SIMULATING THE EFFECTS OF DREDGING TO THE RIVER HYDRAULIC CHARACTERISTICS OF THE AGUSAN RIVER USING LIDAR-DERIVED DIGITAL TERRAIN MODEL

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ABSTRACT: Dredging is known to be the simplest and cost effective way to address the flooding in the rivers by widening and deepening its channels. It is a process wherein materials from the bed or banks of the river are removed and are disposed to a different location. Although this method would increase the capacity of the river to contain and prevent flood waters from spillage, this also causes the flow of the river to become faster going downstream. In this paper, we present the possible effects of dredging to the hydraulic characteristics of a river with the use of high spatial resolution LiDAR-derived Digital Terrain Model (DTM), field surveying, hydrologic modeling and 2-dimensional hydraulic modeling. The analysis involved the comparison of hydraulic simulation results between the models with actual river profiles and hypothetical or dredged river beds at different volumes. The 2D simulations generated several hydraulic characteristics that are to be compared; namely, the river velocity, flood depth, and stream power. The analysis was conducted in Agusan River, Caraga Region, Mindanao, Philippines; wherein industries of fishponds in the estuarine area and water transportation are existing and are currently operating. Aside from simulating the normal flow of the river to the different models, rainfall scenario based events of 2-year, 5-year, 10-year, 25-year, 50-year and 100-year return periods are also simulated and generated with the different hydraulic characteristics. The result of the analysis provides a quantitative approach in determining the maximum limit of volume of soil to be removed on a dredging activity to allow safe navigation for local fishermen in the estuarine areas and serves as an effective tool for monitoring if ever the local government unit are planning or wanted to conduct dredging in Agusan River.

1. INTRODUCTION

1.1 Background

Dredging is scraping the bottom of a river to open up a channel, make the river floor deeper, to accommodate large boats, prevent flooding, or better drain nearby land (Murdock R., 2011). Although this method would increase the capacity of the river to contain more volume of water, improperly handled dredging activity may cause other complications such as erosion and faster downstream flow. The Agusan River is one of the four (4) major rivers in the Philippines which have a planned dredging to be implemented by the Department of Public Works and Highways (DPWH) under the current administration (Butuan Chronicles, 2017). The Agusan River Dredging Plan is one of the proposed solutions to the prevailing problem of flooding in Agusan. Modeling the river dredging scenario in the Agusan River is of primary importance to determine the implications of widening and deepening of the river channels to the outflow of the river in different rainfall scenarios.

An elevation model representing the changed river bed elevation can be produced by hypothetically dredging the bathymetry-integrated Digital Terrain Model (DTM) of Agusan River. A comparative analysis between the actual and the hypothetically-dredged river beds can then be performed by studying the parameters such as flow velocity, river depth, and stream power.

In this paper, the researchers want to predict the possible effects of dredging the Agusan River in Butuan City with the use of high-spatial resolution LiDAR-derived elevation model integrated with actual field datasets. This was done by creating actual and scenario-based numerical simulation models that uses the true and hypothetically dredged river bathymetric data, respectively. The said models compose of hydrologic and hydraulic models that are parameterized using the extracted information from land-cover data generated using Landsat satellite image analysis. Different extreme hypothetical rainfall scenarios were simulated using the models with return periods of 2, 5, 10, 25, 50 and 100-year.

1.2 Study Area

Agusan River basin is located in the north-eastern part of Mindanao Island, draining majority of the Caraga region and some parts of Compostela Valley province. It is the third largest river basin in the Philippines having a total area of 11,937 square kilometers (Wikipedia, 2017). The study was conducted in approximately twenty kilometers (20-km) river length from the mouth to the upstream portion of Agusan River, Butuan City, Philippines (see Figure 1).

