FLOOD HAZARD SIMULATION USING BETA VERSION HEC-RAS 5.0 IN BALATUCAN RIVER BASIN, MINDANAO, PHILIPPINES

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ABSTRACT: Flooding accounts for 47% of all weather-related disasters affecting 2.3 billion people wherein 95% resides in Asia. The Philippines has consistently ranked among the top 5 most vulnerable country (UNISDR 2015). Vulnerability is high resulting to loss of lives and damaged to livelihood and infrastructures. While disaster-related data sets are available, the quality and scope is limited. The availability of data and analytic tools is determined by reliable data (ADBI 2013). This paper is part of the overall Hazard Mapping of the Philippines using the Light Detection and Ranging technology (Phil-LiDAR 1) Program aimed at generating high resolution flood hazard maps for the Philippine river systems. The objective of this paper is to simulate flooding and generate corresponding flood hazard maps for the Balatucan River Basin in Mindanao, Philippines, affected by flooding in recent years resulting paralysis of a major bridge connecting two regional centers in Northern Mindanao. To simulate flood hazards, the Hydrologic Engineering Center (HEC)-Hydrologic Management System (HMS) and River Analysis System (RAS) 5.0 Beta Version, a hydrologic and hydraulic modelling software were used. The following data sets served as inputs in the hydrologic model preparation: 10m Synthetic Aperture Radar (SAR) DEM, land cover and soil map, river widths derived from field surveys. Simulation run were then applied to calibrate the model. Accuracy tests were conducted using Nash–Sutcliffe Efficiency (NSE), Standard Deviation Ratio (RSR), and Percent Bias (PBIAS). The calibrated model is used to simulate outflow from Rainfall Intensity Duration Frequency (RIDF) generated from historical data of the nearest rain gauge station. A hydraulic model is then created for flood simulation producing Balatucan River Basin flood hazard maps for 5, 25, 50 and 100-year period. Overlaid with high resolution LiDAR DSM provided the flood exposure data sets, which local disaster risk reduction stakeholders can use as tool for flood hazard response.

1. INTRODUCTION

1.1 Review of Literature

Majority (90%) of disasters between the period 1995-2015 are weather-related, wherein 47% are associated with flooding. Disasters have become intense and frequent affecting 2.3 billion people wherein 95% resides in Asia. The Philippines, ranked among the top high risk countries has consistently been in the 2nd or 3rd spot (CRED and UNISDR 2015). The country's exposure to risk is primarily due to its geographic location. Furthermore, the impact of changing climate makes exposure to risk more pronounced as illustrated in Mindanao which has experienced increased frequency and intensity of typhoons. A new typhoon period between October to February has been observed in Northeastern Mindanao generating unprecedented volume of rainfall (Bruno, et. al., 2015).

The high vulnerability has resulted to loss of lives and damaged to livelihood and infrastructures. Typhoon Bopha (2012) and Super typhoon Haiyan (2013) for instance now holds the Philippine record with the highest number of casualties, amount of damage and number of people affected. One of the strategy is to generate flood hazard maps from different rainfall scenarios. Flood inundation models aims to simulate flood behavior including extent and depth of flood waters at specific location allowing decision makers choose from among the possible scenarios, including allocating limited resources (Goodell and Warren 2006). Nonetheless, flood hazard simulation is constraint by quality of terrain data, cross-section configurations, the hydraulic model, and analytic tools availability, compounded by limited quality and scope (ADBI 2013). However, availability of high resolution terrain data such as LiDAR, availability of of two-dimensional hydraulic models and access to high end computers has revolutionize flood simulation (Cook 2008).

The University of the Philippines-Diliman, with 14 other Higher Education Institutions (HEIs) pioneered the use of LiDAR technology across the country through the Phil-LiDAR 1 Program. Funded by the Department of Science and Technology (DOST), it aims at producing updated, high resolution flood hazard maps in more than 200 river systems nationwide. The Central Mindanao University (CMU) is assigned to 13 rivers in Mindanao. The basic approach in generating flood hazard maps is the utilization of HEC-HMS and HEC-RAS, a hydrologic and hydraulic modelling software. However, to produce the two-dimensional flood hazard maps, Phil-LiDAR 1 uses the licensed two dimensional software. This paper explores the use of HEC-RAS 5.0, an open source software capable of two-dimensional modelling. Until recently, HEC-RAS is limited to one-dimension hydraulic model. In river systems with steep terrain and draining within a confined valley, one dimensional modelling is suitable. However, where flow pattern is highly irregular with wide flood plain and flood waters running to different directions, a one-dimensional model will be challenging (Crampton and Zgonina 2016).

