NEAR-REAL TIME SIMULATION AND GEO-VISUALIZATION OF FLOODING IN THE PHILIPPINES' DEEPEST LAKE

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ABSTRACT

An automated approach for near-real time simulation and geo-visualization of flooding, including estimation of affected infrastructures, in Lake Mainit, considered the Philippines' deepest lake is presented. Perennial flooding in several areas around the lake due to increase in the lake's water level during the rainy season and during the passing of tropical storms exemplified the need for rapid determination of the lake's current and future water levels, and more importantly, the depth and extent of flooding that will result from the increase in water level. The approach made use of LiDAR-derived topography of the lake's coastal zone, lake bathymetry, near-real time lake water level and rainfall information from monitoring stations, and a hydrological model. The synergistic combination of these datasets and techniques resulted to automated and near-real time generation of current and future (forecasted) flood depths and extents, which can be viewed in a web-based geo-visualization platform. It also allows estimation of infrastructures that are affected by a current or future flooding scenario. This platform can be used as an early warning system for communities residing near the lake.

Index Terms— Simulation, geo-visualization, flooding, Lake Mainit, Philippines.

1. BACKGROUND

With a maximum depth reaching about 223 m, Lake Mainit (Figure 1) is considered to be the Philippines' deepest lake [1]. It also ranks fourth to Laguna Lake as one of the largest lakes in the Philippines, with a surface area of 149.86 km^2 based on physical surveys conducted in 2003 [2]. The lake is shared by the provinces of Surigao del Norte and Agusan del Norte, in the Island of Mindanao. The lake receives inflows from several major and minor tributaries located in the municipalities of Mainit and Alegria (Surigao del Norte) and Kitcharao and Jabonga (Agusan del Norte). During heavy rainfall events, inflows from these tributaries increase the lake's water level and causes flooding of barangays located near the shore. Perennial flooding in several areas around the lake due to increase in the lake's water level during the rainy season and during the passing of tropical storms exemplified the need for rapid determination of the lake's current and future water levels, and more importantly, the depth and extent of flooding that will result from the increase in water level.

In this work, we present an automated approach for near-real time simulation and geo-visualization of flooding, including estimation of affected infrastructures, in Lake Mainit. The approach made use of detailed topographic information of the lake's coastal zone derived from LiDAR, lake bathymetry, near-real time lake water level and rainfall information from monitoring stations, and a hydrological model.

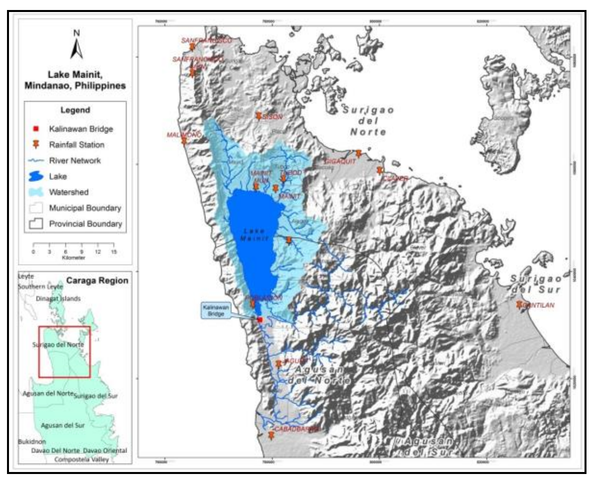

Figure 1. Lake Mainit in Mindanao, Philippines.

2. CONCEPTUAL BASIS AND SIGNIFICANCE

With the near-real time availability of water level data recorded by monitoring stations, and in combination of various analytical and computing techniques, it is possible to generate the current extent of flooding in a certain water body (e.g., lakes, rivers). In the case of lakes, the depth and extent of flooding can be obtained using GIS-based inundation mapping techniques provided that elevation of the water surface is known (which can be provided by water

