City of Hoboken, NJ
Sewer Monitoring Program Observations and Data Analysis

# FINAL REPORT NOV. 15TH, 2011
## PREPARED BY EMNET, LLC

## Executive Summary

In order to better understand its' flooding problem, the City of Hoboken, NJ installed an extensive sewer monitoring system throughout its collection system. The data from the monitoring system was then analyzed in order to determine:

- Which outfalls are able to overflow during the observed storm events
- The impact of drainage area interconnections on flooding during the observed storm events
- Where additional means of flood mitigation are necessary for a variety of storm events

The hydraulics of the collection system was analyzed for two groups of storm events: typical, medium storm events (that occurred between March and May, 2011) and large, severe storm events (including Tropical Storm Irene). From this analysis, the following conclusions were made:

*For Medium Storm Events*

- All of the detected flooding during these storm events occurred in the H1 drainage area, and it is expected that the presence of the Observer Highway ejector pump will prevent this type of flooding from happening in the future.
- In the analyzed medium storm events, no flows from other drainage areas entered the H1 drainage area. This may have been due to sediment buildup in the H1/H4 interconnection and blockages in the H1/H3 interconnections. This situation may change after the H1/H4 interconnection is cleaned.
- Flow did enter the H1 drainage area from the H3 drainage area in ensuing storm events. Given the relatively high elevation of the H3 drainage area, it was unlikely that this area would flood if these interconnections are completely closed off. Doing so would decrease the amount of flooding in the H1 drainage area.
- The southern regulators were unable to overflow during the medium storm events, but this only caused flooding in the H1 drainage area.
- The northern regulators were able to overflow during the medium storm events.

- If flooding occurred at Grand and Sixteenth during these storm events, an ejector pump may be necessary to prevent this flooding. This drainage area was able to relieve excess flows into the H5 drainage area during medium storm events, but it was unclear if this would prevent the possible flooding.

*For Large Storm Events*

- Flooding was detected in the H1, H4, and H5 drainage areas during these large storm events. Flooding also likely occurred in the H7 drainage area.
- The southern regulators were unable to overflow during large storm events.
- The northern regulators were able to overflow during large storm events.
- Flows from the H3 drainage area into the H1 drainage area aggravated the H1 flooding problem without providing any benefit to the H3 drainage area.
- Flows out of the H5 drainage area aggravated flooding in the H7 and H4 drainage area.
- The H5 drainage area was able to relieve excess flows into the H4 and H7 drainage areas. If these areas had ejector pumps, then no additional pump would be required to prevent flooding in the H5 area.
- Flow conditions during large storm events in the H1/H4 interconnection and the H4/H5 interconnections could not be determined due to removed or damaged equipment.
- Ejector pumps are necessary to prevent flooding in the H1, H4, and H7 drainage areas.

*Other Conclusions*

- After the completion of the Observer Highway ejector pump, it is expected that H1 drainage area will likely be able to withstand a 6 month storm event before flooding occurs.
- The collection system has the ability to store several million gallons of water before flooding begins.

## INTRODUCTION

The City of Hoboken, NJ has a combined sewer system, which conveys all of the dry weather flow to the wastewater treatment plant (WWTP). During wet weather, the storm runoff also enters the sewers, thereby exceeding the capacity of the WWTP. The system is designed to discharge this excess flow into the Hudson River at seven outfalls. Unfortunately, several portions of the City are below the high tide elevation of the Hudson River. When a storm occurs during high tide, the outfalls are not able to discharge the excess water into the river. This excess flow then backs up into the system, until it causes flooding in the lowest lying areas. Figure 1 shows the flood prone areas identified by the City.

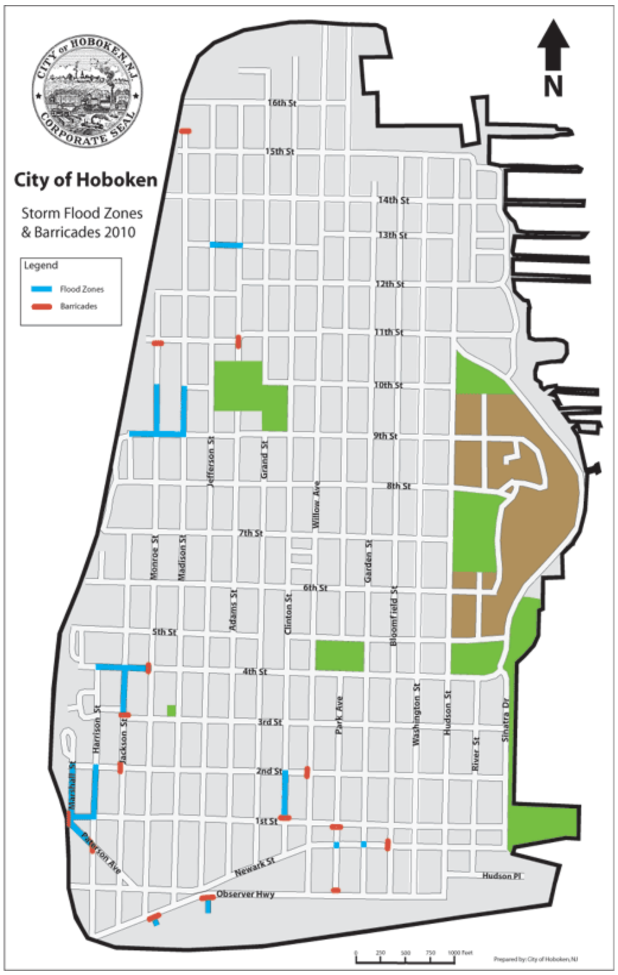


Figure 1. Flood Prone Areas Identified by the City (source:www.hobokennj.org)

The City's collection system is divided into seven primary drainage areas (see Figure 2). The flow in each drainage area converges into one large trunk line, which then conveys the flow to the regulator. During dry weather, these regulators send the flows to the WWTP via two lift stations, located at Fourth St and Eleventh St. During wet weather, these regulators send as much flow as possible to the WWTP, and then attempt to overflow the rest. When this collection system was modeled, only the trunk lines, the regulators, and the lift stations were included. Based on this model, it was determined that four ejector pumps were required to pump the water that would have overflowed during low tide into the Hudson River for storms that occur during high tide.

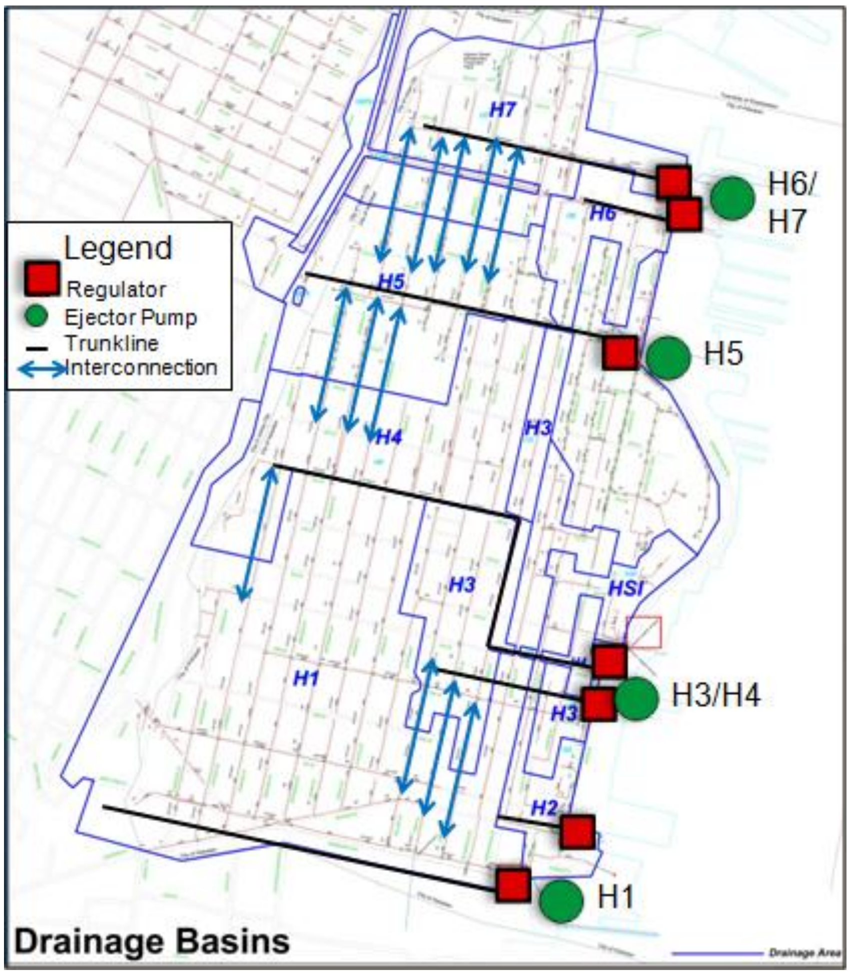


Figure 2. Hoboken's Drainage Areas, Regulators, Trunk lines, Drainage Area Interconnections, and Proposed Ejector Pump Locations

The City's collection system, however, contains several interconnections between the various drainage areas, also shown in Figure 2. These interconnections allow flows from one drainage area to freely enter another. This may mean that flows from non-flooding drainage areas may be aggravating flooding in a flood prone area or that flows from one drainage area may be able to be relieved into another drainage area in order to prevent flooding. The impact of these interconnections on the overall flooding problem is not fully understood.

