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FLOOD EViDENS: A WEB-BASED APPLICATION FOR NEAR-REAL TIME FLOOD EVENT VISUALIZATION AND DAMAGE ESTIMATIONS

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ABSTRACT: The Web-based Near-real Time Flood Event Visualization and Damage Estimations (Flood EViDEns) is an online geo-visualization application developed through the Phil-LiDAR 1 project of Caraga State University. The application is targeted to be utilized by the Local Government Units (LGUs) and communities in the Caraga Region, Mindanao, Philippines to assist them in geospatially informed decision making in times of flood disasters. The application is an amalgamation of web mapping technology, various geospatial datasets including LiDAR-derived elevation and information products, hydro-meteorological data, and flood simulation models to visualize in near-real time the current and possible future extent of flooding and its associated damages to infrastructures. The Flood EViDEns application facilitates the release and utilization of this near-real time flood-related information through a user-friendly front end interface consisting of web map and tables. The application's back-end consists of computers running flood simulation models and geospatial analysis to dynamically produce (in an automated manner) current and future flood extents, and tabulated information on the structures affected by flooding including hazard types. These outputs are forwarded into a PostgreSQL/PostGIS spatial database where it is accessed by the front end interface for web visualization. The information provided by Flood EViDEns is very important especially to the 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.

1. INTRODUCTION

Flood-related disasters in the Philippines have become more pronounced in recent years, majority of which have been caused by tropical storms and low pressure systems which bring along rains of varying duration, volume and intensity. An infamous example would be that of Tropical Storm (TS) *Ondoy* (International name: Ketsana; September 2007) which dumped a month's worth of rain in less than 24 hours and caused flooding in Metro Manila, killing at least 300 people and displacing another 700,000 (Cheng, 2009). Since then, similar flooding occurrences became frequent and more intense, and has continued to negatively impact and bring costly damages to human lives and properties such that Local Government Units (LGUs) are now using flood susceptibility and hazard maps as part of their flood disaster risk reduction and management activities. Presently, most of the LGUs rely on Mines and Geosciences Bureau (MGB) flood susceptibility maps (http://gdis.denr.gov.ph/mgbgoogle/), and if available, the flood hazard maps generated through the Project Nationwide Operational Assessment of Hazards (NOAH) and displayed in its website (http://noah.dost.gov.ph; Lagmay, 2012) in their flood hazard assessment activities. However, these hazard maps are static and only represent specific flooding scenarios. In the Project NOAH website, near-real time flood extent maps (i.e., flood extent maps that are generated and displayed as it happens) and rainfall scenario-based flood hazard maps derived through the use of flood model simulation models and Light Detection and Ranging (LiDAR) topographic datasets are also available but only for limited number of areas.

Although the flood susceptibility maps provided by MGB and the online flood maps in Project NOAH are important sources of information necessary for flood hazard assessments, some enhancements and additional functionalities are necessary to generate additional information that can aid LGUs in geospatially-informed decision-making before, during and after a flood disaster. These enhancements and additional functionalities may include the following:

- The capability to generate publicly-accessible near-real time flood hazard maps (as flooding progresses), especially during occurrence of heavy to torrential rainfall events. Currently, only flood extent (no hazard level categorization) maps are available online in near-real time in the Project NOAH website.
- The capability to generate publicly-accessible forecasted flood hazard maps (i.e., expected flooding in the next hours or days)

- The capability to analyze and estimate in near-real time the possible damages (e.g., counting of affected structures according to hazard levels) caused by flooding events.

The above capabilities can be useful in localized flood disaster management as it can assist in careful planning and preparation of evacuation strategies, 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.

In this paper, we present how these capabilities can be realized through the development of the web-based Near-real Time Flood Event Visualization and Damage Estimations (Flood EViDEns) application. Flood EViDEns is an application developed under the Caraga State University Phil-LiDAR 1 project that utilizes LiDAR-derived elevation and information products as well as other elevation datasets, water level records by monitoring stations, and flood simulation models to visualize in near-real time the current and possible future extent of flooding (and its associated damages to infrastructures) due to occurrence of a rainfall event, including various flooding scenarios caused by rainfall events of varying duration and intensity.

The conceptual framework, design and implementation of this application are discussed in the following sections.

2. CONCEPTUAL BASIS

The concept for Flood EViDEns is an expanded version of the design concept used in the development of the “I aM AWaRe: An Online Geo-visualization Tool for Inundation Monitoring And Water Level Forecasting in Rivers” web application (Santillan, 2013).