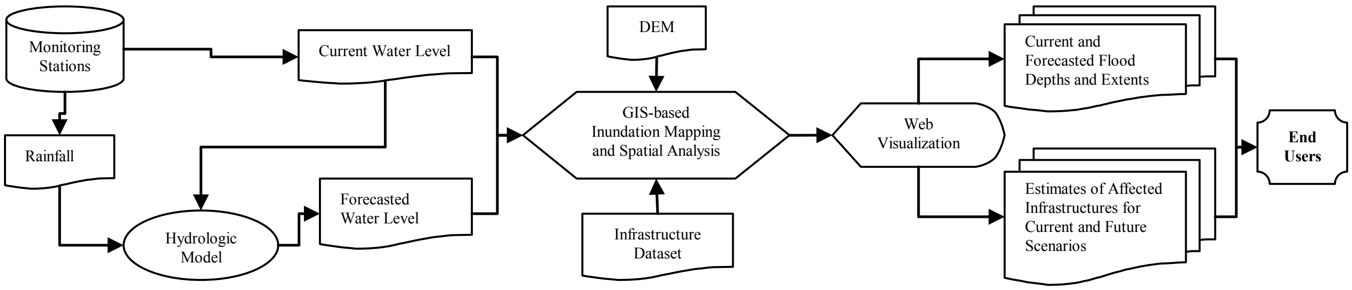

Figure 2. Generalized flow of procedures for near-real time simulation and geo-visualization of flooding in Lake Mainit.

level monitoring stations), and that information on the lake's bathymetry and coastal topography is available. By projecting a surface representing the lake's water level onto a digital elevation model (DEM) representing the lake's bathymetry and topography, one can estimate the depth and extent of flooding. On the other hand, during actual rainfall events, the changes in the lake's water level in the next number of hours or days can be predicted/forecasted using hydrological models. Because of this possibility to forecast, it follows that the extent and depth of flooding in the next number of hours or days can also be estimated by the synergistic utilization of the hydrological model's forecasted water levels and the DEM to derive very detailed flood depth and inundation maps in near-real time. These near-real time maps, which can be visualized in a web platform, are very important during actual flooding events especially to the Local Government Units (LGUs) and the community as it can increase awareness and responsiveness of the public to the impending flood disaster. Providing this kind of information during a heavy rainfall event is useful as it could assist in preparation for evacuation, in easily identifying areas that need immediate action, in identifying areas that should be avoided, and in estimating the severity of damage to people and infrastructure as flooding progresses [3].

3. SIMULATION AND GEO-VISUALIZATION PROCEDURES

Figure 2 summarizes the procedures for the near-real time simulation and geo-visualization of flooding in Lake Mainit. The procedures can be grouped into three: (i.) current flood depth and extent estimation; (ii.) forecasted flood depth and extent estimation; and (iii.) spatial analysis and web visualization.

3.1. Current Flood Depth and Extent Estimation

The latest water level (WL) of the lake (in m from the Mean Sea Level – MSL) is determined based on the water level recorded by an automated water level monitoring sensor at Calinawan Bridge (see Figure 1) installed by the Advanced Science and Technology Institute of the Department of Science and Technology (ASTI DOST). Water level information is automatically sent by the sensor to ASTI DOST's server at 10-minute interval, and a "Comma Separated Values" (CSV) file of WL records for each day is publicly accessible online via PREDICT's website . The latest value of the WL is then used as input to Spatial Analyst of ArcGIS 9.3 to create an ESRI GRID file representing a continuous surface of the lake's water level (denoted as *WSE_Current*). Using map algebra, the depth and extent of flooding is determined by the equation: *Depth_Current* = *WSE_Current* – *DEM*, where *DEM* represents an ESRI GRID file of the lake's bathymetry/bed and coastal zone topography (Figure 3). The *DEM* has a spatial resolution of 1 m, and is a mosaic of LiDAR-derived Digital Terrain Model and interpolated lake bed topography/bathymetry. The *Depth_Current* grid is further processed to categorize depths into 3 hazard classes: low (0.10 - 0.50 m depth), medium (0.50 m – 1.50 m depth), and high (>1.5 m depth). The resulting grid is exported to GIS shapefile and denoted as *Hazard_Current.* A time stamp is added to attribute table of the shapefile.

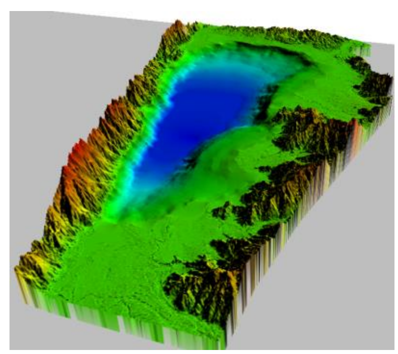

Figure 3. DEM of Lake Mainit, in 3D view.