The purpose of this study is to determine what mechanisms cause or aggravate the Hoboken flooding issue and which areas would require additional means of flood prevention during the observed storm events.

## OBJECTIVES

The objectives of this study are to:

- Deploy an expansive sewer monitoring system in order to determine the hydraulics in the collection system during a variety of storm events
- Determine which outfalls are able to overflow during the observed storm events
- Determine the impact of the sewer interconnections on flooding during the observed storm events
- Determine where additional means of flood mitigation are necessary for a variety of storm events

## MONITORING SYSTEM DESIGN AND IMPLEMENTATION

In order to accomplish these objectives, a sewer monitoring system was implemented at the following locations:

- The flood prone areas identified by the City
- Representative interconnections between the drainage areas
- Near each of the active outfalls
- At a point indicative of the tide elevation

Figure 3 shows the locations of the monitoring locations with respect to the flood prone areas identified by the City.

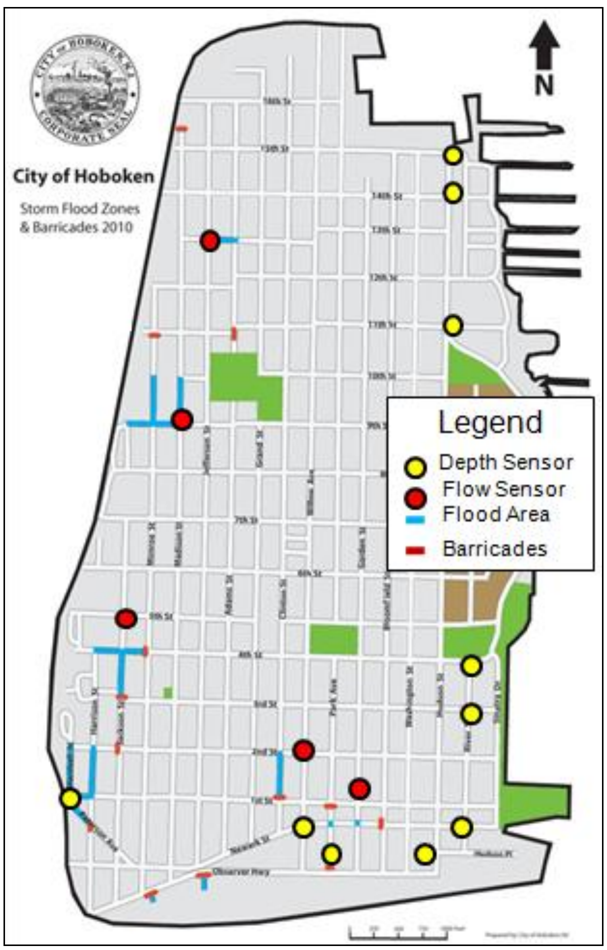


Figure 3. Location of Monitoring Points in Relation to Flood Prone Areas

Figure 4 shows the locations of the monitoring points with respect to the drainage area interconnections and the regulators. The regulator monitoring points were typically located one manhole upstream of the regulator chamber. The one exception was the monitoring point near the H7 regulator. This monitoring point is located in the overflow chamber on the downstream side of the weir. From this position, the monitoring point is able to measure the elevation of the Hudson River during dry and wet weather. A complete list of the monitoring point locations, their purposes, and the parameters measured at each location is listed in Table 1.

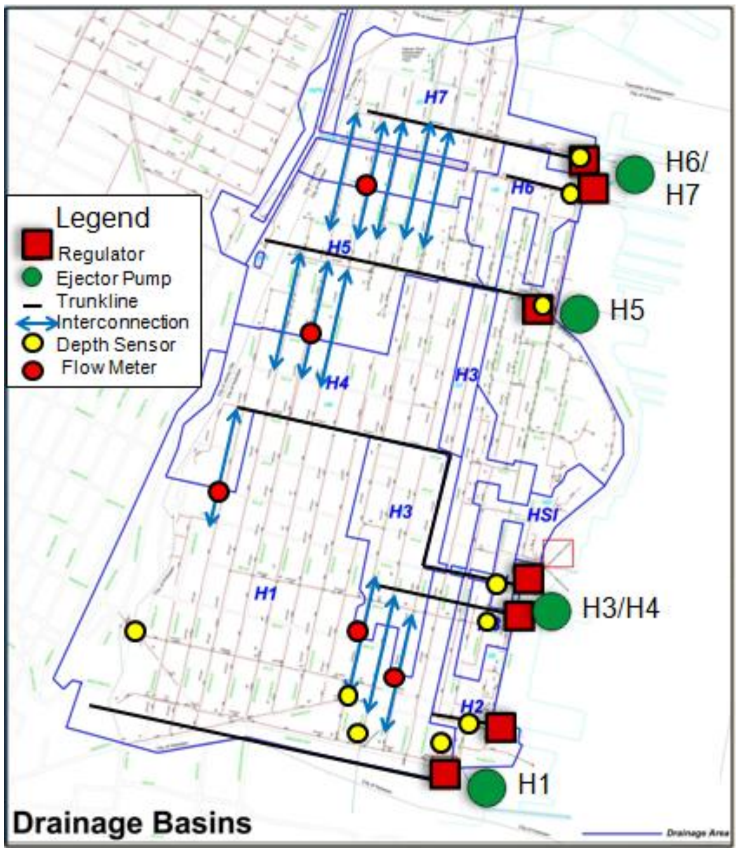


Figure 4. Location of Monitoring Points in Relation to the Interconnections and Outfalls

Table 1.

Location and Purpose of Monitoring Points

| Location | Purpose | Parameter(s) Measured |
|---|---|---|
| **Marshall and First** | Flood Prone Area | Depth |
| **Willow and Newark** | Flood Prone Area | Depth |
| **Jackson and Fifth** | Flood Prone Area/ Interconnection Between H1 and H4 Drainage Areas | Flow, Depth, and Velocity |
| **Madison and Ninth** | Flood Prone Area/ Interconnection Between H4 and H5 Drainage Areas | Flow, Depth, and Velocity |
| **Jefferson and 13th** | Flood Prone Area/ Interconnection Between H5 and H7 Drainage Areas | Flow, Depth, and Velocity |
| **Willow and Second** | Interconnection Between H1 and H3 Drainage Areas | Flow, Depth, and Velocity |
| **Garden and First** | Interconnection Between H1 and H3 Drainage Areas | Flow, Depth, and Velocity |
| **Park and Observer** | Upstream of Regulator H1 | Depth |
| **Court and Observer** | Upstream of Regulator H1 | Depth |
| **River and Newark** | Upstream of Regulator H2 | Depth |
| **River and Third** | Upstream of Regulator H3 | Depth |
| **River and Fourth** | Upstream of Regulator H4 | Depth |
| **Hudson and Eleventh** | Upstream of Regulator H5 | Depth |
| **Hudson and Fourteenth** | Upstream of Regulator H6 | Depth |
| **Hudson and Fifteenth** | Tide in Hudson River, Downstream of Regulator H7 | Depth |

The monitoring system was installed between March1, 2011 and March 3, 2011, and has been operational ever since. When the flow meter at Jackson and Fifth was installed, the pipe was found to be nearly full with sediment. This monitoring location was removed in June, 2011 for sewer cleaning, which is still ongoing at the time of this report. The monitoring point at Madison and Ninth was damaged during a street paving project when it was accessed without EmNet's knowledge or permission. The monitoring point consists of a computerized manhole cover which collects the data from the sensor(s) and uploads it to a website through a cellular connection. The composite manhole cover was removed and replaced with a cast iron cover, which made it impossible for the monitoring point to transmit its data. The monitoring point has since been repaired, but no data was received from this location during the month of August, 2011.

