of the digital terrain model (DTM), considered roughness coefficients, as well as boundary conditions (such as discharge and water level) [15]. The aforesaid information are vital towards the development of the 1D model to properly approximate the spatial flood extents.

3.2. RAS Model of Tarlac River

Tarlac River flow depth was modelled based on the different computed extreme value for rainfall. The developed model was based on the concept that there is no base flow before the occurrence of the different extreme rainfall. The no base flow concept was anchored on the flow depth observed at the Tarlac River before the occurrence of Typhoon Lando on October 18, 2015. Based on the observed flow depth data gathered from the ARBFFWC, most of the time the river had no base flow or had insignificant water flow within the river reach. Observable flowing water at the Tarlac River only occurs during the heavy monsoon rains or typhoon.

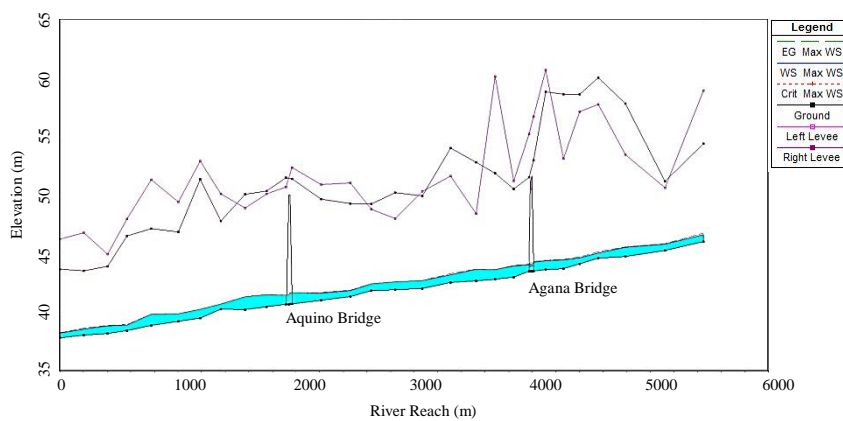


Figure 5. Modelled Water Profile of Tarlac River (2-year Extreme Rainfall)

The hydrograph outputs of the HMS model, based on the different computed extreme rainfall, were inputted to the RAS model to arrive at the water profile for the Tarlac River. Presented in Figure 5 is the water profile of Tarlac River based on the 2-year extreme rainfall event. The parameters used in the developed HMS and RAS models are based on the calibrated HMS and RAS models. The result of the RAS model, based on the 2-year computed extreme rainfall, revealed that the maximum water elevation at the Agana Bridge was 44.53 meters. This is lower as compared with the actual river flow depth observed during the occurrence of Typhoon Lando which was 45.76 meters. With the said rainfall event, maximum observed water level at the Agana Bridge along Tarlac River will be observed after 14 hours of such rainfall event.

The modeling of the Tarlac River based on the 5-year extreme rainfall event resulted to the water profile as presented in Figure 6. The result of the model revealed that the maximum water level at the Agana Bridge rose to a maximum elevation of 44.94 meters. The modelled water profile is lower as compared with the actual flood flow recorded during the occurrence of Typhoon Lando in 2015 wherein the observed water elevation at the Agana Bridge was 45.76 meters. As regards the occurrence of the maximum flood depth, 15 hours of such rainfall event would result to the maximum observable flow at the Agana Bridge. This is one (1) hour longer as compared to the 2-year extreme rainfall event modelled in this study.

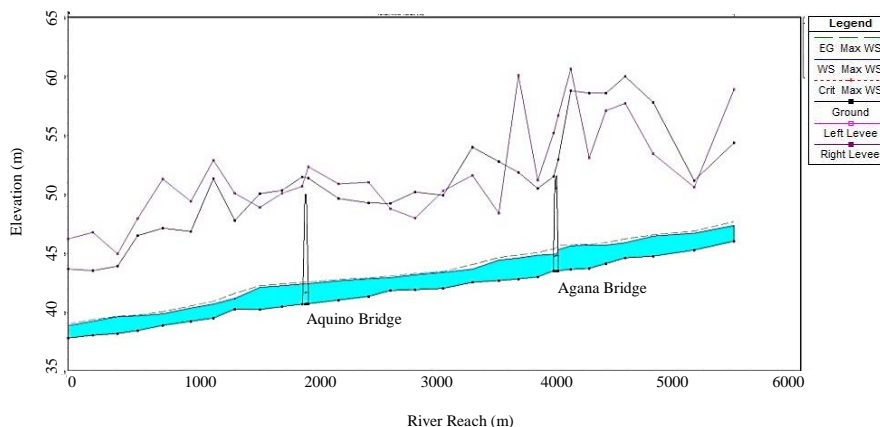


Figure 6. Modelled Water Profile of Tarlac River (5-year Extreme Rainfall)

