Determination of River Water Level Triggering Flood in Manghinao River in Bauan, Batangas, Philippines

C E F Monjardin, K M Transfiguracion, J P J Mangunay, K M Paguia, F A A Uy, F J Tan*
School of Civil, Environmental and Geological Engineering, Mapua University, Manila Philippines
**cefmonjardin@mapua.edu.ph*

ABSTRACT

Flooding is one of the problems experienced by many countries no matter what their economic status is. Even rich and developed countries experience it too. Flooding is mainly caused by natural events such as typhoons and monsoon rains even anthropogenic causes that sometimes could not be stopped even if there are flood control structures in place. The Philippines is located in the Pacific Ring of Fire and is visited by an average of 20 typhoons each year. People are used to experiencing flooding and it is about time that we somehow do something about it. There have been many technologies available right now that could aid us to improve our capability to adapt to such phenomena. Heavy precipitation is usually experienced during the monsoon season that leads to severe flooding in a specific area. The application of HEC-RAS (Hydrologic Engineering Centre's River Analysis System) Modelling Software was used in the study in Manghinao River for comprehensive hazard mapping and risk assessment in the downstream area of the Bauan River for 100-year return period flood. 2D flood hazard simulation was done and the river water level that would trigger flooding downstream was identified. At 0.5 m of flood height, people are considered immobilized to move from one place to another so the best time to evacuate people is before the flood reaches that level. Results showed that LGU has 4 hours to evacuate people starting when the river water at the gaging station reads 0.5 m, this gives them enough time to give warning and ask people to move to evacuations sites to prevent them being stranded in their houses. This study can support future planning and for the development of flood control plans and flood mitigation measures to minimize

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the losses due to flood disasters in Batangas Province, Philippines particularly in the Bauan area.

Keywords: *Flood; HEC-RAS Modelling Software; 2D flood modeling; Return Period*

Introduction

Many urban areas in the Philippines experience extreme flooding problems when heavy rainfall occurs. Flooding is caused by different factors such as insufficient drainage systems, improper waste disposal, and deforestation [1]. Flooding is severe in areas near rivers due to the rising of river levels that may cause danger to the community [2]. Bauan, Batangas as shown in Figure 1 is one of the first-class and most industrialized municipalities in the region. It is one of the low-lying areas in central Batangas as it is situated in the southern part of the province along the coastal area.

Figure 1: Location Map of Bauan, Batangas.

In 2011, tropical storm Noul hit southern Luzon. Two days of heavy rainfall caused a 2-meter flood in some parts of Bauan. The municipal council immediately declared a state of calamity to address the needs of its people. Lowland areas were swept specifically Aplaya, New Danglayan, San Roque, San Pedro, Poblacion 2, Santo Domingo, San Andres I, and San Andres proper. A lot of flood-prone areas do not have enough flood risk reduction programs that can help people in the community to be ready when the flood comes [3]. The sudden water level rise of a river can cause panic and disaster in areas near the river if not monitored. A system in monitoring the status of river water level and a forecast on how the river water level will rise as soon as the rainfall occurs are very useful in preparation for evacuation and will also lessen the damage of the flood [4].

This study has a purpose to determine the water level in rivers that will trigger flooding in the downstream area using 2D HEC-RAS Modelling

System. The study specifically aimed to provide hydrologic and hydraulic models in the area which are necessary to identify the timing of flooding in the area [5]. Another is to determine flood inundation extent in the area using Lidar DEM. LiDAR is known to have a vertical accuracy of ± 15 cm [6]. And lastly is to have an integrated warning and emergency response program that can detect flood threats and most probably provide a timely warning. It could be done by having a gaging station in the river located in the upstream part of the watershed. The water level in that gaging station will be monitored and could be the basis to know if people downstream will be flooded and to know how much time they have to evacuate. For example in Marikina city, they have this warning system that when the river reaches a certain depth they are enforcing different warning signals to notify people if there is a need to evacuate but unlike in the said city where that gaging station is already downstream [7], the one to be implemented in Bauan is much better since the gaging station will be located in the upstream to give people enough time to evacuate since the detection was done upstream.

The research was limited to the Manghinao River in Bauan, Batangas only, and didn't include nearby areas. The study aimed to prepare the community in the areas of Bauan against the sudden and unexpected rise of the river water level. The main concern is to provide a protocol to prepare the people living in the community and inform them how they should react if the river water level suddenly rises. This could greatly help the local government to give warnings and precautions to its people so that panic will be prevented, and people will be organized. Early preparation for flooding leads to a ready community and that lessens severe danger: loss of lives, disruption of livelihoods, damage to property, etc [8].

