An Entry for the ACRS 2013 - Web Contest (WEBCON 3) by:

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I aM AWaRe: An Online Geo-visualization Tool for **I**nund**a**tion **M**onitoring **A**nd **W**ater Level Forec**a**sting in **R**iv**e**rs

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ABSTRACT

I aM AWaRe is a online geo-visualization tool for monitoring flood inundation and forecasting of water levels in rivers as applied to the Marikina, San Juan and Pasig Rivers in Metro Manila, Philippines. This web application was developed to address the need for two levels of information during flooding events: (1) near-real time information on the status of water levels all throughout the river, specifically information on the current extent of inundation or flooding along the river and the areas that are presently flooded, and (2) forecasts on how water level will rise (or recede) at different locations along the river as rainfall events occur in the watersheds. It aims to increase awareness and responsiveness of the public during flooding events. I aM AWaRe is developed through three components: (1) Information Generation Component (IGC) – computers running the models and upload inundation and water level forecasts information to a server; (2) Information Storage Component (ISC) – used to store latest information (flood inundation extent and water level forecasts, in Keyhole Markup Language format) for access by the user through the online visualization component; and (3) Online Visualization Component (OVC) – this is the I aM AWaRe web app which is available at **http://iamawareph.wordpress.com**.

Keywords: I aM AWaRe, geo-visualization, inundation monitoring, water level forecasting, Philippines

BACKGROUND

Floods are a persistent problem that needs to be addressed in a more scientific way in order to mitigate its costly impacts to properties and human lives. In the Philippines, especially in Metro Manila and nearby provinces, the need for an accurate and reliable flood monitoring tool has been exemplified in several occasions. The first was in September 2009 when torrential rainfall brought by Tropical Storm (TS) Ketsana (Local Name: Ondoy) caused overflowing of rivers (especially Marikina and San Juan Rivers) that resulted to exceptionally high and extensive flooding in areas surrounding the rivers. TS Ketsana 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). The second and third was in August 2012 and August 2013, respectively, when periods of torrential rains and thunderstorms brought about by the strong movement of the Southwest Monsoon caused several rivers in Metro Manila and nearby provinces to overflow and brought damages to places near the banks of the rivers.

Some studies have been conducted to understand flooding especially in Marikina River (Badilla, 2008; Abon et al., 2011). Several water level and rainfall monitoring stations are also in place in major rivers that can provide up-to-date status of water levels at selected sections of the rivers, and of rainfall depth at different locations. However, these efforts appear to be lacking in terms of providing near-real time information on the status of water levels all throughout the river, especially if one wanted to know the current extent of flooding along the river and the areas that are presently flooded.

DESIGN CONCEPT

During a flood event, there are two levels of information that are needed:

- information on the current extent of flooding along the river and the areas that are presently flooded; and
- forecasts on how water level will rise (or recede) at different locations along the river as rainfall events occur in the watersheds.

Usually, the first information can be obtained by direct observation (i.e., visiting the areas affected, taking pictures) but this is often difficult and risky. Alternatively, numerical models (i.e., flood models) can be used to estimate the current extent of flooding ("inundation") by utilizing water level recorded by monitoring stations in a river. Given that the geometry of the river is known before hand, the model can compute the level of water all throughout the river if the water level at the upstream and the downstream are known. Through GIS analysis, this can be converted to inundation extent.

The second information can be known by use of numerical models (i.e., watershed hydrologic models) that can compute how much runoff or "flood water" will be generated and goes down the river when a rainfall event occur. 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.

Based on these concepts, it is very possible to generate these two levels of information during a flood event. And through the use of web geo-visualization technologies (Google Map, Google Earth), this information can be relayed through the internet for easy access by the public – this is what **I aM AWaRe** is all about.

PURPOSE

I aM AWaRe is developed with the aim to increase awareness and responsiveness of the public during flooding events by providing answers to the following questions:

- Is the river in my community have already overflowed?
- Where are the flooded areas?
- How large is the extent of flooding?
- Has the flooding receded?

- It is raining very hard right now. How high will the water level in the river be in the next hours?

Providing this kind of information during a heavy rainfall event is useful in informing the public as to the current extent and depth of flooding in rivers. It may assist in preparation for evacuation; and it may aid in identifying areas that need immediate action, in identifying areas that should be avoided; and in estimating the severity of damage as flooding progresses.

FRAMEWORK

I aM AWaRe is built upon the framework (Figure 1) that numerical models must first be developed that can generate the needed information. The development of the model is crucial and requires data from several sources. Once the information is generated, it can then be uploaded to a web server. The user can access this information online through the use of third party application (Wordpress+Google Map).