## ANALYSIS ASSUMPTIONS

In order to perform the analysis required for this study, the following assumptions were made:

- The H7 outfall, located at Hudson and Fifteenth is always able to overflow. This was stated in the 1996 CSO Monitoring Study for the North Hudson Sewerage Authority (NHSA), and is confirmed by the fact that this outfall does not have a tide gate. This means that the depths upstream and downstream of the weir are the same during high tide overflow events.

- The elevations of the manhole rim are accurate to within 0.2'. These elevations were provided by Boswell Engineering from a 1996 aerial flyover as the best available approximation of the rim elevations.

- The City of Hoboken is 90% impervious, meaning that 90% of the rainwater enters the collection system almost immediately.

- Flows in one interconnection pipe are indicative of flows between all interconnections between the same two drainage areas.

- The rain gauge from Central Park in New York City, NY accurately represents the rainfall for the City of Hoboken.

- The Hudson and Fifteenth monitoring point provides an accurate representation of the tide elevation in the Hudson River. The depth sensor is located in the overflow chamber, which contains a drain and an elevated overflow line (see Figure 5). The tide is able to enter and leave this chamber freely, as seen in the tidal pattern recorded by this sensor (see Figure 6).

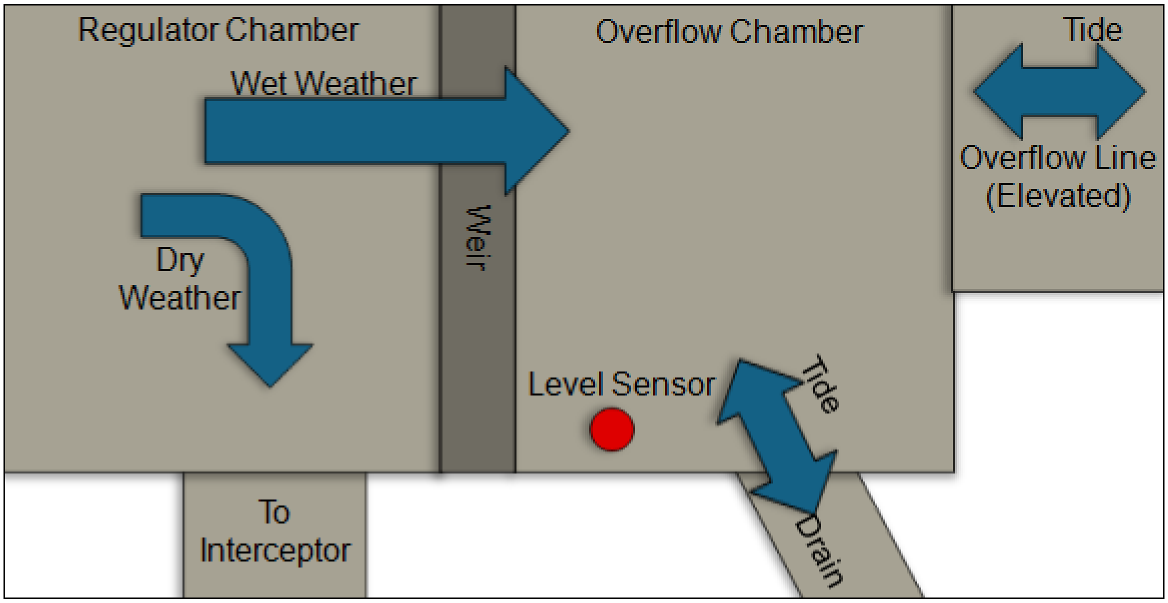


Figure 5. Configuration of Tide Monitoring Location

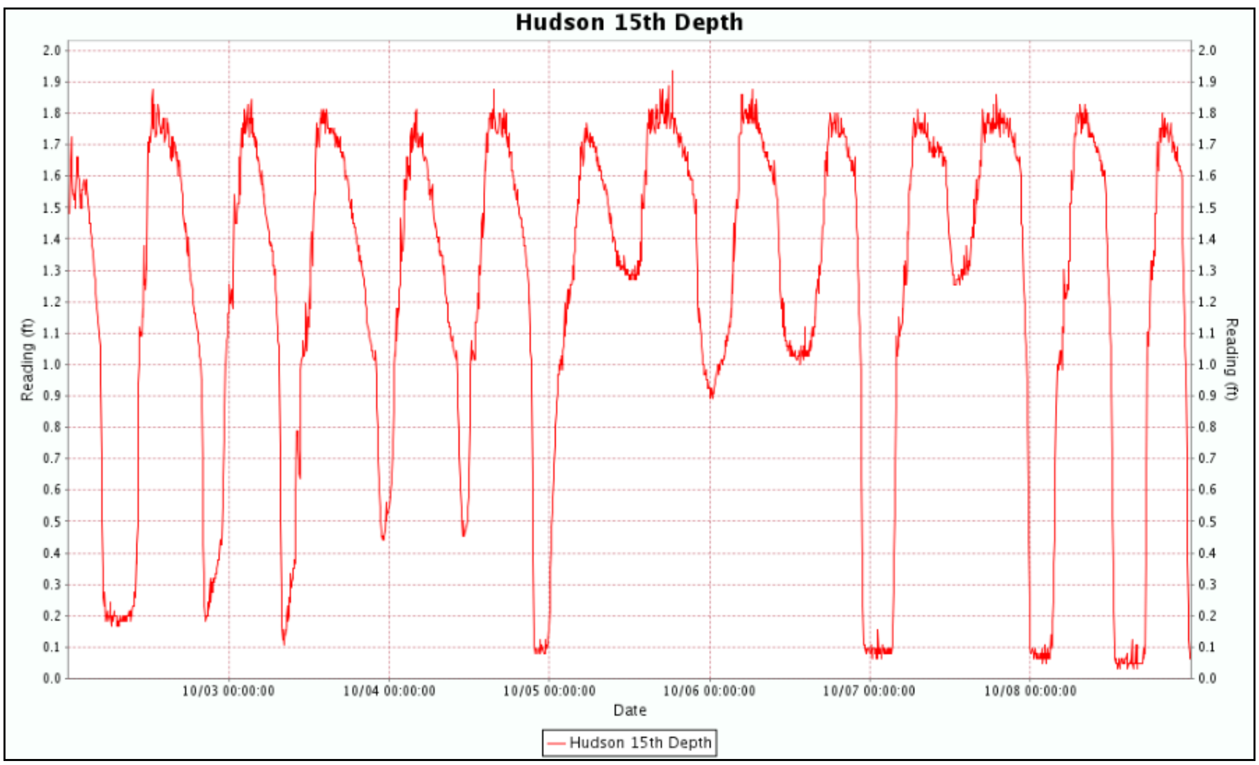


Figure 6. Depth at Tide Monitoring Location, Showing a Typical Tidal Pattern

## SYSTEM OBSERVATIONS DURING MEDIUM STORM EVENTS

*Storm Event Descriptions*

The analysis of the monitoring data was done twice, using two different sets of storm events. The first analysis period focused on the storm events that occurred between March and May, 2011, typically known as the “Spring Rains”. It is these events that are typically used for the calibration of the hydraulic computer models. Table 2 gives a brief description of these storm events.

Table 2

Storm Events With Street Flooding

| Date | Total Rainfall (in) | Duration (hours) |
|---|---|---|
| **March 6-7, 2011** | 2.10” | 19 |
| **March 10-11, 2011** | 1.98” | 24 |
| **April 12-13, 2011** | 2.00” | 21 |
| **April 16-17, 2011** | 1.78” | 13 |
| **May 17-19, 2011** | 3.04” | 28 |

As seen in Table 2, the storm events in this time period all have comparable characteristics. Not surprisingly, the collection system behaved similarly during each storm event. For the purposes of this report, results are shown from two representative storm events in this period. The March 6-7, 2011 storm event was selected because it had the highest peak rain intensity (similar to that of a 5 year design storm) of any storm event in this time period. The May 17-19, 2011 storm event was selected because it was the largest storm event in this time period and resulted in the most severe flooding. The figures shown in these report from these two storm events were selected because they best represented the general trends that were observed during all of the storm events.

*Detected Flooding During Medium Storm Events*

During each of the storm events in this time period, the monitoring system detected flooding at the following locations:

- Marshall and First

- Jackson and Fifth
- Willow and Newark

All of the detected flooding occurred in the H1 drainage area, which contains most of the lowest lying areas of the City (see Figure 7).

