A WEB GIS-BASED VISUALIZATION AND ANALYTICAL PLATFORM FOR NEAR-REAL TIME FLOOD CHARACTERIZATION, FORECASTING AND IMPACT ASSESSMENT

Jojene R. Santillan (1,2), Edsel Matt O. Morales (1), Meriam Makinano-Santillan (1,2), Arthur M. Amora (1), Jennifer T. Marqueso (1), Amor L. Gingo (1)

[1] Caraga Center for Geo-Informatics, Caraga State University, Butuan City, 8600, Philippines

[2] Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University, Butuan City, 8600, Philippines
Email: jrsantillan@carsu.edu.ph; mmsantillan@carsu.edu.ph

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ABSTRACT: Access to near-real time information on the spatial distribution and detailed characteristics of the current and future (forecasted) flood scenarios is crucial for effective flood forecasting and early warning, especially when formulating decisions related to evacuation and response before, during, and after a flood scenario. In this paper, we present the development and application of a web GIS platform called "Near-real Time Flood Event Visualization and Damage Estimations (NRT-Flood EViDEns) that has the capability to show detailed maps of current and forecasted flood characteristics, including the capabilities to analyze and provide maps and statistics of the impacts of flooding to various infrastructures such as buildings, roads and bridges. The flood information reported by the platform are sourced from a two-dimensional flood model based on HEC RAS 5 that utilizes high-resolution LiDAR data, satellite-derived land-cover, and near-real time hydrological and meteorological data as among its vital inputs. The 2D flood model simulates historical (last 24 hours), current, and future (next 24 hours) flood scenarios at 30-minute interval. A combination of web mapping data storage, visualization and analysis tools that include OpenLayers, Geoserver, GeoDjango, Javascript, and PostgreSQL/PostGIS are utilized to enable the user to perform flood characteristics visualization and spatial overlay analysis for impact assessment. The accuracy of the flood depths and extents generated by the platform was determined to range from 52 to 71% overall accuracies and Root Mean Square Errors ranging from 0.30 to 0.58 m based on historical flood events that were simulated. The web platform is expected to be used for operational flood monitoring and forecasting, and is envisioned to be an important tool for geo-spatially informed decision making in Butuan City.

1. INTRODUCTION

Near-real time (NRT) information on the spatial distribution and detailed characteristics of the current and future (forecasted) flood scenarios is crucial for effective flood forecasting and early warning. Flood characteristics such as flood elevation, flood depth, flood velocities, arrival times, flood duration, and flood recession times are very important to consider when formulating decisions related to evacuation and response before, during, and after a flood scenario. In comparison with static flood hazard maps which are generated using hypothetical rainfall scenarios, NRT flood information can be considered advantageous as it depicts the flood characteristics that can be expected based on the actual time pattern and intensity at which actual rain is falling or occurring over a particular area.

Figure 1. Left: Location of Butuan City relative to the Agusan River Basin, Mindanao, Philippines. Right: The city traversed by Agusan River, as viewed in Google Earth.

NRT flood information are usually generated by flood monitoring and forecasting systems involving a network of water level and rainfall monitoring sensors that feeds information into a suite of flood modeling software (Mioc et al., 2008; Merkuryeva et al., 2015; Loi et al., 2018). In developing a flood forecasting system, precise and reliable simulation of hydrologic and hydraulic processes by the flood models is very important (Loi et al., 2018). These flood models are then used to forecast water levels in the next hours, and more importantly, to simulate possible flooding scenarios. The forecasted flood maps can then be visualized using Web Geographic Information System (GIS), a popular and effective information dissemination platform, offering online analysis of model-forecasted flood scenarios (Cheng et al., 2004). With Web GIS, the transfer of information and knowledge from the hydrological scientists and managers to decision makers has been streamlined (Cheng et al., 2004).

