Tide Gate Sensor Network as a Forensic Tool:
Establishing Facts during Superstorm Sandy

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ABSTRACT
This study presents a Sensor Network based Tide Gate Monitoring System (SensorTGMS) that automatically collects the real-time water levels at tide gates in the New Jersey Meadowlands District where ninety percent of which lies within two feet of the high water mark. We report our experience of developing the SensorTGMS, and how the real-time water level data from the sensor-enabled tide gates provide water level alerts for government officials and citizens for planning evacuations and allocating resources by identifying risk areas in timely manner. The data, augmented with the social media data shared by citizens on their flood incident episodes can provide real-time situation awareness and promote community-based incident management during and after a disaster. Additionally, the SensorTGMS data supports the objective unbiased account of the progression of flood events. The animated visualization of the water levels over a time line can be a powerful tool for understanding where and how residents and infrastructure were affected by a high energy rain event and/or a tidal surge. This objective data captured by the system can be used as a forensic tool for understanding the weak points of coastal defenses and to assess the magnitude of the flood damages.

Categories and Subject Descriptors
H3.5 [**Online Information Services**]: data sharing, J7 [**Computers in Other Systems**] real time

General Terms
Management, measurement, performance, verification

Keywords
Sensor network, Tide Gate Monitoring System, Flood alerts, Superstorm Sandy, hurricane, emergency management, forensic analysis, hurricane damages, water level, water quality

1. INTRODUCTION
The New Jersey Meadowlands District is located in a low lying glacial valley of the lower Hackensack River where the average elevation is 2 foot above the high water mark. The District consists of 14 Municipalities and each with their limited resources independently oversees flood prevention structures. They are assisted by a regional planning agency (NJMC) that has helped maintain ditches and tide gates. An extensive network of legacy berms constructed during the 1930's for mosquito control purposes along with a system of tide gates make up the coastal defense system protecting residential and industraila areas from sea surge events.

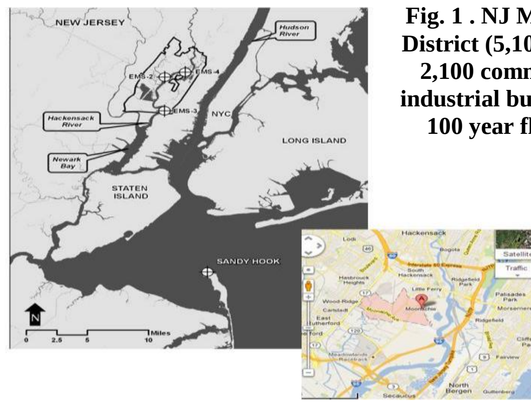

Fig. 1 . NJ Meadowlands District (5,100 homes and 2,100 commercial and industrial buildings in the 100 year flood plain)

2. TIDE GATE SENSOR NETWORK
Tide gates are structures that prevent the passage of water from the sea side to the land side while allowing the free flow of water from the land to the sea. They may malfunction (e.g. clogs from debris) resulting in roads, parking lots and buildings flooding. We have developed the Tide Gate Sensor Network for the tide gates at various locations in the District (see Fig. 2a). Each sensor station consists of pressure transducers and solar powered data loggers equipped with satellite phones for data transmission (see Fig. 2b and 2c).

3. FLOOD INFORMAION SYSTEMS
The Tide Gate Monitoring System has been prototyped and implemented to monitor and share real-time water-levels around tide gates throughout the District. Fig. 3 shows the sensor-based tide gate monitoring system that provides water level data in a tide gate in Moonachie.

In addition to the tide gate sensors, NJMC has sensor-based water monitoring stations to collect real-time water levels and water quality parameters from four different locations of the lower Hackensack estuary. This water level data and water quality data is used to alert citizens, scientists and government officials for potential issues with water quality and sea surge events that may flood residential and industrial areas. Our previous work in [1][2] presented the Flood and Environmental Warning System used to generate warnings, the visualization tools and maps to alert local government officials, citizens or scientists.

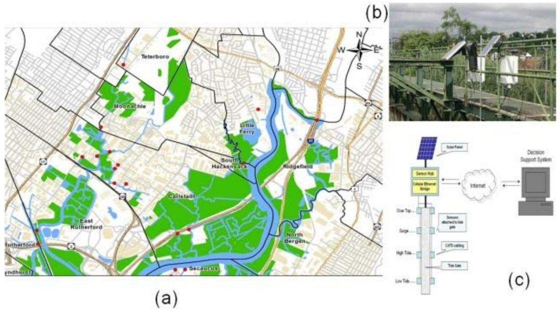

Fig. 2 (a) Tide Gates Locations (red dots) in Moonachie, Carlstadt, Little Ferry towns of tidal basin 1.5 feet; (b) a Tide Gate with Solar-powered Sensor Hub; (c) Sensors on a Tide Gate: low, high, surge, and over top levels.