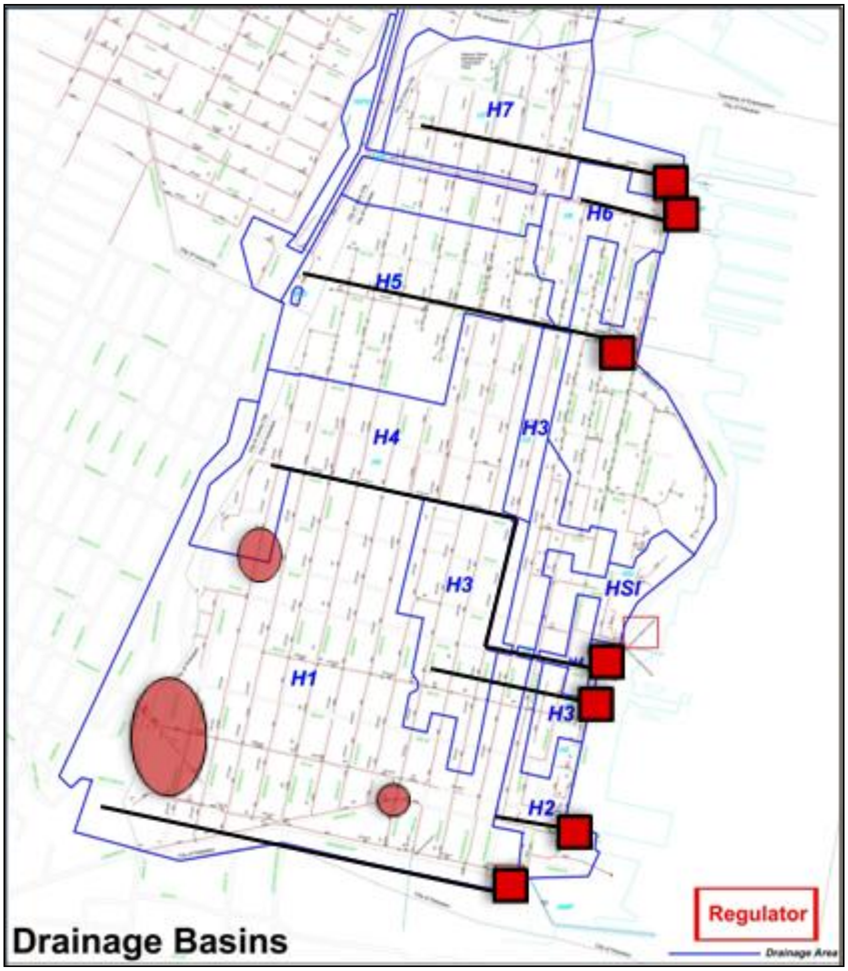


Figure 7. Typical Detected Flooding Locations During Medium Storm Events

*Interconnection Flows During Medium Storm Events*

The flows though the drainage area interconnections were also analyzed for these storm events. In areas where flows were not measured or where the flow meters did not record any measurable flow, the hydraulic head at the neighboring monitoring points were compared. If the two locations are hydraulically linked, the difference between the water elevations at these two locations should be relatively constant. This means that an increase in water elevation at one point will cause a corresponding increase in water elevation at the other point. If this is not the case, then it can be determined that the two locations are not hydraulically linked.

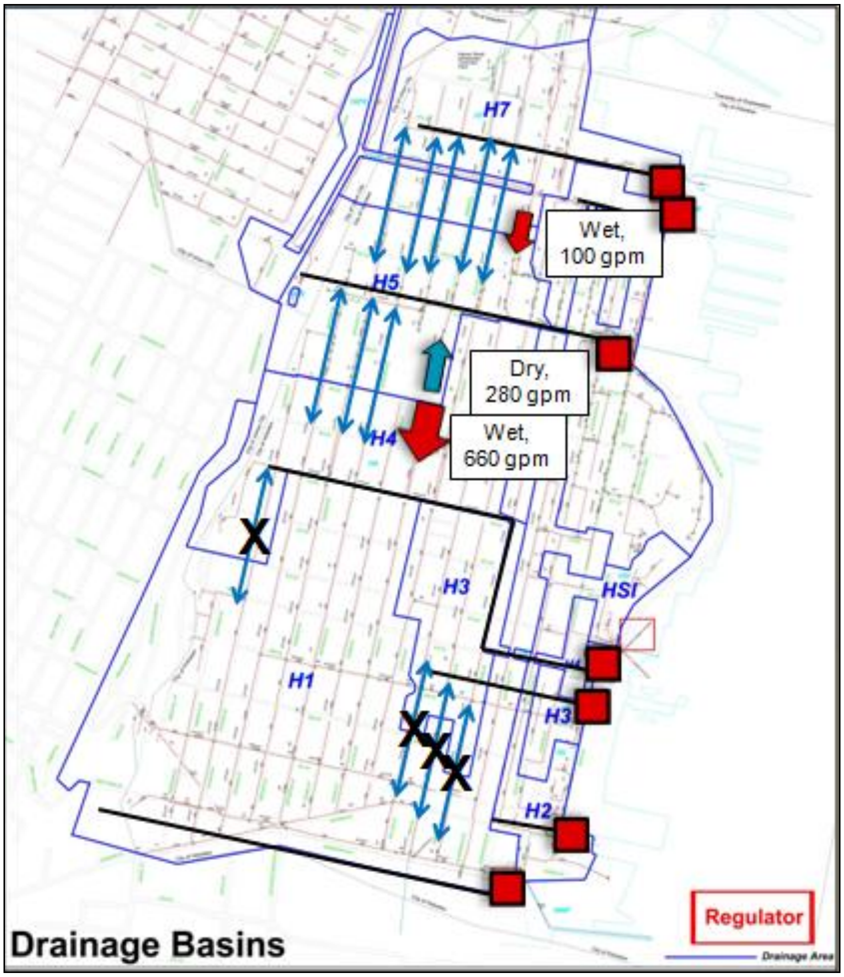


Figure 8. Flow Trends in Interconnections During Medium Storm Events
(Numerical values are from the May 17-19, 2011 storm event)

Figure 8 shows the typical flow trends in the drainage pipe interconnections during medium storm events.

