A Sensor Network Based Real Time Flood Warning System

Final Report

Project Period: 12/12/08 --- 6/30/2010

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1. Ocean Surge based Flood Warning System for NJ Meadowlands Municipalities

Predicting an upcoming flood event allows the NJMC district municipalities to prepare for the flood incidents. This can help planning evacuation and having appropriate resources available before the disaster occurs. This project's objective is to develop an automated flood warning system that is reliable and sending flood warnings based on the ocean surge data in NJ port Sandy Hook. Since the water level of tributaries in the Meadowlands district area gets impact from the ocean surge level, the flood warning system should consider the storm surge level, distance from the ocean front, and elevation of a particular location in the district. We have build a Web-based application system that monitors the ocean surge level data from the Sandy Hook station in New Jersey that are captured at NOAA, calculates the predicted NJ district flood levels for three different locations, Kearny, Berrys Creek and Mill Creek. Depending on the predicted level of flood, a flood warning message and corresponding flood maps are disseminated to local municipality emergency managers. The messages are directed to appropriate roles in the district depending on the flood levels. Furthermore the Predicted Value, observed Value and the Residual Value of each of the three stations is recorded in the database to analyze the accuracy of prediction model.

We have designed an Automated Flood Monitoring and Warning System for NJMC

- To continuously monitor the NJ ocean surge levels
- To convert the ocean surge levels into Meadowlands specific flood levels
- To generate the flood warning messages and map data
- To disseminate the messages based on roles of the end users.
- To provide and maintain the end user subscription database and update utility
- To provide a tool to view the flood prediction errors with the actual observation data and
- To run the system in a testing mode.

The system architecture is shown in Figure 1.

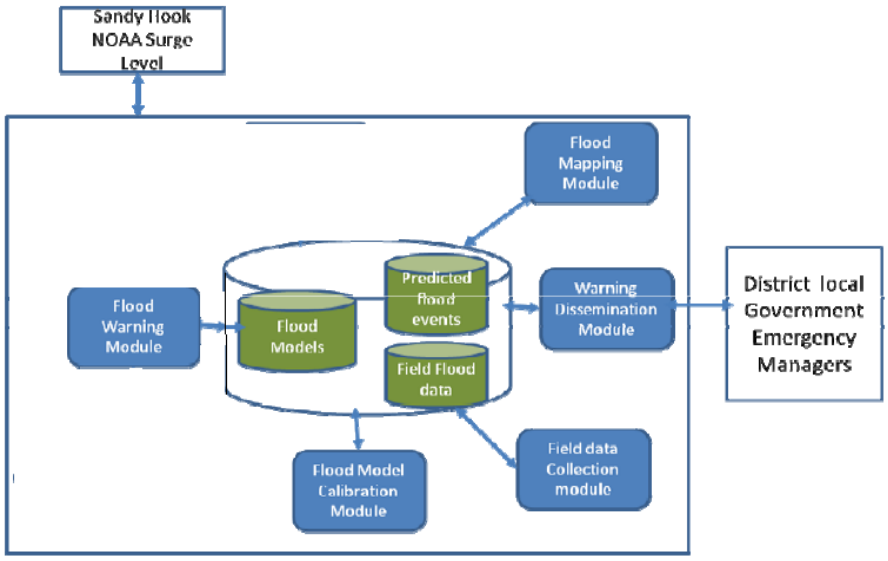
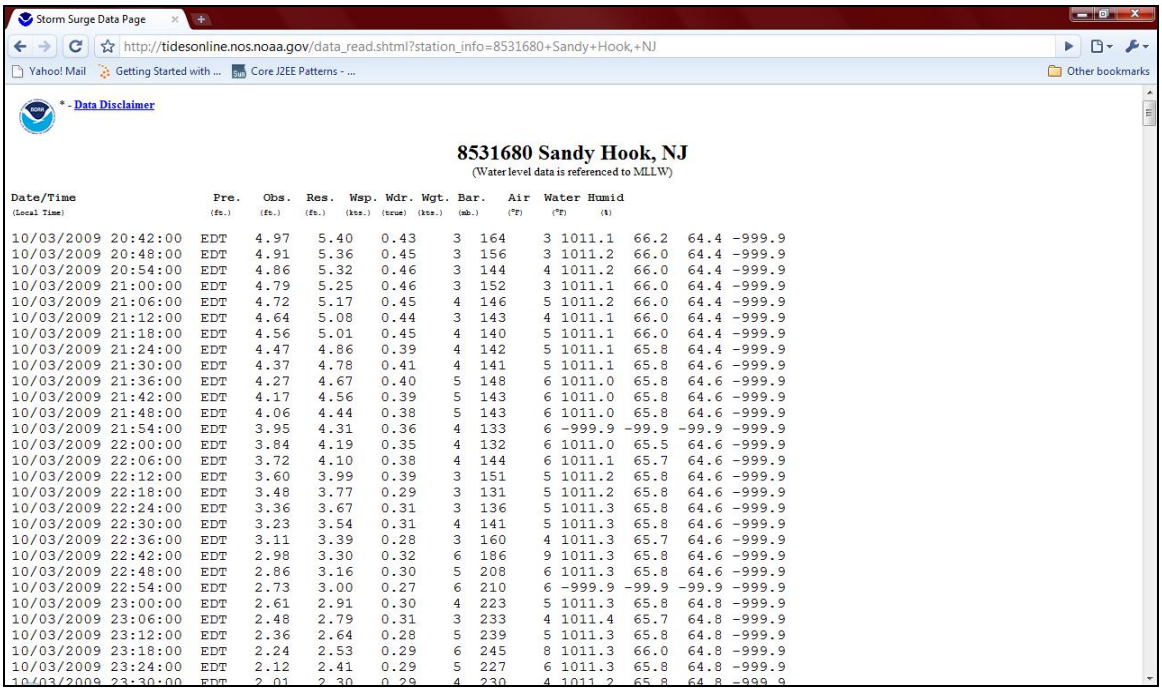


Figure 1 Architecture of Flood Warning System

1.1 Ocean Surge Data Monitoring and Data Extractor:

We have implemented the flood warning system that is based on the ocean storm surge data logged at Sandy Hook station by NOAA data logger. This NOAA station captures observed ocean water level, predicted ocean water level data as well as the residuals (the error between observed and predicted values). The NOAA publishes the ocean surge data and updates observed and predicted values at Sandy Hook every six minutes.

Figure 2 shows the NOAA ocean water level data at Sandy Hook Station with date, time, observed and predicted data values, along with other weather parameters such as wind, humidity, etc.



Date/Time (Local Time)		Pre. (ft.)	Obs. (ft.)	Res. (ft.)	Wsp. (kts.)	Wdr. (true)	Wgt. (kts.)	Bar. (mb.)	Air (°F)	Water (°F)	Humid (%)	
10/03/2009 20:42:00	EDT	4.97	5.40	0.43	3	164	3	1011.1	66.2	64.4	-999.9	
10/03/2009 20:48:00	EDT	4.91	5.36	0.45	3	156	3	1011.2	66.0	64.4	-999.9	
10/03/2009 20:54:00	EDT	4.86	5.32	0.46	3	144	4	1011.2	66.0	64.4	-999.9	
10/03/2009 21:00:00	EDT	4.79	5.25	0.46	3	152	3	1011.1	66.0	64.4	-999.9	
10/03/2009 21:06:00	EDT	4.72	5.17	0.45	4	146	5	1011.2	66.0	64.4	-999.9	
10/03/2009 21:12:00	EDT	4.64	5.08	0.44	3	143	4	1011.1	66.0	64.4	-999.9	
10/03/2009 21:18:00	EDT	4.56	5.01	0.45	4	140	5	1011.1	66.0	64.4	-999.9	
10/03/2009 21:24:00	EDT	4.47	4.86	0.39	4	142	5	1011.1	65.8	64.4	-999.9	
10/03/2009 21:30:00	EDT	4.37	4.78	0.41	4	141	5	1011.1	65.8	64.6	-999.9	
10/03/2009 21:36:00	EDT	4.27	4.67	0.40	5	148	6	1011.0	65.8	64.6	-999.9	
10/03/2009 21:42:00	EDT	4.17	4.56	0.39	5	143	6	1011.0	65.8	64.6	-999.9	
10/03/2009 21:48:00	EDT	4.06	4.44	0.38	5	143	6	1011.0	65.8	64.6	-999.9	
10/03/2009 21:54:00	EDT	3.95	4.31	0.36	4	133	6	-999.9	-99.9	-99.9	-999.9	
10/03/2009 22:00:00	EDT	3.84	4.19	0.35	4	132	6	1011.0	65.5	64.6	-999.9	
10/03/2009 22:06:00	EDT	3.72	4.10	0.38	4	144	6	1011.1	65.7	64.6	-999.9	
10/03/2009 22:12:00	EDT	3.60	3.99	0.39	3	151	5	1011.2	65.8	64.6	-999.9	
10/03/2009 22:18:00	EDT	3.48	3.77	0.29	3	131	5	1011.2	65.8	64.6	-999.9	
10/03/2009 22:24:00	EDT	3.36	3.67	0.31	3	136	5	1011.3	65.8	64.6	-999.9	
10/03/2009 22:30:00	EDT	3.23	3.54	0.31	4	141	5	1011.3	65.8	64.6	-999.9	
10/03/2009 22:36:00	EDT	3.11	3.39	0.28	3	160	4	1011.3	65.7	64.6	-999.9	
10/03/2009 22:42:00	EDT	2.98	3.30	0.32	6	186	9	1011.3	65.8	64.6	-999.9	
10/03/2009 22:48:00	EDT	2.86	3.16	0.30	5	208	6	1011.3	65.8	64.6	-999.9	
10/03/2009 22:54:00	EDT	2.73	3.00	0.27	6	210	6	-999.9	-99.9	-99.9	-999.9	
10/03/2009 23:00:00	EDT	2.61	2.91	0.30	4	223	5	1011.3	65.8	64.8	-999.9	
10/03/2009 23:06:00	EDT	2.48	2.79	0.31	3	233	4	1011.4	65.7	64.8	-999.9	
10/03/2009 23:12:00	EDT	2.36	2.64	0.28	5	239	5	1011.3	65.8	64.8	-999.9	
10/03/2009 23:18:00	EDT	2.24	2.53	0.29	6	245	8	1011.3	66.0	64.8	-999.9	
10/03/2009 23:24:00	EDT	2.12	2.41	0.29	5	227	6	1011.3	65.8	64.8	-999.9	
10/03/2009 23:30:00	EDT	2.01	2.30	0.29	4	230	4	1011.2	65.8	64.8	-999.9	