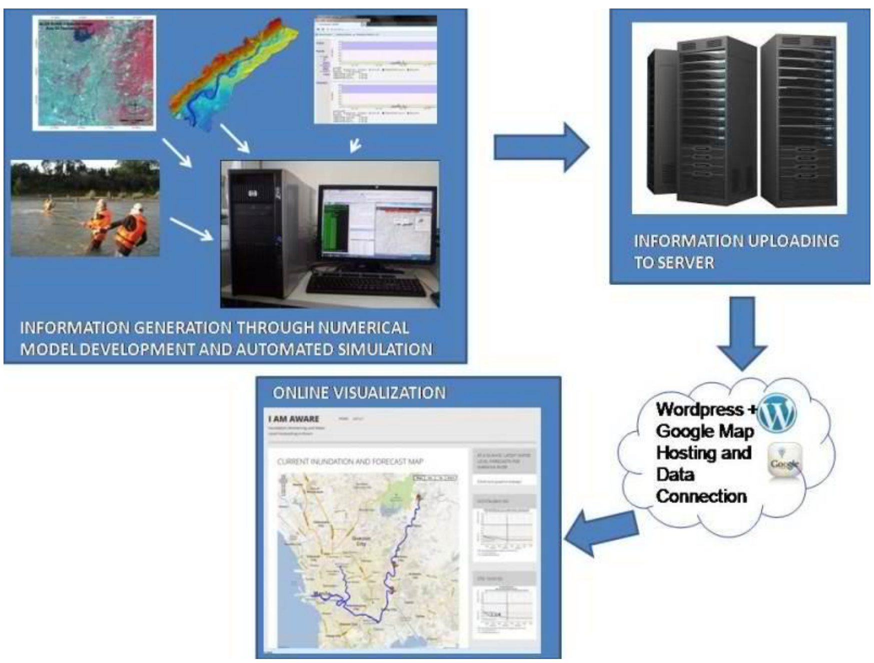


Figure 1. I aM AWaRe framework.

AREA OF APPLICATION

I aM aWaRe covers three major rivers of Metro Manila, Philippines (Figure 2): Marikina River, San Juan River, and Pasig River. However, for water level forecasting, only Marikina River is covered at the moment. Although forecasts are generated for different locations along this river, the generation of this information is actually obtained by considering the whole Marikina River Basin.

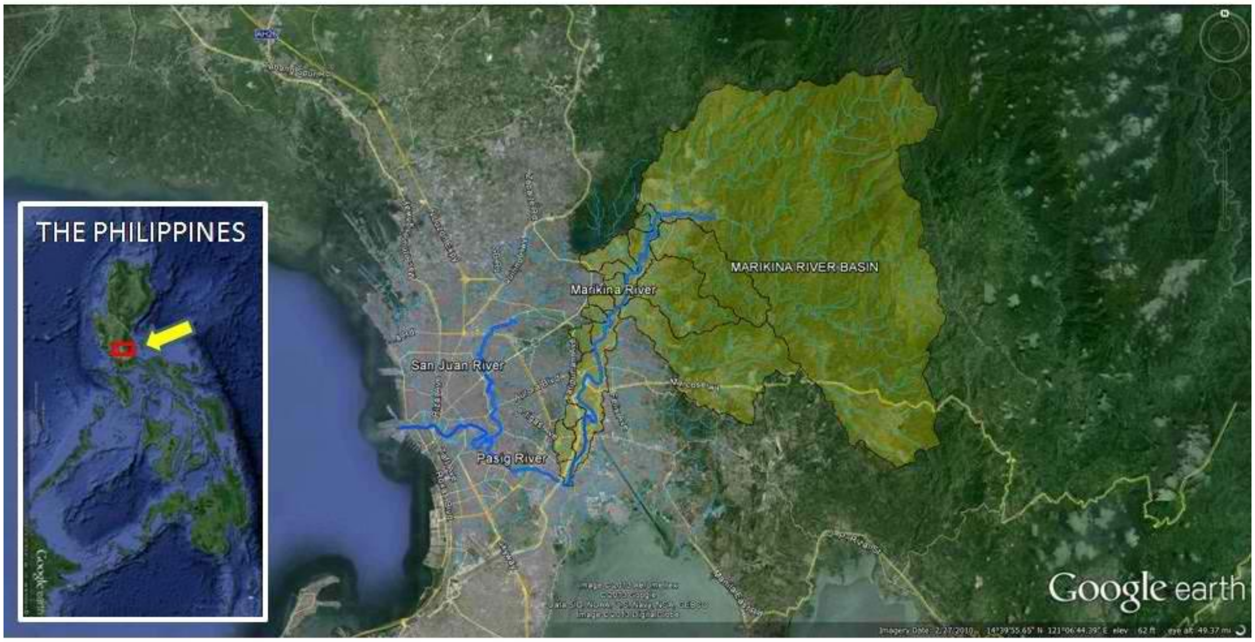


Figure 2. The area of application for I aM AWaRe.