3.2. Forecasted Flood Depth and Extent Estimation

A calibrated hydrologic model is used to generate forecasts of water level within the next 6 hours from 'current' time. This model, reported in [4], uses rainfall information for the last 3 days as recorded by rain gauges that were installed by ASTI DOST in the lake's vicinity (see Figure 1), in order to compute the volume of water ("discharge", in m^3/s) draining from upstream watersheds into the lake at 10-minute interval starting from 3 days before up to 6 hours after the current time. Using a stage-discharge relationship [4], the model can transform the discharge into WLs. The WL time series for the next 6 hours (i.e., the forecasted WL) is then extracted, and the maximum WL is determined. Then, the same procedure as employed earlier is used to generate *Hazard_Forecast* shapefile which represents the maximum depth and extent of flooding that is predicted to occur within the next 6 hours (indicated in the shapefile's attribute table).

Prior to the use of the model for water level forecasting, a simulation of the January 2014 flooding due to Tropical Storm *Agaton* (International Name: Lingling) was conducted. Results of the simulation showed that the model have more than satisfactory performance in predicting water levels, with a Nash-Sutcliffe Coefficient of Model Efficiency (E) of 0.97 which indicates acceptable model simulated results [4].

3.3 Automation

All the procedures for the generation of the *Hazard_Current* and *Hazard_Forecast* shapefiles are completely automated through a combination of *python* and *arcgisscripting*. Once the *Hazard_Current* and *Hazard_Forecast* are generated, they are then imported and stored in a PostgreSQL-PostGIS spatial database. The entire process is repeated every 10-minutes using an HP Z420 workstation running Windows 7 Professional 64-bit operating system.

3.4. Spatial Analysis and Web Visualization

In order to visualize and facilitate the release and utilization of these near-real time flood-related information, a web GIS-based application called "Flood Event Visualization and Damage Estimations" or "Flood EViDEns" was developed, utilizing the PostgreSQL/PostGIS database as source of information for display and spatial analysis over the web. To support estimation of affected structures, additional layers of information such as a shapefiles of infrastructures (roads, buildings) are also imported into this database. Flood EViDEns is discussed in detail in [5], however, we describe here some of its important functionalities.

The online visualization/platform for Flood EViDEns (Figure 4) is a webpage configured to display maps of flood hazards and affected structures as well as processed textual information (e.g., statistics of affected structures) coming from the PostgreSQL (PostGIS) spatial database. Basically, the webpage has three major functional segments: (i.) generalized flood hazard information segment; (ii) a web map segment; and (iii.) localized flood hazard information segment.

The generalized flood hazard information segment allows the user to display a summary of the number of structures affected by a flooding event. The web map segment displays flood hazard, structures (buildings), and other associated layers (e.g., political boundaries). In the web page, the user can select which layers to display. For example, a user can display both the near-real time flood hazard map as well as location of affected structures which are color-coded according to hazard level. Clicking in an affected structure in the web map will display important attributes such as name of structure (head of the family if the structure is a residential building), type, location, and many others. The localized flood hazard information segment is designed to have "Search/Filter" utility where the user can search flood affected structures according to barangay and type of structure. The resulting list categorizes the structures according to flood hazard level, and if clicked, the user can see the actual location of these structures in the web map (e.g., the structure's location is zoomed-in in the map).

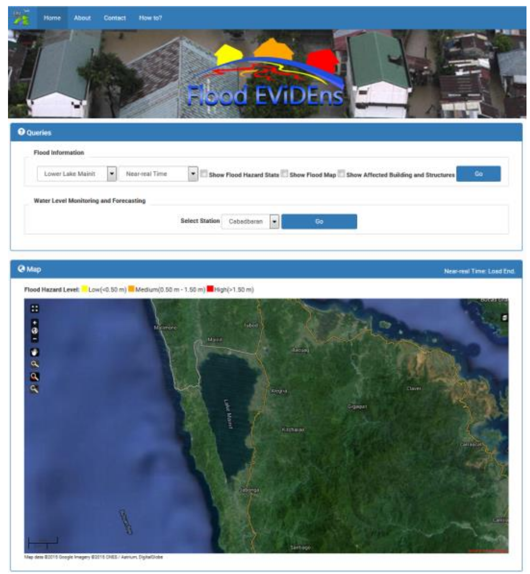

Figure 4. Web interface of Flood EViDEns.