In recent years, a number of flood forecasting systems for near-real time flood information generation have been developed. Santillan et al (2012) developed and parameterized a near-real time flood extent monitoring model for Marikina River, Philippines using the Hydrologic Engineering Center - River Analysis System (HEC RAS). A model-based warning system was developed by Desalegn et al. (2016) to forecast floodplain inundations for a watershed in Ethiopia by integrating the Soil and Water Assessment Tool (SWAT) and LISFLOOD-FP models. Loi et al. (2018) have developed a system which integrates a coupled hydrological-hydraulic modeling system based on SWAT and HEC RAS, weather station network, and stream gauges in a web-based visualization environment with computational efficiency of less than 5 minutes processing time.

The goal of this paper is to present the development and application of a web GIS platform called "Near-real time Flood Event Visualization and Damage Estimations" (NRT-Flood EViDEns) that has the capability to show detailed maps of current and forecasted flood characteristics, including the capabilities to analyze and provide maps and statistics of the impacts of flooding to various infrastructures such as buildings, roads and bridges. The paper is an implementation of a proposed approach by Makinano-Santillan and Santillan (2016).

Butuan City, a highly-populated and urbanized city located in the downstream of the Agusan River Basin in Agusan del Norte, Mindanao Island, Philippines (Figure 1) was chosen as pilot site for the application. In recent years, the city has experienced major flooding incidents caused by extreme rainfall occurring over the Agusan River Basin brought about by tropical storms, low pressure systems, and tail end of a cold front that resulted to fatalities, and agricultural and infrastructure damages (NDRRMC, 2014, NDRRMC, 2017).

2. METHODOLOGY

The flowchart of activities involved in the development of NRT-Flood EViDEns is shown in Figure 2. Each activity has been described in Makinano-Santillan and Santillan (2016). For reference, they are again discussed here with focus on the actual implementation.

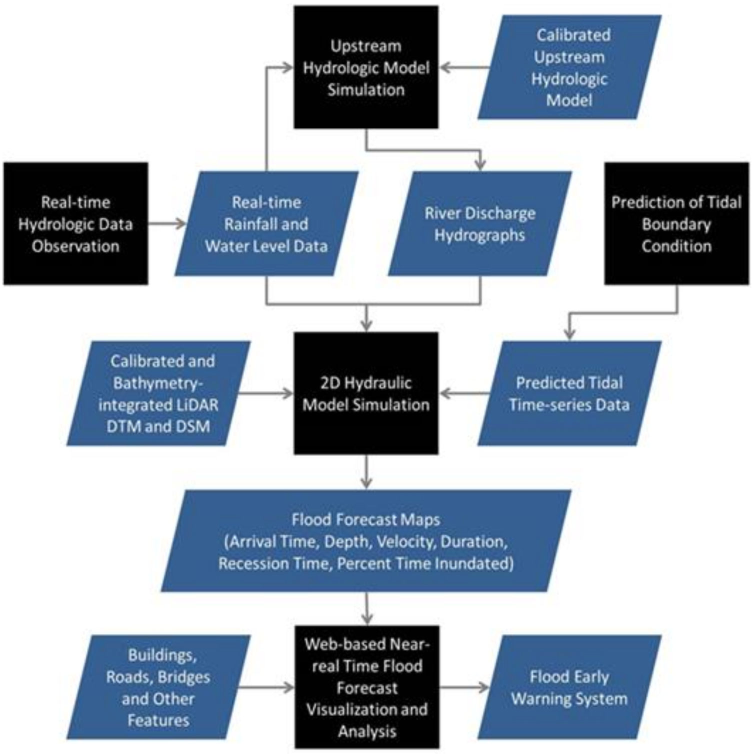


Figure 2. Flowchart of developing the near-real time flood event visualization and damage estimations (Source: Makinano-Santillan and Santillan, 2016).

2.1 Real-time Hydrologic Data Observation

Real-time hydrologic data of rainfall and river water level recorded by Automated Rain Gauges (ARG) and Water Level Monitoring Stations (WLMS) was acquired in near-real time through an Application Programming Interface (API) access to the data repository hosted by the

Advance Science and Technology Institute of the Department of Science and Technology (ASTI DOST). Real-time information is updated every 15 minutes for the rainfall and every 10 minutes for the water level, and was accessed and downloaded in Comma Space Value (CSV) format using automation scripts. The scripts also convert these files into specific format that is compatible with the flood modelling software suites consisting of the Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HMS) and HEC River Analysis System (RAS).