There are several sets of information that maybe used to properly manage an impending flood disaster. Among them are:

1. Information on the current extent and levels of flooding along a water body (in this case, a river) and the areas that are presently flooded;
2. Forecasts on how water level will rise (or recede) at different locations along the river as rainfall events occur in the upstream watersheds;
3. Information on the expected extent and levels of flooding based on the forecasted increase/decrease in water levels;
4. Information on the estimated number of structures (e.g., buildings) that are affected or can possibly be affected by the current and forecasted flooding, including their locations.

The first set can be obtained by direct observation (e.g., visiting the areas affected, taking pictures) - but this is often difficult and risky especially if the flooding situation has already elevated. Alternatively, flood simulation models can be used to estimate the current extent and depth of flooding by utilizing water level and rainfall recorded by monitoring stations as inputs. Based on rainfall data records for the past hours or days, the flood model, through its hydrologic component, can compute how much flood water has been generated from the upstream watersheds. Then, the model’s hydraulic component can simulate how this flood water has traveled towards the downstream areas, including how it overflows, up to the current time. The flood information produced by the flood models can be converted into flood depth and hazard maps showing the information on the current extent and levels of flooding in an area through the use of Geographic Information System (GIS) tools and techniques,

The second and third sets of information can also be obtained by the use of flood simulation models. Since the effect of a rainfall event in making water level rise in rivers is not immediate (usually takes hours before it is felt downstream especially if much of the flood water will come from upstream watersheds), it is then possible to make a forecast on how water will rise or recede at different locations along the river, and to predict in advance the possible flooding levels and extents. The flood model simulations will just have to be extended to a period of several hours or days from the current time in order to generate the forecasts.

The fourth set of information, which may be considered as the most important in flood hazard assessment, can be obtained through GIS-based analysis of the flood maps together with additional spatial datasets such as an exposure geo-database of buildings and other infrastructures. By spatially overlaying the flood hazard maps with the data of buildings and other structures, those structures affected by flooding can be located, and the their numbers can be summarized according to flood hazard levels (e.g., if these structures are in low, medium or high levels of hazards).

Based on the above discussions, obtaining the four sets of information needed for flood disaster management is possible because there are available tools and techniques to generate this information. The challenge, however, is how to generate this information in a timely manner, and make them accessible to disaster managers or even to affected communities for it to be useful in managing flood disasters. It is on this challenge that the Flood EViDEns application was built upon.

3. AREA OF APPLICATION

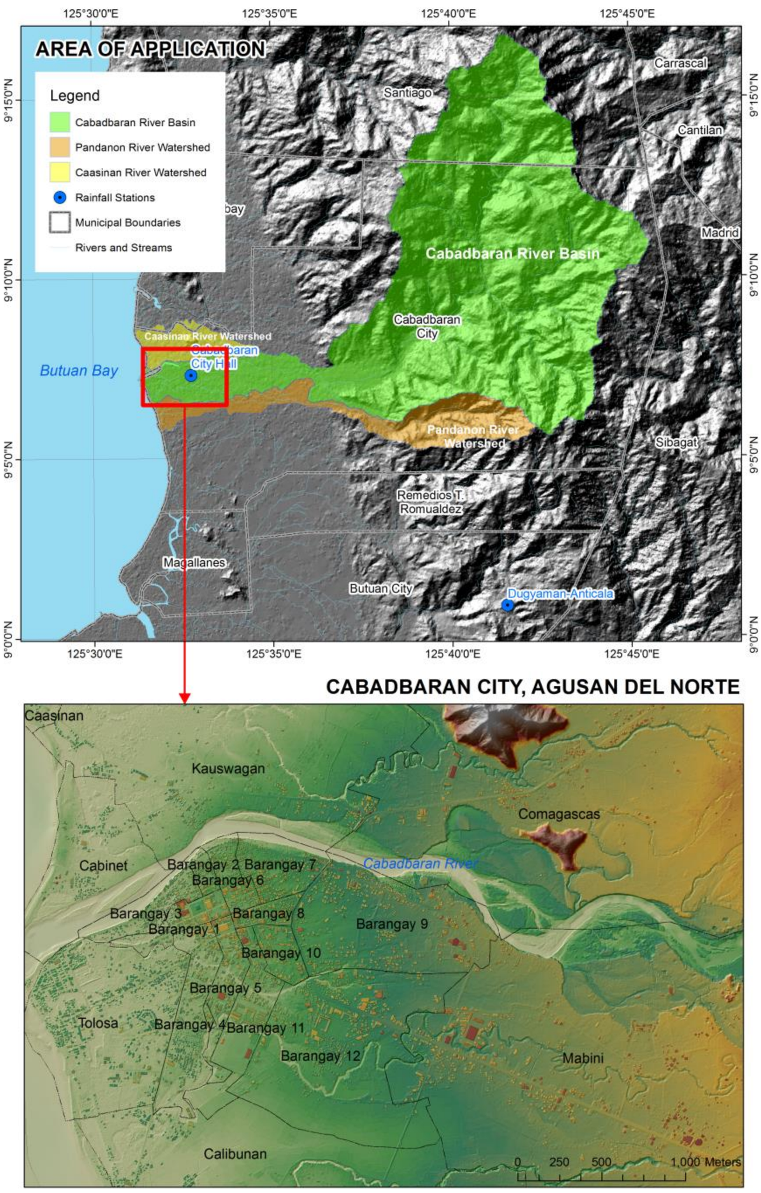


Figure 1. The test area of application which is the Cabadbaran River Basin (CRB) and the nearby Pandanon River and Caasinan River Watersheds in Agusan del Norte, Caraga Region