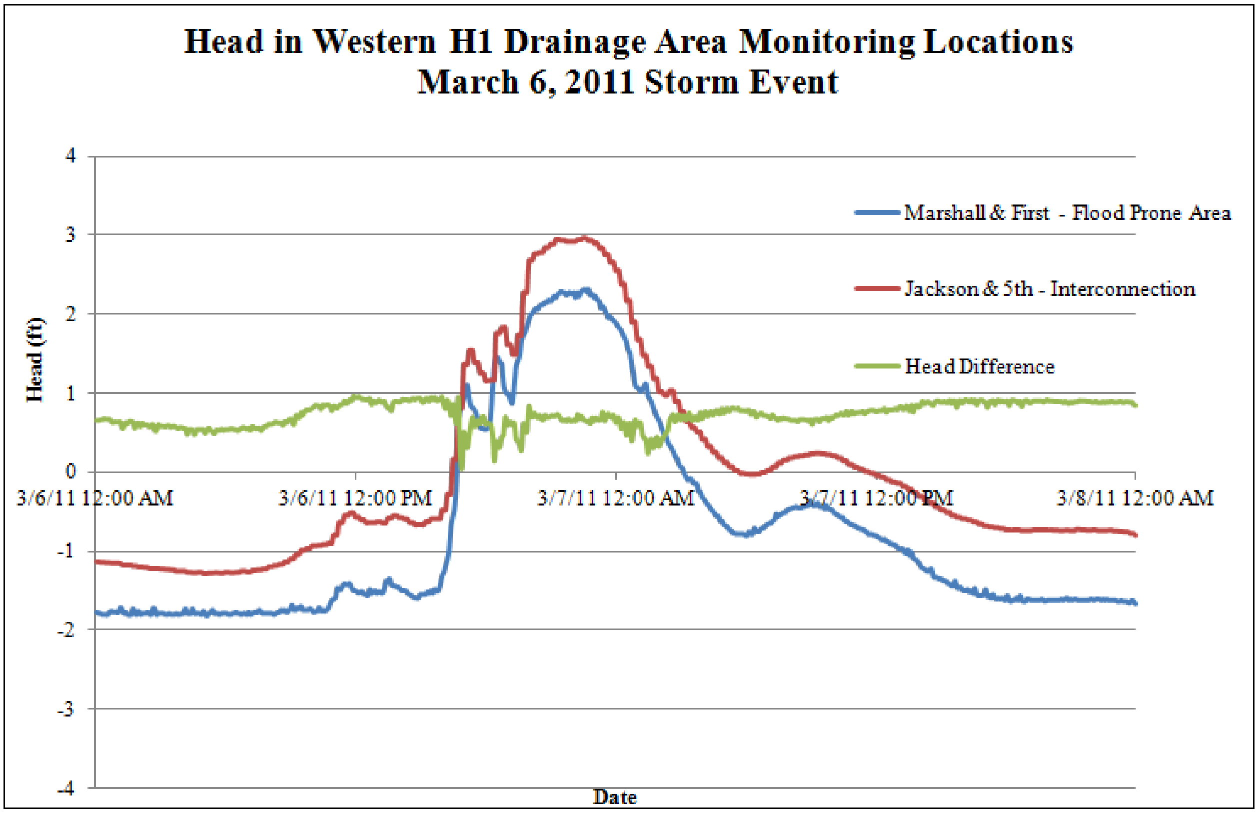


Figure 9. Head Difference in Vicinity of the H1/H4 Interconnection

The flow meter at the interconnection between the H1 and H4 drainage areas did not register any measureable flow (meaning flow with a velocity greater than 0.1 ft/s) during any of the storm events observed in this time period. However, the head difference between the Jackson and Fifth and the Marshall and First monitoring points is fairly constant[1] during the storm events, indicating that these locations are hydraulically connected. The large amount of sediment found in the Jackson and Fifth sewer line may have prevented measurable flow from going between these two locations. The Jackson and Fifth monitoring location was removed in June, 2011 for sewer cleaning, and it is possible that this cleaning will result in flow through this interconnection. At the time this report was written, the sewer cleaning work was still ongoing, and the flow meter had not been reinstalled.

[1] Because the monitoring points do not take measurements at exactly the same time, the graph may show a change in the head difference during periods of rapid change. This is not indicative of a hydraulic disconnect.

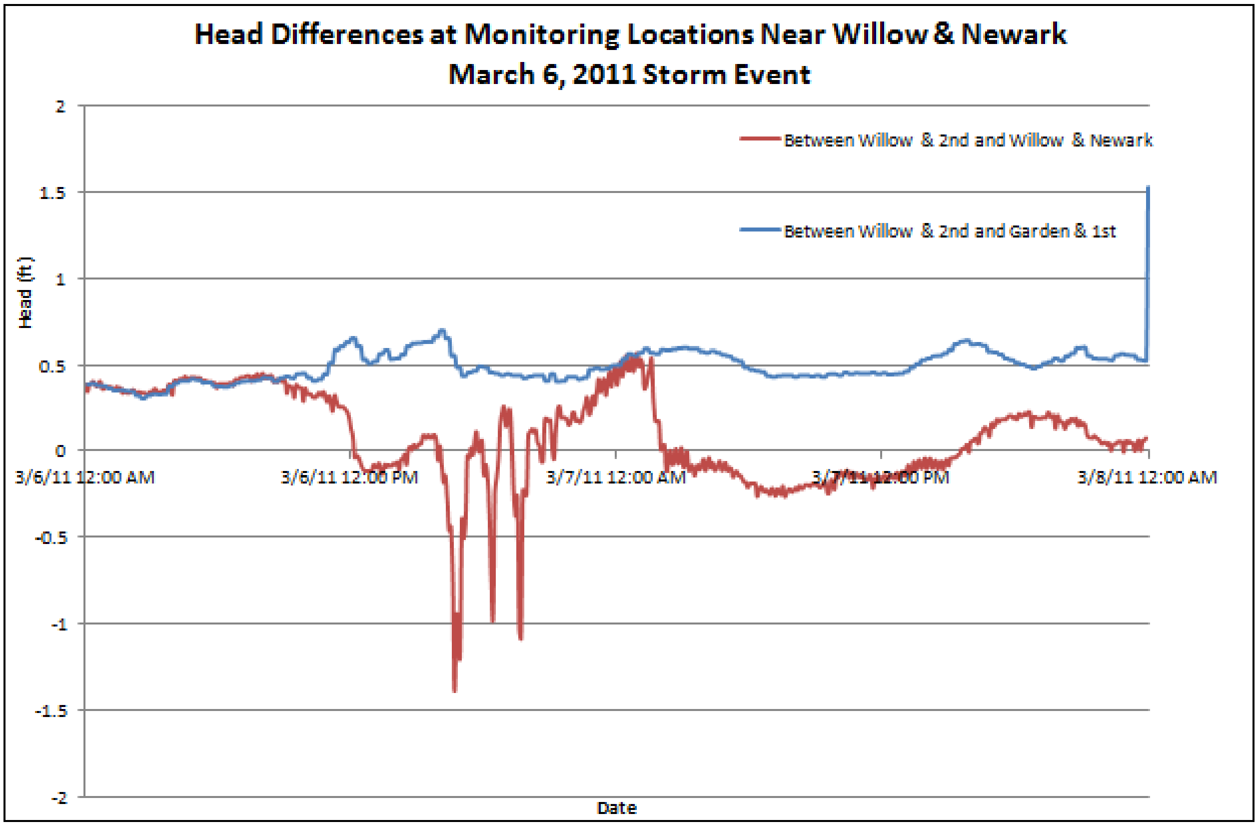


Figure 10. Typical Head Differences Between Monitoring Locations Around H1-H3 Interconnections During Medium Storm Events (Before June 17, 2011)

The two flow meters monitoring the H1/H3 interconnections also did not record any measureable flow during the spring storm events. When the hydraulic heads for the Willow and Newark, Willow and Second, and Garden and First monitoring locations were compared, the head difference between the Willow and Second and Garden and First monitoring locations were fairly constant during these storm events, indicating that these locations are hydraulically linked (see Figure 10). That was expected because these two locations are both at interconnection points and are linked together by the H3 trunk line. Conversely, the head difference between the Willow and Newark and Willow and Second monitoring locations was irregular and had a range of nearly two feet. This indicates that these two monitoring locations were not hydraulically linked during the spring storm events. It should be noted that the Willow and Second monitoring point began recording southward flow during storm events on June 17, 2011 and in ensuing events. The reason for this sudden change is unclear (perhaps the result of sewer cleaning or other maintenance), but after this date, the head difference becomes constant and flow could go between these areas.

During the analyzed medium storm events, no measureable flow from outside of the H1 drainage area aggravated the flooding in that area. The flooding was a result of only the rain that fell on the drainage area itself.

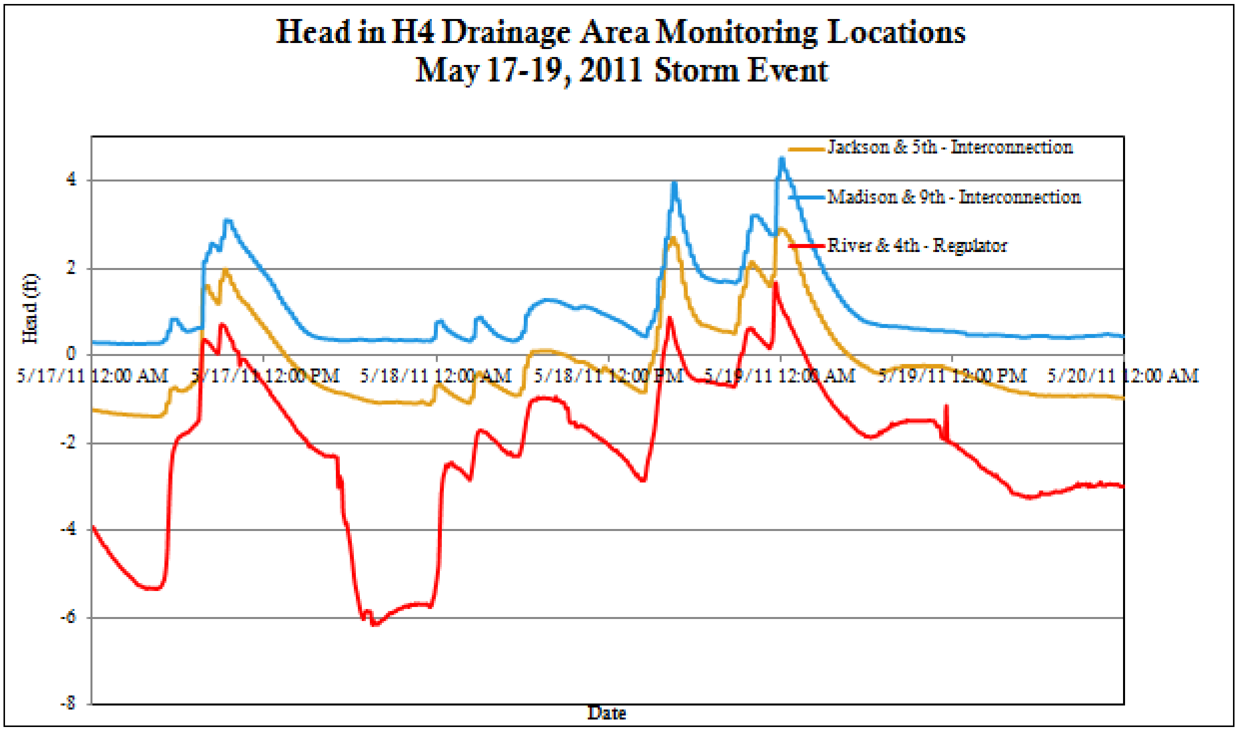


Figure 11. Typical Conditions Around H4/H5 Interconnections During Medium Storm Events