2.2 Upstream Hydrologic Model Simulations using HEC HMS

A hydrologic model based on HEC HMS was developed for the Agusan River Basin using a 10-m Digital Elevation Model derived from RADARSAT-2 (Ramirez, 2014) and provided by the DREAM Program of the University of the Philippines-Diliman; land-cover data from the analysis of 2017 Landsat 8 OLI images; and hydrologic data consisting of rainfall and discharge measured at strategic locations with the basin. It was calibrated using discharge data measured at Dankias Station (see Figure 1), together with rainfall data recorded by 15 stations distributed within ARB. The calibration data period is 14:00, 16 November 2017 – 17:20, 17 November 2017. The Nash-Sutcliffe Coefficient of Model Efficiency (NSE), percentage bias (PBIAS), and the RMSE-observations Standard Deviation Ratio (RSR) were used to evaluate the performance of the hydrologic model based on the guidelines of Moriasi et al (2007). The overall performances of the hydrologic model after the calibration were as follows: NSE = 0.93, PBIAS = -0.53, and RSR = 0.27) indicating "Very Good" model performance. The difference between the simulated and measured peak flow was minimal (24.80 m3/s). Details about the HEC HMS model development are reported in Santillan et al. (2019). The calibrated HEC HMS model was automated using Python, Batch Script, and HMS utilities to generate discharge hydrographs that will be used as inputs into the HEC RAS model for near-real time flood forecasting.

2.3 Near-real time Hydraulic Modeling and Flood Mapping Using HEC RAS

The floodplain hydraulic model was developed using HEC RAS 5.0.7. This version of HECRAS can perform 2-dimensional hydraulic calculations for a full network of natural channels (USACE 2016). 2D modelling will be performed by creating a 2D flow area representing the entire floodplain of the river basin. The primary source of elevation data for the 2D flow area was the 1-m calibrated and bathymetry-integrated LiDAR-derived Digital Terrain Model, and was parameterized with Manning's roughness coefficients extracted from land-cover information derived through the analysis of 2017 Landsat 8 OLI images (Santillan et al., 2019).

Flow hydrographs from the HEC HMS hydrologic simulation, observed hydrologic data (rainfall, water level), and tidal time-series data were combined as inputs into HEC RAS 5's 2D unsteady flow simulation module to simulate the different flooding characteristics (arrival time, depths, velocities, duration, recession time, and percent time inundated) for the current and forecasted events. HEC RAS was automated using AutoIt software. The automation includes updating the unsteady flow data to reflect recent hydrological conditions, updating of initial conditions of the model, performing unsteady flow analysis, computation of flood characteristics such as depth, velocity, duration, etc. using HEC RAS' built-in RAS Mapper, and conversion of flood depth into a shapefile. The result of the simulation represents the current and forecasted flood characteristics which are generated in near-real time. These results are then exported into web GIS-compatible formats using GIS software for visualization and analysis in the web-based platform.

2.4 Web-based Near-real Time Flood Forecast Visualization and Analysis

The various flood layers representing current and forecasted flood events, together with other spatial layers (infrastructures such as buildings, roads, bridges, etc.; administrative boundaries) are then be made available in near-real time through a web GIS platform. This platform is similar to the "Flood Event Visualization and Damage Estimations" or Flood EViDEns (http://evidens.csulidar1.info)" (Santillan et al., 2015). The platform was developed using a combination of web mapping data storage, visualization and analysis tools like OpenLayers, Geoserver, GeoDjango, Javascript, and PostgreSQL/PostGIS. An overview of the system is depicted in Figure 3.