The behavior of Balatucan River flood water poses challenge in hydraulic modelling. Raging flood waters brought by Tropical Typhoon Jangmi in December 2014 damaged a bridge connecting two regional centers: Cagayan De Oro and Butuan (Manlupig 2014). Data from the Balingsag Municipal Disaster Risk Reduction Office (MDRRMO) estimated the damaged to around 1.5 million US dollars. Flood control infrastructure is of no avail as flood waters rampaged to every possible direction.

1.2 Objectives

The paper aims to simulate flooding incidence and generate corresponding flood hazard maps for the Balatucan River Basin in Mindanao, Philippines, using the Beta Version of HEC-RAS 5.0. The specific objectives includes the:

a) Generation of calibrated hydrologic and hydraulic models for the site;
b) Simulation of flood scenarios using different rainfall Intensity Duration Frequency (RIDF); and
c) Risk assessment based on available flood exposure data sets.

2. METHODOLOGY

2.1 Research Site

Balatucan River Basin is located at the province of Misamis Oriental, Northern Mindanao, Philippines. ***Figure 1*** shows the geographical location of the basin covering barangays Kibanban, Quezon, Napaliran, Mandangoa, Mambayaan and Cogon under the Municipality of Balingasag, portions of barangays in Gingoog city, and municipalities of Lagonglong and Claveria. The basin has an area of around 12,184 hectares.

Frequently flooded barangays includes Kibanban, Napaliran, Mambayaan, Mandangoa, Cogon, Linggangao, San Isidro, Talusan, Waterfall, Baliwagan, all in Balingasag including portions of the town center. Inundation also reaches Barangay Kauswagan, Municipality of Lagonglong.

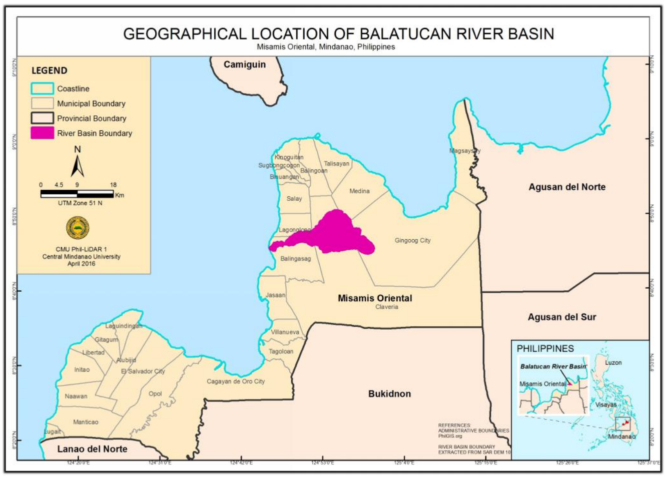


Figure 1: Balatucan River Basin Location

2.2 Hydrologic Modelling and Calibration

A hydrologic and hydraulic models are used to simulate flooding. The Hydrologic Model has three major components: basin model, meteorological model and a set of control specifications. To generate the basin model, a 10-m Synthetic Aperture Radar Digital Elevation Model (SAR DEM) served as input data to delineate the basin and river networks using the Watershed Modelling System (WMS). The Balatucan River Basin hydrologic model was generated and calibrated using the HEC-HMS, designed to forecast precipitation-run-off processes in a watershed. Hydrologic modelling aimed at simulating the river discharge draining from various tributaries of the basin as it enters the flood plain.

Two hydrologic data: rainfall and discharge are needed as input to calibrate the model. Due to absence of hydrologic monitoring station in the basin, CMU installed portable down loadable rain gauge (RG) in Sitio Lantad (upstream), while discharge data was collected at Sitio Kiwali (midstream) as it enters the flood plain, all in Barangay Kibanban, Balingasag. The data used in the calibration was gathered during a rainfall event from 1410 hours 20 May to 0200 hours 21 May 2016. ***Figure 2*** shows the location of the RG and discharge collection site. To compute for river discharge the following data were collected: water level, velocity and river cross-section.