Figure 2 NOAA's Tidal data publication site

We have developed the storm surge extractor that monitors the NOAA data site and extracts actual and predicted storm surge levels at Sandy Hook station.

1.2 LOCAL WATER LEVEL PREDICTIONS

NJMC area's local water levels are calculated at three locations: the three monitoring stations stationed at Kearney, Berry's Creek and Mills Creek. At each of these three locations has the water monitoring station that captures the actual water levels at a given time t. In order to predict the water levels at these locations, the storm surge levels extracted from Sandy Hook Station at time t (observed value) and predicted values at time t+12 hours, and t+24 hours are converted to the local predicted water level values at t+delta at each local station. The predicted water levels are obtained by applying the conversion factor shown in table 1 for each station. This conversion factor is based on a mathematical prediction model developed by MERI scientists based on the distance from the Sandy Hook station to

the local monitoring station and the elevation levels. Table 1 also shows the predicted time for each station.

Table 1: Conversion factors and time delay for predicting flood levels at three NJMC local stations

Station Code	Station Name	Conversion Factor	Projected time delay from SH
EMS 3	Kearny Station	-1.42 ft	+2.12h(=127min)
EMS 2	Berry's Creek	- 2.22 ft	+ 2.80 h (=168min)
EMS 4	Mill Creek	- 2.52 ft	+ 2.92 h (=175min)

The "Conversion Factor" is the value that needs to be applied for a given value at Sandy Hook to obtain projected NAVD water elevation values. These predicted values of storm surge levels at Kearney, Berry's Creek, Mills Creek and the observed value from Sandy Hook are captured in a database every 60 minutes.

Figure 3 shows the Sandy Hook water levels (one observed at time t, and predicted values in 12 hours (t+12hr) and in 24 hours (t+24hr), and the predicted NJMC local predicted water levels and the predicted times.

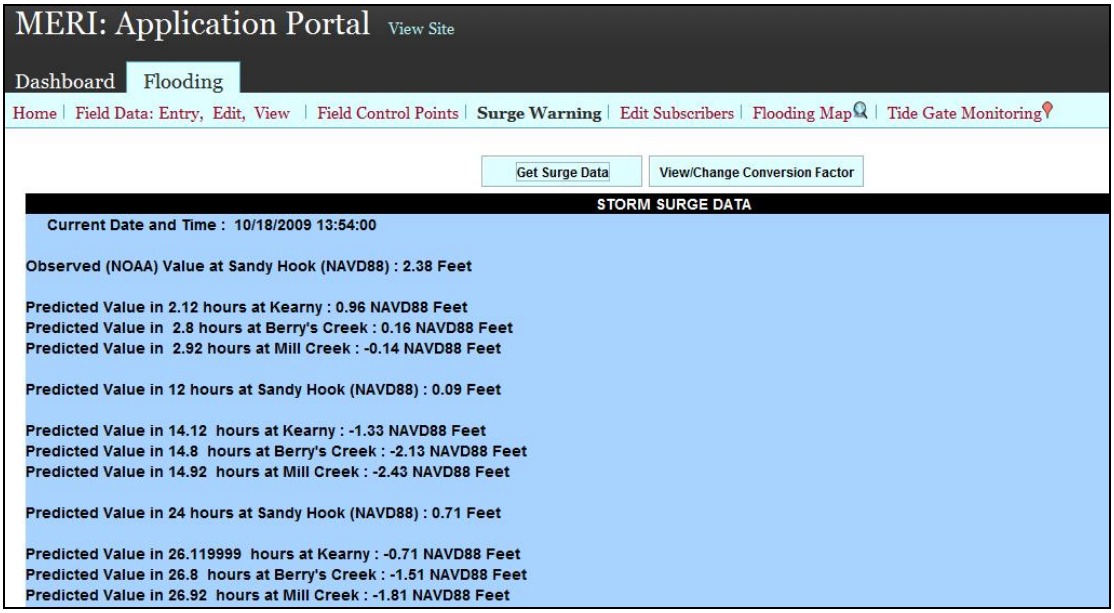


Figure 3 Predicted Flood levels at three NJMC monitoring locations

Figure 4 shows the database snapshot for Barry's Creek, that captures the storm surge data of Sandy Hook at time t and its predicted flood level at Barry's creek and the actual water level at time t. It also captures the error rates between the predicted value and the observed value.

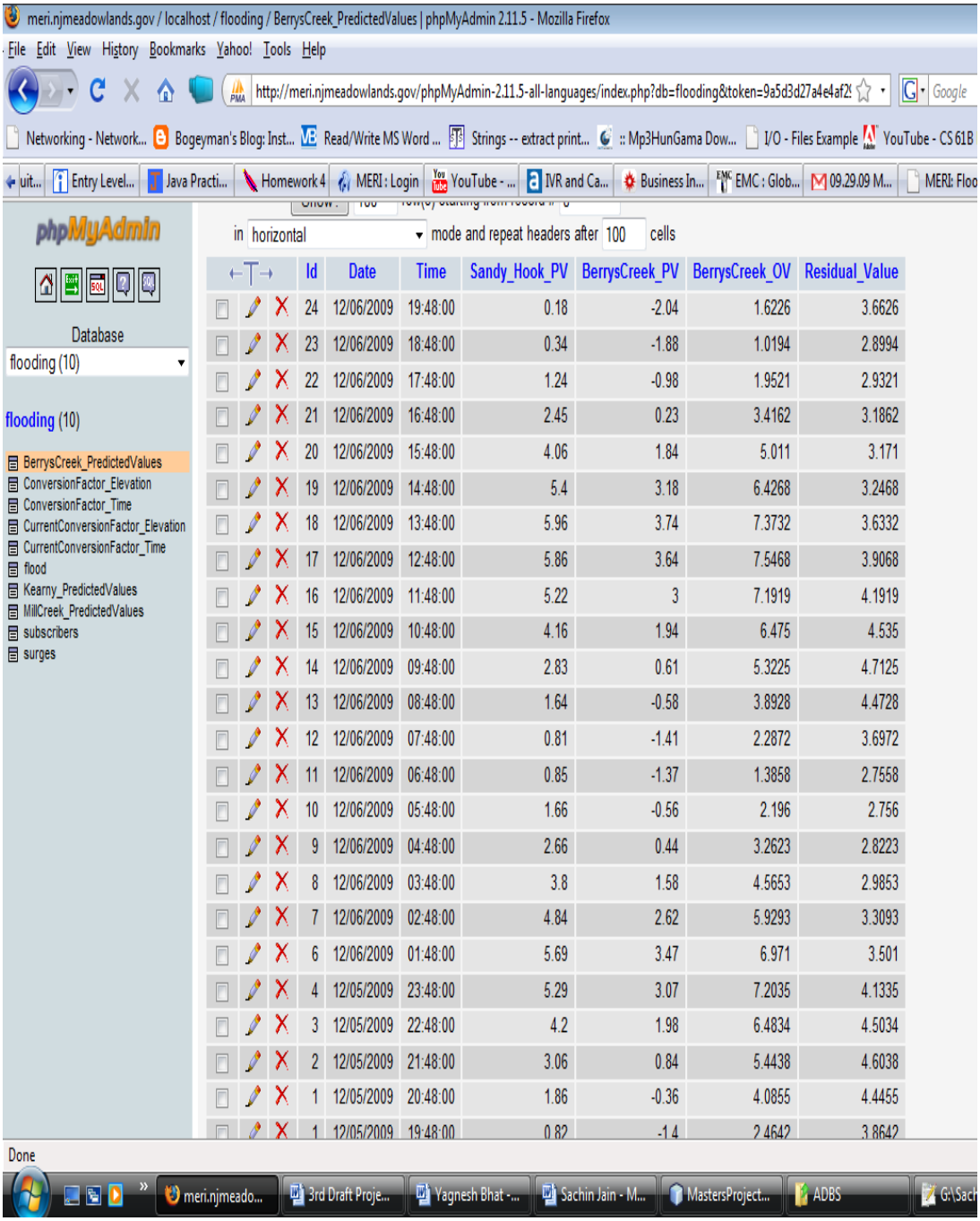


Figure 4 Database table for the Storm surge data at Sandy Hook and Predicted flood levels at Barry's Creek

1.3 Automated Flood Warning Generation and Notification Module

We have implemented the warning notification module. When the surge level exceeds threshold values for different flood levels for each monitoring station, the system automatically generates email alerts and sends them to the list of subscribers. The alert message contains information regarding the

observed and predicted surge level at one of the four locations. This enables the emergency managers to take appropriate actions.