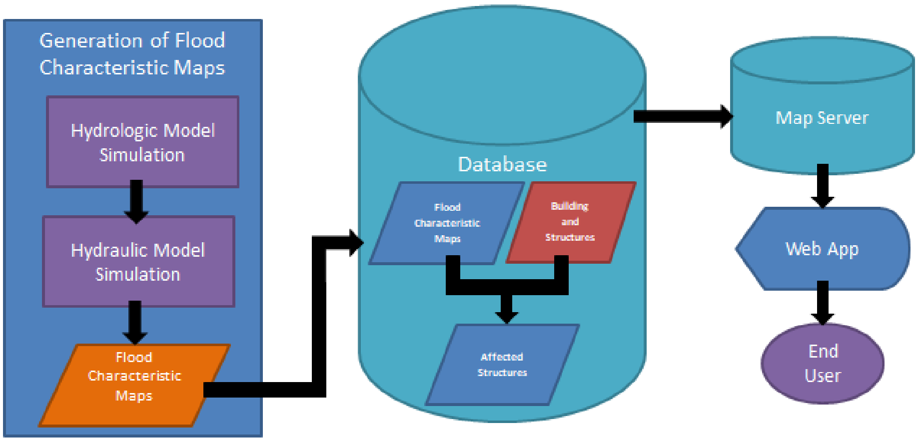


Figure 3. Overview of the NRT-Flood EViDEns.

3. RESULTS AND DISCUSSION

3.1 NRT-Flood EViDEns Web Platform

The system is currently hosted at the Caraga Center for Geo-Informatics, Caraga State University, Butuan City. For the meantime, its web platform not yet accessible via the world-wide web but there are already plans for it to be publicly available.

Figures 4 show the main web interfaces that can be viewed by a user accessing the system. When accessing the system, the user has to option to choose either the current condition or the forecasted conditions (e.g., in the next hours). For each option selected, the user can visualize various flood characteristics (Figures 5-6). The user also has the option to view statistics for the impacts of forecasted flood to structures (Figures 7-8).

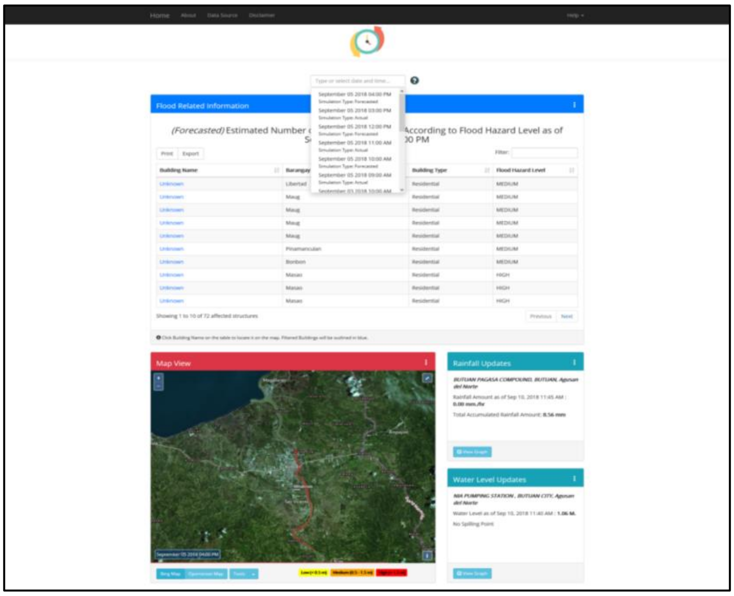


Figure 4. The main interface of NRT-Flood EViDEns.