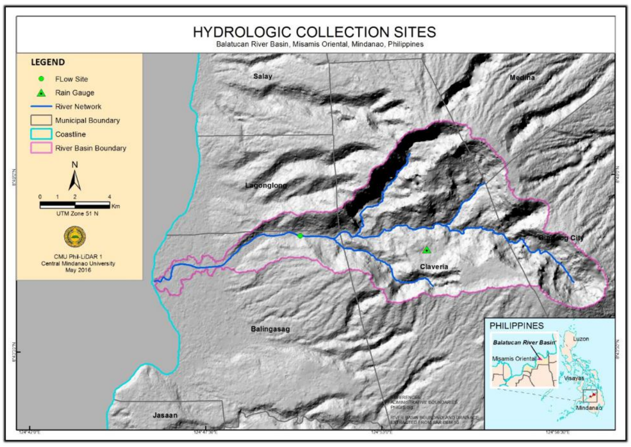


Figure 2: Hydrologic Data Collection Site

2.2.1 Model Calibration and Performance Evaluation

Having defined and completed the basin and meteorological model, control specification and time series data in the HEC-HMS interface, the parameters were adjusted based on the response of the hydrograph as reflected in the relationship of the simulated to the observed data. The parameters includes initial abstraction, curve number, Percent impervious time concentration, storage coefficient, Manning's n value, etc. Manual calibration was done on the HEC-HMS model as it allows adjustment of specific parameter based on local knowledge. The following tests were used to evaluate the performance of the HMS model:

Nash–Sutcliffe Efficiency (NSE): a normalized statistic that determines the mean square error generated simulated variance compared to the observed data variance. An NSE value of 1 indicates a perfect model performance, while a value of 0 indicates poor reliability (Nash and Sutcliffe 1970);

Root Mean Square Error (RMSE)-RSR: RSR standardizes RMSE using the observations' standard deviation and is calculated as the ratio of the RMSE and the standard deviation of the measured data. (Moriasi et al. 2007);

Percent Bias (PBIAS): measures the average tendency of the simulated values to be larger or smaller than their observed ones. The optimal value is 0, with low-magnitude values indicating accurate model simulation. Positive values indicate overestimation bias, whereas negative values indicate model underestimation bias (Yapo et al., 1996).

2.2.2 Discharge Simulation

The calibrated HMS Model is used to simulate discharge using historical rainfall events in a form of Rainfall Intensity Duration Frequency (RIDF). The Lumbia Station in Cagayan de Oro is used being the nearest Weather Monitoring Station with available 26-year historical rainfall data. The RIDF is a probability that particular average rainfall intensity will occur at a specified time period. RIDF data is available at the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). Data of the four return periods namely: 5, 25, 50 and 100-year RIDF were used for the simulation of the calibrated HEC-HMS basin model of Balatucan River.

2.3 Hydraulic Modelling and Flood Mapping Using HEC-RAS 5.0

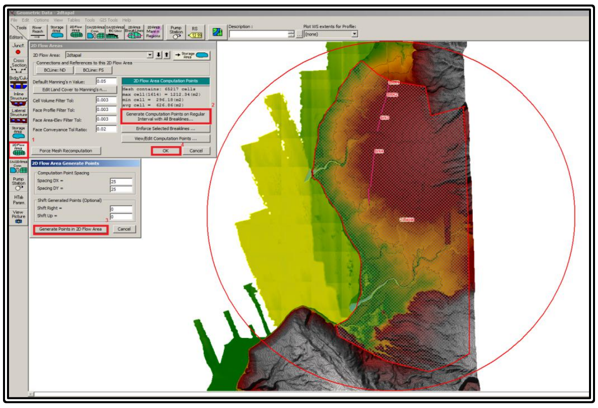
The Beta Version HEC-RAS 5.0 is used to simulate the flood inundation of the Balatucan River flood plain. The general process as described below is adapted from the HEC-RAS Manual:

2.3.1 Terrain Model Development

The basic requirement in 2D HEC-RAS modelling is a high resolution terrain data. For this study, a 1-m resolution LiDAR-derived DTM burned with bathymetric data was used. The model development is processed in the RAS Mapper using GIS Tools. The projection is set to WGS 1984 UTM Zone 51N. Using the "New Terrain Layer" button, the DTM is then loaded. The process allows the naming of New Terrain Layer, selecting the directory, defining the elevation precision of the new terrain data layer. Pressing the "Make Terrain" button converts the grids into GeoTiff(*.tif) file format to allow for smaller storage space and faster speed in generating flood maps. The terrain model is used to compute the hydraulic properties of the 2D flow area and serve as background image during the computational mesh development.