Depending on the predicted level of the flood, the warning messages will be directed to different types of subscriber group. The warning message also contains the link to the designated flood map so that the subscriber could look at the electronic flood maps.

The warning messages are categorized into three types, and the corresponding warning email messages are shown in table 2:

Table 2: Flood warning types and warning messages

Warning Categories	**Water level**	**Flood maps**	**Sample Warning messages**
Minor tidal flood warning	5.45ft – 7.48ft	4Ft flood map	A MINOR TIDAL FLOOD IS POSSIBLE IN 2-3 Hrs FROM NOW FOR AREAS SOUTH OF BERRY'S CRREK (See Flood Map 4 Ft). The forecast is based on the expected tidal flooding during the next 2-3 hours according NOAA's prediction. Additional flooding is possible thereafter. Stay tuned to the NOAA weather radio. To see NJMC flood maps for a range of water levels go to: http://meri.njmeadowlands.gov/njmc/flooding.php
Significant Tidal flood	7.49-8.18ft	6ft flood map	A SIGNIFICANT TIDAL FLOOD IS POSSIBLE IN 2-3 Hrs FROM NOW FOR AREAS SOUTH OF BERRY'S CRREK (See Flood Map 6 Ft). The forecast is based on the expected tidal flooding during the next 2-3 hours according NOAA's prediction. Additional flooding is possible thereafter. Stay tuned to the NOAA weather radio. To see NJMC flood maps for a range of water levels go to: http://meri.njmeadowlands.gov/njmc/flooding.php
Severe Tidal Flood	>=8.19ft	8 ft flood map	A SEVERE TIDAL FLOOD IS POSSIBLE IN 2-3 Hrs FROM NOW FOR AREAS SOUTH OF BERRY'S CREEK (See Flood Map 8 Ft) The forecast is based on the expected tidal flooding during the next 2-3 hours according NOAA's prediction. Additional flooding is possible thereafter. Stay tuned to the NOAA weather radio. To see NJMC flood maps for a range of water levels go to: http://meri.njmeadowlands.gov/njmc/flooding.php

Figure 5 illustrates the 2 feet flood map that shows the areas of flooding in Kearny

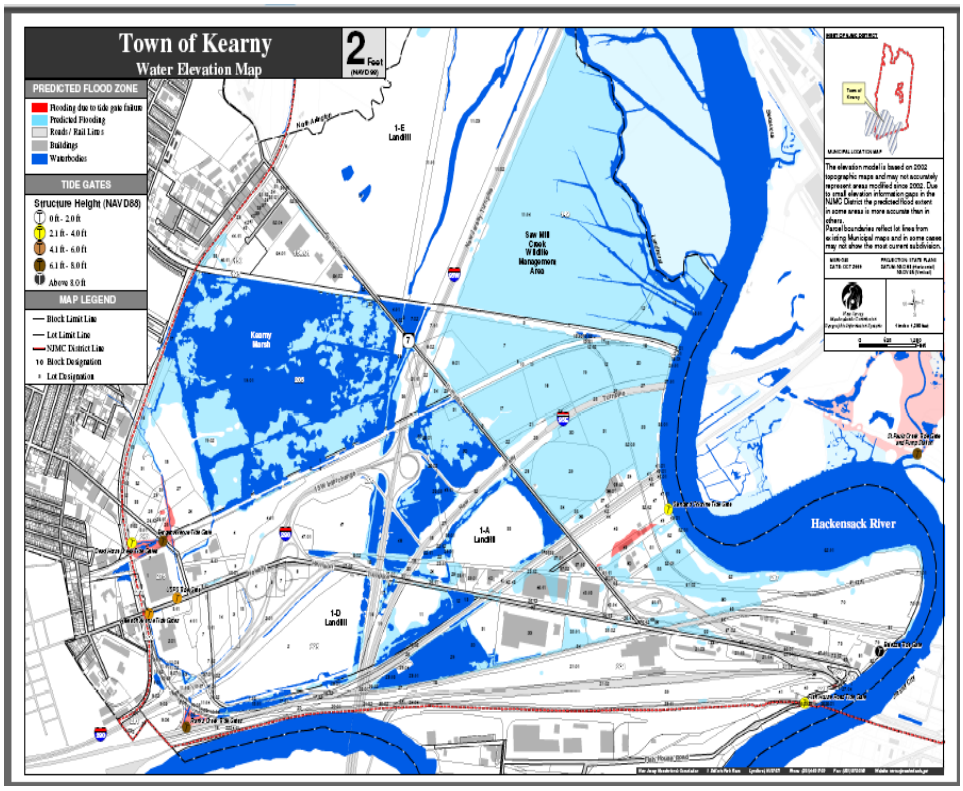


Figure 5 2ft Flood Map of Kearny

The warning system distributes the flood warnings to email distribution list that includes NJ Meadowlands municipal officials as well as MERI staff members. Figure 1 shows the warning message that was sent over via email.

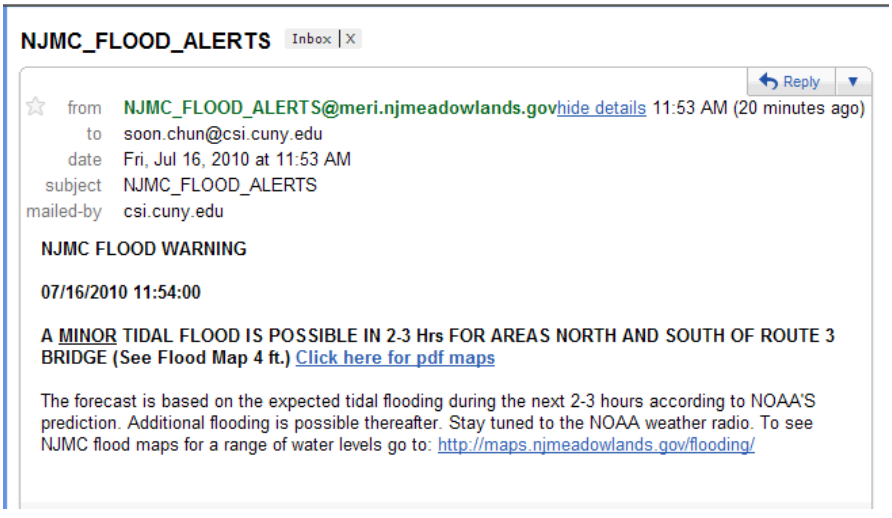


Figure 6 Flood Warning Messages received in Email

1.4 Subscriber Management Tool

In order to keep track of the mail recipients, we have constructed the backend database for the subscribers who will be receiving the warning messages. It keeps track of:

Subscriber_ID: The unique identifier of the subscriber
Email : Email address of the subscriber
Name : The name of the subscriber
Town : Town name where the subscriber works
Join_date : The starting date for the subscription
Title : Job title of the subscriber
Group : Subscription type (Internal vs. external)

The subscribers are emergency managers in the municipal governments within the NJMC area, and MERI Website Administrators. The system continuously monitors the storm surge level and the subscribers get automatically notified by storm surge warning via email alerts. The Administrators have the ability to add, edit and remove subscribers.

In order to avoid the fatigue of warning messages, the minor level warning messages are sent to internal groups only, while the significant and severe warnings are sent to both internal and external users.