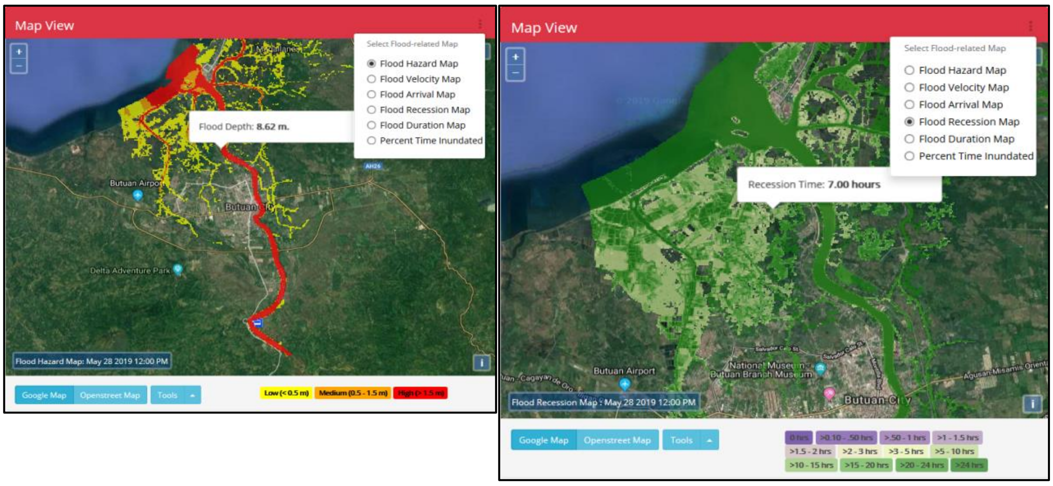


Figure 5. Visualizing flood depth and flood recession time.

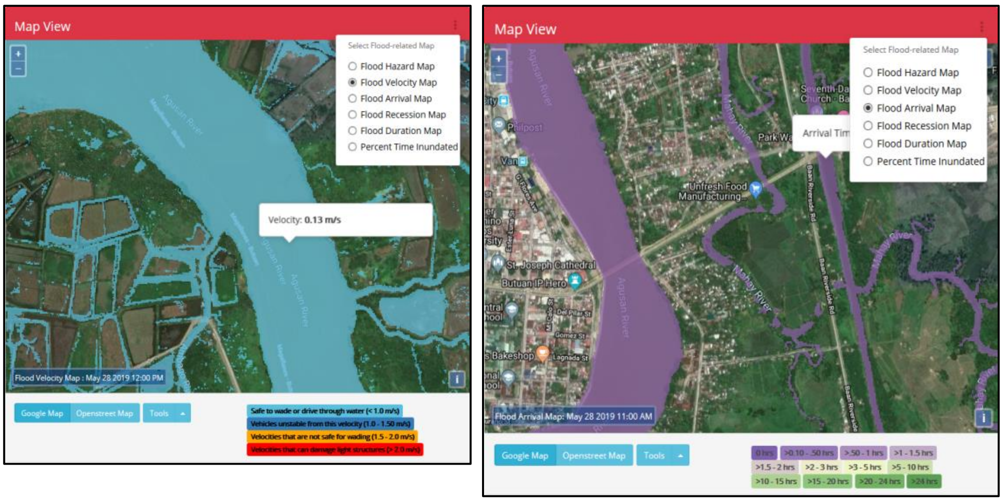
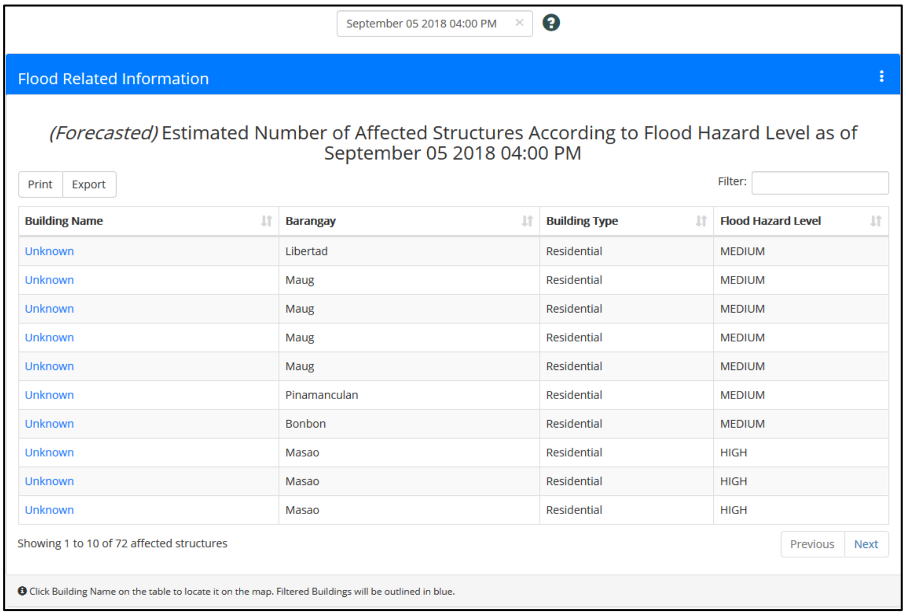


