

# TWO-DIMENSIONAL FLOOD HAZARD MAPPING IN GINGOOG RIVER, MINDANAO

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**ABSTRACT:** This paper presents the application of Hydrologic Engineering Center – River Analysis System (HEC-RAS) version 5.0, the latest version of the program, in the floodplains of Gingoog River, Mindanao by producing flood hazard maps integrated with the high resolution terrain data of Light Detection and Ranging (LiDAR). Aside from its ability to perform two-dimensional (2D) unsteady flow modeling and 2D unsteady flow routing, HEC-RAS 5.0 has expanded capabilities in topographic processing of terrains used in model geometry development and additional post-processing model features such as 2D animations in flood mapping. Utilizing this application, the integration of LIDAR data presents detailed hydraulic table properties for computational cells and cell faces for 2D flood simulation. Resulting generated 2D flood maps shows more enhanced representation and precise quantification of flood extents helpful in identifying the priority areas for immediate responses especially during flood disaster scenarios. Development of these maps answers the dire need of the Local Government Units including the Disaster Risk Reduction Management Council (DRRMC) of Gingoog City to have more accurate and reliable flood maps to a more enhanced disaster strategies as well as to be used as basis for future policy implementation (i.e. land use zoning, construction of establishments).

## 1. INTRODUCTION

The Philippines ranks third of the most hazard-prone country in the world, it is a natural hotspot with approximately 50.3% of its total area and 81.3% of its population vulnerable to natural disaster (Senate Economic Planning Office, 2013). One of the most devastating and frequent natural disasters in the Philippines is flooding that happens expectedly in the populated floodplains adjacent to rivers and streams. Adverse effect on the health and safety of localities and the economy around the country are among of the major impacts of flooding under the new normal. Owing to the continually changing nature, floodplains are mostly prone to flooding that need to be examined in the light of how they might affect or be affected by land use change (Abolghasem *et al.*, 2014).

In recent decades, tropical cyclones with extreme precipitation devastated Northern Mindanao causing rivers to overflow past from the expectation of the local government units and local communities. As a result, damages of properties and loss of lives due to flooding becomes a great challenge on the government both at the national and local level. The use of models has been the trend in quantifying flood extents and river inundations. The Hydrologic Engineering Center- River Analysis System (HEC-RAS version 5.0 beta) the latest version developed by Hydrologic Engineering Center - U.S. Army Corps of Engineers. HEC-RAS 5.0 beta is an integrated system capable of performing two-dimensional (2D) unsteady flow modeling and 2D unsteady flow routing with expanded capabilities in topographic processing of terrains used in model geometry development and additional post-processing model features such as dynamic mapping (on-the-fly) for flood animations (Brunner, 2014). With the integration of LiDAR (Light Detection and Ranging) technology which provides high resolution terrain data, a remote sensing technology acquires terrain information through laser pulses from the airborne Global Positioning System (GPS) receiver with high level of accuracy. The HEC-RAS 5.0 utilizes the high resolution terrain data to produce a sub-grid model which represents the detailed hydraulic table properties for computational cells and cell faces for 2D flood simulation. The resulting 2D flood maps gives enhanced representation and precise quantification of flood extents helpful in identifying the priority areas for immediate responses especially during flood disaster scenarios. The Mines and Geoscience Bureau identified Gingoog River to cause overflowing that resulted to extensive flooding. The river traverses a highly urbanised floodplain wherein the Gingoog City is situated. As the floodplain is host to densely populated areas as well as commercial and agricultural zones, flooding due to overflowing of the river resulting to significant damage to human lives and properties.

During flood incident in 2009, a 1.0 meter flood distresses a total of 2,013 individuals (Gingoog Local Government Unit, 2009). The local government of Gingoog City, especially the Disaster Risk Reduction Management Council (DRRMC) is in need of an accurate and reliable flood map which identifies the affected areas that need immediate response during emergency cases. In addition, flooding information serves as the basis for future policy implementation (i.e. land use zoning, construction of establishments). The study aimed to create flood hazard map using HEC-RAS version 5.0 in the flood plains of Gingoog River, Mindanao. The model was run using 2D flow

areas and 2D unsteady flow routing then it was analysed using RAS Mapper to produce flood maps. The generated maps provide information and visualization as well as, the basis for policy making regarding land use plan, early warning system, location of public establishments and also the safety of property and human lives.