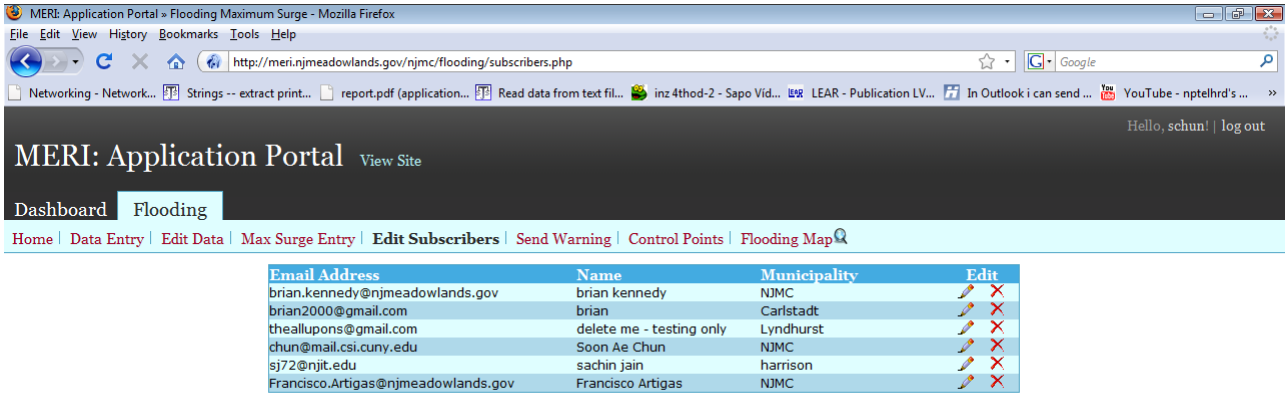


Figure 7 Subscriber Management Tool

1.5 Flood Prediction Calibration Module

The local flood warnings are based on the predicted water levels from Sandy Hook using the conversion factor discussed in section 1.2. The predicted values are compared with the actual observed values at three monitoring stations. The errors (i.e. observed value –predicted value) are captured. When the errors are large, the administrators should be able to adjust the conversion factor. We have developed a tool that allows the user (administrator) to view the flood prediction errors with the actual observation data of each of the three stations. This tool will help the user to study and analyze how the prediction error can be reduced. After detailed analasys the user can change the conversion factor of the station which will result in reduced predicted error for that station.

Figure 7 shows the interface that shows Date, Time, Observed Value at Sandy Hook, Predicted Value and Observed Value at the Station and Residual Value (Error) which is Observed Value minus Predicted Value at the station.

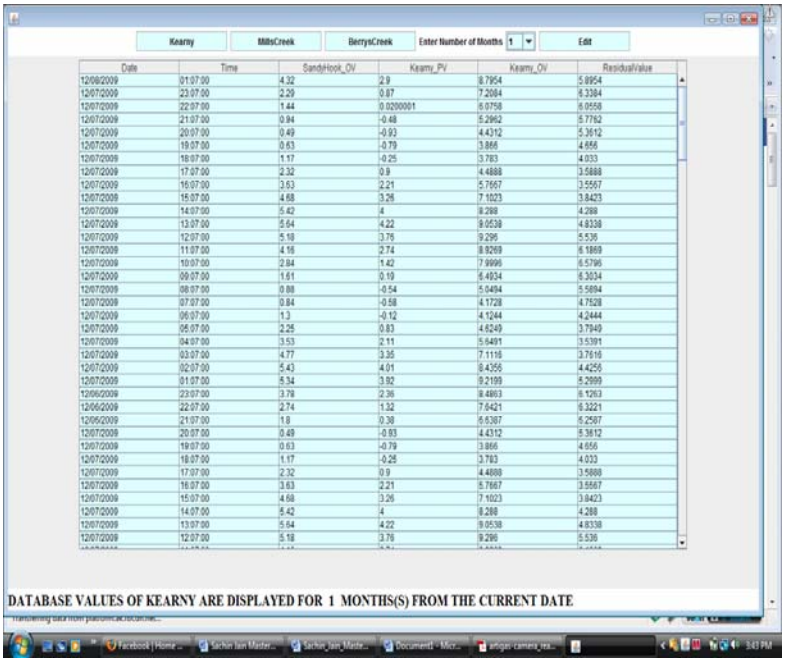


Figure 8 Predicted and observed water levels with errors

Figure 8 is a tool where a user can change and readjust the conversion factors and time delays for each station.

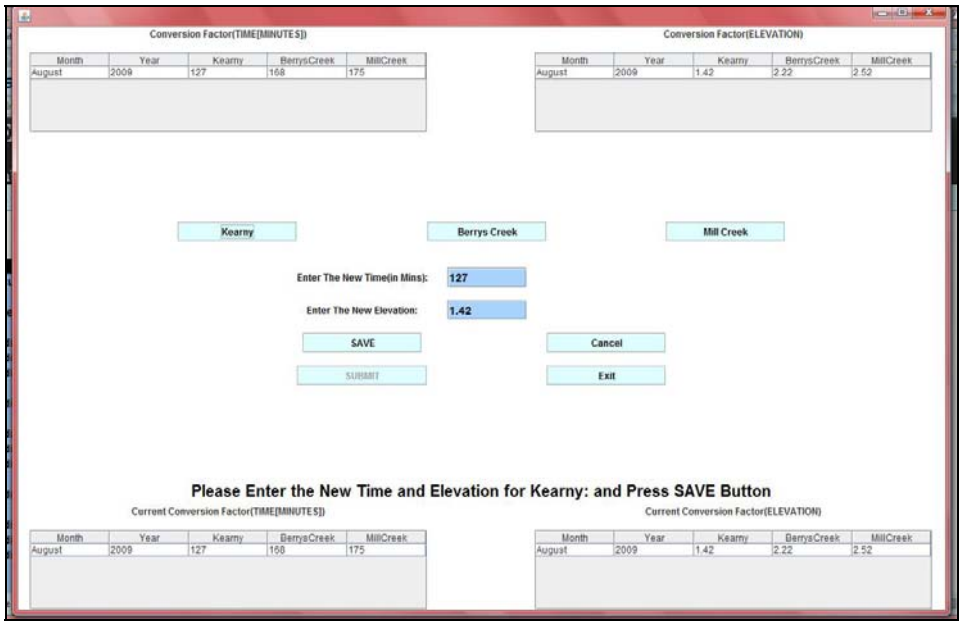


Figure 9 Conversion Factor Modification Module

2. Citizen Community Portal for Flood Management using Web 2.0.

The flood warning system provides a useful tool for flood management decision makers, the system is mostly for the government officials only. We have tried to involve the citizens in flood situation awareness and management efforts, using the Web 2.0 social media. The flood warning messages are not only disseminated to the emergency managers of the municipalities, but also to the citizens, by using a micro-blogging tools such as Twitter. The citizens can benefit from the early warning systems, instead of relying on the traditional notifications through public broadcasts, e.g. radios or TV's. In addition, in the event of the flooding, the flooding situation assessment is crucial for the appropriate response. Thus, we have developed a citizen community portal where the citizens in and around the NJMC region could communicate with the officials as well as other citizens, upload the flood situations via images, and share resources, including services, expertise their assets such as boats or trucks. We consider that the citizens should be notified as early as possible for the impending flood and play an active role in flood management by providing their resources, instead of resorting only to the government resources. We focused on the collaborative aspects of the citizens in the flood management before, and during the flooding events. Figure 10 shows the community based flood information sharing portal:

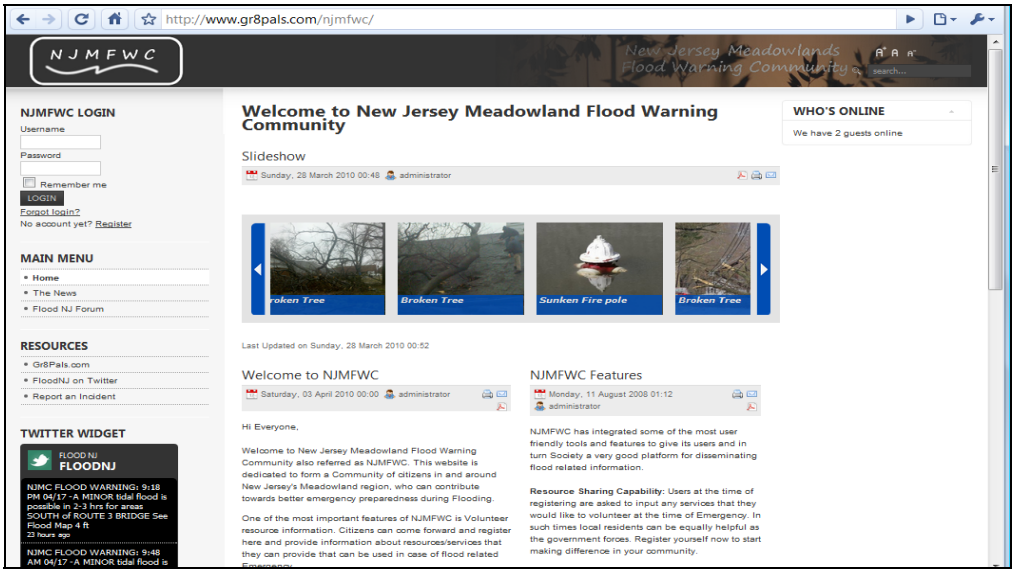


Figure 10 Community-based Flood Information Sharing Portal

This citizen community portal has been developed with an open source Content Management System to manage flood related information sharing, and features the functionalities such as:

1. Twitter-based Flood Warning Dissemination to large group of interested people.
2. Report and share the flood incidents to enhance the flood situation awareness.
3. Services and Resource Sharing module for volunteers to register, search and notify available services, expertise and other resources and assets.
4. Forum to discuss and share flood related information.