DEVELOPMENT OF I aM AWaRE: SYSTEM REQUIREMENTS, SET-UP AND IMPLEMENTATION

I aM AWaRe consists of three components:

- Information Generation Component (IGC) – computers running the models and upload new information to the server
- Information Storage Component (ISC) – a web server installed with Apache. The latest information (flood inundation extent and water level forecasts, in Keyhole Markup Language format) is uploaded here and accessed by the user through the online visualization component
- Online Visualization Component (OVC) – this is the I aM AWaRe web app (http://iamawareph.wordpress.com)

Information Generation Component

Three computers (one computer for each river) are used to run numerical models in order to generate information on the latest flood inundation and water level forecasts. The outputs from these computers are KML files. Each computer has the following specifications:

- CPU: Intel Core 2 Quad, 2.66 GHz
- RAM: 4 GB
- Windows 7 Professional OS

The following free software/programs necessary to generate the information are installed in the computers:

- HEC RAS 4.1 – used to generate flood inundation extent
- HEC HMS 3.5 – used to generate the water level forecasts
- HEC DSS Vue – used for the conversion of text files of water level and rainfall into a format recognizable by the HEC programs; also used to generate the forecast graphs
- FW Tools – a binary distribution of GDAL (Geospatial Data Abstraction Library – gdal.org) libraries and utilities that includes the OGR Simple Features Library for shapefile to KML conversion
- Python 2.7 – used to reformat text files, update model parameters; implement OGR's ogr2ogr.exe to do shapefile to KML conversion; and uploading of information to the server
- AutoIT – used to automate the HEC RAS program
- GNU wget – used to automatically download water level and rainfall data files

The flood inundation information is generated by HEC RAS models of the three major rivers. HEC RAS stands for "Hydrologic Engineering Center – River Analysis System". It is a one-dimensional flood model that utilizes river and flood plain geometric data (from topographic and hydrographic surveys and LiDAR digital elevation model-DEM), land-cover and surface roughness (from remotely-sensed images), and the latest water level data at specific locations of the river (e.g., at the upstream and downstream of a river) 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 DEM. This is done through the "RASMapper", the GIS module of HEC RAS. In order to provide the latest inundation information, the HEC RAS simulation was completely automated starting from the input of latest water level data from the monitoring stations, to running the model and generating a GIS shapefile of inundation extents, to the conversion of this shapefile to KML, until it is uploaded to the data server and displayed in the I aM AWaRE app. The automation was done through the use of automation scripts (wget, python, AutoIT) while the conversion of shapefile to KML was done through python implementation of OGR (ogr2ogr.exe) based upon FW Tools' libraries and utilities. The output of the automated HEC RAS models are KML files of inundation extent (one KML per river). This whole process, summarized in Figure 3, is repeated every 10-minutes through Windows Task Scheduler.