## 2. METHODOLOGY

### 2.1 Study Area

Gingoog River is located at the northern part of Mindanao. Its floodplain covers the City of Gingoog, northern coast of the Province of Misamis Oriental. The city is approximately 122 kilometers east of Cagayan de Oro City and 74 kilometers west of Butuan City. It lies within the grid coordinates of 8.8167 latitudes and 125.1000 longitudes. Majority of the watershed's area lies within Gingoog with a small portion falling under the territory of Claveria at the south. Gingoog City is bounded to the east by the Municipality of Magsaysay and Agusan del Norte; to the south by Agusan del Sur, Bukidnon and part of Municipality of Claveria; to the west by Balingasag and Medina, Misamis Oriental, and to the north by Gingoog Bay (Figure 1).

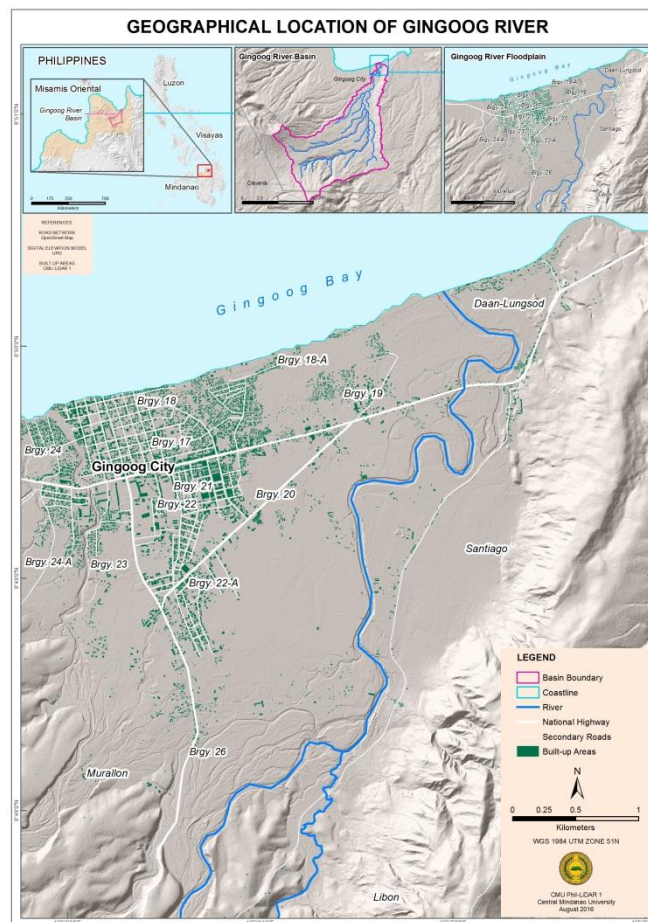


Figure 1. Location of the Gingoog River

### 2.2 Preparation of Discharge Data

The simulated discharge was derived from the calibrated Hydrologic Modeling System (HMS) model of Gingoog River using the Rainfall Intensity Duration Frequency (RIDF) from Butuan rain gauge station (Figure 2). RIDF is computed to generate a graphical representation of the probability that average rainfall intensity will occur. The RIDF curves generated by Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) for Butuan station was based on a 26-year historical rainfall data and were utilized as inputs in the flood simulation for the three (3) return periods namely the 5-, 25- and 100 year. Using these simulated discharge, hypothetical flooding events are simulated which then represent the maximum flood levels and extent caused by rainfall events with varying intensity and duration (i.e., different return periods).

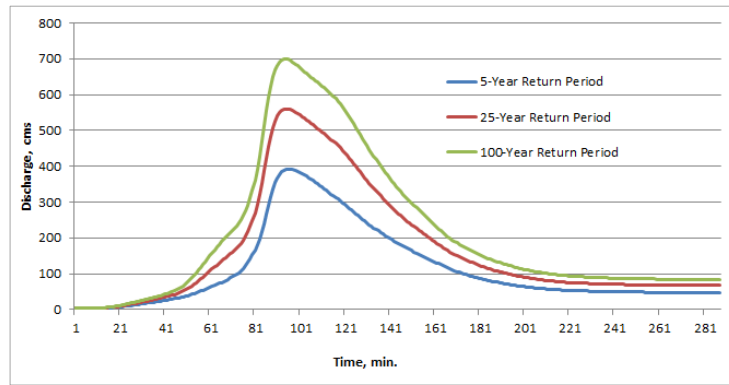


Figure 2. Simulated discharge in Gingoog River using HMS

### 2.3 Development of Terrain Model

The projection was set to World Geodesic System 1984 Universal Transverse Mercator Zone 51 Northern Hemisphere after loading an ArcGIS projection (\*.prj) file which contains the spatial reference within RAS Mapper. The terrain data burned with bathymetric points was processed in RAS Mapper converting the grid into GeoTIFF (Geospatial Tiff with .tif file extension) file format. GeoTIFF files are 2 to 20 times smaller than the original FLT (Float with .flt file extension) file format or any other supported grid files. This file format allows for smaller storage space, faster computational speed (in generating flood maps), as well as dynamic mapping of the results. The terrain model was used for computing the hydraulic properties of the 2D flow area and it serve as the background image in developing RAS geometry (Figure 3).