Methodology

Description of study area

A flood is an overflow of water outside its typical course [9]. Also, according to [10], flooding occurs when a stream comes up short of its limits and submerges encompassing zones. One of the many municipalities in the Province of Batangas is Bauan which is usually hit by typhoons causing major flooding in the area. The area is flood-prone, and most floods were caused by the swelling of rivers. In this study, we were able to determine the water level of rivers in Bauan, Batangas that will trigger flooding in the communities. The researchers were able to gather data with the help of the Mapua FRAMER project which is a government-funded project whose main objective is to provide communities with flood risk maps.

Data acquisition

The researchers in the study used LiDaR technology to capture the terrain of the area which is a very important input in floodplain modeling [11].

Hydrologic and hydraulic models were also developed using HEC HMS and HEC RAS. Models were validated using the data gathered during a typhoon event in the area. Typhoon's name at that time was "Tisoy" (local name) which falls under category 3. Rainfall data were collected, together with the river discharge. These data were acquired by the Mapua-FRAMER team and authorize the researchers to use them in this study. These rainfall and flow hydrograph data are necessary to calibrate the watershed model [12].

HEC-RAS model description

HEC-RAS is a Windows-based hydraulic model also developed by the U.S. Army Corps of Engineers and Hydrologic Engineering Centre (HEC). The model uses an output hydrograph from HEC-HMS as an input to calculate and analyze the floodplain hydraulics. In investigating the hydraulic characteristics of flow in rivers HEC-RAS model can be used to provide the appropriate numerical values. The model is used to simulate steady, gradually varied, rapidly varied, and unsteady one-dimensional flow and to delineate flood zones. The primary procedure used by HEC-RAS to compute water surface profiles assumes a steady, gradually varied flow scenario. The HEC-RAS model could be used to simulate water level, depths, and flow velocities for different flow configurations and different cross-sectional zones [13].

Application of HEC-RAS

This provides an overview of how a study is performed with the HEC-RAS Software. The user may want to formulate several different plans. Each plan represents a specific set of geometric data and flows data. Once the basic data are entered into the HEC-RAS, the modeler can easily formulate new plans. After simulations are made for the various plans, the results can be compared simultaneously [14]. The hydraulic RAS model has the capability to simulate and predict flooding in a continuous time discretization, but calibration should be taken into consideration [15].

Unsteady flow analysis using HEC-RAS 5.0.7

Perform an unsteady flow simulation

The hydraulic model was developed in this study using some of the data collected by the Mapua FRAMER. They gave the researchers full authorization to use the data for this study. Using those data, models were calibrated and were then used to simulate flooding events in the area considering different return periods. Simulation of different return periods plays an important factor to fully understand how floods occur in a certain area [16]. Shown in Figure 2 is the sample settings used in the run of unsteady flow simulation. Shown here is the sample coverage of flood simulation in the area considering a 100-year return period as this is considered to be the most critical scenario in the Philippine setting [17].

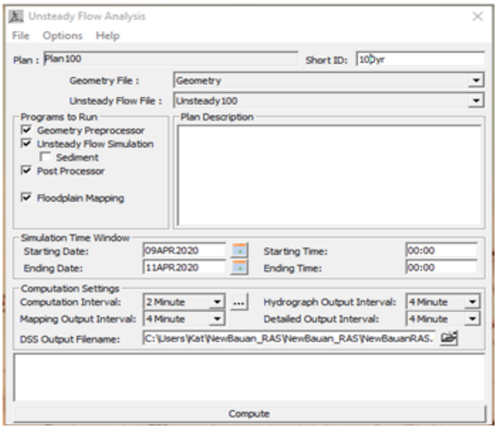

Figure 2: Unsteady Flow Analysis.

Shown in Figure 3 is the RAS Mapper where terrain data is displayed together with the simulation results and other maps/layers that you would like to add. HEC-RAS versions above 5.0 could now load terrain models unlike before that it is dependent on other software for its GIS processing. HEC-RAS now could be considered as standalone software that could function without the help of other software. It can be seen in the figure the terrain of the Bauan area using the Lidar-derived Digital Terrain Model. Using lidar data could produce an accurate flood depth simulation compared to those terrain models with lower accuracy [18].

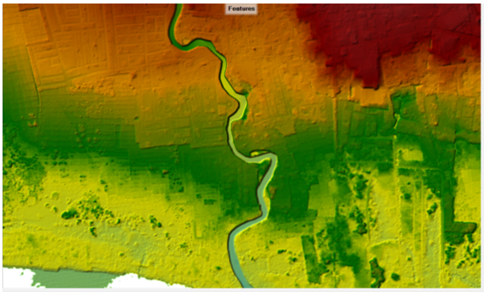

Figure 3: RAS Mapper.

Figure 4 to Figure 6 show the flood arrival time, depth, and velocity in the Municipality considering the 100-year return period. Knowing such data could help the local government to plan ahead of time if there is a need to evacuate people and how much time they have before flood reaches the community [19]. Of course, the simulation cannot predict 100% accurately but at least with this they have an idea of what are they expecting, and these could also help them to convince people to evacuate if needed.