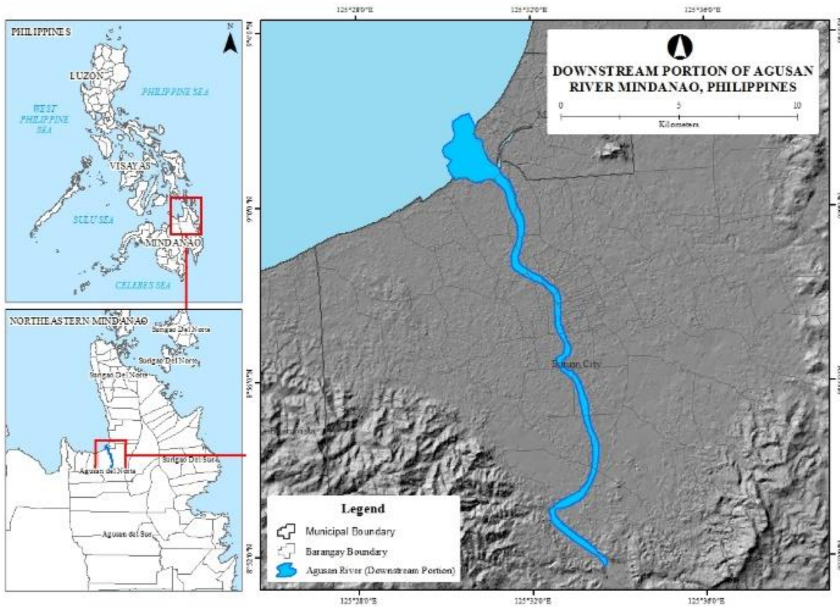

Figure 1. Map of downstream portion of Agusan River

2. METHODOLOGY

2.1 Overview

The numerical modeling consisted of developing the hydrologic model of the river basin which is then used to determine the volume and discharge of water entering the floodplains; and the 2D hydraulic model which simulates the flow of water entering on the rivers and on the floodplains as rain pours to the area (Santillan, J., 2016). The development of 2D hydraulic model utilizes high spatial resolution elevation models with three (3) cases of river bed elevation and was parameterized using the information extracted from the land-cover map. The analysis involved the comparison of hydraulic simulation results between the models with actual river profiles and the two theoretical or hypothetical dredged river beds at different volumes. The 2D simulations generated several hydraulic characteristics that are to be compared; namely,

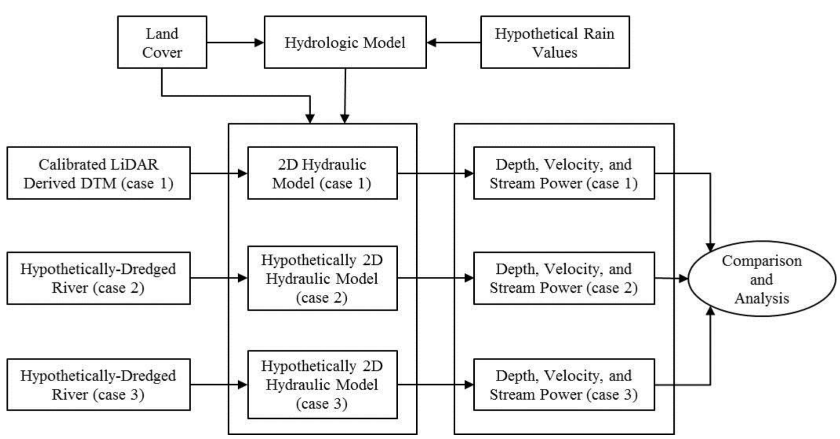

Figure 2. Schematic diagram of the methodological framework

the river velocity, shear stress and stream power. The flowchart shown in Figure 2 summarizes the processes applied in this study.

2.2 Datasets Used

The 1-meter resolution LiDAR-derived Digital Terrain Model (DTM) covering the Butuan City was used in the generation of the hydrologic model of the Agusan River. Aside from the LiDAR DTM, other data used for the generation of the hydrologic model are the 10-meter Synthetic Aperture Radar (SAR) digital elevation model, river networks digitized from Google Earth™, Rainfall Intensity Duration Frequency (RIDF) obtained from the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA), and 2-dimensional (2D) hydraulic model using high spatial LiDAR derived DTM associated with the actual river geometry, obtained from the bathymetric field survey, Manning's roughness coefficient derived from generated land cover, and flow hydrographs.

2.3 Digital Terrain Model Generation

The actual river geometry obtained from the bathymetric survey, is a set of points that corresponds to the left bank, center, right, and cross-section of Agusan River were used to create an interpolated surface using the Inverse Distance Weighted (IDW) tool available in the ArcGIS software. The final elevation data used in this study is the DTM produced from the integration of the bathymetric surface and the Agusan DTM.

The design implemented in the hypothetical dredging activity is a trapezoidal-shaped river bed wherein the base corresponds to the lowest elevation in the river's cross-section profile at 1-km interval. There were cases that the lowest elevation of the cross-section is higher than lowest elevation of the previous cross-section. In order to have a gradual decrease in river bed elevation to downstream the lowest elevation is adjusted so that the water would not backflow. Three (3) sets of DTM were produced to simulate the three (3) scenarios to be observed in this study. Figure 3 to Figure 5 illustrate how the cross-section profiles of a river in the three (3) observed scenarios were made.