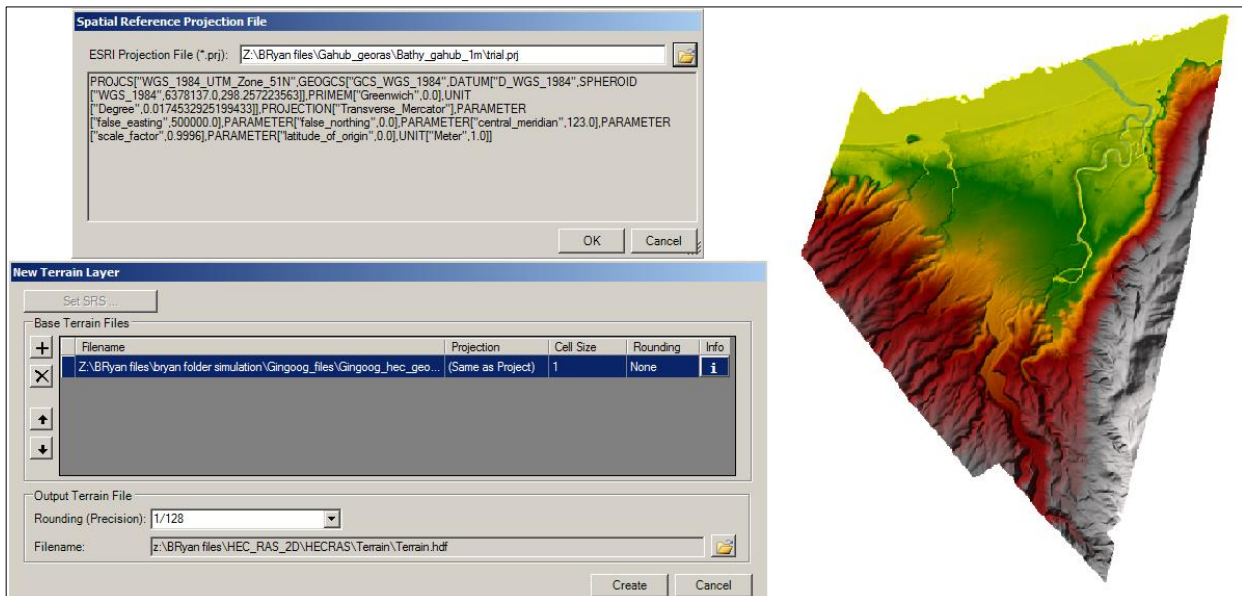


Figure 3. Terrain model development in RAS Mapper

### 2.4 Development of 2D Geometric Data Model

A polygon was created within study domain using the background image (terrain) to define the boundary of the 2D flow area using the 2D Flow Area drawing tool in the Geometric Data Editor. Break lines were added using 2D Area Break Line tool which represents the levees, roads or any high ground that impedes the movement of water. Then the computational mesh (cells and faces) was created with a nominal grid size of 15 meters by 15 meters using the Computational Point Spacing window within the 2D flow area. Other parameters in creating computational mesh were set to default values. The Manning's n values were the roughness coefficient associated with the land cover that affects the water flow. The spatially varied land cover layer was created within the RAS Mapper which contains the Manning's n values for each land cover type. Due to discrepancies (out dated boundary) with river polygon in the land cover layer, the Manning's n value polygon for river channel was created using the 2D Area Mann n Region tool which provides the exact shape of the river with a Manning's n value of 0.04. For this case, it was assume only for the river channel. Then, the external boundary conditions were created along the outer boundary of the 2D flow area (upstream and downstream portion) using the SA/2D Area BC Lines tool within

geometric data editor. Unsteady flow data were required in order to perform an unsteady flow analysis. Unsteady flow data consists of boundary conditions as well as initial conditions. The boundary condition type and boundary condition data were entered within the unsteady flow data editor window. The boundary condition type for the upstream portion was set to a Flow Hydrograph which generally used to bring flow into the 2D flow area (using the simulated discharge in HMS and Energy Slope set to 0.0001) and for the downstream portion was set a Normal Depth that used to take flow out of the 2D flow area which requires a friction slope value which was set to 0.0001 as the default. The Initial conditions were set to default in which the initial elevation of the 2D Flow Area was left blank to start a dry condition during the simulation. Figure 4 shows the geometric data (computational mesh, boundary conditions, break lines and Manning's n for river) of Gingoog River. Subsequently, the model is ready for association and pre-processing.