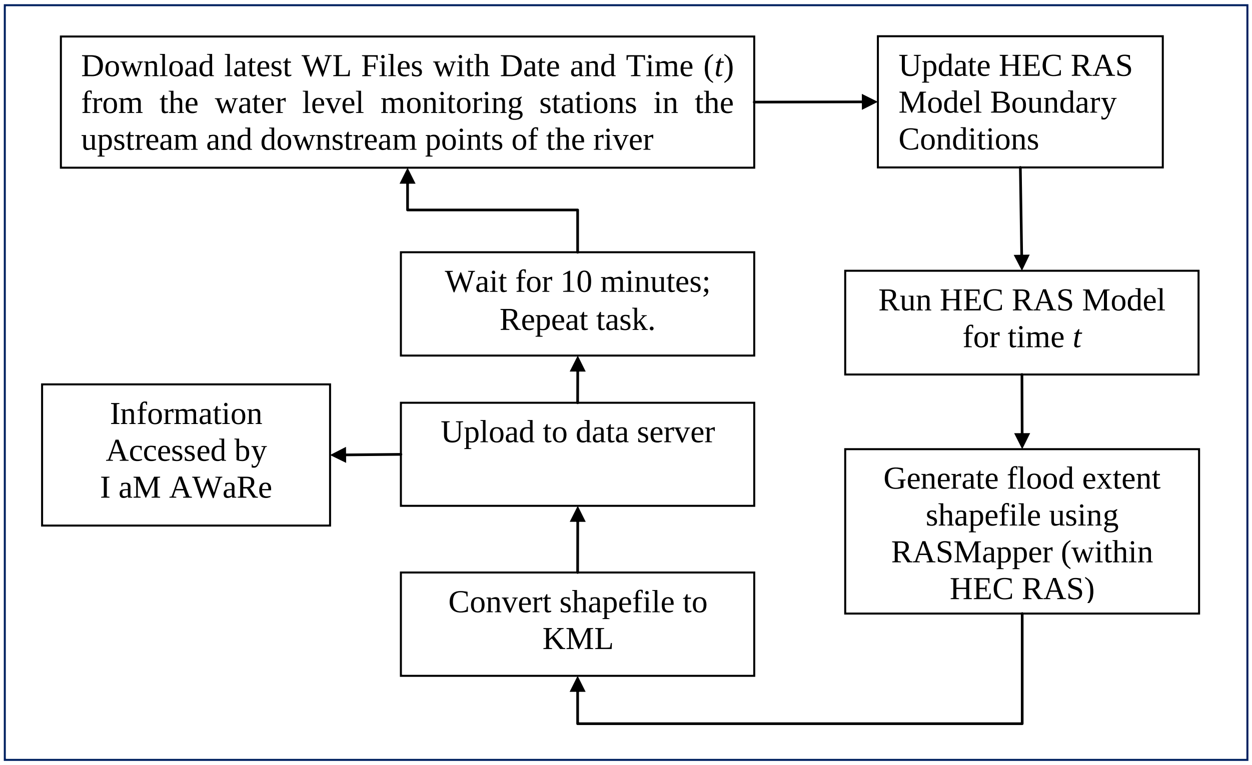


Figure 3. The process flow for generating flood inundation extents. The whole process is automated.

On the other hand, water level forecasts for Marikina River are results of model simulation of basin hydrology as well as river and flood plain hydraulics, using recorded data of rainfall events 3 days ago to present time as primary input of the models. This means that water levels at specific locations along Marikina River (MONTALBAN, STO. NINO, ROSARIO) for the next 48 hours are computed using the model to estimate the effect of rainfall events, if there are any, that have occurred 3 days ago to present time in the Marikina River Basin. The effects of possible rainfall events in the next 24 or 48 hours are not simulated, although it is possible to incorporate rainfall forecasts into the model. Each time the model generates a forecast (i.e., every 5 minutes), rainfall data from nearest active rainfall stations are utilized using an inverse-distance approach. The starting water level for the forecast is computed based on the latest water level data from the monitoring stations which are also downloaded. The forecast model (which has been calibrated and validated) is based on the United States Corps of Engineers (USACE) Hydrologic Engineering Center – Hydrologic Modeling System (HEC HMS). The model was completely automated (from data input to output) using a combination of wget, Python, Jython and native HEC HMS scripts. The outputs of the automated HEC HMS are tabular files of water level forecasts which are then plotted into forecast graphs through HEC DSSVue. The forecast graphs are then uploaded to the server using a python script. This whole process, summarized in Figure 4, is repeated every 10-minutes through Windows Task Scheduler.