The test area of application is the Cabadbaran River Basin (CRB) and the nearby Pandanon River and Caasinan River Watersheds in Agusan del Norte, Caraga Region (Figure 1). With a total area of 238 km^2, these river basins and watersheds cover a major portion of Cabadbaran City which was reported to be one of those affected by flooding during the onslaught of tropical storms “Agaton” and “Seniang” in the year 2014. These flooding incidents make the city an ideal site for the development of the application, and to illustrate how the application can be useful during flood events.

4. DESIGN AND DEVELOPMENT

Flood EViDEns is envisioned to be a web platform where disaster managers, LGUs and the community can easily access the four sets of localized flood hazard information (cited and explained in the previous section) for near-real time assessment and geo-spatially informed decision making. These decisions may be related to (i.) providing appropriate early warning to possible communities that could be affected by flooding, (ii.) locating and estimating the number of affected communities; (iii.) preparations and formulation of advisories necessary for evacuations; and (iv.) relief operations, among others.

To make this possible, the application was designed and developed with three major components:

- Flood information generation

- Information storage
- Online visualization/web platform

4.1 Flood Information Generation Component (IGC)

The IGC consist of computer workstations running flood simulation models to generate near-real time flood information that includes the current and forecasted flood inundation extent and flood hazard levels, and water level forecasts. The flood simulation software/programs used are the Hydrologic Engineering Center Hydrologic Modelling System (HEC HMS) version 3.5 and HEC River Analysis System (HEC RAS) version 4.1. Various geospatial datasets were utilized in the development of flood simulation models (Figure 2). In HEC HMSmodel development, a 10-m Synthetic Aperture Radar (SAR) Digital Elevation Model (DEM) was used for sub-basin delineations and for derivation of topography-related parameters of the model such as slope and elevation. Images acquired by the Landsat 8 satellite were also utilized to derive a landcover map using Maximum Likelihood classification. The landcover map is necessary for the derivation of land-cover-related model parameters such as surface roughness coefficient, and runoff/infiltration capacities. River width and cross-section data obtained from field surveys as well as those extracted from 1-m resolution LiDAR-derived Digital Terrain Model (DTM) were also used to estimate the channel routing parameters of the model. For HEC RAS model development, river bed topography (obtained from bathymetric surveys), sea bed topography (obtained from a NAMRIA topographic map), LiDAR DTM, building footprints (with top elevation) extracted from LiDAR Digital Surface Model (DSM), and the same landcover map derived from Landsat 8 OLI satellite image were used as major inputs.

The HEC HMS-based hydrologic model computes for the volume of water coming from the upstream watersheds caused by rain falling in these areas. Rainfall depths recorded by rain gauges within and in the vicinity of the river basin are being used as input into the HEC HMS to compute discharge hydrographs for specific locations in the river basin, specifically at those locations where the upstream watersheds ends and the floodplain portions begin. The discharge hydrographs depict the volume of water per unit time (in m3/s) that drains into the main river at these locations. These hydrographs are then used as basis to generate water level forecasts, and as inputs into the HEC RAS hydraulic model to generate the flood depth and hazard maps (for the current and forecasted flood events). HEC RAS is a one-dimensional flood model that utilizes river and flood plain geometric data (from topographic and hydrographic surveys and LiDAR Digital Terrain Model - DTM), land-cover and surface roughness (from remotely-sensed images), and discharge hydrographs in order to compute water levels all throughout the river. Once these water levels are computed, the flooded or inundated areas along the river and in the floodplains are estimated by intersecting the water surface profiles into a high resolution LiDAR DTM. This is done through the “RASMapper”, the GIS module of HEC RAS. This process generates a flood depth map, which is further processed to generate flood hazard levels by categorizing flood depths into low (depth <0.5 m), medium (0.5 ≤ depth ≤ 1.5 m), and high (depth > 1.5 m) hazards. The flood hazard maps produced from this process are in GIS shapefile format (one file each for the current flood hazard map, and forecasted flood hazard map), and are forwarded to the Information Storage Component.