Flow in the H4/H5 interconnections typically moved north to the H5 trunk line during dry weather, but then switched and moved south to the H4 trunk line during wet weather. During the peak of the storm event, the southward flow was as much as twice the typical northward dry weather flow. Once the flow reached the H4 trunk line, it could either move west toward the H1/H4 interconnection (Jackson and Fifth) or east to the H4 regulator (River and Fourth). As seen in Figure 11, the hydraulic head at these three locations followed the same pattern during the peak of the storm events, indicating that they were all hydraulically linked. Since the H4 regulator had the lowest head, flows from the H1/H4 interconnection and the H4/H5 interconnection went toward the H4 regulator. If the water was not able to overflow, it would gradually build up in the H4 trunk line until the water elevation was higher than the tide elevation or flooding occurred. Since no flooding was observed in the H4 or H5 drainage areas, the storage in the trunk line and/or the regulator's ability to overflow were sufficient to prevent flooding in these drainage areas during medium storm events.

Flow in the H5/H7 interconnections was typically stagnant during dry weather, but a small amount of flow (up to 100 gpm) moved southward to the H5 trunk line during medium storm events. In a conference call with the NHSA in October, 2011, the NHSA stated that flooding occurs at Grand and Sixteenth in addition to the flooding locations that the City identified. Since this was not originally listed as a flood-prone area, no monitoring location was installed at this location. The southward flow into the H5 drainage area may have relieved or prevented flooding at this location, but its full impact could be determined at this time.

*Conditions at the Outfalls During Medium Storm Events*

Since the flooding in Hoboken is cause by the inability of some of the drainage areas to overflow, water elevations near the regulators/outfalls were analyzed. If the head in the trunk line was higher than the tide elevation, the drainage area was able to overflow. Conversely, if the tide elevation was higher, then water would be stored in the trunk line until the water elevation became higher than the tide elevation (at which point it would overflow) or the water broke the ground surface and caused flooding.

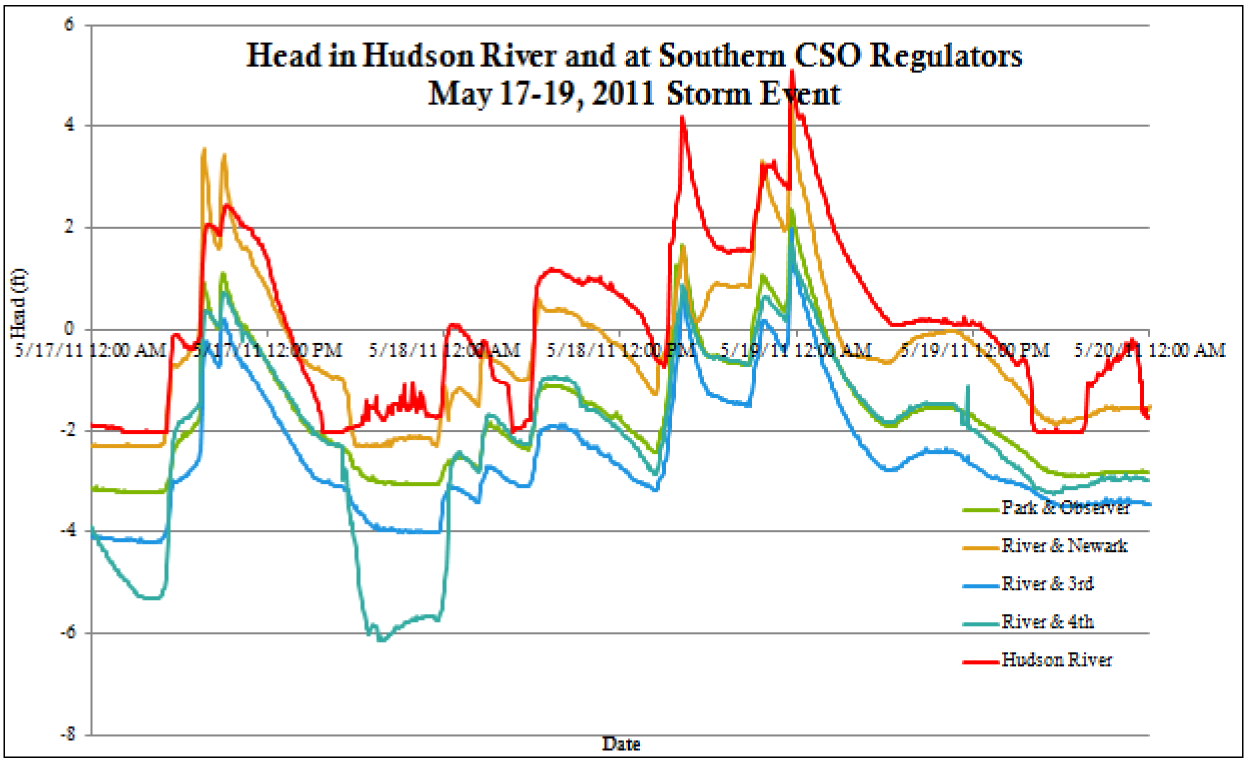


Figure 12. Typical Head Readings for the Southern Outfalls During Medium Storm Events, Compared Against the Tide Level in the Hudson River

The water elevations near the southern outfalls (i.e., H1, H2, H3, and H4) were typically below the tide elevation for the medium storm events (see Figure 12). Only the H2 outfall (at Newark and River) was able to overflow for short periods during these storm events. Because flooding was only observed in the H1 drainage area and no measureable flows from other drainage areas entered the H1 drainage area during these storm events, only the H1 drainage area needed an ejector pump to prevent flooding. All of the other southern drainage areas were able to store water in the trunk line until the end of high tide or until the WWTP could handle the flow. These drainage areas did not require an ejector pump to prevent flooding during these storm events.