Figure 7 shows the modelled water profile of Tarlac River based on the 10-year extreme rainfall. The water elevation at the Agana Bridge based on the model is 45.53 meters. The modelled water profile based on the 2, 5, and 10-year extreme rainfall events did not match the observed water elevation at the Agana Bridge during Typhoon Lando. The observed water elevation during that time was 45.76 meters. A difference of 0.23 meters can be expected between the Typhoon Lando river flow depth and the modeled 10-year extreme rainfall event. This means that the rainfall poured by Typhoon Lando was beyond the 10-year computed extreme rainfall. Regarding the occurrence of maximum flooding along the river, it would take 18 hours based on the developed model.

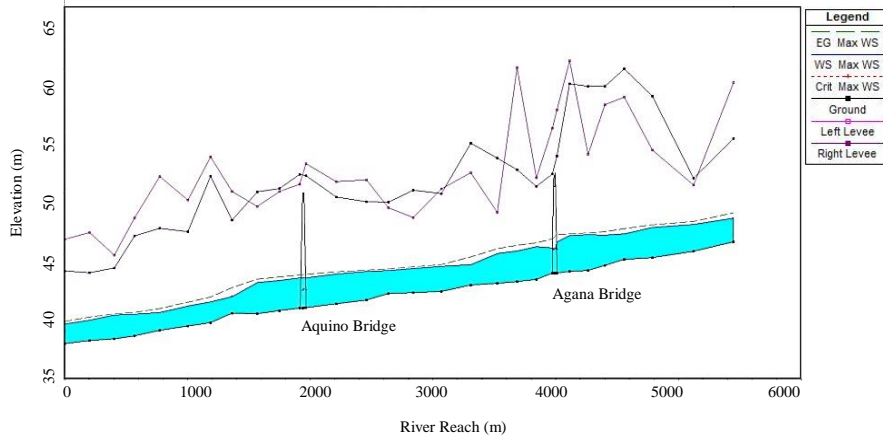


Figure 7. Modelled Water Profile of Tarlac River (10-year Extreme Rainfall)

Figure 8 shows the modelled water profile of Tarlac River based on the 15-year extreme rainfall. The model reveals that the water profile elevation at the Agana Bridge is 45.92 meters. As compared with the water elevation observed during the occurrence of Typhoon Lando the modelled flow at the Tarlac River, based on the 15-year extreme rainfall, surpasses it by about 0.16 meters. This result reveals that the 15-year extreme rainfall is comparable to the Typhoon Lando river flow depth more than the other extreme rainfall events modelled in the study. Furthermore, as regards the developed model, 18 hours of such rainfall event would result to the maximum flooding along the river.

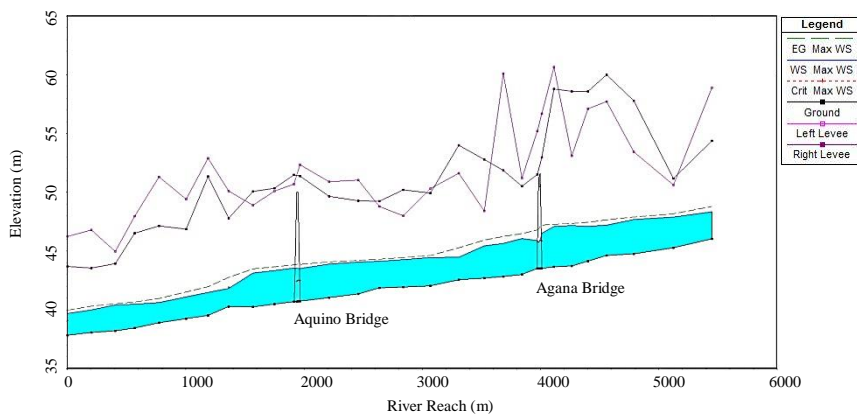


Figure 8. Modelled Water Profile of Tarlac River (15-year Extreme Rainfall)