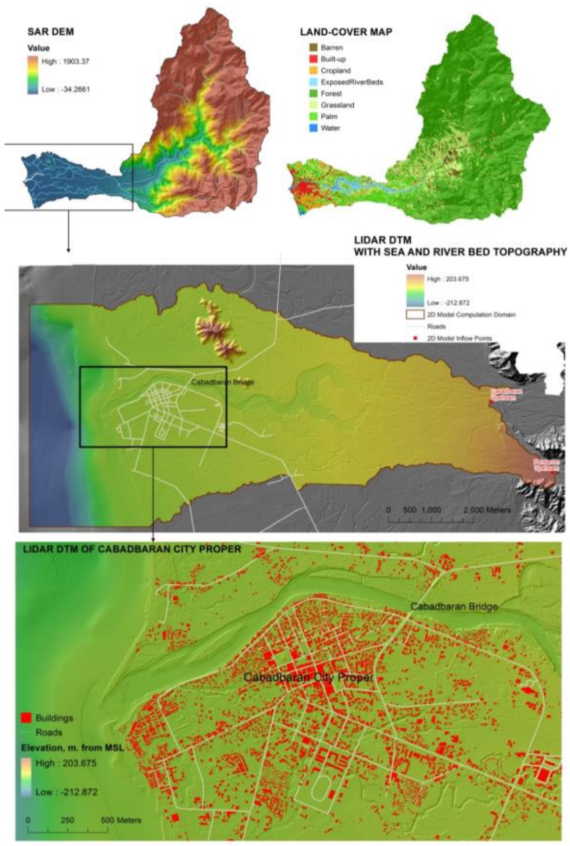


Figure 2. Some of the geospatial datasets used in the development of the flood models.

Since the aim is to provide the latest and forecasted flood information in near-real time, the flood simulations were automated using a combination of Python, wget, AutoIT and batch scripts. The automation includes downloading rainfall and water level data from an online data server/repository, formatting these datasets into HEC HMS and HEC RAS usable files, running the HEC HMS and HEC RAS models, generating the flood hazard map shapefiles, extracting the water level forecasts from the HEC HMS simulation results and exporting to tabular text files, and

then storing all of them into a spatial database (in the Information Storage Component). This whole process is repeated every 10-minutes through Windows Task Scheduler. It should be noted that flood hazard maps and water level forecasts are generated by running the HEC HMS model with a simulation period starting five days before the current time up to the next six hours. The forecasted flood hazard map represents the maximum extent and level of flooding with the next six hours.

In addition to the near-real time flood hazard maps, scenario-based flood hazard maps were also generated using the HEC HMS and HEC RAS models, and stored in the spatial database. These scenarios represent maximum flooding caused by rainfall events of varying duration and intensity (e.g., rainfall events with return periods of 2, 5, 10, 25, 50, and 100 years). Each of these scenarios is characterized by specific amounts of accumulated rainfall in a 24-hour duration that can cause flooding. Including these scenario-based flood hazard maps in Flood EViDEns can aid rapid flood hazard assessment and damage estimation using only the amount of 24-hour accumulated rainfall as indicator (e.g., if a user knows the amount of rainfall accumulated in the last 24 hours, he/she can make assessments and estimations by selecting one of the scenario-based flood hazard map that correspond to the amount of accumulated rainfall).

4.2 Information Storage Component

Once the water level forecast text files and GIS files have been generated by the flood models, they are automatically stored and loaded into a PostgreSQL database extended with the PostGIS plugin to handle and support geographic objects (e.g., shapefiles). This spatial database is configured in a data server connected to the internet.

4.3 Online Visualization/Web Platform

The online visualization/platform for Flood EViDEns is a webpage configured using Bootstrap and Javascripts 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. For example, a user can select a certain flood event and then send a query to the spatial database to display the statistics of structures affected by the selected flood event. The query and the display of information is handled using GeoDjango framework, i.e., by performing a query (intersects or ST_Intersects in PostGIS) using Django Object-relational mapping (ORM). If a certain structure intersects the flood hazard layer, it will be counted (considered as affected) depending on what hazard level it intersected. There are some cases in which a structure intersects multiple times with a flood hazard layer with different hazard level e.g. in medium and high hazard levels. In that instance, the structure will be counted according to the highest hazard level it intersects.

The web map segment displays flood hazard, structures (buildings), water level forecast location, and other associated layers (e.g., political boundaries). The visualization of these layers is a two-step process. First, the map layers requested by the user are accessed and processed (published) by GeoServer Web Map Service (WMS). Then, the display/rendering of these layers is handled by OpenLayers. 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. The categorization/color-coding of the affected structures according to hazard levels is handle using GeoDjango framework (for the query, e.g., for determining the hazard level of a structure by “spatially intersecting” the structures layer with the flood hazard layers) and Geoserver (for the visualization). The “Water Level Station” layer is also included in the web map segment. When activated, the user can view the graph of water level and rainfall records in the last 24 hours, and the forecasted water level for the next 6 or more hours. The information is rendered using HighCharts and Javascripts.