(i) Case I - Calibrated LiDAR-derived DTM of Agusan River cross-section profile

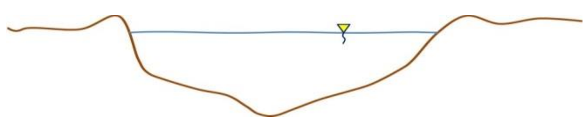

Figure 3. Cross-section profile of calibrated LiDAR-derived DTM of Agusan River

(i) Case II - Hypothetically-dredged river with base equal to the lowest elevation in the river's cross-section profile

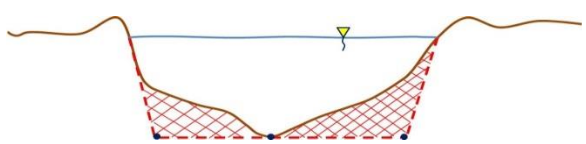

Figure 4. Cross-section profile of hypothetically-dredged river with base equal to lowest elevation

(i) Case III - Hypothetically-dredged river with base that is a meter less than the lowest elevation in the river's cross-section profile

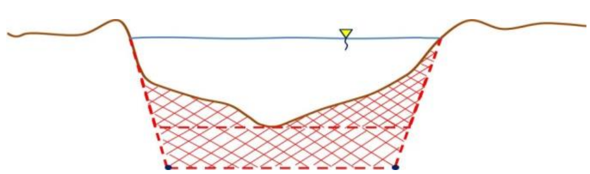

Figure 5. Cross-section profile of hypothetically-dredged river with base that is a meter less than the lowest elevation

2.4 Hydrologic Model Development

The Hydrologic Engineering Center Hydrologic Modeling System (HEC HMS) Version 3.5, a program specifically designed to simulate the precipitation-runoff processes of watershed systems was used to develop the hydrologic model of Butun City River Basin. The basin model, which is the physical representation of the watershed, was developed by utilizing a 10-m Synthetic Aperture Radar Digital Elevation Model (SAR DEM) and the rivers networks in the delineation of watersheds; and was parameterized using the information from the land-cover map that was generated through Maximum Likelihood (ML) classification of Landsat 8 OLI satellite images. The hydrologic model can simulate hypothetical rainfall events by using the Rainfall Intensity Duration Frequency (RIDF) data from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). RIDF curves provide information on the likelihood of rainfall events of various amounts and durations. For this study, the RIDF of the Butuan PAGASA Weather Station which is nearest to the basin was used. These extreme rainfall events are expressed as “return period”. For every rain return period, a 24-hour duration rainfall scenario was constructed in HEC HMS wherein the rain was set to peak at the sixth hour from the start of the simulation.

3.3 Hydraulic Model Development

The Hydrologic Engineering Center River Analysis System (HEC RAS) version 5.0, which is designed to perform one-dimensional (1D), two dimensional (2D), or combined 1D and 2D hydraulic calculations for a full network of natural and constructed channels (USACE, 2016) was used to develop the 2D hydraulic model of Butuan City River Basin. For Agusan River, 2D modeling was performed with no 1D element present. The 2D HEC RAS model was developed by creating a 2D flow area (i.e., the 2D model domain) representing the entire floodplain of the river basin and was computed using a 60-m by 60-m cell size having an approximate 2D flow area mesh of 135.93 km_2. A total of 38,504 cells was computed with the aid of break lines representing the roads, dikes, levees and river banks. The 1-m spatial resolution LiDAR-derived DTM and the Manning’s roughness coefficients extracted from the land-cover map were used as inputs in setting the model’s geometric data. The model consisted of two (2) boundary conditions in which one (1) is inflow from upstream river, and one (1) as tidal data condition at the sea.

4. RESULTS AND DISCUSSION

4.1 Digital Terrain Model Generation for Three Scenarios

The DTMs resulting from the interpolation of the riverbed through the Inverse Distance Weighted method is shown in Figure 6. The total volume of materials hypothetically-dredged from the rivers shown in Case II and Case III are 69,521,171 m^3 and 78,368,273 m^3, respectively. As shown in **Error! Reference source not found.**, zoomed-in images of the portion of the river visually shows the difference between the actual depth of the river before (Case I) and after the hypothetical dredging (Case II and Case III) was applied.

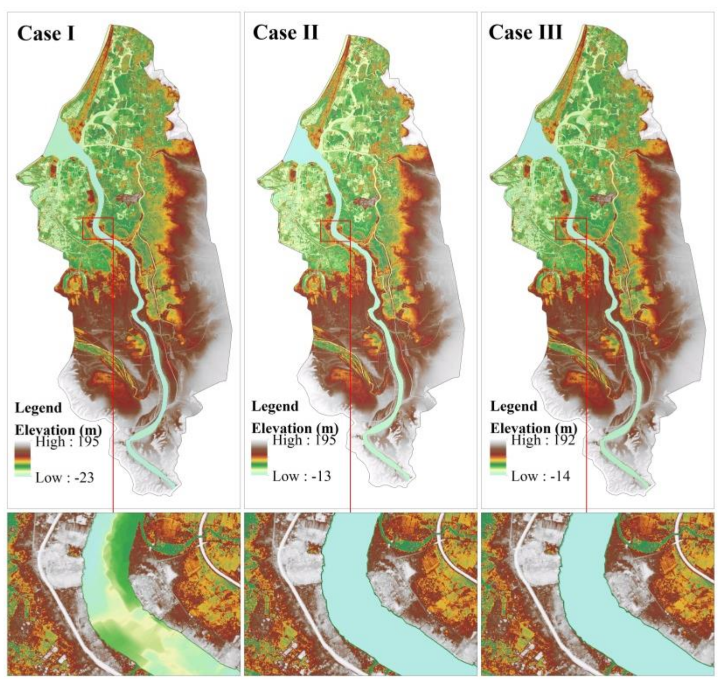

Figure 6. Digital Terrain Model in three (3) observed cases.