2.1 *Disseminating the Flood Warnings using Twitter*

In addition to email warnings to the municipal officials, we extended the implementation that takes the output of the warning system's flood warnings and micro-blogs to the twitter account using Twitter API. Twitter is a social networking and micro blogging service that enables its users to send and read messages known as tweets. Tweets are text-based posts of up to 140 characters displayed on the author's profile page and delivered to the author's subscribers who are known as followers. Twitter has very fast become a convenient way of sharing information and updates and also has become very popular among users. The flood warning messages twitted at FloodNJ twitter account is shown in figure 11.

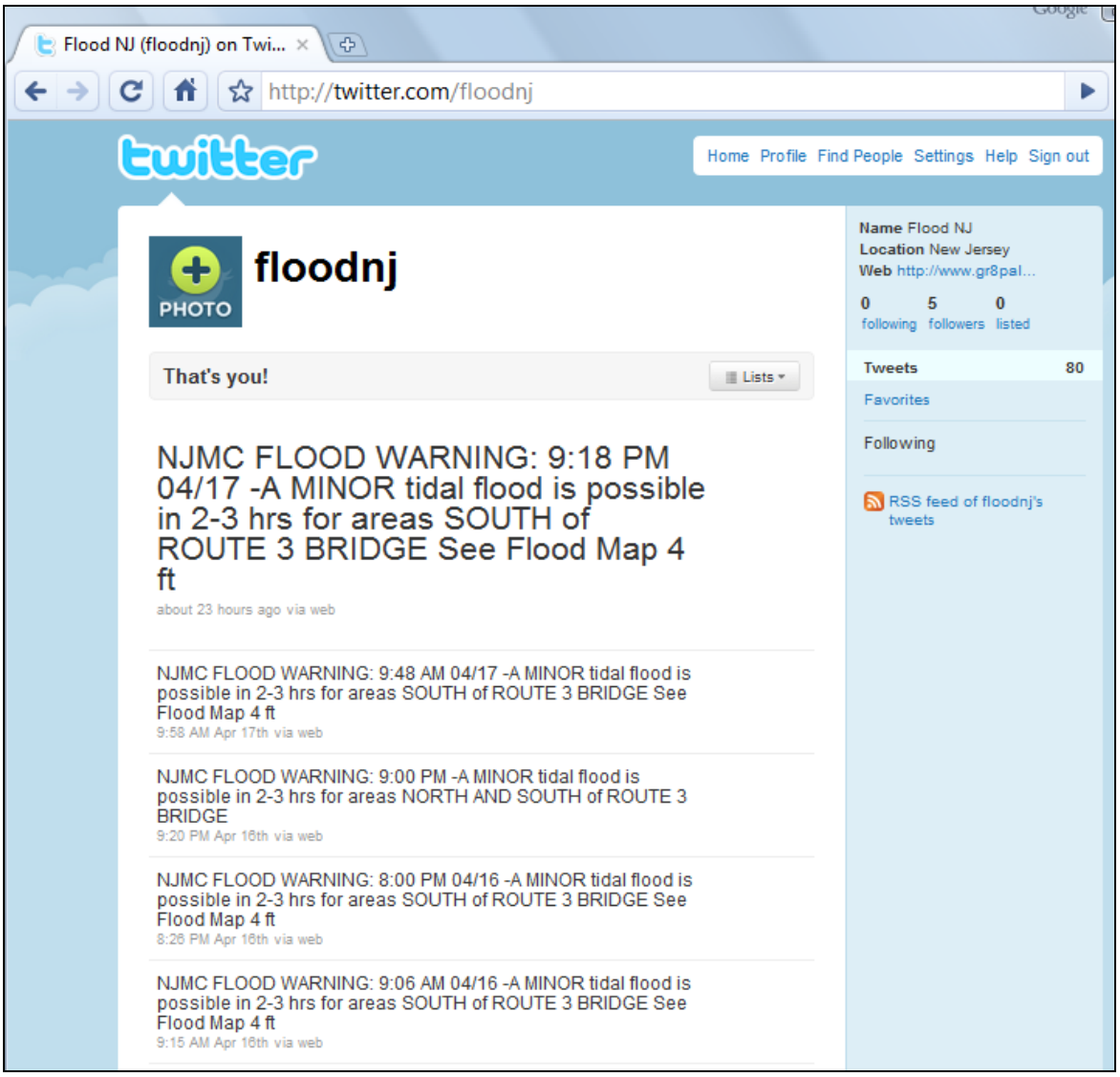


Figure 11 Flood Warnings disseminated via Twitter

The tweets can be forwarded to one's mobile devices, which allows sharing of information in real-time. The following figure 12 shows the flood warning tweet on a mobile phone. The citizens can now follow this twitter sites for getting notified with the upcoming flood warnings, and the warnings can delivered to their mobile devices.

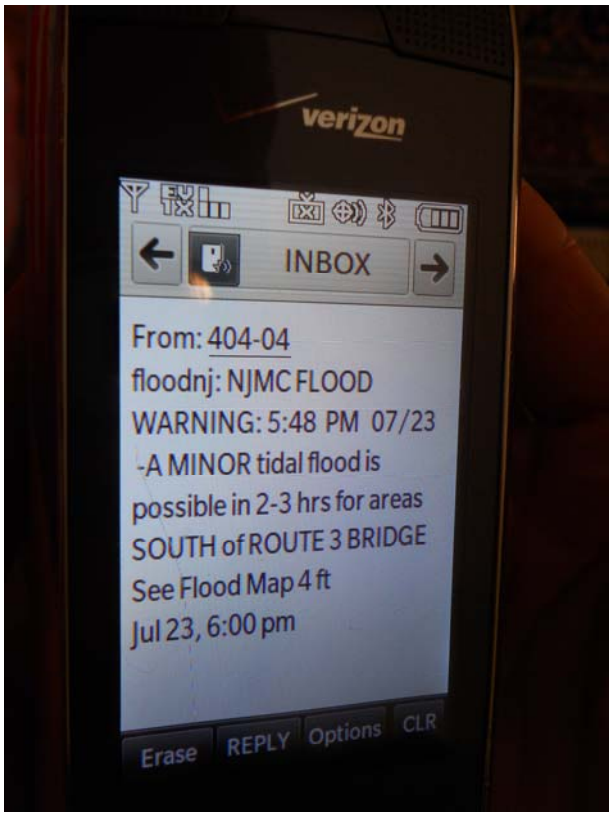


Figure 12 Twitter flood warning message sent to a mobile phone

2.2 CROWDSOURCING TO REPORT AND SHARE FLOOD INCIDENTS

During the flood incidents, the citizens can now report the flooding incidents that they witness through the web-based map interface. We have implemented a popular open source web application to report the flood related incidents.

Users can use the incident reporting tool to report an incident they witnessed. They can upload images, associate videos and a news source of an incident. Each incident report should specify a location and an incident type. The location of the incident can be explicitly specified via a form-based interface or implicitly via selecting a location on the map. They can also search for the exact place by using the 'Find Location' search bar below the map. Figure 15 shows the incident reporting interface.