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). The generation of the detailed list is also handled using GeoDjango framework.

5. RESULTS/IMPLEMENTATION OF THE APPLICATION

There are two versions of Flood EViDEns currently available: full version (available at the CSU Phil-LIDAR 1 Project Office in Caraga State University) and the initial, public version (available at **http://121.97.192.11:8082**). In the full version, the user can access 'near-real time' flood hazard map information. However, this functionality is not yet fully tested and its enhancement is on-going. This is the reason why it has not yet been included in the public version.

Figure 3 shows the user interface of the application as accessed through a web browser, with the three segments of the application indicated.

To use the application, the user can start by selecting a flood event in the generalized flood information segment. Clicking the "Show" button will display the list of affected structures categorized according to flood hazard levels (Figure 4).

To view the flood hazard maps and other information, the user can click the desired flood hazard layers on the left side of the web map segment (Figure 5).

A localized search of flood affected structures (based on the currently displayed flood hazard information) can be done by the user by doing a selection according to municipality, barangay, and type of structure (Figure 7).

The water level forecast function of the application can be activated by first, enabling the "Water Level Station" layer in the Overlays section, and then clicking on the water level station in the web map to display the water level forecasts (Figure 8).

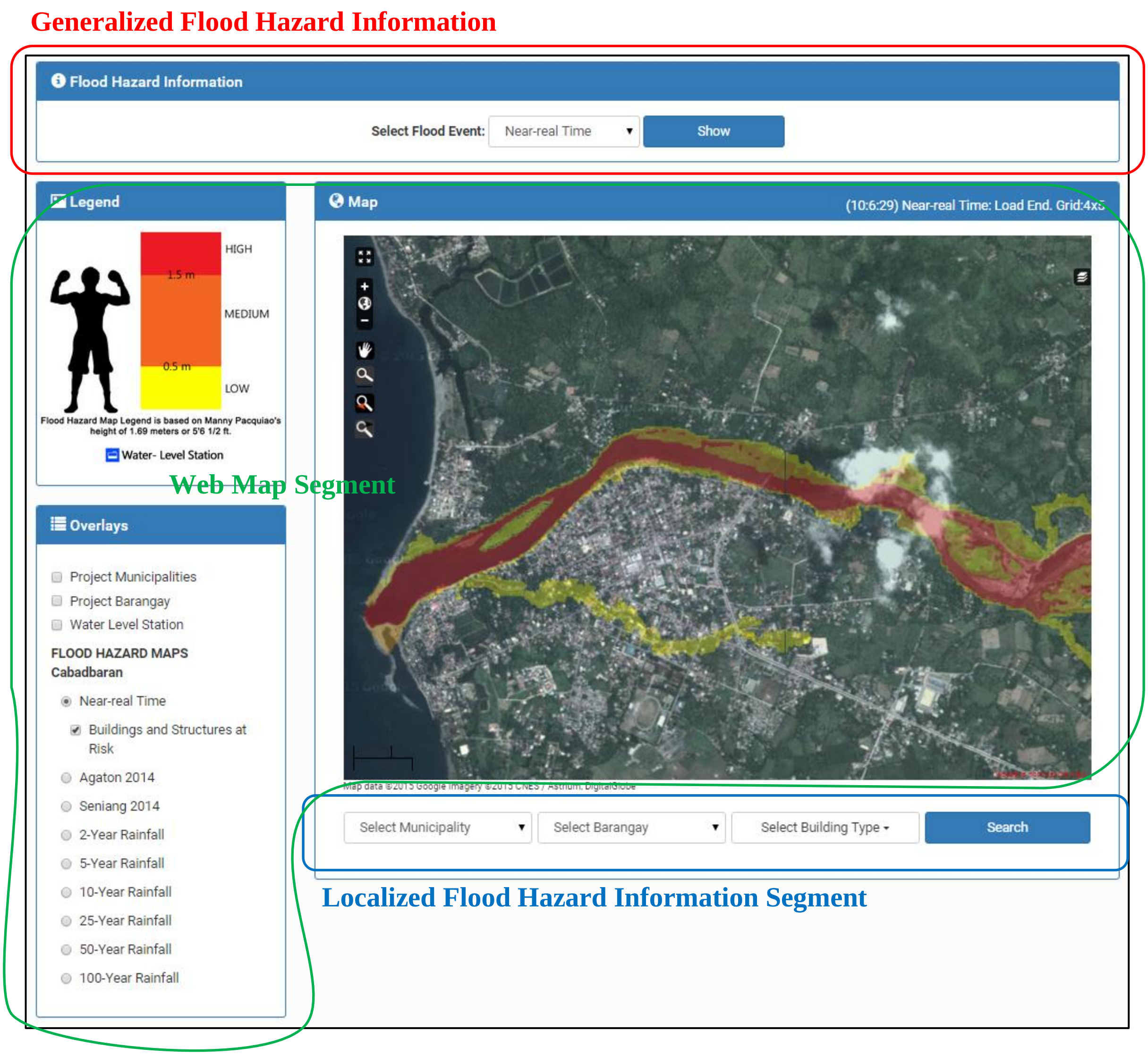
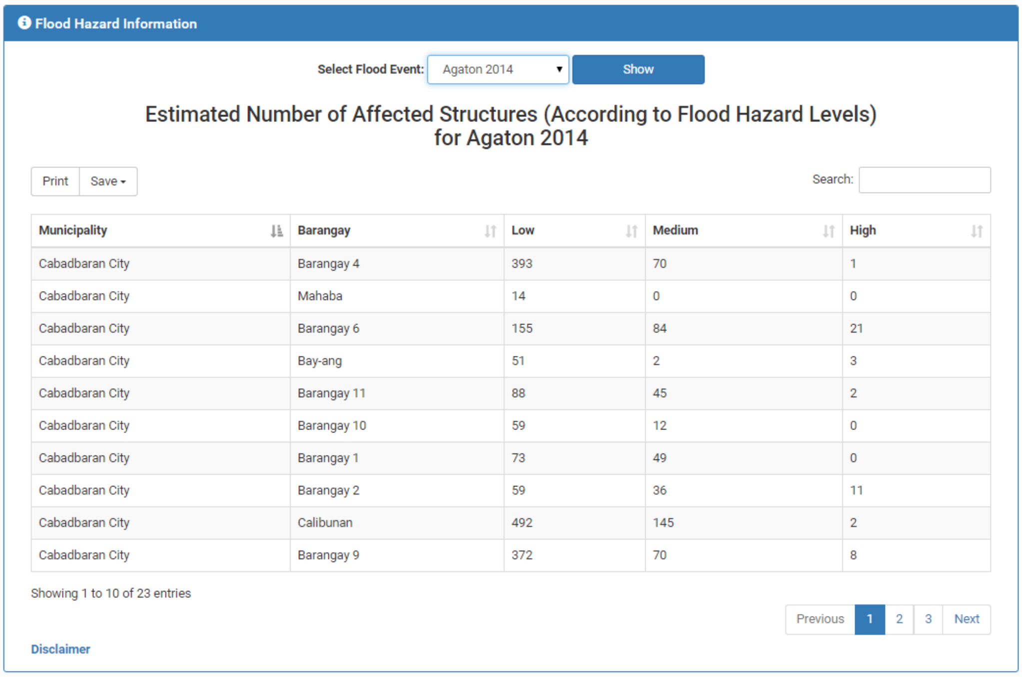