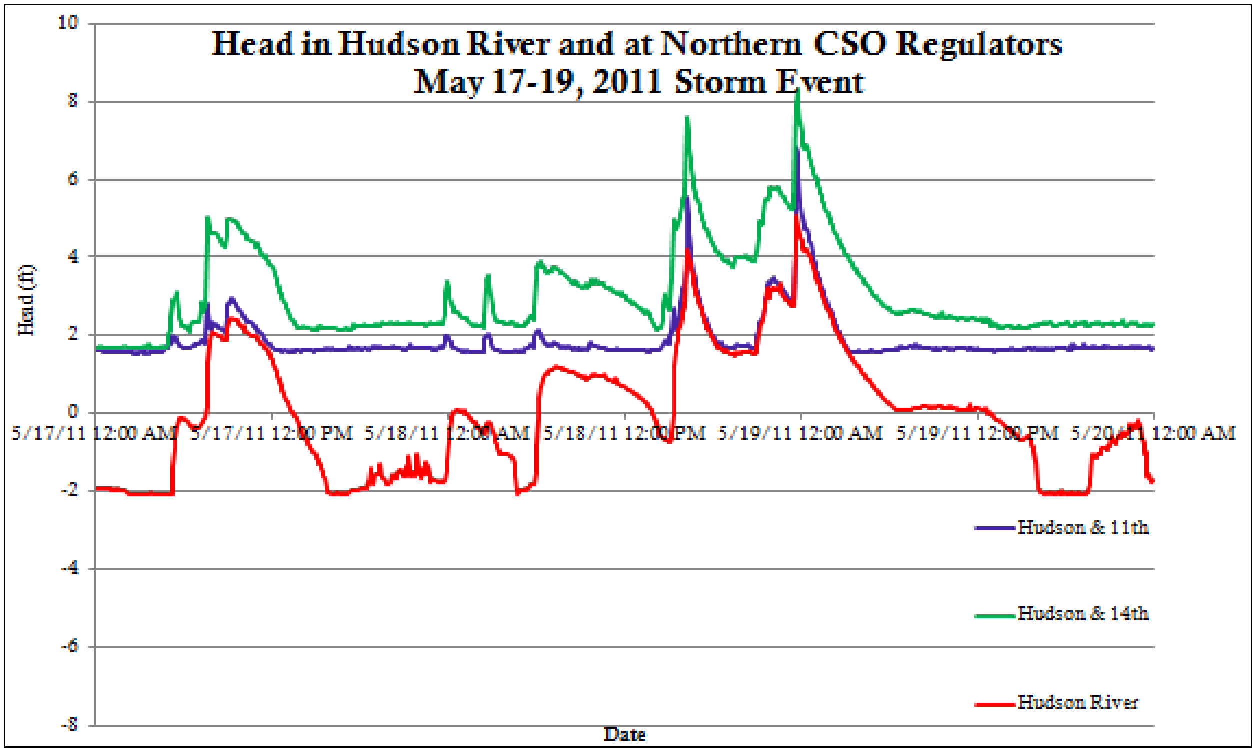


Figure 13. Typical Head Readings for the Northern Outfalls During Medium Storm Events, Compared Against the Tide Level in the Hudson River

At the northern regulators (i.e., H5, H6, and H7), the water elevation at the regulators/outfalls remained higher than the tide elevation. These regulators were able to overflow at all times during these storm events. No flooding was detected in these drainage areas during these storm events, but flooding may have occurred at Grand and Sixteenth. If flooding occurred at this location, an ejector pump may be required to prevent flooding in the H7 drainage area. If no flooding occurred, no ejector pump is required to prevent flooding in these drainage areas.

## System Observations During Large Storm Events

*Storm Event Descriptions*

The second group of storm events that were analyzed occurred in August, 2011. These storm events were significantly larger than the storm events expected in a typical year. Descriptions of the storm events are listed in Table 3.

Table 3.

August, 2011 Storm Events

| Date | Total Rainfall (in) | Duration (hours) | Notes |
|---|---|---|---|
| **August 9, 2011** | 2.09” | 2.5 | Short, very intense storm event |
| **August 14-15, 2011** | 5.81” | 23 | Larger than a 10 year storm event |
| **August 27-29, 2011** | 6.87” | 26 | Tropical Storm Irene, 50 year storm event |

In August, 2011, three large storm events occurred in Hoboken. Tropical Storm Irene can be regarded as one of the worst case scenarios for street flooding, since it was an unusually large storm event for the City. All figures in the following sections show data from this storm event, but the general trends were also seen in the two other storm events in this time period.

*Detected Flooding During Large Storm Events*

During each of the storm events in this time period, the monitoring system detected flooding at the following locations (see Figure 14):

- Marshall and First
- Jackson and Fifth
- Willow and Newark
- Madison and 9$^{th}$

Since the monitoring location at Jackson and Fifth was removed for sewer cleaning during this time period, the presence of flooding at this location was determined by using the head at Marshall and First to calculate the expected head at Jackson and Fifth. The monitoring point at Madison and Ninth was damaged during a road paving operation and was not operational during this time period. The presence of flooding at this location was determined by using the head at Jefferson and Thirteenth to calculate the expected head at Madison and Ninth. Each of these monitoring sites had previously been determined to be hydraulically linked.

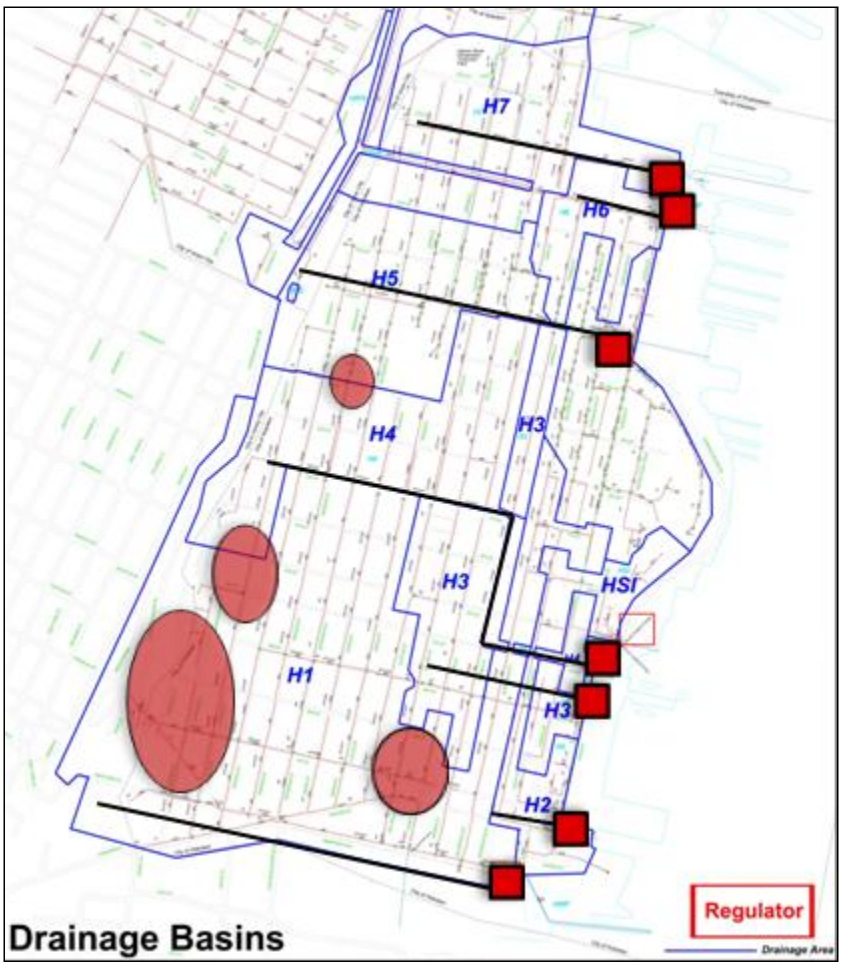


Figure 14. Typical Detected Flooding Locations During Large Storm Events

The presence of flooding at Grand and Sixteenth could not be confirmed or denied with the current monitoring system. Given the severity of the storm events, it can be assumed that flooding did occur at this site.

*Interconnection Flows During Large Storm Events*

The interconnection flow trends during the August, 2011 storm events are shown in Figure 15. For the aforementioned reasons, flow conditions in the H1/H4 interconnection and the H4/H5 interconnections could not be determined for these storm events.

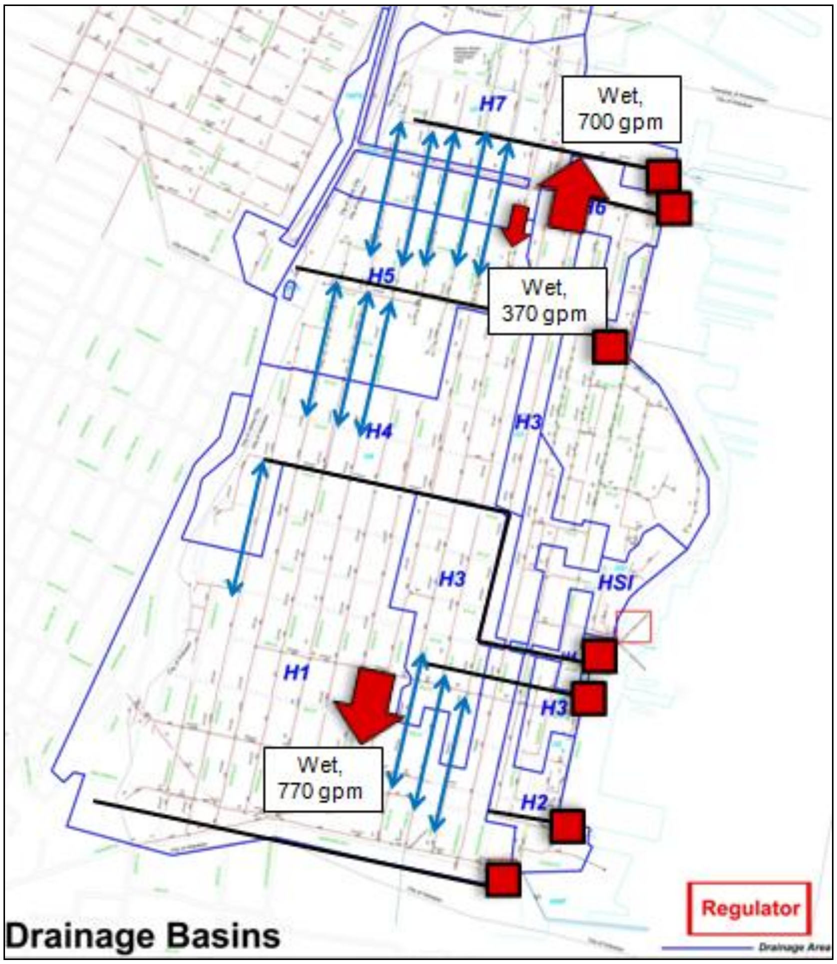


Figure 15. Flow Conditions in Interconnections During Large Storm Events
(Numerical values are from the August 27-29, 2011 storm event)