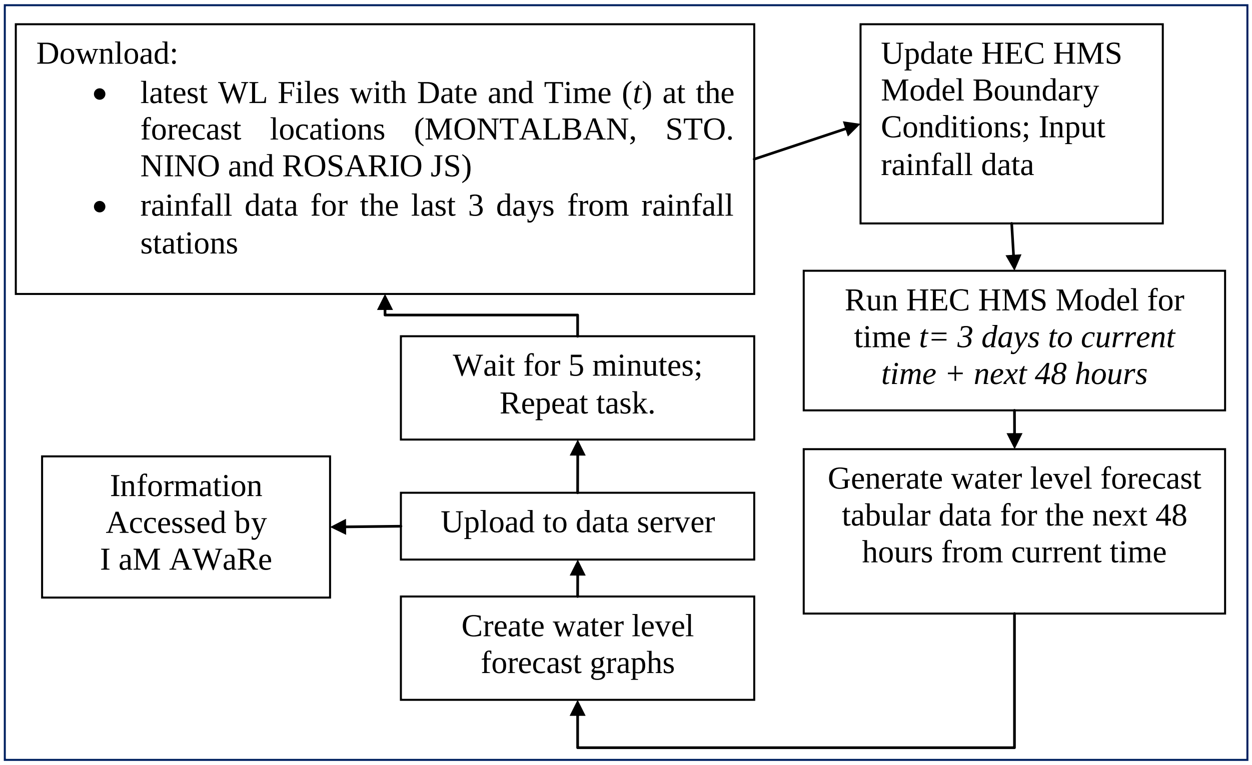


Figure 4. The process flow for generating water level forecasts. The whole process is automated.

The development of I aM AWaRe was actually started by the **Marikina RELiEF web application** (http://mrbforecast.wordpress.com/). I aM AWaRe can be said to be an upgraded version of Marikina RELiEF because flood inundation information is already included in the I aM AWaRe app.

Information Storage Component

A data server (HP Z800, Intel Xeon, 32GB RAM installed with Apache) which is connected to the internet is used to store the KML files of inundation extents and JPEG files of water level forecast graphs. In order for this files to be viewable in a web browser, a "mother" KML file is created wherein the three KML files and the JPEG files are "network-linked" (i.e., KML files within a KML file, linked to their source files in the data server). This mother KML file is the one called by the I aM AWaRe app in order to display the inundation extents and forecast graphs. Note that only the KML files of inundation extents and the JPEG files are updated every 10-minutes not the mother KML file.

Online Visualization Component

The OVC consist of Google Map embedded in a WordPress.com free web site (http://iamawareph.wordpress.com, Figure 5). The HTML codes for the embedded Google Map was generated by calling the mother KML file in map.google.com (i.e., putting the link to the mother KML file in Google Map's search button), and then using available tools in Google Map to set the map size to 800 x 800 resolution. The application is best viewed in the latest version of

Mozilla Firefox. There are some issues when the app is viewed in Internet Explorer (e.g., the side bars are mis-aligned).

There are advantages in using Google Map and WordPress as hosts for I aM AWaRE:

- there is no need to develop and maintain a geodata server (like MapServer, GeoServer and the like) because everything needed is already provided, and for free
- there is no need to maintain hardware of the website; the app rides on WordPress which is accessible all the time
- fast delivery of information — the end-user's browser only needs to download the KML files from the data server; other information are provided by Google Map
- Google Map has the basemap and background information necessary to supplement the information delivered by I aM AWaRe such as, but not limited to:
    - Road network
    - Placemarks
    - High resolution satellite imagery showing built-up areas and other land-cover classes that can be used to assess/estimate areas affected and the amount of damage during flood events