4.2 Maximum Flood Depth Simulation Results

The maximum flood depths simulated by the three 2D hydraulic models using the different cases of DTM (i) with true river bed elevation, (ii) hypothetically-dredged with base equal to lowest river bed elevation, and (iii) hypothetically-dredged with base that is a meter less than the lowest river bed elevation for the 2-year and 100-year return periods are shown in Figure 7 to Figure 8. The simulated maximum flood depths in 2-year return event using the case I DTM depicts that the floodplain areas were 32.56% covered with flood waters while the simulated maximum flood depths using DTM with hypothetically-dredged riverbed elevation shows that the flood water covers 22.07% and 22.03% for the Case II and Case III, respectively (see Figure 7). For the worst-case scenario, 100-year return event inundated a total of 82.61%, 55.67%, and 44.02% in the floodplain areas as shown in Figure 8. Figure 9 shows the graph of the inundated areas for all the rain return periods.

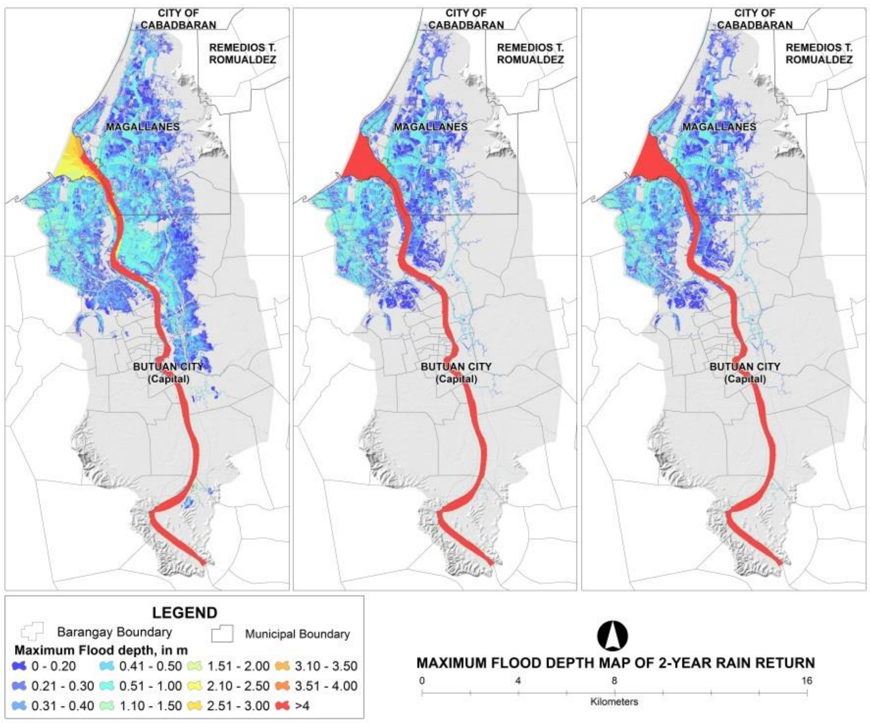

Figure 7. Maximum Flood Depth of a 2-year rain return period for the three (3) observed cases.