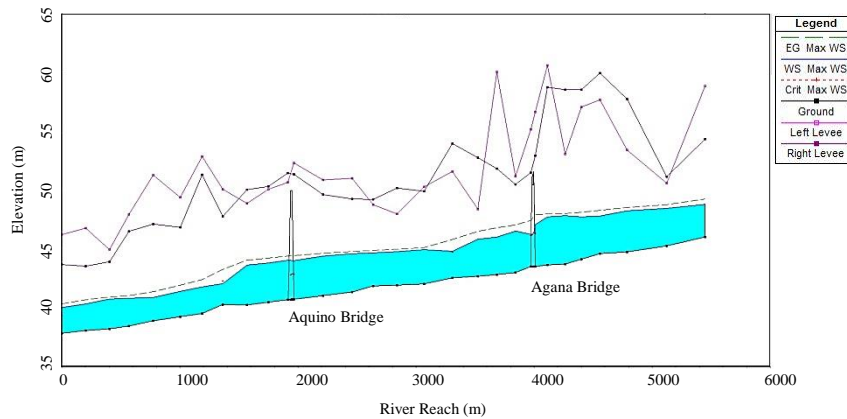


Figure 9. Modelled Water Profile of Tarlac River (25-year Extreme Rainfall)

Based on the model considering the 25-year extreme rainfall event, it is expected that the water elevation at the Agana Bridge reaches 46.41 meters. Comparing water elevation for the 15-yr and 25-year rainfall, there will be an increase of 0.41 meters of water level as compared with the previous model result. The modelled water profile for Tarlac River based on the 25-year rainfall event is presented in Figure 9. Based on the developed model, the maximum time for it to reach the highest flood depth is within 18 hours of such rainfall event. The occurrence of the maximum flood depth is comparable to the developed model of 15-year extreme rainfall event.

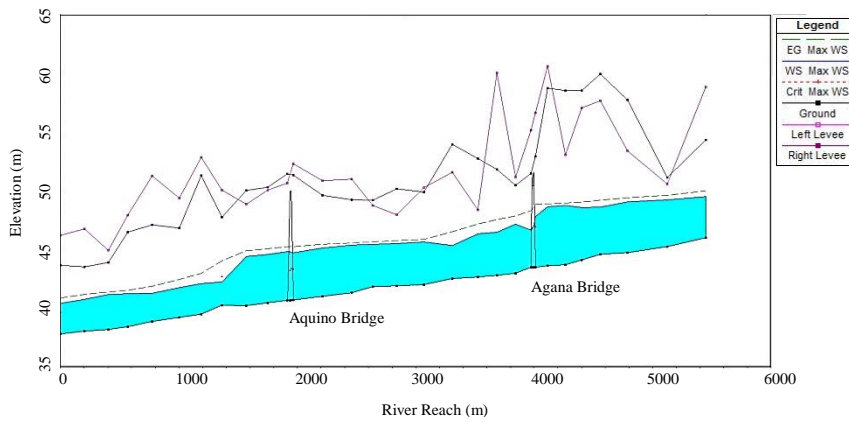


Figure 10. Modelled Water Profile of Tarlac River (50-year Extreme Rainfall)

Figure 10 shows the modelled water profile of Tarlac River based on the 50-year extreme rainfall. At the Agana Bridge, water elevation of 47.07 meters can be expected based on the model. This is 0.66 meters higher as compared with the 25-year extreme rainfall event modelled in the study. Such increase in water level is evident that there is still enough freeboard before the flood water from Tarlac River can overtop the river system. The maximum water elevation for such extreme rainfall event can be observed within 18 hours based on the developed model. This is similar to the 15 and 25-year extreme rainfall events modelled in this study.

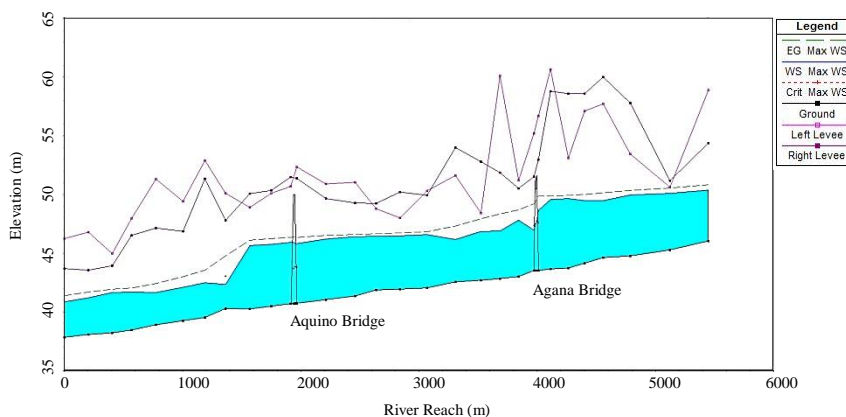


Figure 11. Modelled Water Profile of Tarlac River (100-year Extreme Rainfall)