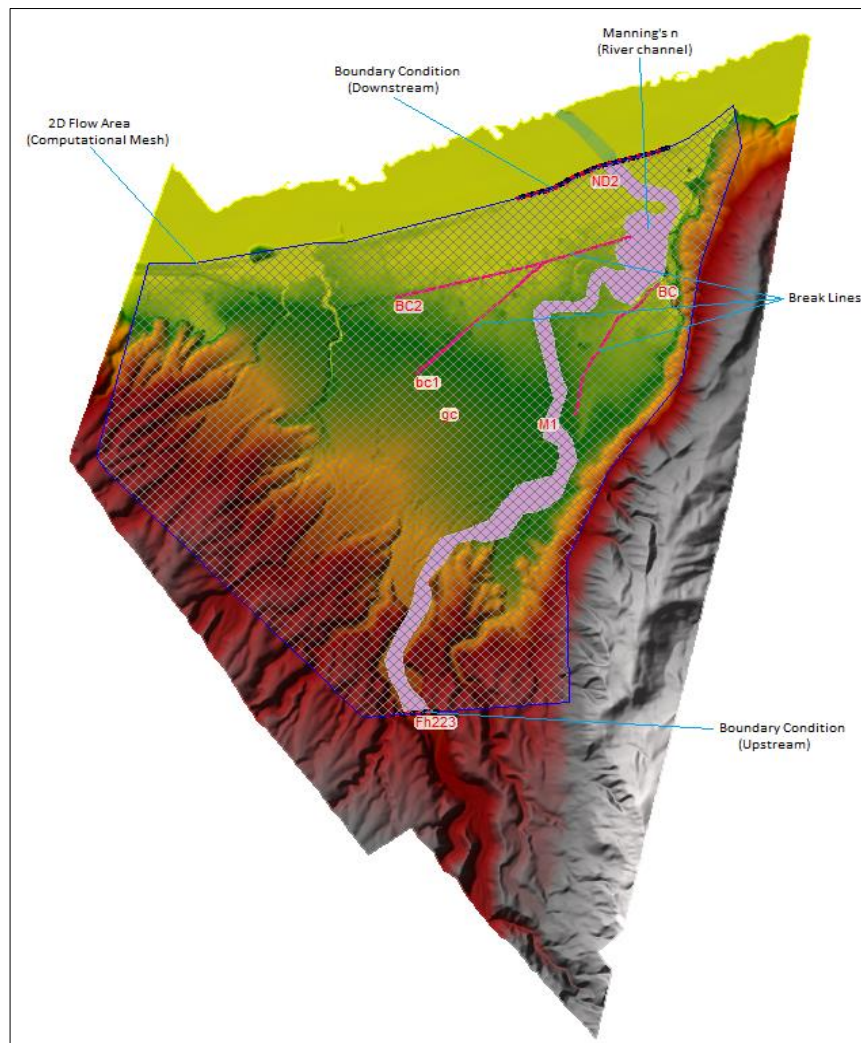


Figure 4. Geometric data of Gingoog River

The created geometric data (computational mesh) was associated with terrain and land cover layer using manage geometry association option under geometries in the RAS Mapper. Each cell and cell faces of the computational mesh were pre-processed using compute 2D flow areas hydraulic tables option under 2D flow area layer in geometry file in order to develop the detailed hydraulic property tables (elevation-volume, profile, area and wetted perimeter relationships) based on the underlying terrain used in the modeling process (Figure 5).