4. ACTUAL APPLICATIONS

Example results of the near-real time simulation and geo-visualization of flooding in Lake Mainit are shown in Figures 5. The figure shows the summary of affected structures categorized into three hazard levels as well as the map of flooding that have occurred in Jabonga, Agusan del Norte (in the southern portion of the lake) on January 20, 2014 11:10 PM, approximately one day after the impact of Tropical Storm *Agaton*. During this particular period, the water level in the lake reached 37.65 m from MSL, an increase of more than 3 m from its normal level. Also shown in the map are the affected structures color coded according to hazard level (see Figure 6 for a zoomed-in version). In addition to locating those affected structures, household information can also be viewed (Figure 7).

5. CONCLUSIONS

In this paper we have presented an automated approach for near-real time simulation and geo-visualization of flooding, including estimation of affected infrastructures, in Lake Mainit. The approach made use of LiDAR-derived topography of the lake's coastal zone, lake bathymetry, near-real time lake water level and rainfall information from monitoring stations, and a hydrological model. The synergistic combination of these datasets and techniques resulted to automated and near-real time generation of current and future (forecasted) flood depths and extents, which can be viewed in a web-based geo-visualization platform. It also allows estimation of infrastructures that are affected by a current or future flooding scenario. At present, the application is being used to monitor and assess the flooding situation in Lake Mainit. It is also planned to be used as an early warning system for communities residing near the lake.

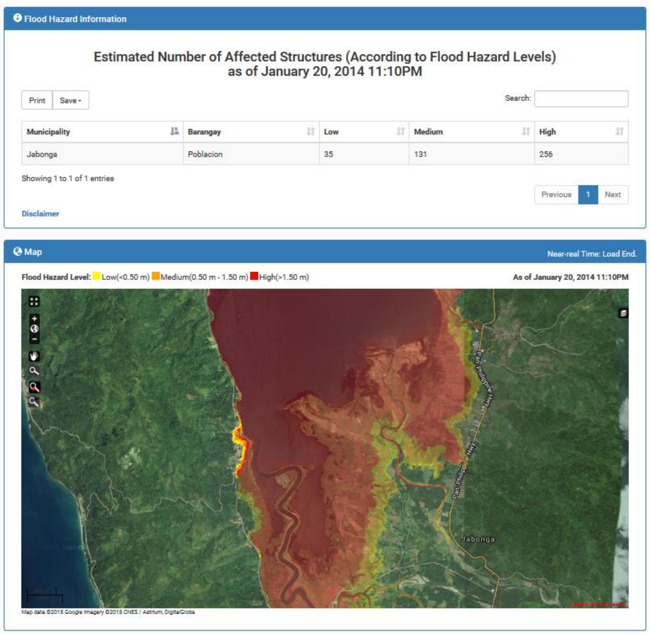

Figure 5. Generated statistics and map of flooding and affected structures for Jabonga, Agusan del Norte after the impact of Tropical Storm *Agaton* as view in Flood EViDEns.

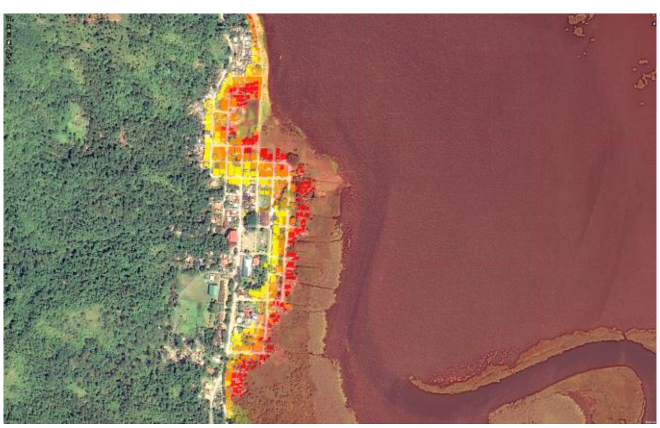

Figure 6. A zoomed-in version of the web map showing affected structures color coded according to hazard level (yellow: low; orange: medium; red: high)

Figure 7. Household information of an affected structure can also be viewed in Flood EViDENs. Note: some confidential information in the figure was intentionally hidden.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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