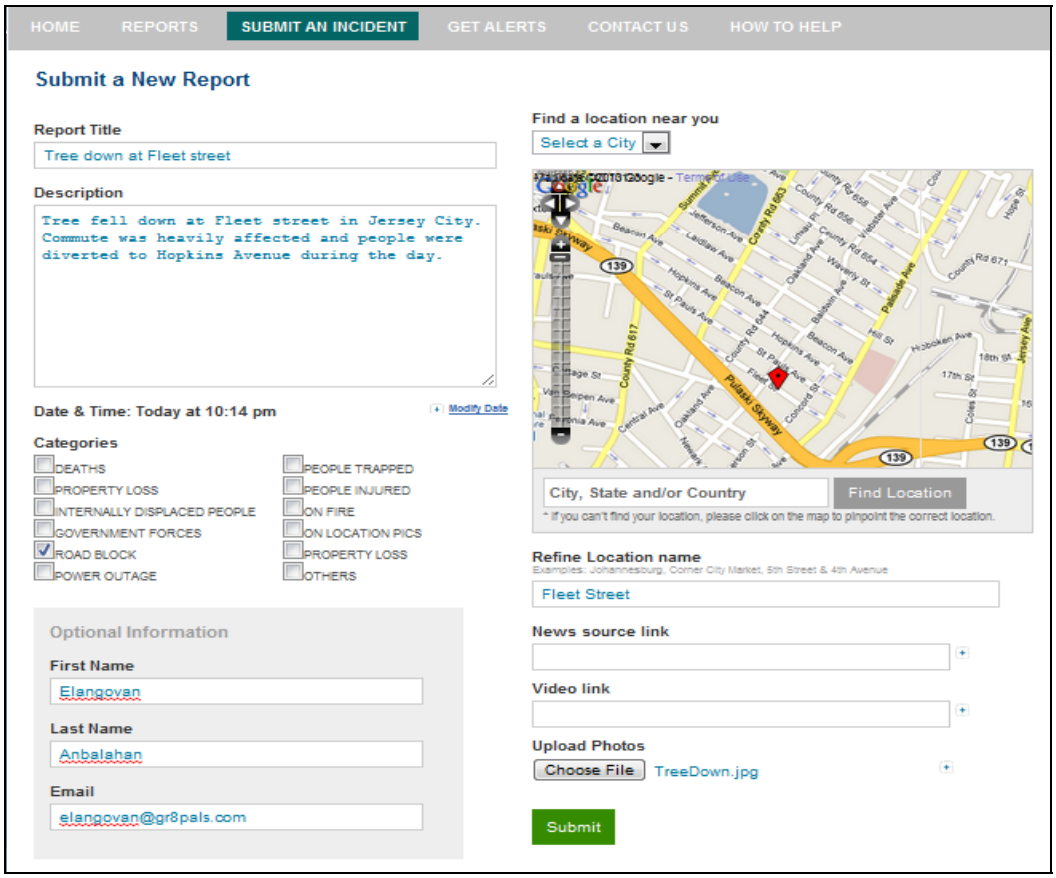


Figure 13 Incident Report Interface

Figure 14 (a and b) shows the incidents reported by the citizens. The reported incidents are depicted by the red dots on the map. Figure 14 (b) shows that the incidents can be filtered by category or type such as Power Outage, People Injured, Road Blocks, etc. In this case, only road block related incidents are shown by selecting the "road block" incident type. The user can click on one of the incidents to see the list of incidents reported at that particular location as shown in Figure 15.

Users can click the incident headings to see more details about the incidents as shown in Figure 16 with text description, images, documents and videos, etc. Users can also zoom in to see more accurately the place of the event, or they can zoom out to see other incidents reported in that area or region.

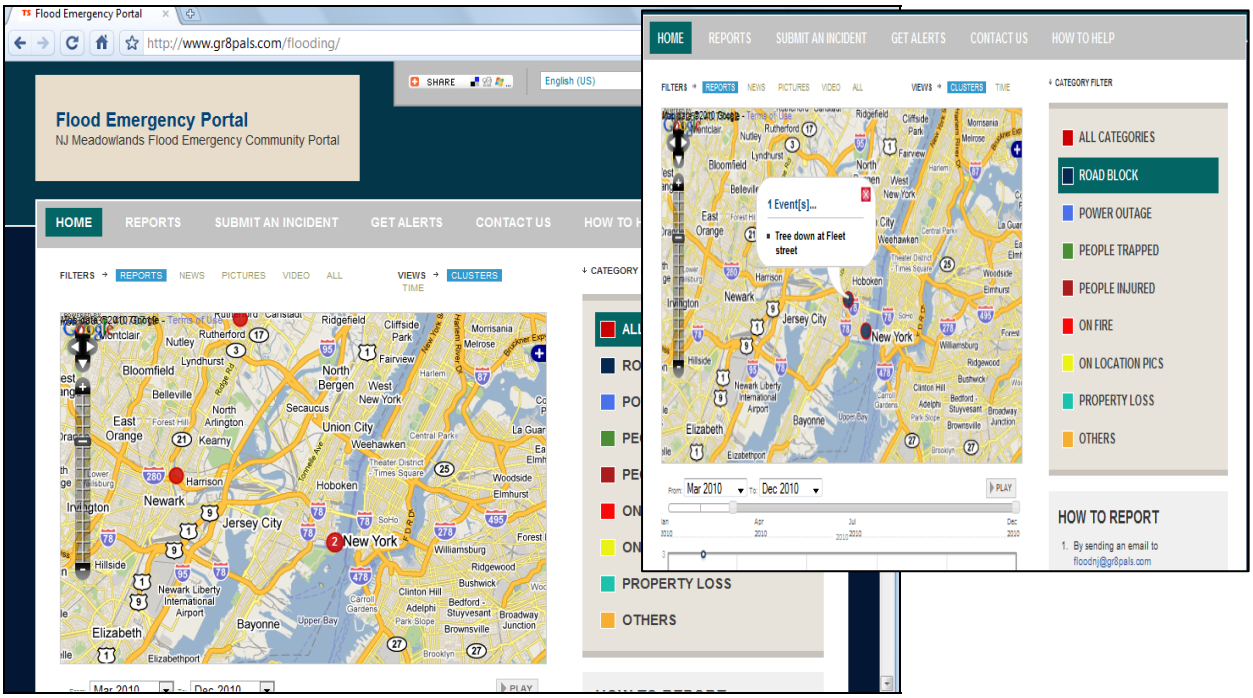


Figure 14 (a) Reported Incidents shown on a map; (b) View incidents by Category (road block)