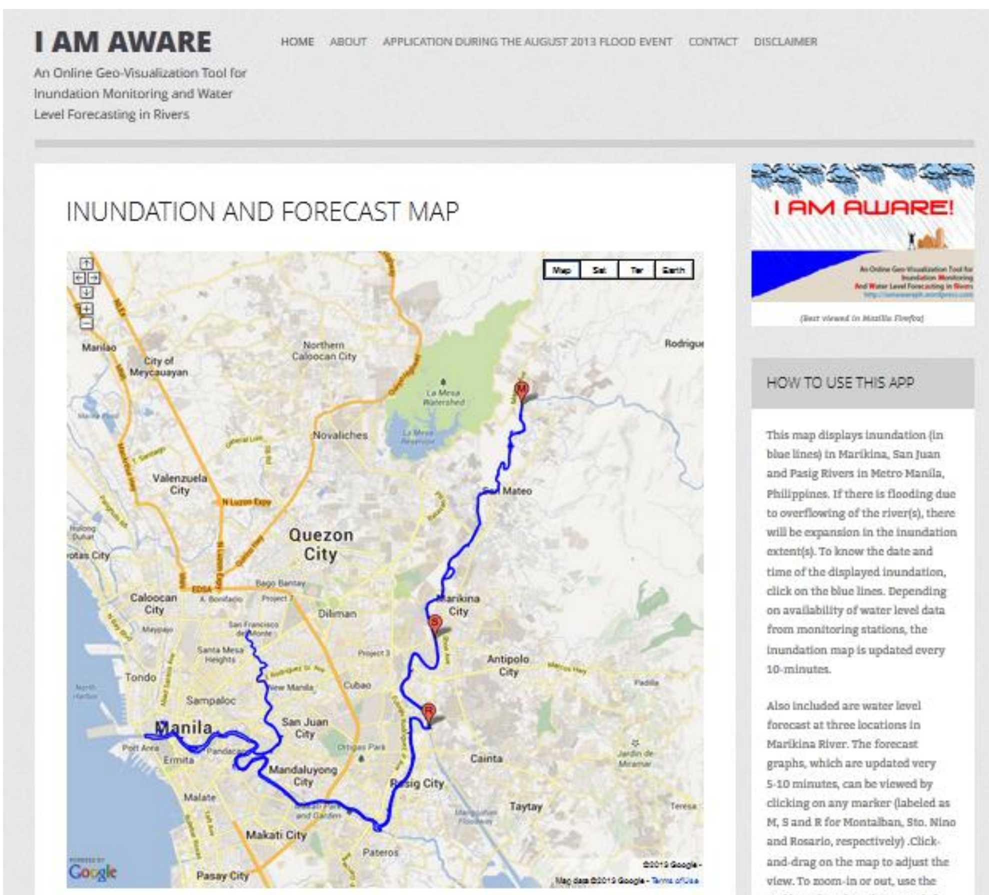


Figure 5. The interface of I aM AWaRe as accessed online via http://iamawareph.wordpress.com

FUNCTIONS OF I aM AWaRe

The app is very easy to use. The map displays inundation (in blue lines) in Marikina, San Juan and Pasig Rivers in Metro Manila, Philippines. If there is flooding due to overflowing of the river(s), there will be expansion in the inundation extent(s). To know the date and time of the displayed inundation, one just need to click on the blue lines. Depending on availability of water level data from monitoring stations, the inundation map is updated every 10 minutes. Also included are water level forecast at three locations in Marikina River. The forecast graphs, which are updated every 5-10 minutes, can be viewed by clicking on any marker (labeled as M, S and R for Montalban, Sto. Nino, and Rosario, respectively).

Default Google Map buttons are available for use in the I aM AWaRe web app. This includes:

- Zoom-in
- Zoom-out
- Pan
- Option to view a larger map of the app in map.google.com ("View Larger Map" button is available)
- Options to view different backgrounds:
    - Street Map View ("Map")
    - Satellite Imagery View ("Sat")
    - Street Map with Terrain ("Ter")
    - 3D Imagery View ("Earth")

HOW ACCURATE ARE THE NUMERICAL MODELS?

There are three papers that discuss the development of these models and their accuracy (Santillan et al.., 2013a; Santillan et al., 2013b; and Santillan et al., 2012). The accuracy of the HEC-RAS based Marikina River Flood Inundation Model is summarized in Figure 6.

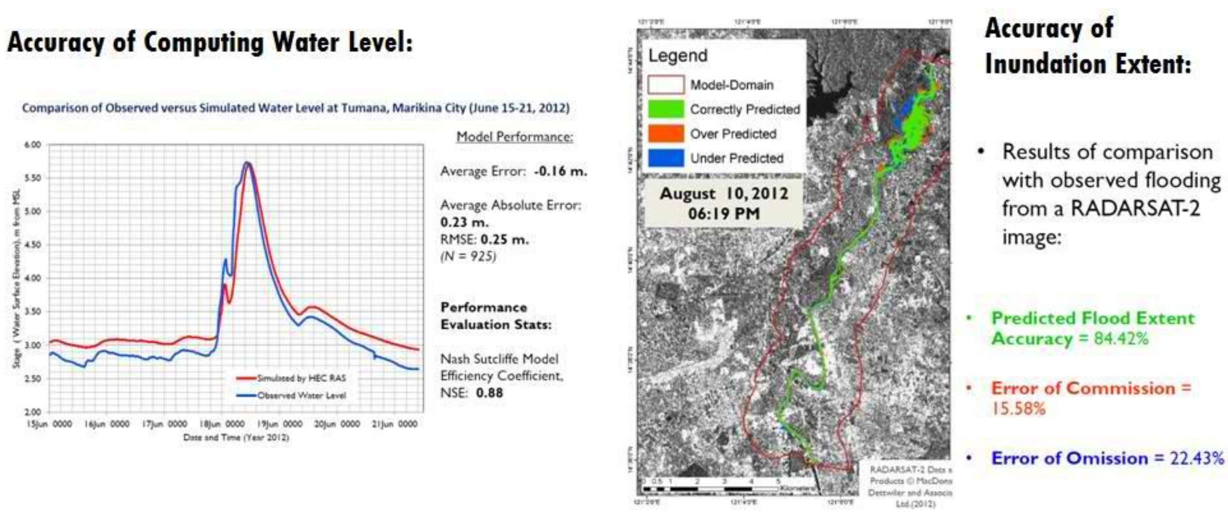
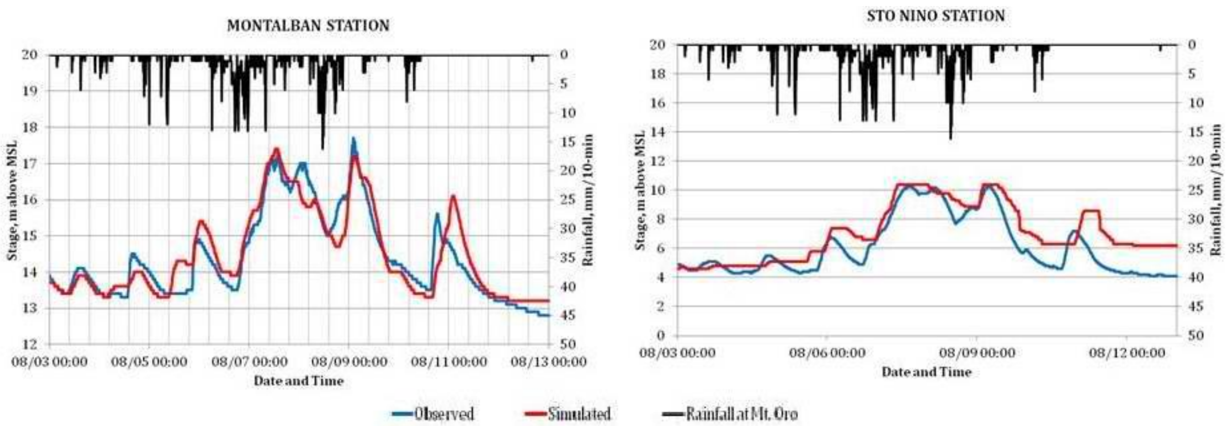