Figure 6. Visualizing flood velocity and flood arrival time.



September 05 2018 04:00 PM

Flood Related Information

(Forecasted) Estimated Number of Affected Structures According to Flood Hazard Level as of September 05 2018 04:00 PM

Print Export Filter:

Building Name	Barangay	Building Type	Flood Hazard Level
Unknown	Libertad	Residential	MEDIUM
Unknown	Maug	Residential	MEDIUM
Unknown	Maug	Residential	MEDIUM
Unknown	Maug	Residential	MEDIUM
Unknown	Maug	Residential	MEDIUM
Unknown	Pinamanculan	Residential	MEDIUM
Unknown	Bonbon	Residential	MEDIUM
Unknown	Masao	Residential	HIGH
Unknown	Masao	Residential	HIGH
Unknown	Masao	Residential	HIGH

Showing 1 to 10 of 72 affected structures Previous Next

Click Building Name on the table to locate it on the map. Filtered Buildings will be outlined in blue.

Figure 7. Example of statistics generated for estimating the impacts of a forecasted flooding to structures.

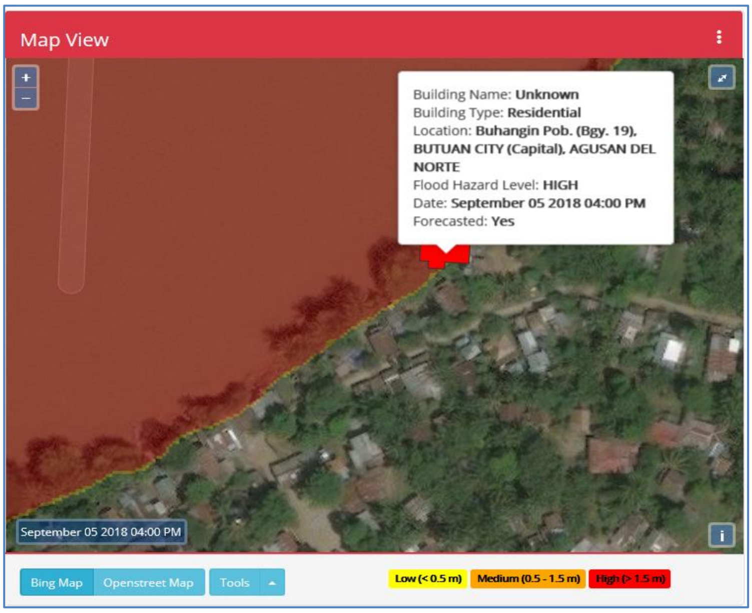


Figure 8. Point-and-click assessment of impacts of a forecasted flooding to a structure.

3.2 Accuracy of Simulated Water Level, Flood Depths and Extents

To determine the level of accuracy of the flood information reported by NRT-Flood EViDens, simulations of non-flood and flood conditions in Butuan City were conducted. Water levels simulated by the model were compared with recorded data by automated water level sensors (AWLS) (Figures 9-10). The accuracy of the flood depths and extents generated by the platform was determined to range from 52 to 79% overall accuracies and Root Mean Square Errors ranging from 0.30 to 0.58 m based on three historical flood events that were simulated. Figures 11-13 provide graphical summaries of the accuracy assessments that were undertaken.