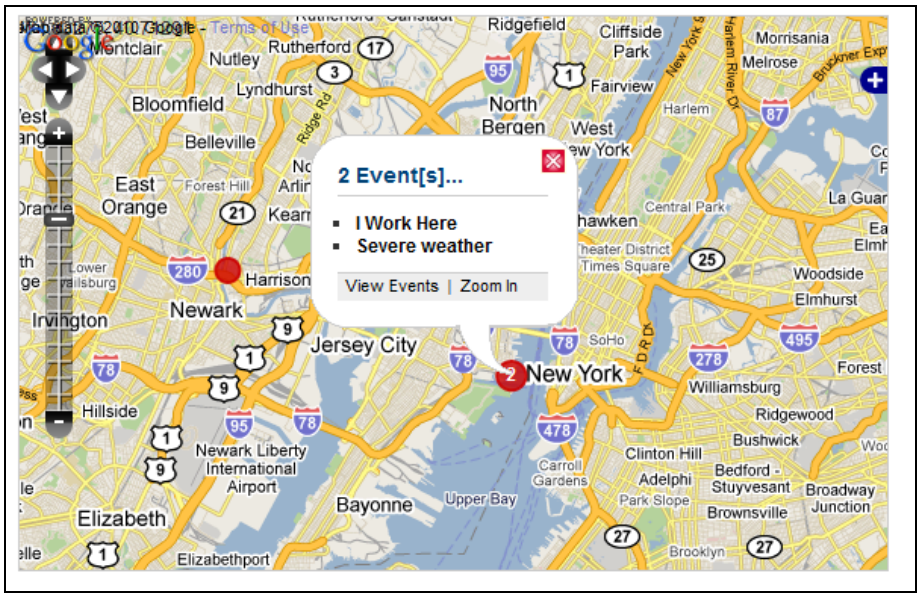


Figure 15 Flood incident details

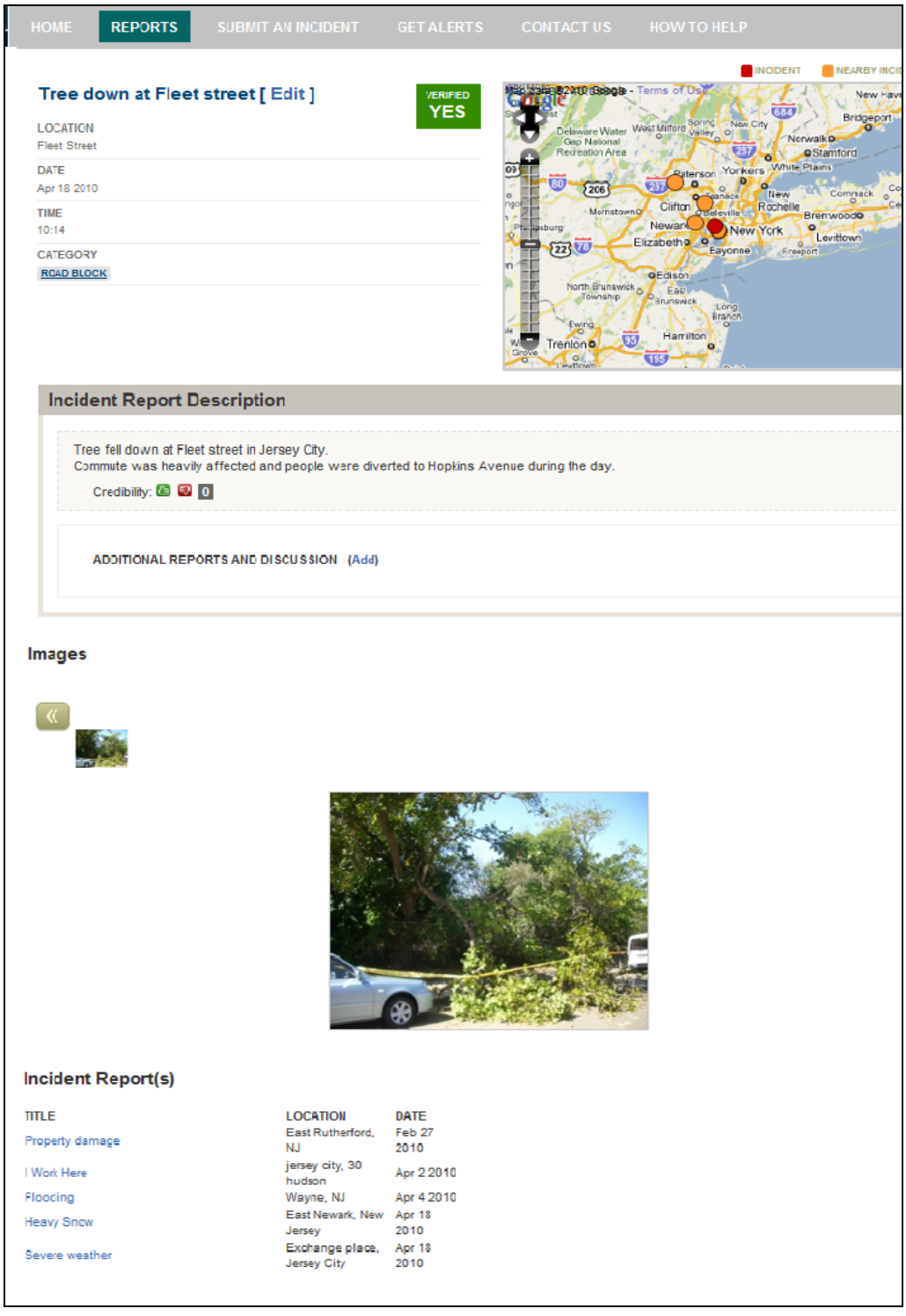


Figure 16 Incident Details with description and Images

2.3 CROWDSOURCING TO SHARE VOLUNTARY SERVICES AND RESOURCES

Resource Sharing is one of the key in managing the incidents. Traditionally, the governments and government authorized entities' resources are only utilized for incident response. We have implemented the resource sharing components that allows the citizens to volunteer their resources, such as services and equipments at the time of emergency. Local authorities and people can equally benefit from this feature for better preparing and combating any emergency situations and at responding to the flooding-related incidents.
For this purpose we have implemented the resource and service registration, search and browse available services and resources, as well as location-based resource search and request components.

A: SERVICES AND RESOURCES REGISTRATION

When registering to the community portal, the citizens can select any voluntary services and or equipment he/she wishes to share at a time of emergency (See Figure 17). The registered members can search other members, services or equipment. The types of volunteer services include Fire Fighter, Doctor, Electrician, Plumber, etc and equipment resource includes Handsaw, Bulldozer, Ambulance, etc. Users can add new services and equipment by filling in 'Did we miss any services' field.

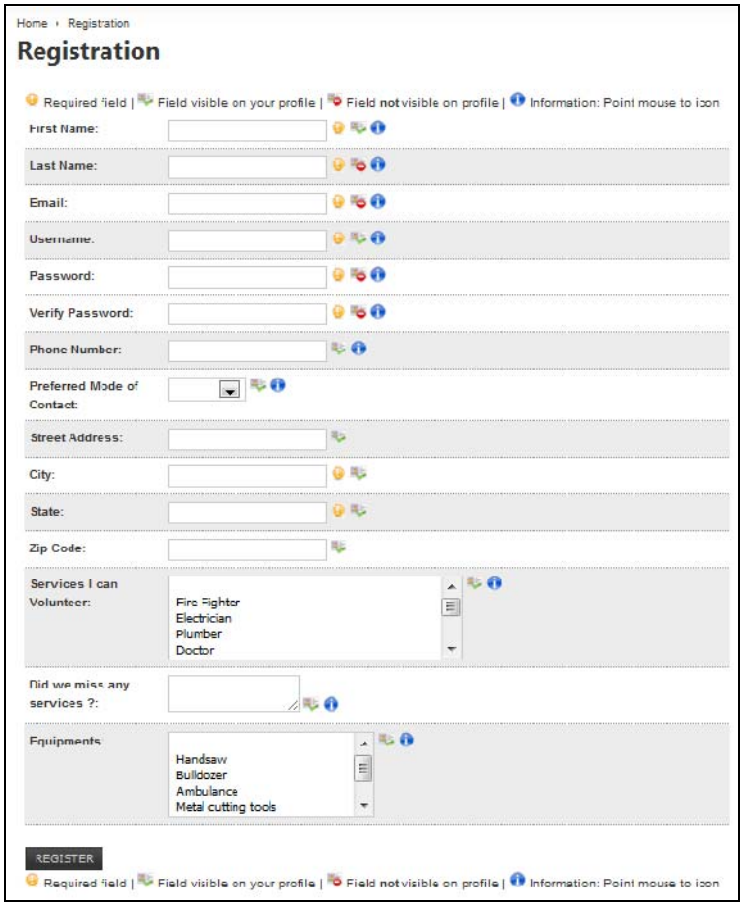


Figure 17 The user registration for volunteer services and resources

B. SEARCH AND BROWSE VOLUNTEERS, SERVICES AND EQUIPMENT

Once logged on as a registered member, citizens have the ability to search other users, and for resources volunteered by fellow citizens (Figure 18) and to browse other member's profiles, which shows the member information including volunteer services and resources. In addition the resources can be browsed in the map interface as shown in Figure 19.

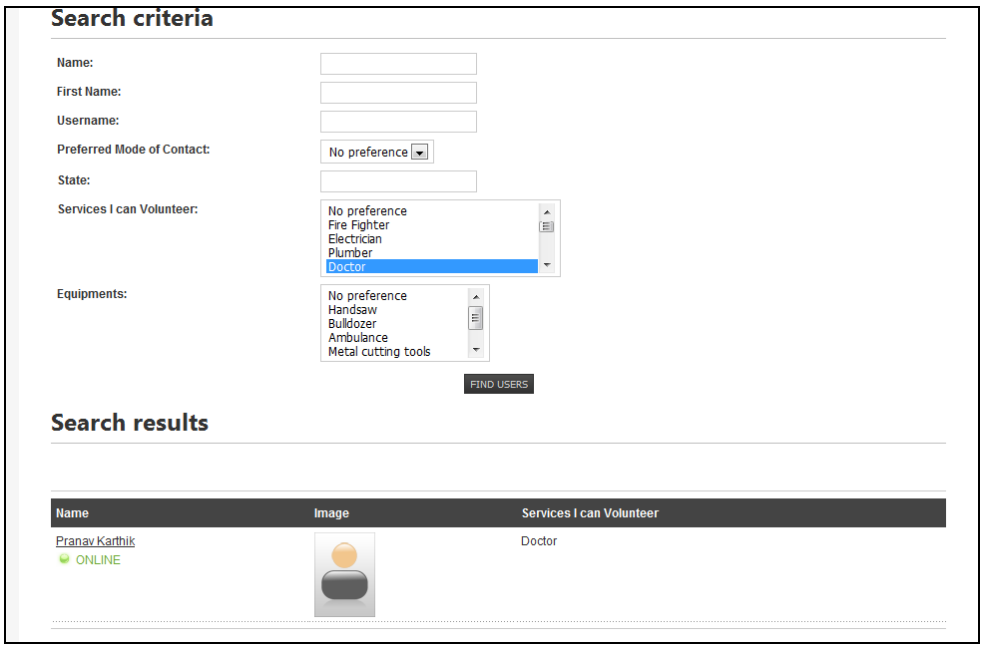


Figure 18 search by services and resources and search result matching with the criteria

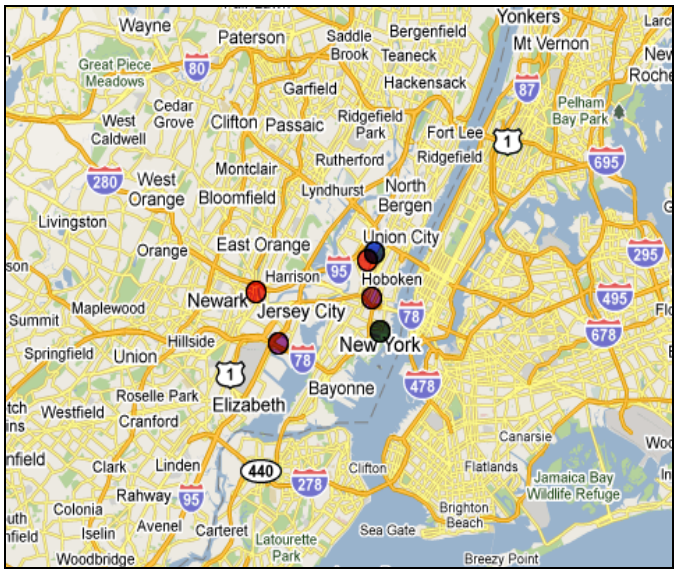


Figure 19 Map visualization of resources

C: Service and Resource RESOURCE REQUEST AND ALERTING SERVICES

Any user can search for services and or equipment volunteered by other users by location and can request an alert email whenever the service or equipment becomes available.

Users can select from the available list of services and resources, and can enter city and state information where they are looking for these resources. (See Figure 20). The search results shown in the bottom of Figure 19, will list the services available in the selected area. It does not disclose any information of the member who has volunteered to offer the service. This is done to keep the anonymity of the members intact.