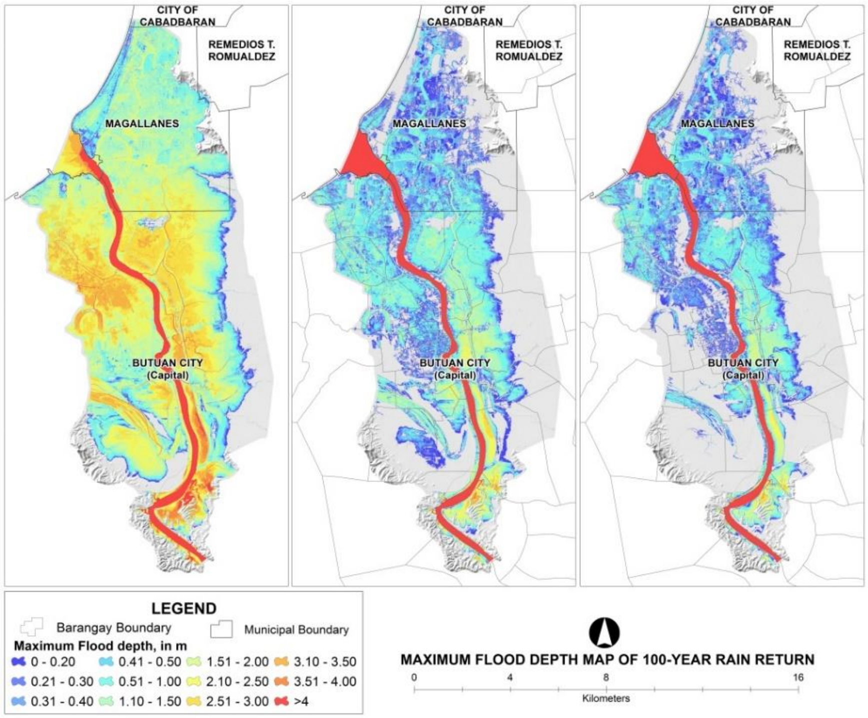

Figure 8. Maximum Flood Depth of a 100-year rain return period for the three (3) observed cases.

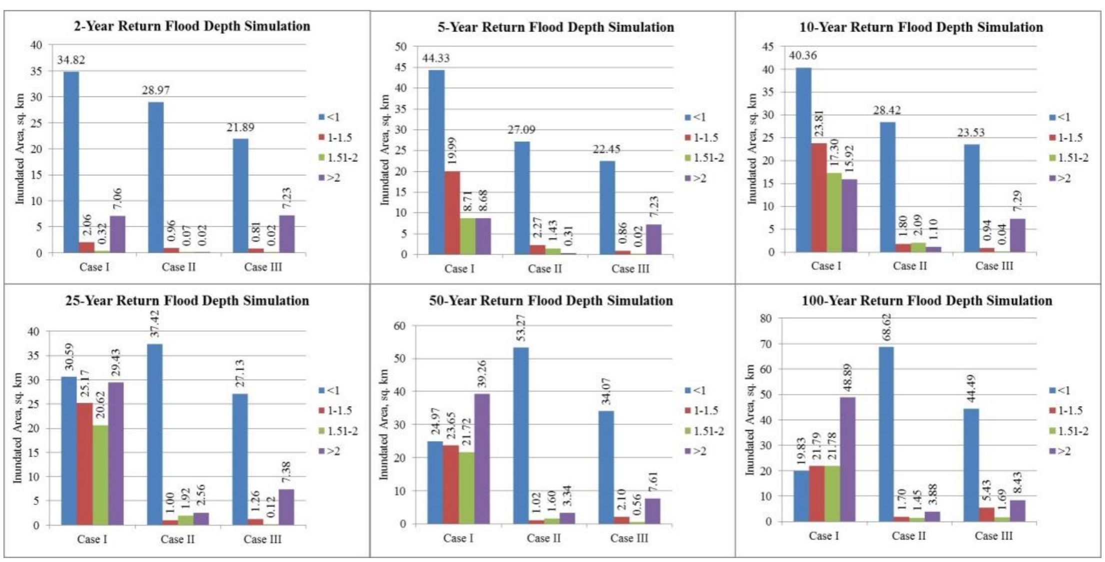

Figure 9. Amount of area inundated in different rain return periods based on the flood depth simulation.

4.3 Maximum River Velocity Simulation Results

The simulated maximum river velocities is categorized into four classes namely: river velocity at less than one meter per second, one to one and a half meter per second, one and a half to two meter per second, and river velocity at more than two meter per second. For the 2-year return event, a total of 32.15% covered with flood waters while the simulated maximum flood depths using DTM with hypothetically-dredged riverbed elevation shows that the flood water covers 21.62% and 21.57% for the Case II and Case III, respectively (Figure 10). For the worst-case scenario, (100-year return) inundated a total of 82.40%, 55.20%, and 43.53% in the floodplain areas as shown in Figure 11.