4. SUMMMARY AND CONCLUDING REMARKS

In this paper, the development and application NRT-Flood EViDEns was presented. The application has the capability to show detailed maps of current and forecasted flood characteristics, including the capabilities to analyze and provide maps and statistics of the impacts of flooding to various infrastructures such as buildings, roads and bridges. The flood information reported by the platform are sourced from a two-dimensional flood model based on HEC RAS 5 that utilizes high-resolution LiDAR data, satellite-derived land-cover, and near-real time hydrological and meteorological data as among its vital inputs. The 2D flood model simulates historical (last 24 hours), current, and future (next 24 hours) flood scenarios at 30-minute interval. A combination of web mapping data storage, visualization and analysis tools are utilized to enable the user to perform flood characteristics visualization and spatial overlay analysis for impact assessment.

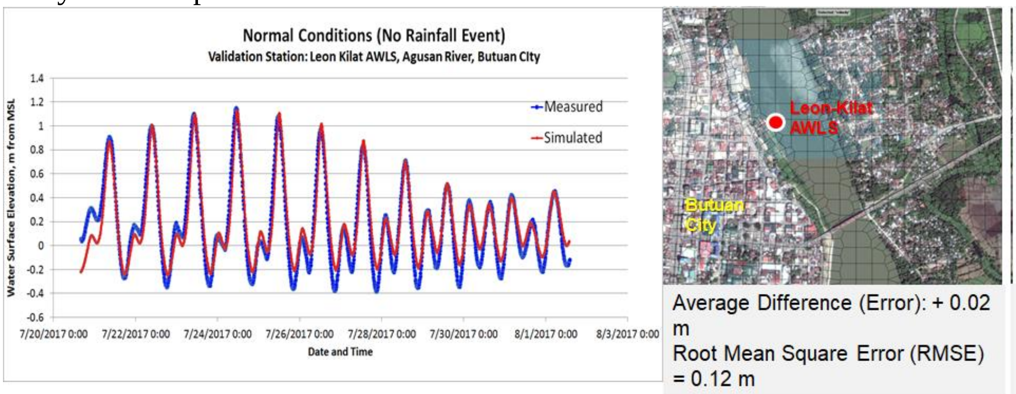


Figure 9. Example simulated water surface elevation/level (WL) for “normal” or non-flooding condition. The simulated levels were compared with data recorded by a WL sensor.