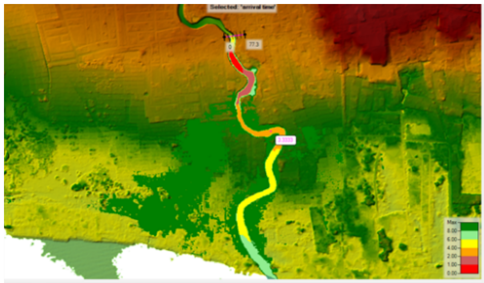

Figure 4: RAS Mapper – Arrival Time.

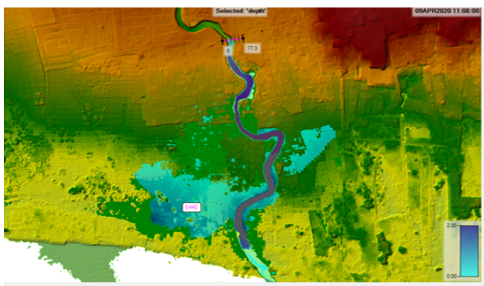

Figure 5: RAS Mapper – Depth.

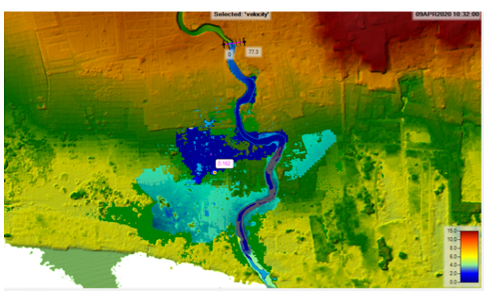

Figure 6: RAS Mapper – Velocity.

Results and Discussion

Disasters such as floods and landslides are very common here in the Philippines, with different transboundary floods with a high number of fatalities [14]. After gathering data and thorough calibration and analysis of the model, the researchers arrived at the important findings of the study.

Using HEC-RAS, researchers were able to simulate the flood extent and depth in the area considering a 100-year rainfall event. Map layers were produced in the RAS mapper where the data in Table 1 were extracted. The elevation model used in the simulation was a Terrain model that captures the elevation of the bare earth which is usually used in flood simulations.

Depth

Table 1 shows the gaging stations and other stations considered in the river. Utilizing the 100-year return period simulation done in Ras, researchers were able to identify the maximum flood height that could occur in the area and the time of arrival considering 12:00 am as the start of the simulation. Stations were named 1 to 4 and the location of each station could be seen in Figure 7 starting from the upstream area of the river to downstream. The peak river depth at the gaging station was 2.9 m at 9:20 am, this indicates that water that could flood downstream already passed through this station. This could be used as a basis to determine how long it will take before floods reach the downstream. At 10:10, the water already reached the downstream area at station 1 with a maximum flood depth of 4.53 m. Station 4 had the lowest flood depth with 3.7 m and was expected to be flooded 3 hours after the peak flood occurred in the gaging stations. Knowing these peak floods in each station is not enough to be used in flood evacuation plans. We should also identify at what certain level of flood height people could be immobilized. Researchers did a survey to the local government in the area, they were asked based on their experience at what flood level people are having a hard time moving from one place to another. Researchers decided that it is much better to ask this from the people living in the area rather than rely on other studies which could have a different situation with the concerned area in this study.

Table 1: Peak River Depth

Station (m)	Date and Time	Peak River Depth (m)
Gaging Station	09:20 am	2.9
Station 1	10:10 am	4.53
Station 2	10:50 am	4.30
Station 3	11:50 am	4.12
Station 4	12:15 pm	3.7

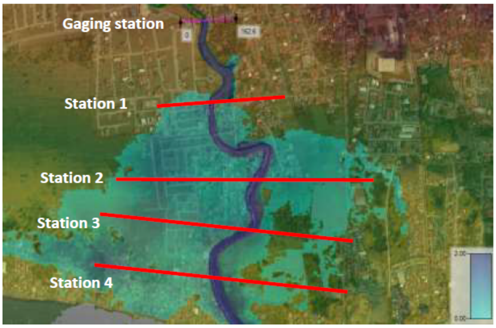

Figure 7: RAS Mapper Depth Simulation.

Arrival time

Arrival time is the computed time in hours or days from a defined time in the simulation when the depth of water reaches a specified threshold depth [11]. Based on the interview done with the LGUs of the municipality, it was found out that at a flood depth of 0.5 m people are starting to have a hard time moving from one place to another. That's why this flood depth was considered by the researchers to be the threshold value in the analysis.