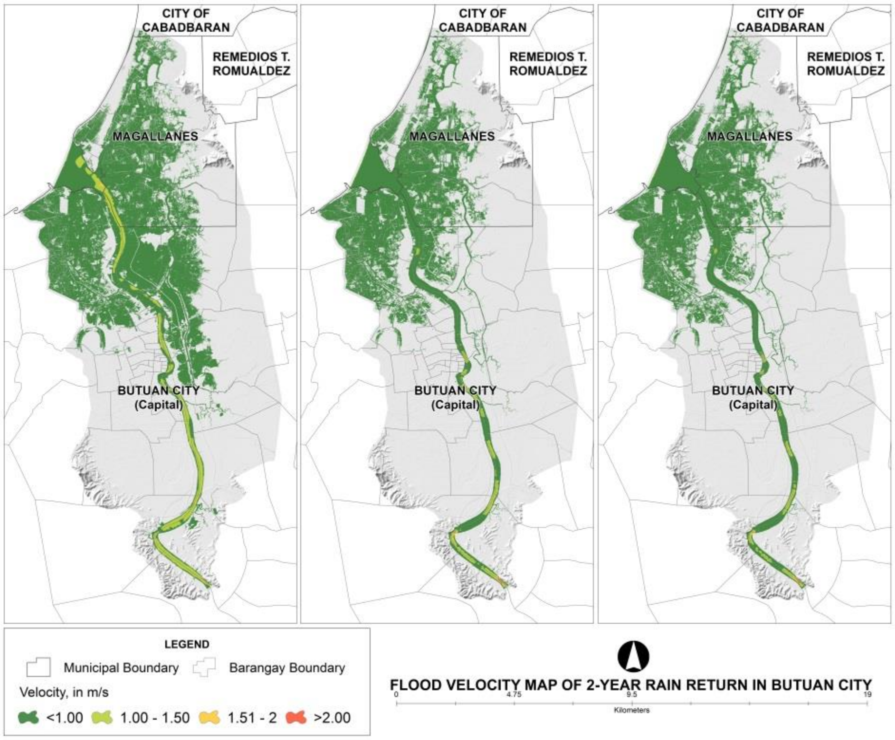

Figure 10. Inundated areas based on the flood velocity of a 2-year rain return period for the three (3) observed cases.

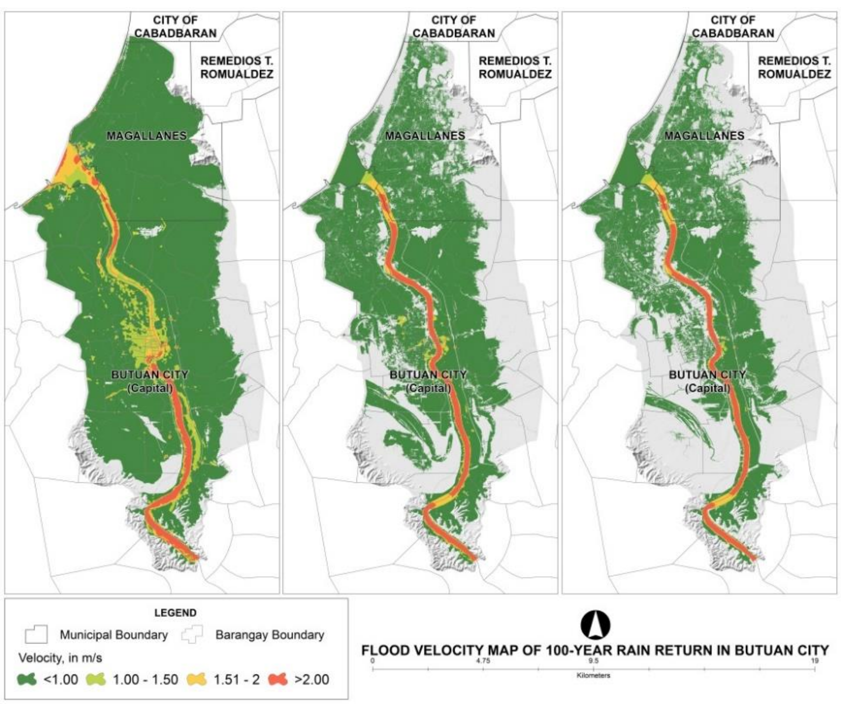

Figure 11. Inundated areas based on the flood velocity of a 100-year rain return period for the three (3) observed cases.

A similar analysis was also performed for the 5-year, 10-year, 25-year, 50-year return events. Figure 12 shows the graph of the inundated areas in different rain return periods.