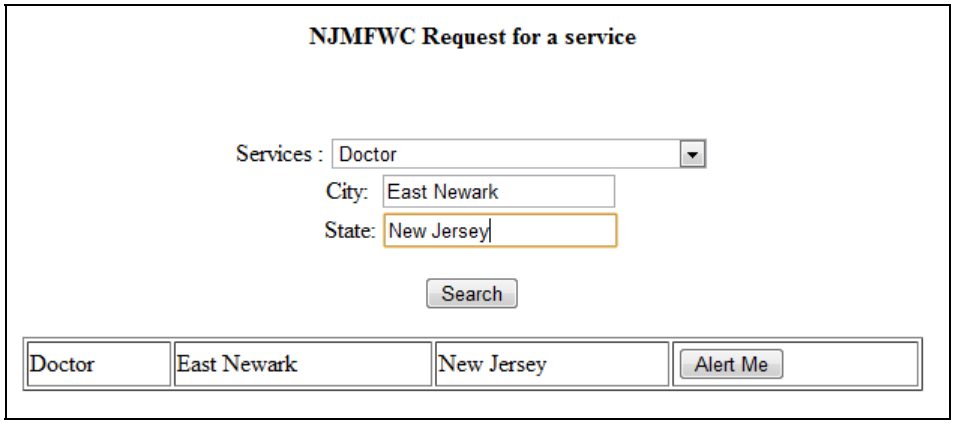


Figure 20 The Service Request by location and the result

Users can choose to receive email alerts when a particular service becomes available, by clicking on the 'Alert Me' button. Clicking 'Alert Me' brings up a form (Figure 21) wherein a user can enter his/her contact details (Name and Email). When the service or resources are available, the email will be sent to the requester. This promotes citizen to citizen as well as citizen to government collaboration in responding and managing the flood incidents.

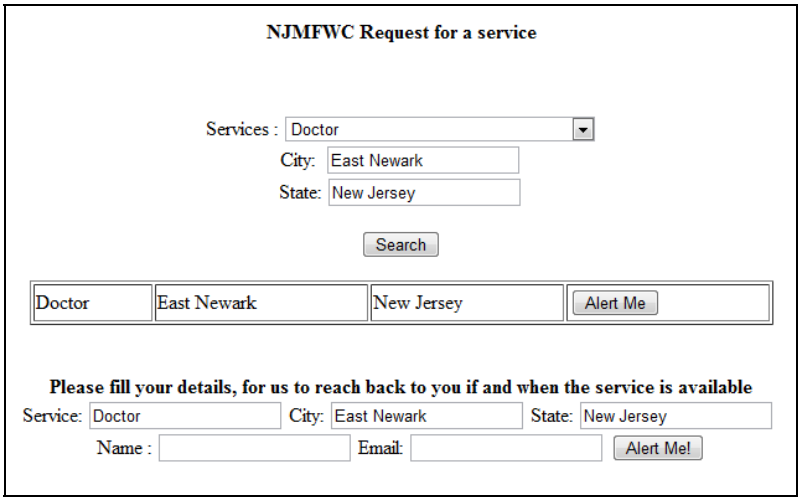


Figure 21 Service/resource availability alert service

2.4 FORUM FOR DICUSSIONS

The citizen-based flood community portal also provides an online bulletin board for online discussions. The members post messages and comment on messages of others. Figure 22 shows the forum interface.

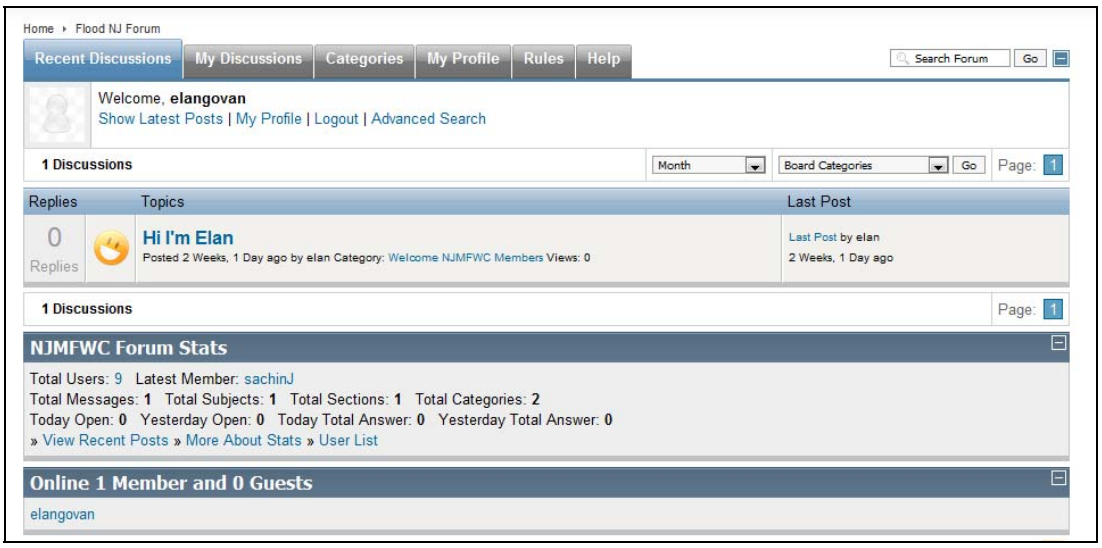


Figure 22 Online Discussion Forum for Communication and Information Exchange

3. Flood Gate Water Level Sensor Implementation

The tide gate monitoring module is implemented to monitor and report water levels around tide-gates in real-time by the project subawardee, Gotham Analytics informatics. The two tide gate sites (East Riser and West Riser tide gates) are now equipped with the sensors and data transmission capabilities. We have tested the sensor data capture capabilities and data transmission capabilities. Several site visits were conducted for implementing the sensors and data logger and data transmission hub. The future work should include the data calibration and data integration and visualization for accurate flood levels and verification of tide gates' functionalities.

The following figure shows the photograph of the West Riser tide gate with implemented sensor and data transmission devices.

Figure 23 Tide Gate at West Riser with Water level Sensor and Data Transmission Hub

This sensor system is according to our initial specification and architecture as shown in Fig 4.

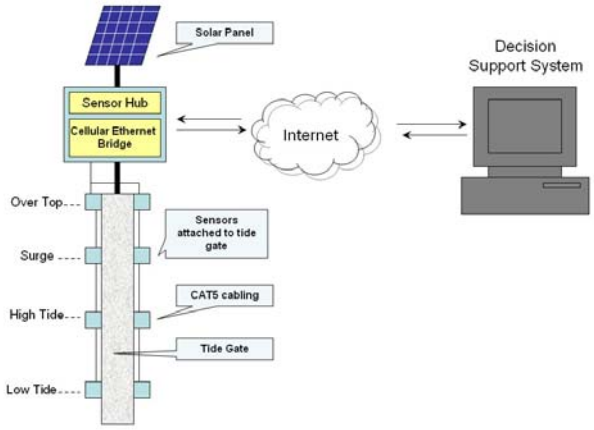


Figure 4 Arrangement of sensors on the tide gate showing enclosure with Sensor Hub and Ethernet Bridge. A solar panel powers the sensors and enables wireless communication

The hardware was purchased and implemented for tide gate water sensors. The list consisted of:

- 2 RDU's one for each tide gate installation
- 2 analog sensors (Stevens Water Monitoring) 4 - 20 milliamp output for West Riser installation
- 2 analog sensors (Keller America) with 0 - 3 volts output for East Riser installation
- 150 ohm resistors to convert output from milliamps to volts for West Riser installation
- wire crimpier to modify CAT 5 cables
- a power inverter between DC and
- lantern battery used as a power source to test the sensor

4. Partcipants:

4.1 Subcontractors

- Yogi Sookhu: He has purchased and implemented the prototype flood gate sensors that can measure the water levels at two flood gates. This captures the water level at a flood gate and send to the base station to monitor the water levels and to monitor the functionalities of the flood gates.

- James Geller: Professor of Computer Science at NJIT designed and guided the implementation process for the flood warning system and supervised the progress of the two masters students.

4.2 Student Participants

- Fabiola Bois: An undergraduate student at College of Staten Island/CUNY conducted literature survey on the water level prediction models. She is a minority female student with good academic standing.

- Sachin Jain: Master's Student at NJIT. His master's project entitled "DATABASE ACCESS AND MATHEMATICAL MODELING FOR COASTAL FLOOD WARNING SYSTEM" has been completed with the implementation of the flood warning system and the database backend.

- Elangovan Anbalahan: Master's student at NJIT. He has completed a study on "A Community based flood Management System using WEB 2.0 Technologies," as a part of his master's project.

5. Publications

- F. Artigas, S. Chun and Y. Sookhu (2009) Real-time Ocean Surge Warning System, Meadowlands District of New Jersey, *Proceedings of the 10th International Conference on Digital Government Research* : pp 216-222.

- S. Chun & F. Artigas (in preparation) Real-time Flood Warning and Management using Citizen Participation.