2.3.2 Computational Mesh Development

A Finite -Volume solution scheme is used in HEC-RAS 2D modeling, an algorithm allowing a structured or unstructured computational mesh. The mesh is built by creating a polygon boundary of the 2D area in the Geometric Data Editor. To establish the 2D flow area boundary, the terrain data is used as background image aimed at limiting the boundary within the floodplain. Break Lines which includes levees, roads or high ground that impedes flow of water is added, then computational mesh was generated.Then the Manning's roughness is Incorporated. ***Figure 3*** shows the Balatucan River 2D Terrain Model flow with Break Lines.


Geometric Data - 2dtapal

2D Flow Areas

2D Flow Area: 2dtapal

Default Manning's n Value: 0.05

Cell Volume Filter Tol: 0.003

Face Profile Filter Tol: 0.003

Face Area-Elev Filter Tol: 0.003

Face Conveyance Tol Ratio: 0.02

```
Mesh contains: 65217 cells
max cell(1614) = 1212.34(m2)
min cell =  296.18(m2)
avg cell =  626.86(m2)
```

2D Flow Area Generate Points

Spacing DX = 25

Spacing DY = 25

Shift Right = 0

Shift Up = 0

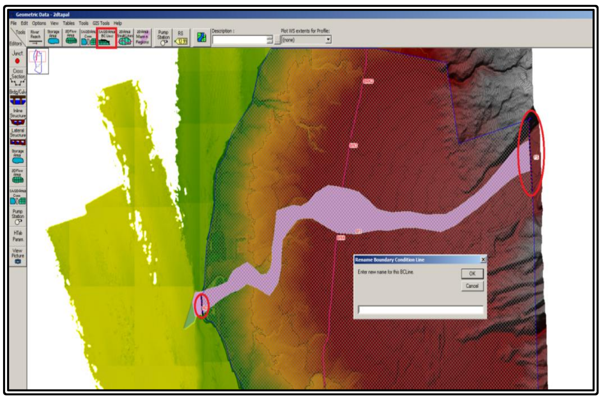
Figure 3: 2D Flow Area with Break Lines

2.3.3 Creating Manning's Roughness Data Set and Hydraulic Property Tables

The Manning's n value or roughness coefficient is the resistance of a flow to a surface associated with land cover. A Manning's polygon is created using the "2D Area Mann n Region" button, then digitizing the river channel. The software prompts to name each of the Manning's polygon. The values of n for this study is set to 0.03. The new terrain layer in the RAS Mapper must be associated with all the geometry files. Then the 2D Computation Mesh is pre-processed into an elevation-volume curve for each cell, and a series of hydraulic property curves for each cell face. The hydraulic property tables are derived from the terrain used for the model, and the defined Manning's n value set in the geometry file. Then set the boundary conditions.

2.3.4 External 2D Flow Area Boundary Conditions

The 2D Flow Area Boundary Conditions are where the flow enters or drains the 2D Flow Area. The Flow Hydrograph and Normal depth are used for this purpose created within the "Geometric Data Editor" window entered in the Unsteady Flow Data window. Flow hydrograph was set upstream portion of the 2D flow area consisting of time series data from the HMS Model simulated discharge. While the Normal Depth was set downstream portion which requires a friction value for slope (set to 0.0001). ***Figure 4*** shows the data entry of boundary condition. The Initial conditions were set to default, while the Initial Elevation was left blank which prompt the the software to start dry during the simulation.


Geometric Data - 2dtapal

Rename Boundary Condition Line

Enter new name for this BCLine

Figure 4. 2D Flow Area Boundary Conditions

2.3.5 Running the 2D Unsteady Flow Analysis

Running a 2D unsteady flow model in HEC-RAS is no different than running a standalone 1D unsteady flow model. The 2D unsteady computational module is built directly into the HEC-RAS unsteady flow computational engine. The model is run in the Unsteady Flow Analysis Window. Some of the values are adjusted depending on the range of parameters, including the adjustment of flood extent, if necessary. The default values was left unchanged but the Initial Condition Time, Initial Condition Ramp-Up Fraction, Number of Time Slices and Boundary Condition Volume were changed to 10 hours, 0.1, 10 and checked box, respectively. Then run the "Unsteady Flow Analysis".

2.3.6. Viewing 2D Output in RAS Mapper and ArcGIS

Once the unsteady-flow run of the model is completed, the 2D output results can be viewed within RAS Mapper. A static map is created from the RAS Mapper stored in the directory that is viewed or imported to ArcGIS for viewing and map layouting as shown in ***Figure 5***.