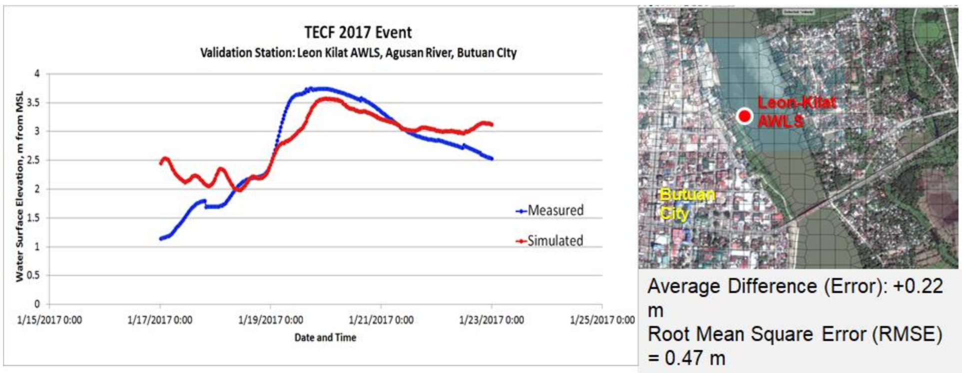
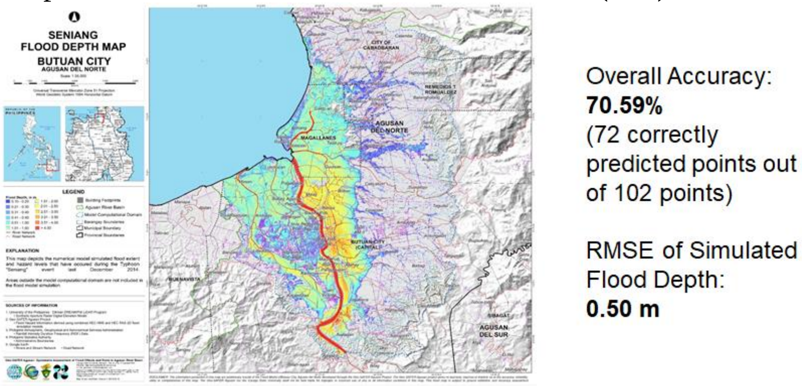
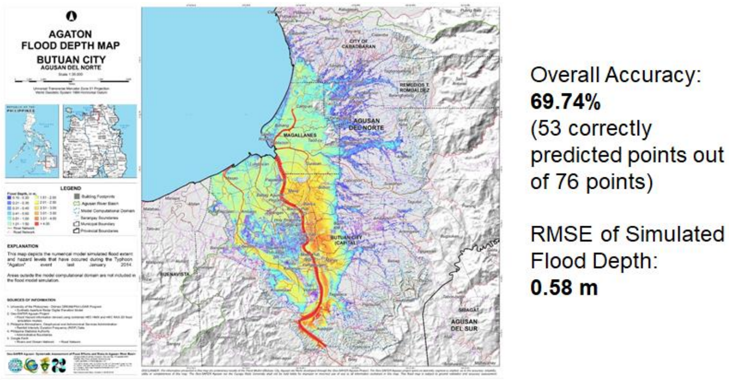


Figure 10. Example simulated water surface elevation/level (WL) for flooding condition.



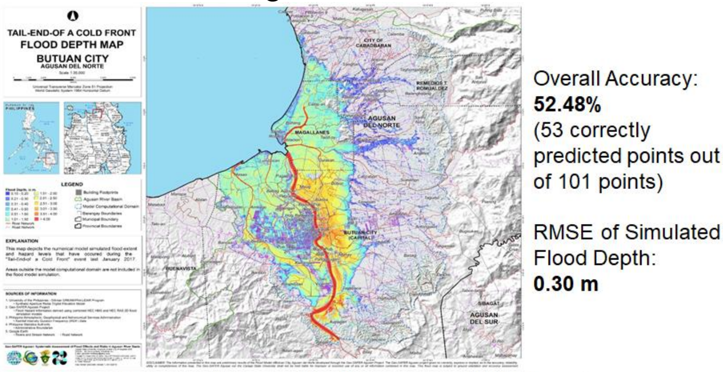
Error Matrix: Seniang	Actual Flooded	Actual Not Flooded	Total	User's Accuracy (%)
Model Flooded	32	20	52	61.54
Model Not Flooded	10	40	50	80.00
Total	42	60	102	
Producer's Accuracy (%)	76.19	66.67		
Overall Accuracy (%):	**70.59**			

Figure 11. Graphical summary of the flood model accuracy assessment using the December 2014 “Seniang” flood event.



Error Matrix: Agaton (2014)	Actual Flooded	Actual Not Flooded	Total	User's Accuracy (%)
Model Flooded	28	20	48	58.33
Model Not Flooded	3	25	28	89.29
Total	31	45	76	
Producer's Accuracy (%)	90.32	55.56		
Overall Accuracy (%):	69.74			

Figure 12. Graphical summary of the flood model accuracy assessment using the January 2014 "Agaton" flood event.



Error Matrix: TECF (2017)	Actual Flooded	Actual Not Flooded	Total	User's Accuracy (%)
Model Flooded	22	41	63	34.92
Model Not Flooded	7	31	38	81.58
Total	29	72	101	
Producer's Accuracy (%)	75.86	43.06		
Overall Accuracy (%):	52.48			

Figure 13. Graphical summary of the flood model accuracy assessment using the January 2017 flood event.

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