Figure 3. Interface of Flood EViDEns as accessed through a web browser.



Flood Hazard Information

Select Flood Event: Agaton 2014 Show

Estimated Number of Affected Structures (According to Flood Hazard Levels) for Agaton 2014

Print Save Search:

Municipality	Barangay	Low	Medium	High
Cabadbaran City	Barangay 4	393	70	1
Cabadbaran City	Mahaba	14	0	0
Cabadbaran City	Barangay 6	155	84	21
Cabadbaran City	Bay-ang	51	2	3
Cabadbaran City	Barangay 11	88	45	2
Cabadbaran City	Barangay 10	59	12	0
Cabadbaran City	Barangay 1	73	49	0
Cabadbaran City	Barangay 2	59	36	11
Cabadbaran City	Calibunan	492	145	2
Cabadbaran City	Barangay 9	372	70	8

Showing 1 to 10 of 23 entries

Previous 1 2 3 Next

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Figure 4. The generalized flood hazard information displayed in Flood EViDEns.

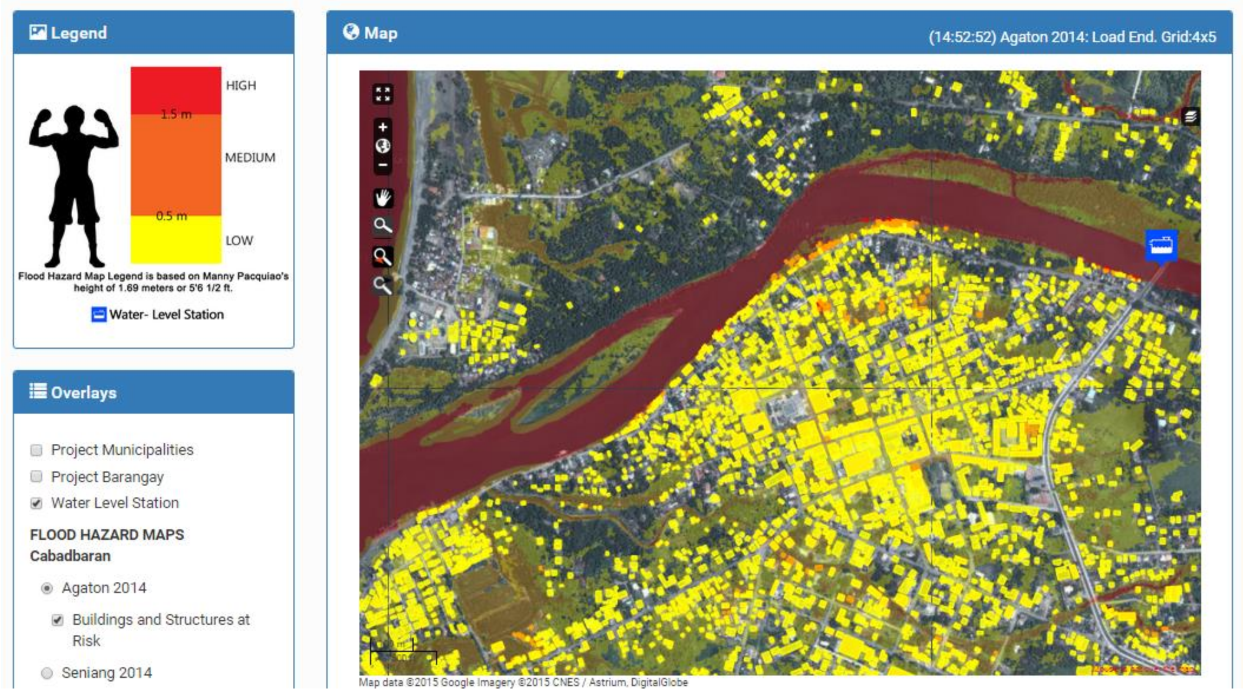
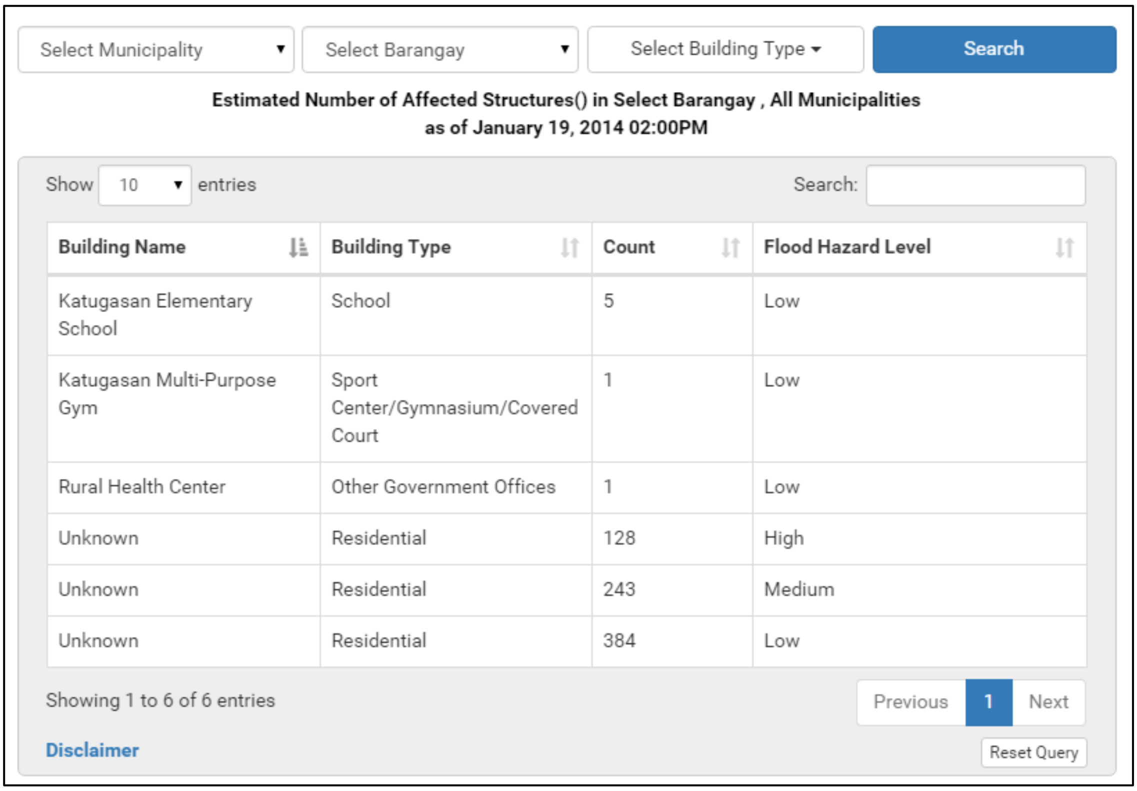


Figure 5. The web map interface, showing the flood hazards and affected structures.