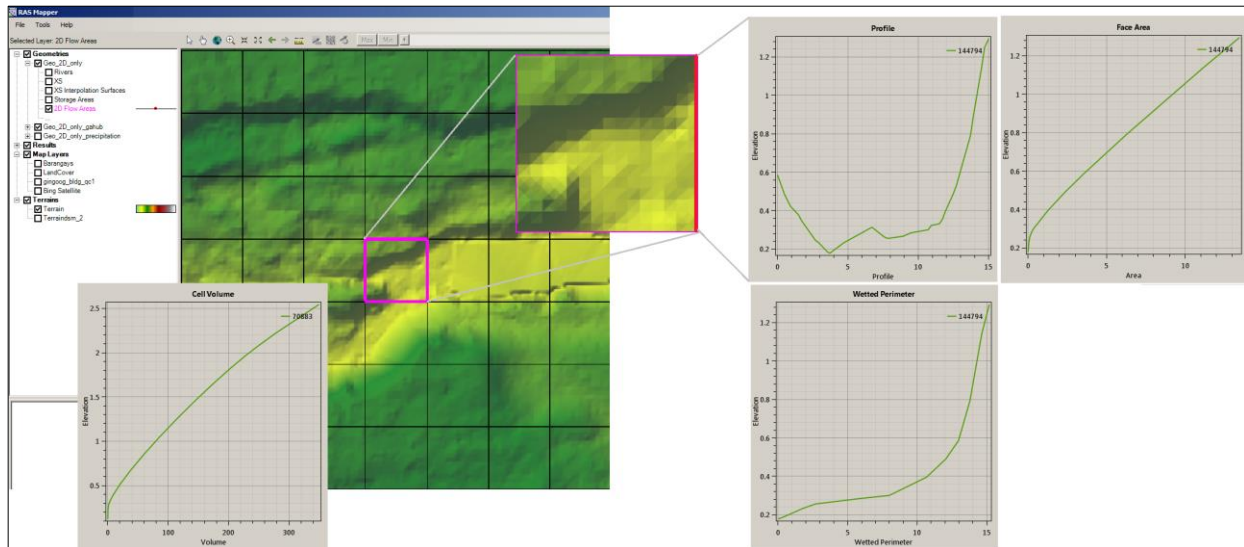


Figure 5. Cell and cell faces processed into detailed hydraulic tables

## 2.5 Performing Hydraulic Computation

The model was run using the Unsteady Flow Analysis within HEC-RAS. A Plan together with a Short ID was created that contains the geometry file (2D Flow Area) and unsteady-flow file (hydrograph) of which serves as the basis for the model to run the hydraulic computations. Under the Programs to Run option, the geometry preprocessor (assumed that the geometry preprocessor for 2D flow area in the RAS Mapper was not run) and unsteady flow simulation (flood simulation) were checked. For the Simulation Time Window, the time frame of the simulation was based on the hydrograph data from the simulated discharge using HMS. Under the Computational Settings, 10-minute interval was used to set the computational, hydrograph output, detailed output and mapping output interval that were used in RAS Mapper for creating dynamic maps (computed on-the-fly in memory) and for performing animation of flood maps (Figure 6).