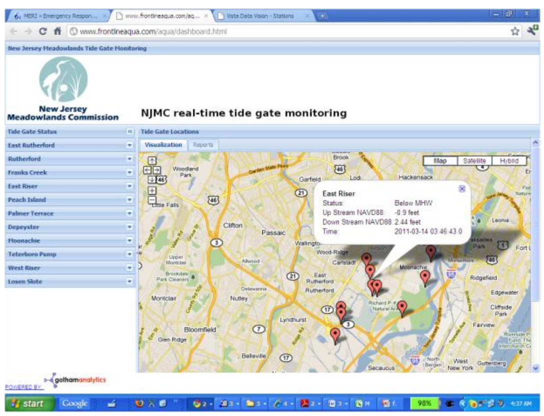

Fig. 3 Tide Gate Information System from Sensor Network

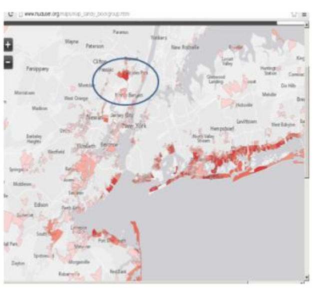

Fig 4 Sandy damage estimates by block group – HUD.gov (% Housing Units flooded)

>72,000 damaged or destroyed homes and businesses in New Jersey; ~1,400 in the NJMC District (~19%)

4. SUPPORT FOR FORENSIC ANALYSIS

Hurricane Sandy in 2012 was category 2 hurricane when it pounded the Northeastern states, but caused the most devastation with over 75 deaths and approximately $71.4 billion dollar damages in properties, let alone the psychological impacts. (In NJ, 37 death, over $30 billion damages and over 2.6million people without power for days and weeks.) In the early morning of October 30, the towns of Moonachie, Little Ferry and Carlstadt were underwater after a berm overflowed, prompting the evacuation of around 2,000 residents. Fig 4 shows the damage areas in New York and New Jersey region, where the three towns in NJMC area (in circle) are marked as severely damaged area even though it is quite inland from the ocean. It is important to investigate and establish the facts on what exactly happened with the berms and flooding.

The tide gate sensors' water level data has been logged by the tide gate sensors. These sensor data were used to show the town officials and the state and local emergency managers to understand the exact event sequences, and provided the powerful tool for damage assessment and for future disaster preparations. Specifically, the water level sensor data could show:

1. Unusually high tidal surge different from the usual tidal cycle (Fig 5a) that shows the water levels in the peak period of hurricane event
2. Surge water level (8.6 Feet) exceeded the mean berm height (5 Feet), lasting 6 hrs with above 7 ft. water level (Fig 5b)
3. Animation to show the water levels affecting towns over time and the risk areas with tide gate control levels. The flood event animation on LIDAR satellite map was constructed with tide gate data which were over the 8ft berms.

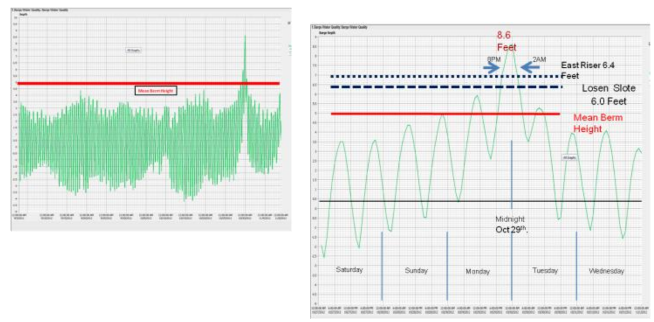

Fig. 5 (a) High water level during Sandy: ~ 4 - 5 feet above the highest tide.; (b) The surge proper (>7 feet) lasted for six hours

5. CONCLUSIONS

The tide gates that were equipped with sensors to measure the water levels of different tributaries in NJMC area was gathering data at the time of disaster events like Hurricane Sandy. The data not only provides the actual water levels over the hurricane period, but also could visualize the flood damage areas over time. This sensor network based tide monitoring system plays an important forensic tool for the emergency managers and government officials to understand and explain the flood events over time, and to better prepare for the similar future events. It also supports the damage assessment that can be compared with the estimated damage levels.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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