Presented in Figure 11 is the modeled water profile of Tarlac River based on the 100-year extreme rainfall event. The modeling result reveals that the water level at Agana Bridge may rise to a maximum water elevation of 47.72 meters for such rainfall occurrence. The modeled water level is 1.96 meters higher as compared with the water level observed during Typhoon Lando which was measured at elevation 45.76 meters. This reveals that the 100-year extreme rainfall will not overtop the Tarlac River for there is enough freeboard on river reach. As regards the time of occurrence of the maximum flooding along the river, this can be observed within 17 hours based on the developed model. The occurrence of the maximum flooding is one (1) hour earlier as compared to the 15, 25 and 50-year extreme rainfall events.

Based on the different models developed on the Tarlac River, there is no expected overtopping by flood water as regards the different extreme rainfall events modeled in the study. The RAS model simulation considered in this study is based on the concept that there is no base flow observed within the river reach before the occurrence of any extreme rainfall event. Henceforth, there is still no 100 percent assurance that the river reach will not be overtopped with the occurrence of initial base flow in combination with the occurrence of higher extreme rainfall events. Further studies or investigations should be delved into such combination of events.

3.3. Implication to Disaster Risk Reduction Planning

Flood hazard is a phenomenon which is encountered in many areas around the world. This is predominantly encountered by low lying areas as well as areas surrounded by hills or mountains. As regards flood risk management,

research is increasingly informed; however the nature and role of flood risk perception are still under-developed [16]. The lack of focus or research agenda relative to projecting hydrological behavior and improving probabilistic forecasting has a consequential effect as to disaster response and preparedness as well as to planning and decision-making processes [17]. This emphasizes the need for regular monitoring or modeling of flood hazards which can significantly affect the populace.

As regards flood mitigating strategies, the use of engineering as well as non-structural solutions or intervention strategies can be preferred options as to flood risk management [18]. In this regard, better flood risk interventions could be identified by focusing and having a better understanding of response efficacy, self-efficacy, and response costs [19]. In managing flood, measures such as construction of short spurs and bed bars for diverting flow to save agricultural land, property and human lives should be adopted [20]. Flood mitigating structures such as dam can be helpful in reducing the severity and frequency of damage caused by floods in downstream areas [21]. Strengthening and adding levees as well as regulating the river bottom can minimize the possibility of flood risk to areas near the waterways. Furthermore, flooded areas ought to be forested and/or kept as park area to lessen flood risk to the community [22]. Such interventions could be considered by the disaster risk reduction offices of the local government units as regards addressing the possible flood hazard as well as risk towards the community.

4. Conclusion

As to the river flow modeling, there was an observed 0.70 meter difference between the modelled flow and the observed flow depths. Though several parameters were adopted to reduce the difference between the modelled and observed depths, the best model was the adoption of the 90 percent rainfall distribution over the watershed basin and the use of initial abstraction equal to 0.20 of the potential maximum retention.

The developed flood models of the Tarlac River, based on its present condition as well as on the computed extreme rainfall events, resulted to the following conclusions. First, based on the concept of no initial baseflow along Tarlac River, the results of the developed models revealed that there is no expected overtopping of the river even for the 100-year computed extreme rainfall event. Second, to further strengthen the result of the study, other typhoon events, which are properly documented by the CDRRMO and with corresponding rainfall and flow data by the ARBFFWC, can be used to validate the developed model. A survey of the cross-sections of Tarlac River as well as the bridges can be implemented to further enhance the model. Furthermore, base flow for the modeling of the river system can be considered; also the installation of flow meter at the Agana Bridge can be considered to further enhance the HMS model parameters.

With the increasing extreme rainfall events, measures on how to mitigate the overtopping or possible levee breach of the Tarlac River can be considered for future study. Incorporation of the flood mitigating interventions such as construction of dam, water impounding structures, and improvement of levees along Tarlac River can likewise be incorporated in future modeling scenarios.

5. Funding and Acknowledgement

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6. Conflict of Interest

The author declares no conflict of interest.

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