Figure 6. Accuracy of the Marikina River flood inundation model.

Figure 7 summarizes the accuracy of the HEC-HMS based Marikina River Water Level Forecasting Model through comparison with actual water level data during the August 2012 Southwest Monsoon Flood Event).



Comparison of actual water levels versus simulated water levels during the August 2013 Southwest Monsoon Flood Event

Station	Average Error	Nash-Sutcliffe Coefficient
MONTALBAN	**-0.10 m.**	**0.70**
STO. NINO	**-0.80 m**	**0.41**

Note: Error = Actual – Simulated; Negative (-) error indicates overestimation.

Figure 7. Accuracy of the Marikina River water level forecasting model.

Results for the accuracy assessment of the San Juan and Pasig River models will be available soon.

APPLICATION OF I aM AWaRe DURING THE AUGUST 2013 FLOODING IN METRO MANILA

Starting August 17, 2013, heavy to torrential rains were pouring over Metro Manila and nearby provinces. Raining continued for more than 3 days and caused flooding in different areas, most especially in the vicinity of Marikina, San Juan and Pasig Rivers. During these times, the flood inundation and water level forecasting models are providing inundation extents and water level forecast in near-real time at an interval of 10 minutes. Figure 8 shows a snapshot of the application of I aM AWaRE during this kind of events. This is also available in the online application.