2.4 Flood Risk Assessment

Using the LiDAR-derived DSM features and validated on the ground, features within the defined flood plain have been extracted. The flood hazard maps are then overlaid with flood exposure data sets for a flood risk assessment.

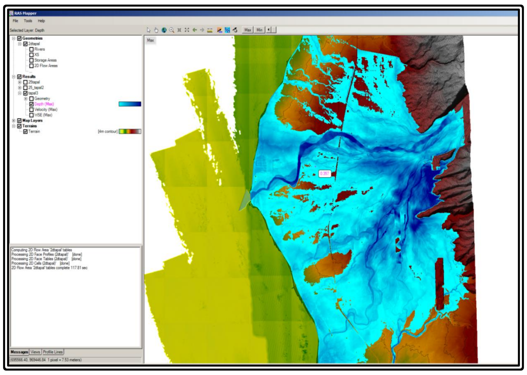


Figure 5. Flood Inundation in RAS Mapper

3. RESULTS AND DISCUSSION

3.1 Balatucan River Basin Model

The WMS tools generated basin model consisting of 61 sub-basins, 58 reaches, and 61 junctions (including the main outlet) as shown in ***Figure 6***. Soil and land cover characteristics of the area were identified on each subbassin. The delineated subbasins range from 0.003 to 4.64 km^2 in area, and with an average area of 2.01 km^2. Delineation of subbasin area was based on the threshold area defined before the delineation.

3.2 Hydrologic Data

The rainfall data Total rainfall collected was 39.2 mm with peak rainfall at 11.0 mm recorded on 1515hh May 20, 2016. River outflow was measured during the rainfall event from 1410hh May 20, 2016 to 0200 May 21, 2016. Peak discharge is 36.40 m3/s on 1820hh May 20, 2016. ***Figure*** *7* illustrates the rate of the river flow at a specific time as influenced by the rate of the rainfall. The lag time between the peak rainfall and discharge is four (4) hours and fifty five (55) minutes.

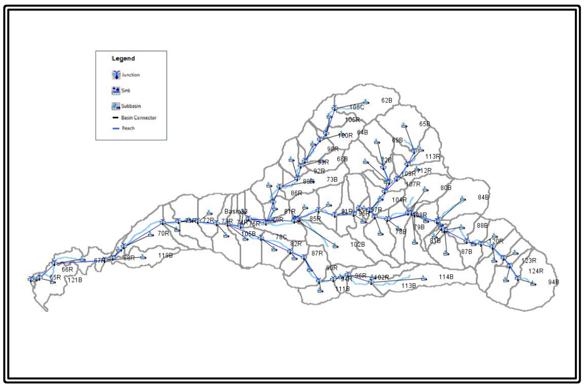


Figure 6: Balatucan River Basin Model

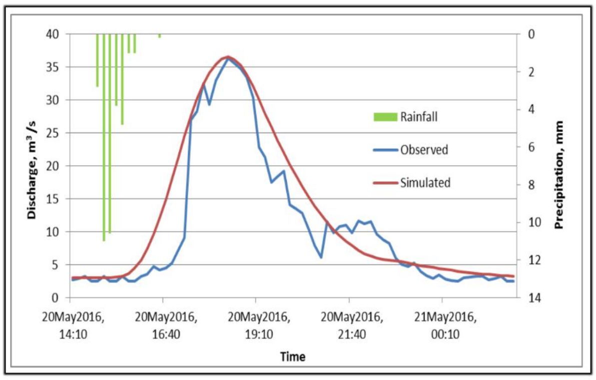


Figure 7: Balatucan River Hydrograph

3.3 HMS Model Performance Evaluation

Table 1 shows the performance evaluation standards and the corresponding results. The pre-calibration values indicates unsatisfactory results. However, post-calibration test showed the model with “very good” RSR at 0.42, “very good” NSE at 0.82 and “satisfactory” PBIAS at 22.12.

Table 1: Performance Evaluation

	Performance Standards		
Performance Rating	RSR	NSE	PBIAS
Very Good	0.00 < RSR < 0.50	0.75 < NSE < 1.00	PBIAS < ± 10
Good	0.50 < RSR < 0.60	0.65 < NSE < 0.75	± 10 < PBIAS < ± 15
Satisfactory	0.60 < RSR < 0.70	0.50 < NSE < 0.65	± 15 < PBIAS < ± 25
Unsatisfactory	RSR > 0.70	NSE < 0.50	PBIAS > ± 25
	Performance Evaluation Results		
Pre-Calibration	1.35	-0.83	83.53
Post-Calibration	0.42	0.82	22.12

Using the gathered stage and discharge data, a rating curve (see ***Figure 8***) was developed to illustrate the relationship between the observed stage of the river and discharge. Stage was determined using a calibrated water level while discharge was calculated using the cross section area, water level, and river velocity measured using a mechanical flow meter. The attained rating curve is expressed as Q = 2.4693e6.7291h.