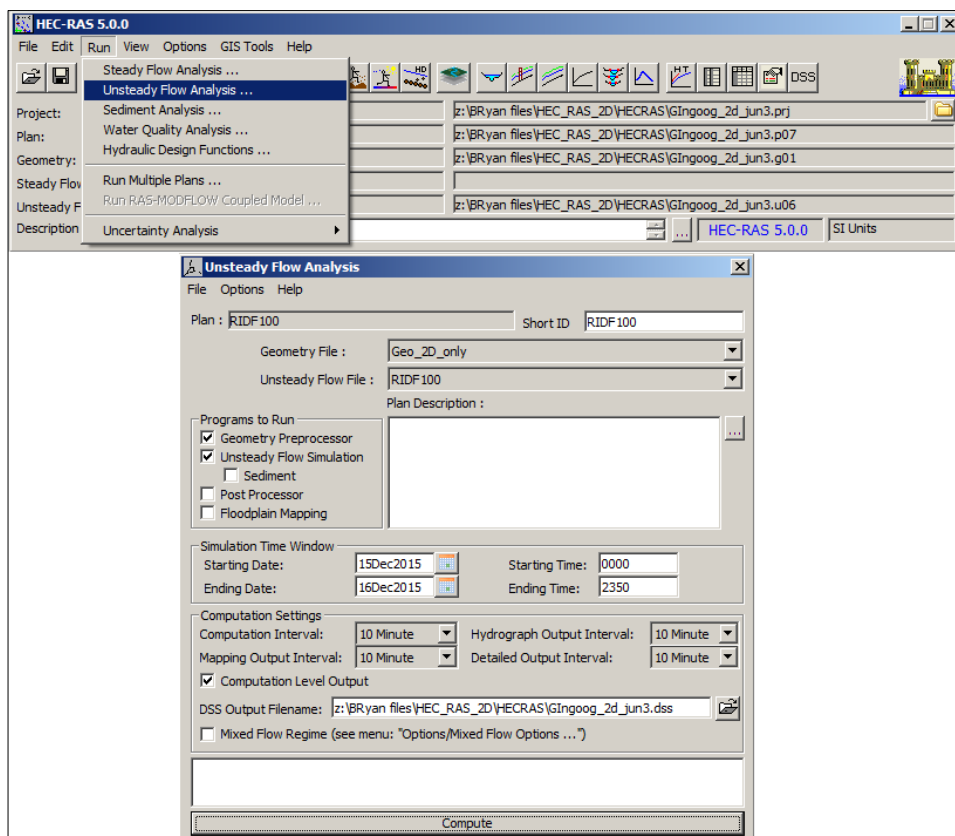


Figure 6. Unsteady flow analysis simulation

Shown in Figure 7, the computation options and tolerances for the 2D flow computation were set in calculation options and tolerances button under options menu within unsteady flow analysis window. The number of cores to use in 2D computations was set to “All Available” which means that the HEC-RAS 2D computations use as many Central Processing Units (CPU) cores available in the computer (8 CPUs in this case). The Theta and Theta Warmup parameters were set to 1.0 as the default which means the weighting factor that is used to weight spatial derivatives between the current solution time line and the previous computed time line. The water surface tolerance (m) was the basis for iteration scheme (tolerance was set to 0.003 meters). If the solution of the equations gives a numerical answer that has less numerical error than the set tolerance, then the solver is done with that time step. If the error is greater than the set tolerance, then the program iterates to get a better answer dependent on the maximum number of iterations set by the user. The Maximum Number of Iterations was set to 20 as the default for the program. It was used by the program attempting to resolve the equations in order to get an answer that has a numerical error less than the 0.003 meter tolerance at all locations in the 2D computational mesh domain (2D flow area). The Full Momentum was set as the HEC-RAS 2D computational module option (Equation Set). The Initial condition Ramp up Time (hrs.) and Boundary Condition Ramp up Fraction (0 – 1.0) were set to 2 hours and 0.5, respectively which means the 50% of the 2 hours were used to ramp up the boundary conditions allowing to run the computations for the 2D Flow Area while slowly transitioning the flow boundaries from zero to their initial value (referring to the initial discharge in the hydrograph). The Number of Time Slices (Integer Value) was set to 20 which mean the computational time steps for a 2D area that is a fraction of the overall unsteady flow computation interval. The mentioned unsteady flow overall computation was set to 10 minutes, then setting a value of 20 in this field means that the computation interval for the 2D area will be 1/20 of the overall computation interval. For this case would be half minute or 30 seconds (e.g.  $10/20 = 0.5$ ). Other parameters were left blank and the Ok button was clicked to close the window. After the click in the compute button and a successful simulation in unsteady flow analysis, the computational level output was written into a “.dss” output file within the output directory and the flood maps were visible in the RAS Mapper.