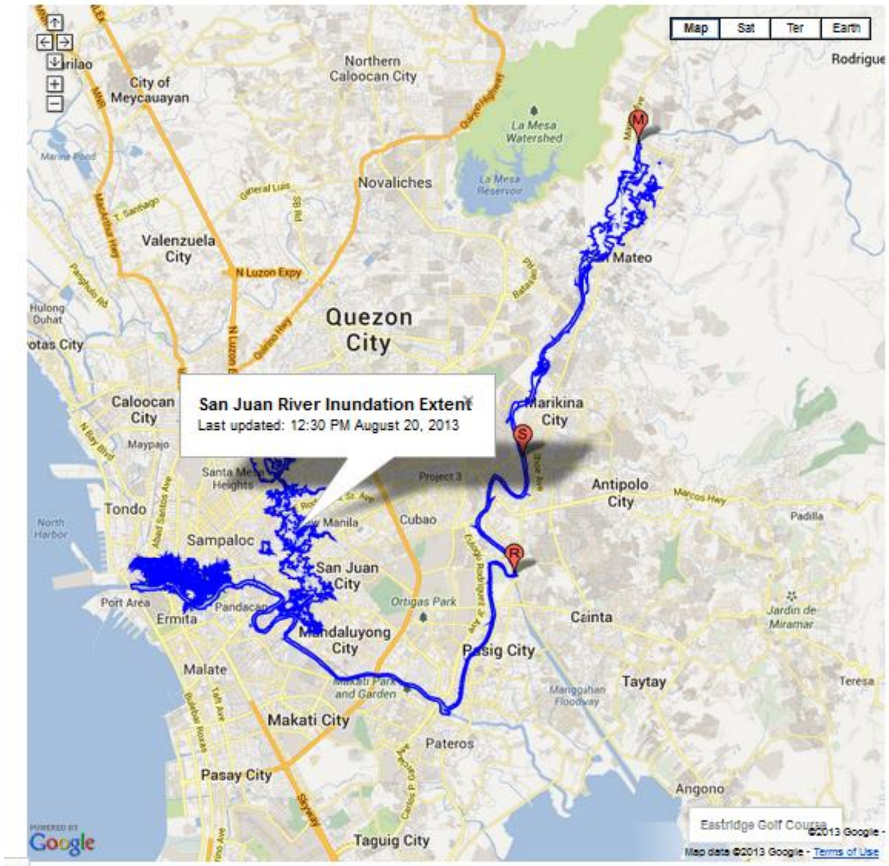


Figure 8. A snapshot of the application of I aM AWaRE during the August 2013 flooding in Metro Manila. This is also available online.

AVAILABILITY OF FLOOD INUNDATION INFORMATION IN PROJECT NOAH

The flood inundation extent information generated for the three rivers have been contributed to the Project NOAH (Nationwide Operational Assessment of Hazards) of the Philippine's Department of Science and Technology at http://noah.dost.gov.ph. The information is accessed by clicking on *Flood Map –> Flood Inundation Monitoring.*

Although it is already made available in Project NOAH, a more dedicated app just like I aM AWaRe is necessary especially if we only wanted to get informed about current inundation condition in rivers as well as forecast of water levels.

LIMITATIONS

I aM AWaRe can only provide flood inundation extents and water level forecasts based on available water level and rainfall datasets:

- If a water level monitoring station (at the upstream or downstream or both) have stopped recording water level data, latest flood inundation information will not be generated and only the last generated information will displayed
- The water level forecasting model will continue to provide forecast even if one or more rainfall stations have stopped recording data. When this happens, the model will utilize rainfall data from other "active" rainfall stations. This may lead to inaccurate forecast as rainfall data may be incomplete.
- Also, the water level forecasting model will continue to provide forecast even if one or more water level monitoring station have stopped recording data. In this case, water level data used to "initialize" the model will use the last recorded data. This may lead to inaccurate forecast as the starting water level data for the forecast is not based on "current" conditions of the river.

At the moment, only flood inundation extents are displayed in I aM AWaRe. The next updates will include the display of flood depths (both for current conditions and for forecasted conditions.)

CONCLUSIONS

In this paper, the development of I aM AWaRe has been presented. This app can be accessed online at http://iamawareph.wordpress.com.

ACKNOWLEDGEMENTS

I aM AWaRe is an output of the project "Modeling of Flash Flood Events By Integrated GIS and Hydrologic Simulations" under the "Surveys and Measurement Technologies for Flood Control, Mitigation and Management Systems (SMTFCMMS)" Program implemented at the Research Laboratory for Applied Geodesy and Space Technology of the Training Center for Applied Geodesy and Photogrammetry, University of the Philippines, Diliman. The project is funded by the Philippine Council for Industry, Energy and Emerging Technology Research and Development (PCIEERD) of the Department of Science and Technology.

The numerical models were developed using spatial and meteorological data from various sources:

- Project NOAH and MMDA's Enhanced Flood Control and Operation Warning System (EFCOS) - for the real-time rainfall and water level data
- Collective Strengthening of Community Awareness for Natural Disasters (CSCAND) agencies for allowing us to use the LiDAR digital elevation dataset that was used as main source of topographic information during model development
- National Mapping and Resource Information Authority (NAMRIA) – for the ALOS AVNIR 2 satellite images used in the land-cover parameterization of the HEC HMS and HEC RAS models

The contributions of the following individuals are also gratefully acknowledged:

- Dr. Enrico C. Paringit, Project Leader of SMTFCCMS and DREAM Program Leader – for his numerous support and for lending a workstation to be used as the data server;
- Ms. Nena Carina Espanola of ASTI-DOST — for allowing me to use and modify the AutoIT script necessary to automate HEC RAS;
- Mr. Robert T. Mendoza of ASTI-DOST — for providing access to some of the DSS files of Marikina River;
- Ms. Jenalyn Alconis of NIGS-UP Diliman — for allowing me to use and modify the Shape to KML python implementation of ogr2ogr.exe;
- Engr. Roseanne V. Ramos, Ms. Girlie David, Ms. Sabrina Recamadas, and Engr. Rudolph Peralta (all research personnel of the project) – for their assistance in the development of the models, including field data collection; and
- Engr. Jessie Linn P. Ablao, Engr. Edgardo Macatulad, Engr. Joemarie Caballero, and all our field survey assistants — for their assistance in the hydrographic surveys.

Wordpress.com, Google Map and the respective owners/developers of all software and programs used in building I aM AWaRe are also acknowledged.

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