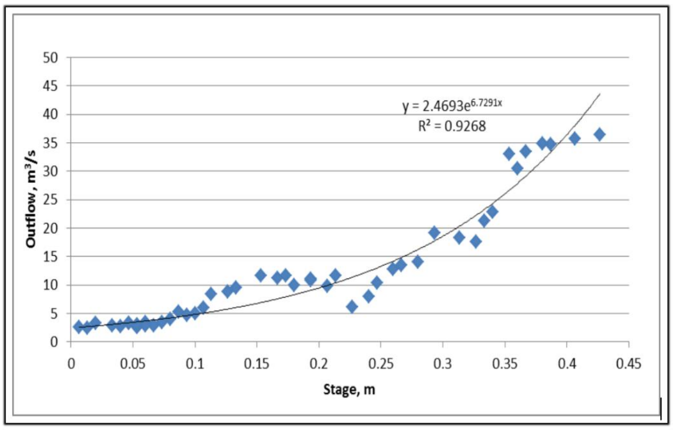


Figure 8: Balatucan River Rating Curve

The relationship is expressed in the form of the following equation:

$$Q=a^{nh}$$

Where, Q : Discharge (m^3/s);
h : Gauge height; and,
a and n : Constants

3.4 Simulated Discharge Using RIDF

Figure 9 shows the Balatucan River Simulated Discharge Using various RIDF, while ***Table 2*** shows the different return periods with corresponding peak outflow, total precipitation, total precipitation and time to peak. Four (4) return periods are used; 5, 25, 50 and 100 year all for the duration of 24 hours and peak at 12 hours. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases.

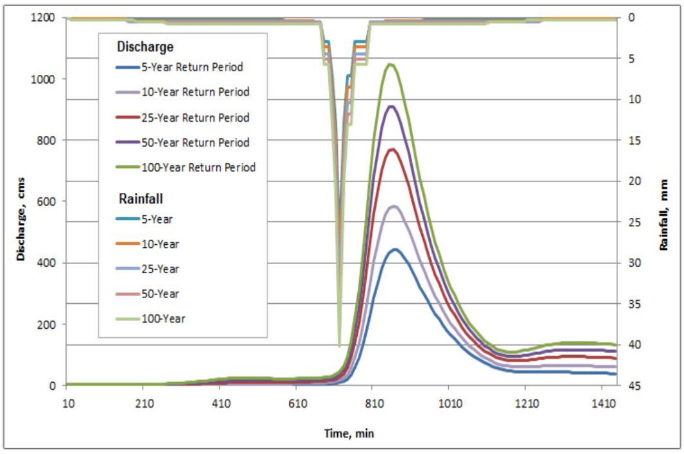


Figure 9: Balatucan River Simulated Discharge

Table 2: Return Periods and the Hydrograph

RIDF Period	Total Precipitation (mm)	Peak Rainfall (mm)	Peak Outflow (cms)	Time to Peak
5 Year	129.2	27.1	443.4	3 hours and 50 minutes
25 Year	189.7	34.2	769.5	2 hours and 20 minutes
50 Year	214.8	37.2	907.5	2 hours and 20 minutes
100 Year	239.7	40.2	1048.3	2 hours and 10 minutes

3.5 Flood Hazard Analysis

To establish the unit of analysis, a flood plain has been delineated using two parameters: $\leqq$100 masl and $\leqq 18^0$ slope which has a total area of 4,573.53 hectares. ***Figures 10 to 13*** shows the two dimensional flood hazard maps for 5-year, 25-year, 50-year and 100-year return periods respectively, generated using HEC-RAS 5.0. ***Table 3*** shows the statistics in terms of area per hazard level categorized as: low (0-0.5m), medium (>0.5<1.5m) and high (>1.5m). It also compares flood depth across return periods.