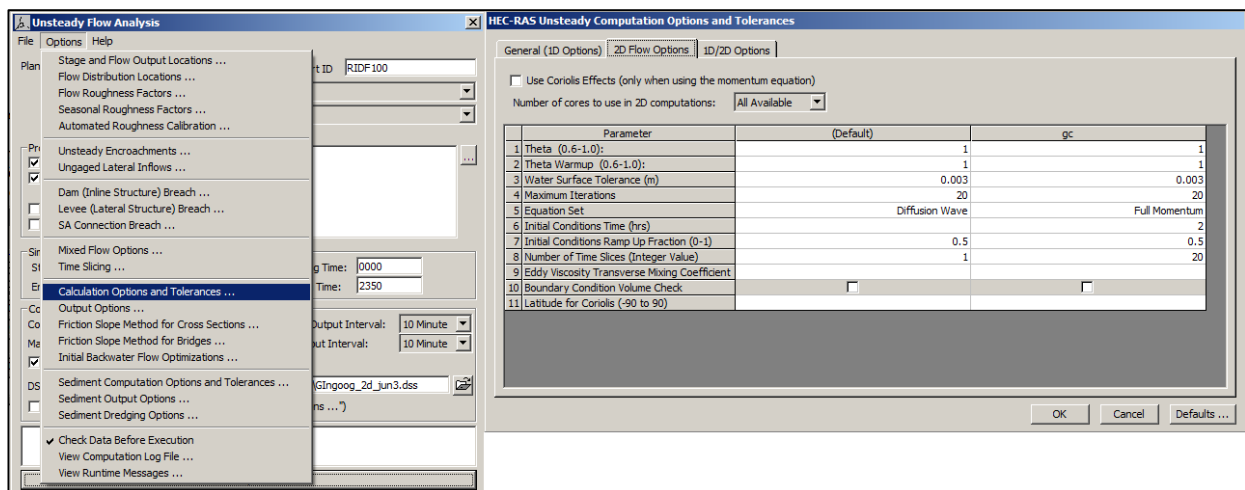


Figure 7. Setting the computation options and tolerances

## 2.6 Flood Map Generation

The 2D output results were viewed within the RAS Mapper after the unsteady flow simulation of the model. The RAS Mapper provides the visualization of the depth layer as well as the velocity layer within the 2D flow area. The maximum depth and velocity maps of the different return periods were created using the Compute/update stored maps tool under the depth layer within the RAS Mapper and the resulting layers was converted by the program into a grid file (GeoTIFF file) that were saved within the project directory. The depth and velocity grid layers were imported to ArcGIS for classification of flood hazards and for map layouting.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Flood Hazard Maps

Shown in Figure 8 are the maximum flood maps simulated by the 2D hydraulic model. It shows the flood extent at peak flow for the 5-year, 25-year and 100-year return periods. These maps show the areas that have been flooded, including the maximum depth of flood within the duration of the simulation periods. It can be observed that the flood extent is increasing evident from 5-year to 100-year return period. The spatial distribution of flood extent is covering in areas with relatively low relief corresponding to agricultural, reclamation, and near river channel which

covers an area of about 4.68 km<sup>2</sup>, 5.74 km<sup>2</sup> and 6.37 km<sup>2</sup> for the three return periods, respectively. The result of the overlay identified the affected built-up areas in the barangays of Gingoog City such as residential, commercial, and road network. Flood hazard expressed in terms of depths ranges from 0.0 - 0.5 m (Low), 0.51-1.50 m (Medium), and above 1.51 m (High), indicated with yellow, orange and red in the map, respectively.