Building Name	Building Type	Count	Flood Hazard Level
Katugasan Elementary School	School	5	Low
Katugasan Multi-Purpose Gym	Sport Center/Gymnasium/Covered Court	1	Low
Rural Health Center	Other Government Offices	1	Low
Unknown	Residential	128	High
Unknown	Residential	243	Medium
Unknown	Residential	384	Low

Figure 6. Localized flood hazard information that can be displayed in Flood EViDEns.

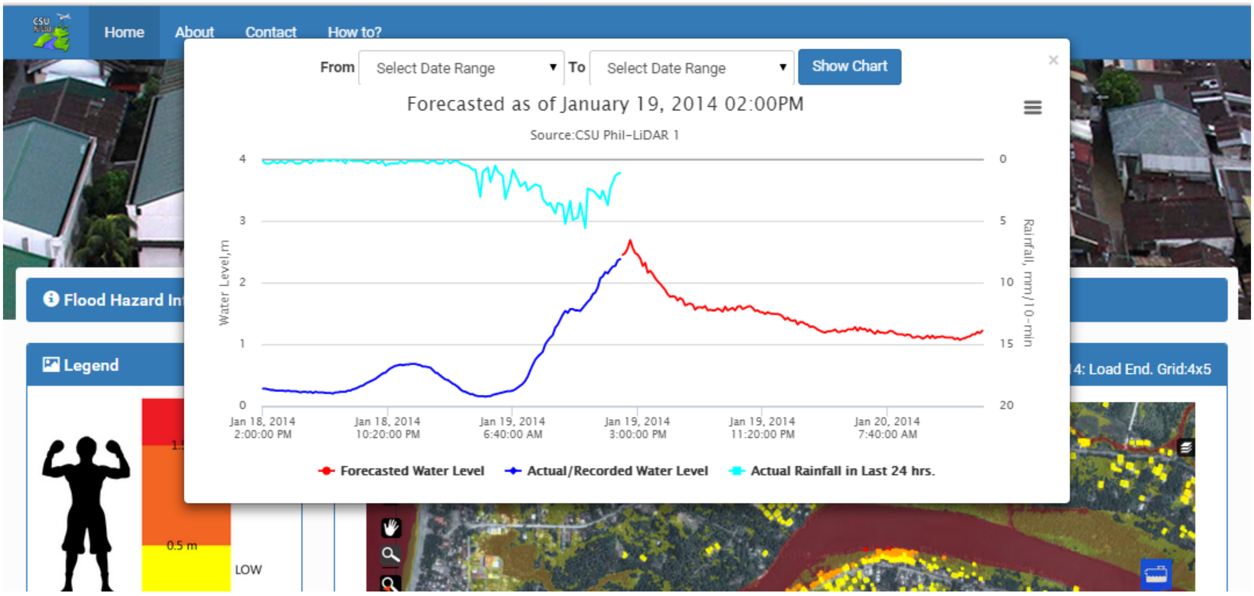


Figure 7. The water level forecast information available in Flood EViDEns.

6. CONCLUDING REMARKS

In this paper, we presented the development of the web-based Near-real Time Flood Event Visualization and Damage Estimations (Flood EViDEns) application. The application is aimed to be useful in localized flood disaster management by providing publicly-accessible near-real time flood hazard maps (as flooding progresses), especially during occurrence of heavy to torrential rainfall events and forecasted flood hazard maps (i.e., expected flooding in the next hours or days), including the capability to analyze and estimate in near-real time the possible damages (e.g., counting of affected structures according to hazard levels) caused by flooding events.

At present, Flood EViDEns is continuously being improved to achieve the set of objectives it was originally designed for. A public version of the application is already accessible at **http://121.97.192.11:8082.** This version will be enhanced in the following months, with the addition of fully-tested "near-real time" functionality.

ACKNOWLEDGEMENTS

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AUTHOR CONTRIBUTIONS

Jojene Santillan and Meriam Makinano-Santillan conceptualized the idea behind the application. The flood models that generated the scenario-based maps and near-real time flood hazard maps and water level forecasts were prepared and calibrated by Jojene Santillan. The application's information storage and online visualization/web platform components were developed by Edsel Matt O. Morales. The full paper was written by Jojene Santillan and Meriam Makinano-Santillan with contributions from Edsel Matt O. Morales.

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