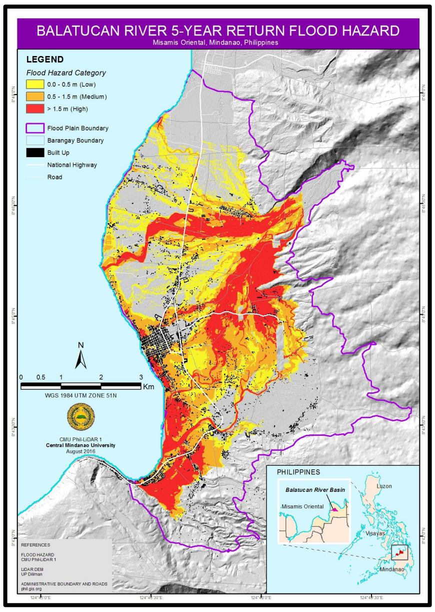


Figure 10: 5-Year Return Period

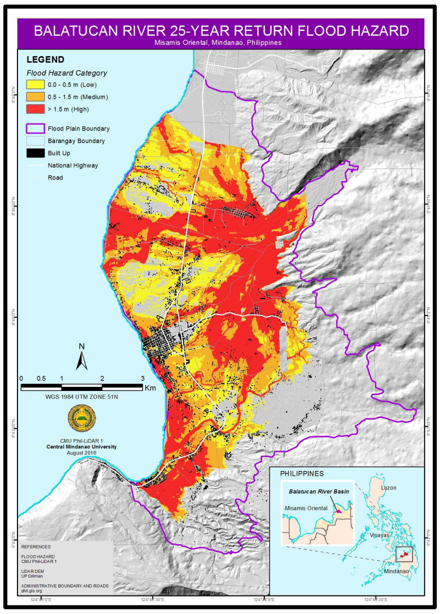


Figure 11: 25-Year Return Period

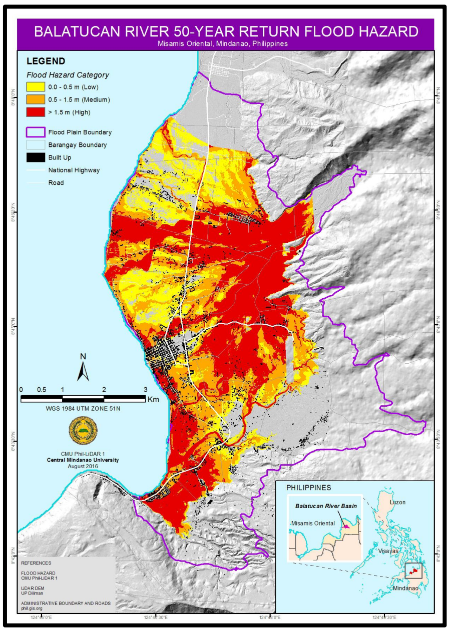


Figure 12: 50-Year Return Period

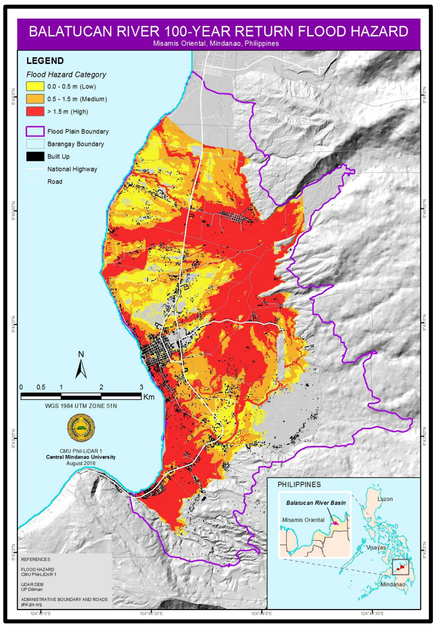


Figure 13: 100-Year Return Period

The results show that even in a 100-year return period, at least 41% of the defined flood plain will not be flooded. These areas are situated in the eastern side towards the higher elevation with minimal population concentration. Worth noting is that the town proper is among the area free from flooding, except that fronting the coast, which is subjected to tidal flooding. In general, a significant decrease in the not flooded area from 5-yr. to 25 yr. period can be observed. The decrease can be correlated to a corresponding increase in the medium hazard areas, and more significantly in the high hazard areas.