Figure 8 shows the arrival time in the downstream area. The map indicates the time when the area will experience a flood depth of 0.5 m. The simulation ranges from 0 to 12 hours as a reference. HEC-RAS was able to simulate the flood arrival time in Bauan, Batangas using the 100 return period data. The generated flood arrival time could also serve as an early warning for the people to evacuate their places.

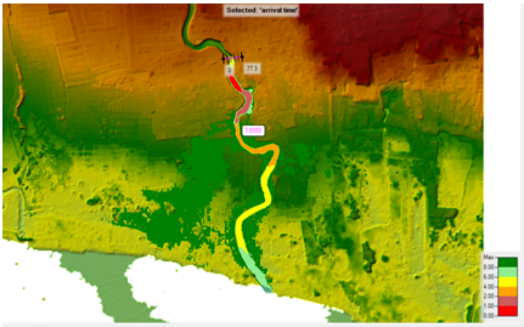

Figure 8: RAS Map Arrival Time Simulation.

Shown in Table 2 are the simulated flood arrival time using the 2D unsteady flow analysis of RAS. A Flood of 0.5 m is a flood height known that could immobilize people in moving from one place to another. That is why it was the threshold used in the study. The table shows that when the level at the gaging station reads 0.5 m, people still have 4 hrs to evacuate before a flood height of 0.5 m reaches their area as an example for station 1. Station 4 which is located at the farthest point will experience a flood height of 0.5 m 5 hrs after the flood level in the gaging station reached 0.5 m. These data could really be utilized by the local government to improve their emergency response procedures/protocol.

Table 2: Arrival time of Flood at 0.5 m depth

Station (m)	Date and Time	Peak River Depth (m)
Gaging Station	0 (reference)	0(reference)
Station 1	4.16 hours	0 (Possible max flood height is less than 1m)
Station 2	4.56 hours	4.5 hours
Station 3	4.76 hours	4.7 hours
Station 4	5.10 hours	5.3 hours

Velocity

The velocity of a river is the speed of water that moves along its channel, according to [15] river velocities are not constant all through its cross-sectional area. In RAS, it just calculates the mean velocity of the river, so it doesn't need to be cross-section specific. Velocities at max flood depth were shown in Table 3. It could be seen that there's only one station where the velocity of the water is at its maximum and it is located at station 4. It may be because station 4 is in the lowest elevation and bed slope there could be much steeper compared to other stations.

Table 3: Velocity

Station (m)	Date and Time	Peak River Depth (m)	Velocity (m/s)
Gaging Station	09:20 am	2.9	0.23
Station 1	10:10 am	4.53	0.41
Station 2	10:50 am	4.30	0.20
Station 3	11:50 am	4.12	2.0
Station 4	12:15 pm	3.7	2.19

Conclusions and Recommendations

The main objective of this study was to create a hydraulic model using the software HEC-RAS in simulating different water levels of the Manghinao river that could trigger flooding in the downstream area. The Manghinao river is usually causing the flood in Bauan. The data acquired from the DOST-MAPUA-FRAMER project played a significant role in the success of this study. The result of the 2D unsteady flow simulation showed that many areas in Bauan will be inundated or flooded when a 100-year rain return period event occurs in the area. The model was able to utilize lidar data with a vertical accuracy of ± 15 cm.

Bauan is one of the many towns in Batangas that has a large boundary. It has an area of 53.31 km^2 (20.58 sq. mi) placing it as the 19th largest town in the province. Manginao river is known to swell most of the time, causing flooding in the area when a strong typhoon hits the municipality. In this paper, the researchers were able to determine the maximum flood heights in the area. Max flood height in the area could happen in station 1 with a height of 4.53 m at which a typical household with 1 floor could be totally flooded. Using HEC-RAS, researchers were able to come up with a flood inundation map showing which area in the municipality could be flooded and at what level. Flood inundation map can also be used for preparation for "what-if" scenarios, and timely response for forecast information.

This paper was able to provide a systematic way of how to notify people in the downstream area if there is already a need for evacuation, that is by having a gaging station upstream that monitors the water level. A certain level of water in the gaging station will give the local government an idea of what announcement to be issued to their community. These flooding scenarios were simulated using HEC-RAS's 2D flow capability with the aid of Lidar DEM. Researchers are very confident of the result and hope that the local government will adopt it.

After conducting the research, the results showed that the possible maximum water levels in each station are 4.53, 4.30, 4.12, and 3.7. Considering the flood height itself it could produce a max of 0.97 m flood height in the community. The said flood height is enough to cause problems to the people in the area. Flooding is most of the time inevitable, but we could adapt by creating a systematic way of evacuating people. The study provided the local government of Bauan with a reliable early warning procedure for evacuation by monitoring the river water level at the gaging station. It was shown that when the water level at the gaging station reaches 0.5 m, the LGU has 4 hours to evacuate the people before the flood height of the area reaches 0.5 m. This gives the LGU enough time to convince people to evacuate.

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