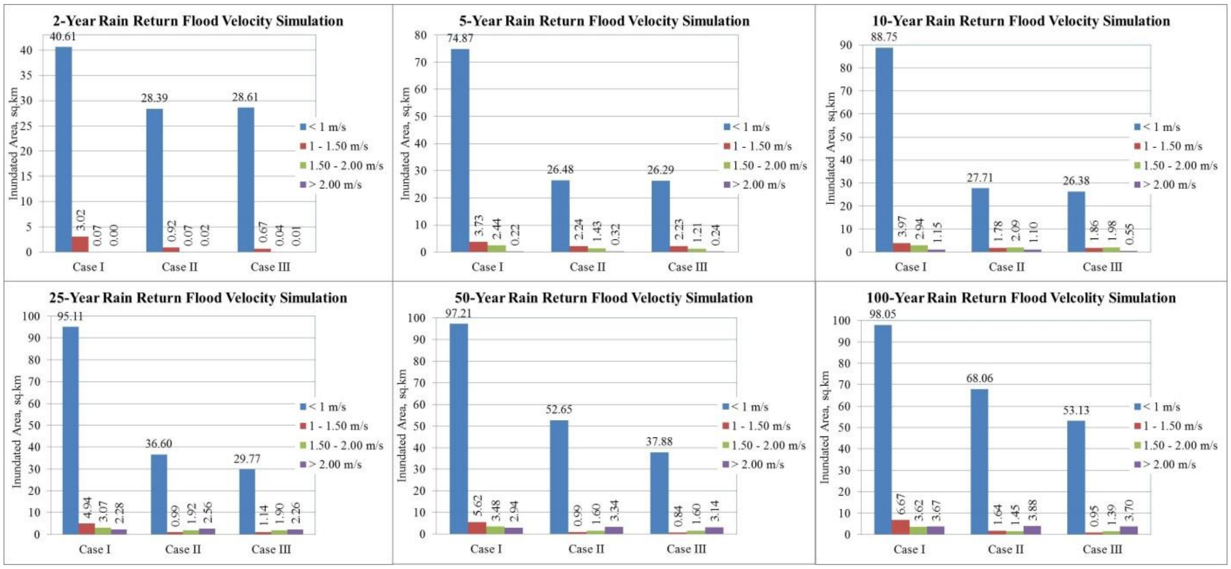

Figure 12. Amount of area inundated in different rain return periods based on the maximum river velocity.

4.4 Maximum Stream Power Simulation Results

The simulated maximum stream power in 2-year return event using the Case I DTM depicts that the floodplain areas were 32.34% covered with flood waters while the simulated maximum flood depths using DTM with hypothetically-dredged riverbed elevation shows that the flood water covers 22.07% and 22.03% for Case II and Case III DTMs, respectively (see Figure 13). For the worst-case scenario, 100-year return event inundated a total of 82.58%, 55.41%, and 43.72% in the floodplain areas as shown in Figure 14.

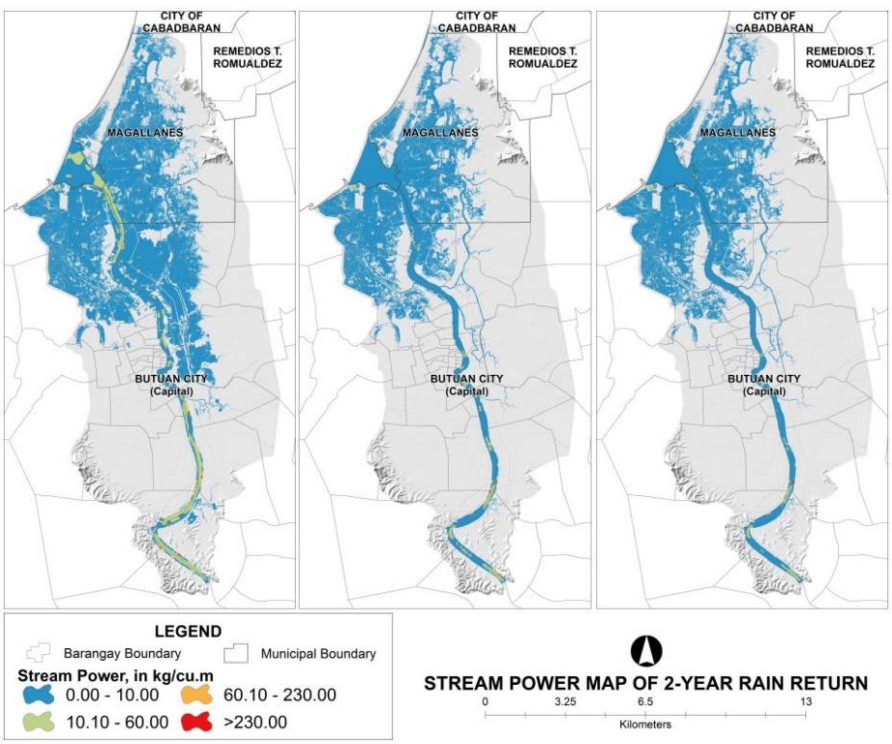

Figure 13. Inundated areas based on stream power of a 2-year rain return period for the three (3) observed cases.