Table 3: Flood Hazard in Different Return Periods Balatucan River Basin Flood Plain

Return Period	LEVEL OF HAZARD								Total Area
	Not Flooded		Low		Medium		High		
	has	%	has	%	has	%	has	%	
5 Yr.	2,667.20	58%	478.30	10%	734.88	16%	679.11	15%	4,559.49
25 Yr.	2,095.32	46%	447.71	10%	869.30	19%	1,147.16	25%	4,559.49
50 Yr.	2,068.59	45%	428.37	9%	837.14	18%	1,225.40	27%	4,559.49
100 Yr.	1,888.63	41%	426.69	9%	907.75	20%	1,336.42	29%	4,559.49

Comparing the flood hazard for different return periods, no significant changes was observed in the low hazard areas. No changes was observed for 5-year and 25-year, while it dropped only to 9% from 10% for both 50-yr and 100 yr. period. The medium hazard areas also has minimal change---16% to 19% for 5-year and 25-year respectively. However, a significant increase of 15% to 25% is observed in the high hazard area for the 5-year to 25-year return period. The pattern suggests two things---first; the transition in flood water rise is too quick towards high hazard, and second; the the critical return period is between the 5-yr. and 25-yr. return, where a significant increase is observed.

Analyzing the maps further reveal that Balatucan River inundation is split into two major routes: east-west and south-west. The former directly hits the bridge at the national highway connecting two regional centers: Cagayan de Oro and Butuan. In a number of flood incidence, the bridge has been damaged. The latter route spreads to a wider flood plain dissipating the current but affecting larger populated areas. Indigenous residents noted the south-west route as the original drainage system of Balatucan River.

Meanwhile, Table 4 shows the Balatucan River Flood Plain Flood Hazard Exposure Per Type of Building using the 5-year return period. Extracted from LiDAR-DSM, a total of 8,489 buildings have been identified within the delineated flood plain, where 94% (7,968) are residential buildings.

Using the 5-year period, it shows that 65% of the residential buildings are susceptible to flooding, 34% at medium and 16% at high hazard level. Potential buildings for evacuation such as schools, baragay halls, churches and covered courts are in the flood-free areas. However, equal percentage of same facilities are located in the medium hazard zones. In general, local risk reduction stakeholders have to seriously protect a significant population in high hazard or relocate them to safer areas.

Table 4: 5-Year Return Period Flood Hazard Exposure Balatucan River Flood Plain

	LEVEL OF FLOOD HAZARD								
TYPE OF BUILDINGS	**Flood-Free**		**Low**		**Medium**		**High**		**Total**
	#	**%**	**#**	**%**	**#**	**%**	**#**	**%**	
Residential	2,791	35%	1,216	15%	2,711	34%	1,250	16%	7,968
Schools	55	37%	32	22%	59	40%	2	1%	148
Commercial	107	38%	54	19%	115	41%	7	2%	283
Barangay Hall	3	21%	3	21%	7	50%	1	7%	14
Churches	2	11%	-	0%	9	47%	8	42%	19
Covered Court and Gymnasium	3	43%	-	0%	4	57%	-	0%	7
Government Facility	3	16%	1	5%	14	74%	1	5%	19
Gas Station	4	67%	2	33%	-	0%	-	0%	6
Hospitals and Health Center	3	30%	-	0%	7	70%	-	0%	10
Market	4	44%	4	44%	1	11%	-	0%	9
Municipal Hall	-	0%	-	0%	1	100%	-	0%	1
Bank	-	0%	-	0%	1	100%	-	0%	1
Fire Station	1	100%	-	0%	-	0%	-	0%	1
Ware House	1	33%	-	0%	2	67%	-	0%	3
									8,489

4. SUMMARY, CONCLUSION AND RECOMMENDATION

The utilization of two-dimensional model in simulating flooding incidence and the generation of corresponding flood hazard maps is a technological advancement in disaster management. This particular paper have highlighted two critical contributions in the Philippine context---use of open source two-dimension flood modelling and an in depth analysis of the Balatucan River flooding.

Practice of two-dimensional flood hazard modelling and mapping for disaster management has not been widely popular owing to the cost of input data, hardware and software. Philippine context presents greater opportunity with available updated data such as LiDAR and interest of various institutions to invest in hardware. The availability of LiDAR-derived DEM (DSM and DTM) data for many river systems due to Phil-LiDAR program opens opportunities to the application of two-dimensional flood modelling software with HEC-RAS 5.0. Meanwhile, the Balatucan River Basin flood maps generated for this paper offers a detailed spatial information to local disaster risk reduction managers. It has generated different flooding scenarios which local stakeholder can use as input to their strategy formulation.

The contributions as presented in this paper likewise carries inherent limitations. The results from using Beta Version HECRAS 5.0 needs further scrutiny given limited time spend at manipulating the potential of the software. This is an attempt to explore the potential of HEC-RAS 5.0, which necessitates further enhancement on the familiarity of the software by the user. But clearly, it presents great potential for an informed disaster management strategies.

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