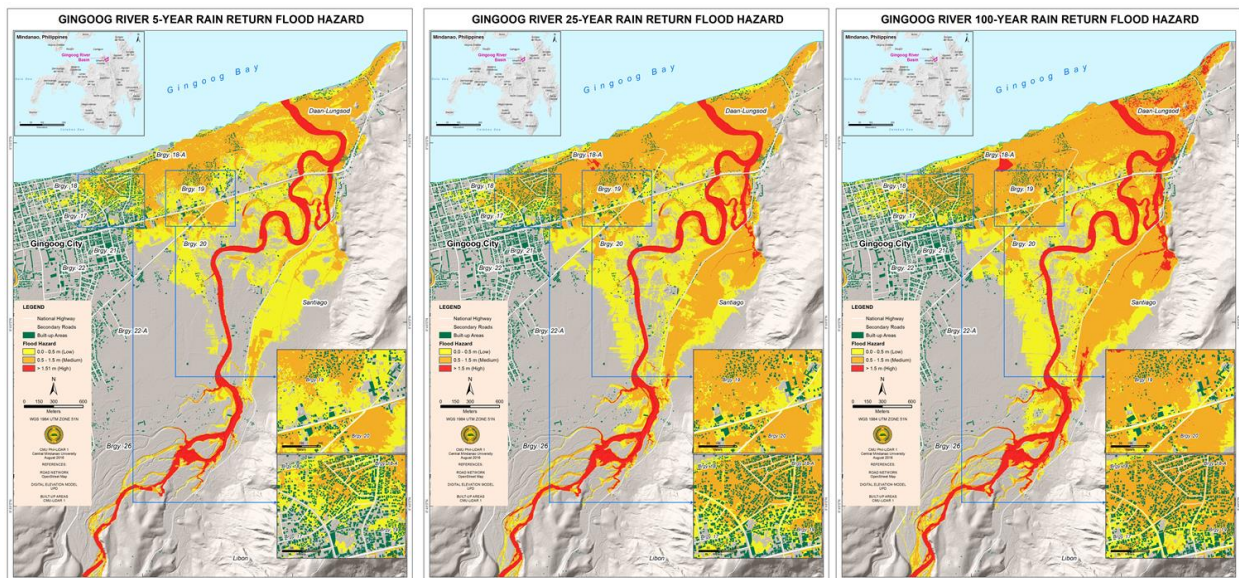


Figure 8. Flood hazard maps of Gingoog River

Shown also in the maps, that the flood provide discontinuity in some areas. This was due to the abrupt change in elevation which serves as levee (high river banks or impedance to the inundation of the river. The major road crossing the river located at the northern part (Cagayan de Oro – Butuan highway) has a bridge with high embankment which provides some protection to the local settlers from river flooding. Generally, high water depth occurred along the river channel and extends gradually to the floodplain areas. Results show that the barangays such as Santiago, Daan-Lungsod, including the barangays near the city like Barangays 17 to 20 were affected. It clearly indicates that areas could potentially be submerged given that flood depth is modeled to occur as deep as more than 1.5 meters. These are very high flood areas and therefore require action from local government units (local disaster management office). These maps are of great value to city planners, disaster experts and rescuers as it identifies priority areas during flood events. People from such areas should be prioritized in terms of prevention and control actions to minimize the risks of the flooding.

### 3.2 Flooded Buildings

Approximately, there were 8,293 buildings within the study area. The results of the overlays and geospatial analysis for the 5-year return flood event revealed that about 62% of these buildings were estimated to be affected by flooding (Figure 9). Around 2,960 were located in low flood hazard areas while 2,177 and 19 were in medium and high flood hazard areas, respectively. In the 25-year return flood event, geospatial analysis showed over 66% of buildings were affected by flooding, about 2,350 were found in low flood areas while in medium and high flood hazard the number of buildings affected by flood were slightly higher than the 5-year return flood. In the 100-year return event, it is the most number of buildings affected by flood. The overlays shown about over 73% of the buildings were affected by flood. A total of 2,295 were located in low flood hazard while 3,520 and 307 were located in medium and high flood hazard, respectively.

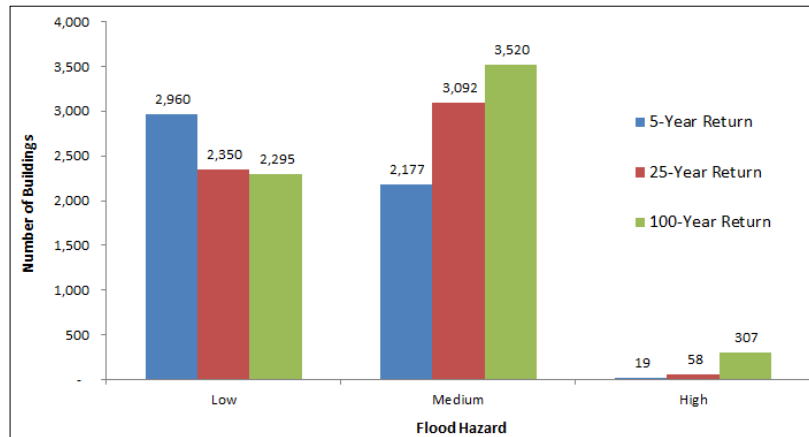


Figure 9. Number of buildings affected by flood per return period

#### 4. CONCLUSION

The HEC-RAS 2D model provides the physical representation of the floodplain regarding simulation of extreme flood events. The floodplain area of the Gingoog River has been successfully delineated and modelled. The map shows the flooded areas along the Gingoog River has provided information, preferably for land use planning and zoning, basis for policy formulation and implementation as well as aid for visualization and quantification. These generated maps will help in further research in the areas of accessing evacuation and route strategies in addition with infrastructural and agricultural damage estimation. This research study has shown clearly that Geographic Information System coupled with terrain model and remotely sensed data is vital in geospatial analysis of the hydrologic cycle including watershed and flood plain delineation and hazard mapping.

With the generation of flood hazard maps and many tools and applications, this study can make proper information and dissemination available to guide watershed, disaster managers and the Gingoog communities to better prepare for impending and potential flood hazards. There were few uncertainties which cannot be overlooked despite the persistent flooded area along the Gingoog River has been modeled and delineated. Periodic change in the topography of the flood plain as well as the land use pattern contributed in some discrepancy between the model results and the data gathered from the field. The lack of intense quality checking in the terrain data for flood mapping affects the product of the model. Current high resolution terrain data (LiDAR DEM) with accurately defined river bed integrated with quality bathymetric points are therefore required so that an actual terrain model can be created for the accuracy of any hydrological model depends mostly on the accuracy of the terrain model used.

#### 5. ACKNOWLEDGEMENT

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