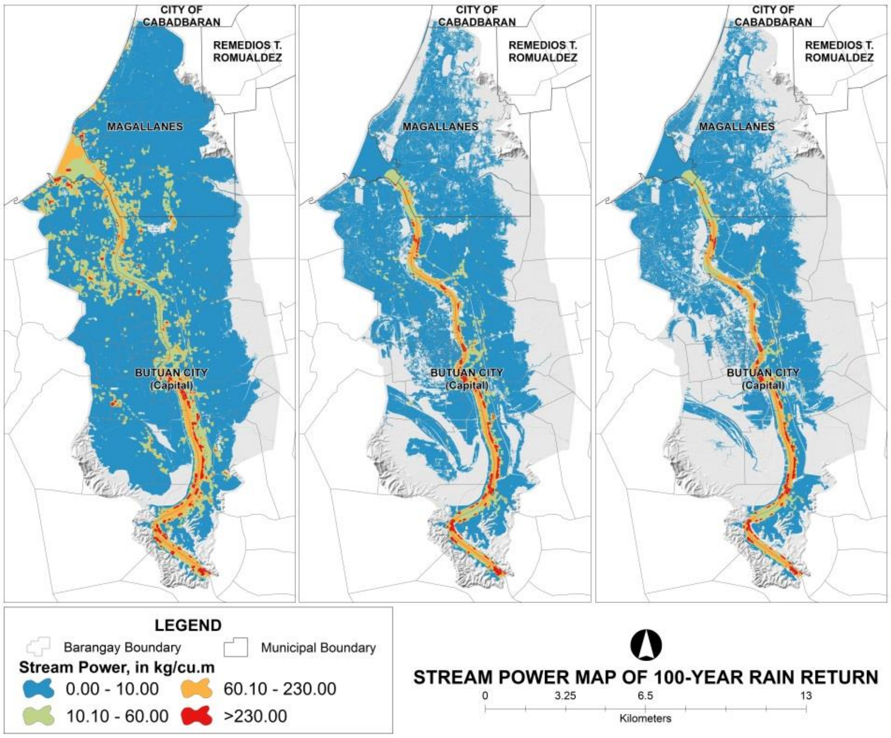

Figure 14. Inundated areas based on stream power of a 100-year rain return period for the three (3) observed cases.

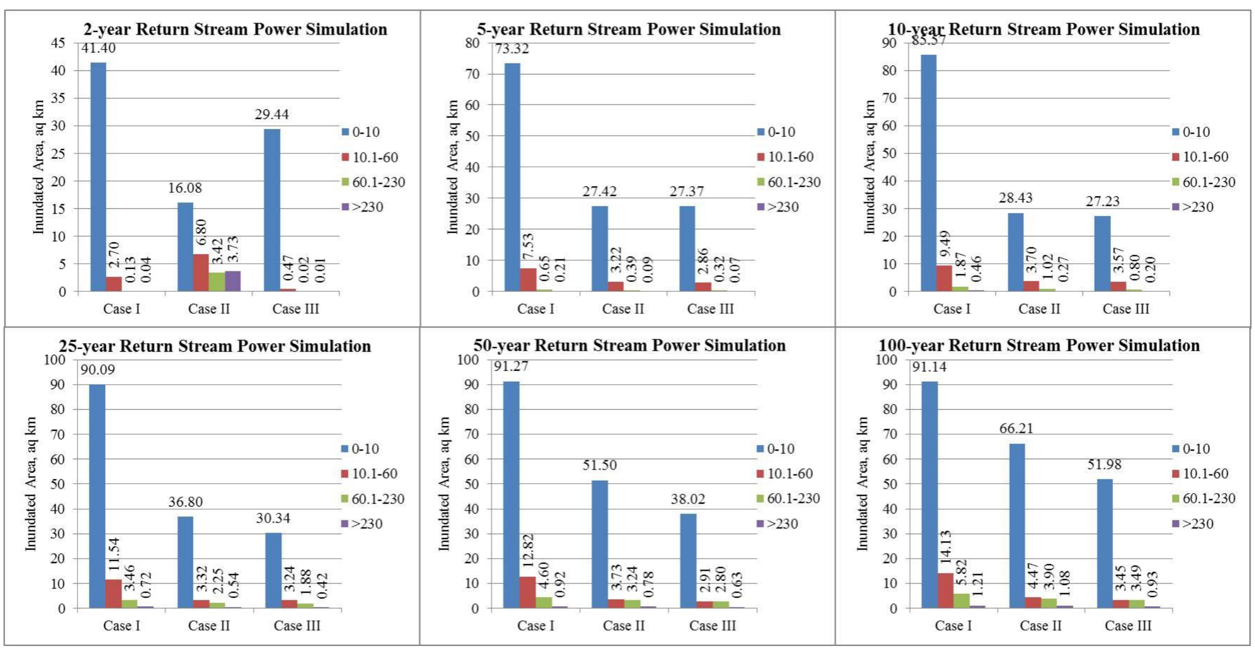

Figure 15. Amount of area inundated in different rain return periods based on the simulated maximum stream power.

5. CONCLUSION

In this study, a comparative analysis between numerical models with actual river profiles and the two hypothetical dredged river beds at different volumes was done to see the possible effects of river dredging with the use of high-spatial resolution LiDAR-derived elevation model and river bathymetric datasets. Based on the results, the researchers found out that dredging the river is an effective approach in addressing the flooding concerns along the

Agusan River in terms of the depth and extent; since it enabled the river to contain more volume of flood water in any given scenario. In the worst-case scenario of a 100-year return flooding event, dredging up to the maximum depth in the river's cross-section profile decreases the flood inundated areas by 27% and more when the dredging was done with more than a meter deeper. However, as dredging also smoothen the river bed, the flood velocity and the stream power along it significantly increased compared to the true scenario. This was greatly observed as the rainfall event becomes more extreme in the area. This effect would greatly impact the river with the possible occurrence of bank erosion and sedimentation; especially that majority of the Agusan river stretch is bare soil. With the use of remote sensing and geospatial technologies, the results of his study have already produced a good reference for the law-makers on how they would take actions on the planned dredging of the Agusan River.

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