The H1/H3 interconnections sent significant flows southward (up to 770 gpm) during these storm events, but were typically stagnant during dry weather. This flow aggravated the flooding that occurred at Willow and Newark. Since the surface elevation in the H3 drainage area is significantly higher than that of the H1 drainage area (the H3 drainage area is almost entirely above the normal storm high tide elevation, while parts of the H1 drainage area are below mean sea level), the H3 drainage area does not need to send flow into the H1 drainage area in order to prevent flooding. These interconnections should be blocked.

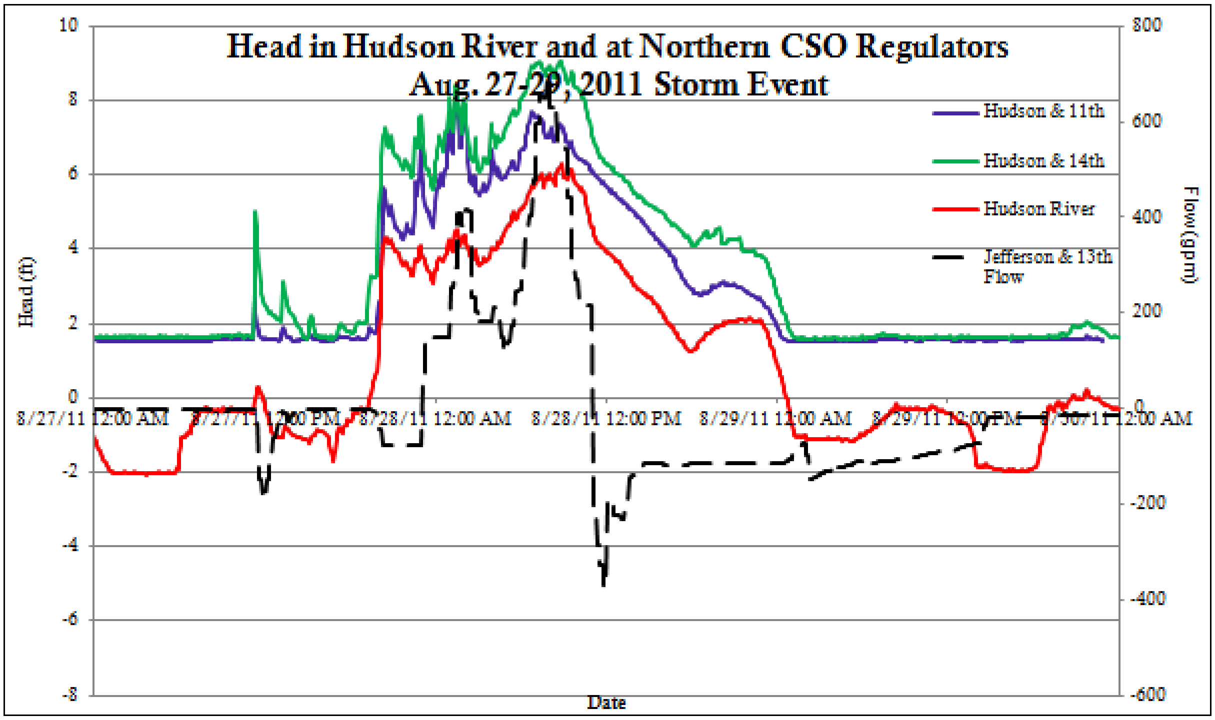


Figure 16. Typical Head Readings for the Northern Outfalls During Large Storm Events, Compared Against the Tide Level in the Hudson River, With H5-H7 Interconnection Flows Shown.
(Southern flow is negative and northern flow is positive)

Flow through the H5/H7 interconnections moved southward to the H5 trunk line during the less severe portions of the large storm events (see Figure 16), thereby relieving any potential flooding at Grand and Sixteenth. During the peaks of the storm events, the flow reversed and moved northward to the H7 trunk line. The northward flow rates peaked at 700 gpm per interconnection, aggravating any flooding that may have occurred at Grand and Sixteenth.

*Conditions at the Outfalls During Large Storm Events*

As in the medium storm events, the heads at the southern regulators remained below the tide elevation for the duration of the large storm events (see Figure 17). These sites could not overflow, resulting in flooding in several portions of these drainage areas.

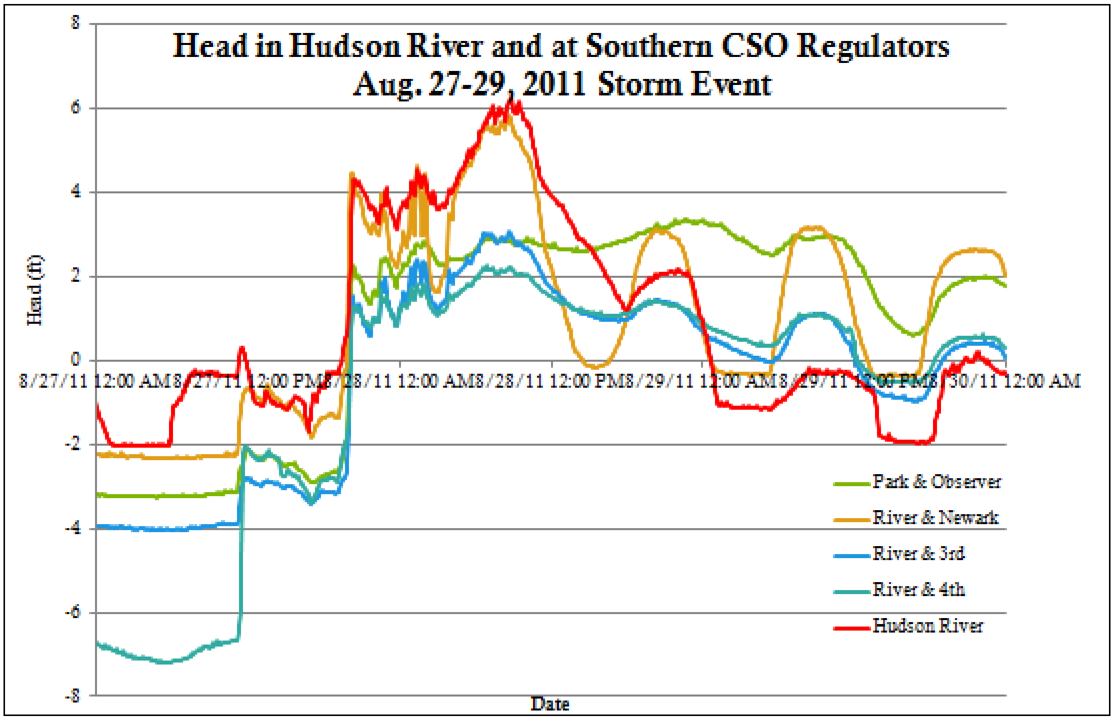


Figure 17. Typical Head Readings for the Southern Outfalls During Large Storm Events, Compared Against the Tide Level in the Hudson River

The extent of the flooding can be seen by comparing the head at the H1 regulator (at Park and Observer) and the H3 regulator (at River and Third) with the tide elevation (see Figure 18). When most of the water in a drainage area is contained in the sewer pipes, the head at the regulators will closely follow the tide elevation. During Tropical Storm Irene, the heads at the H1 and H3 regulators deviated significantly from the tide elevation during the peak of the storm event. This indicates that the H1 pipes could not hold any more water in order to keep trending the tide elevation. All of the rain that fell on the City while this deviation occurred could not enter the sewers, and therefore, worsened the flooding situation. This deviation for the H3 drainage area, which did not flood, indicates that all of the rain that fell on the City while this deviation occurred did not remain in the H3 pipes, but rather moved southward through the H1/H3 interconnections and increased the flooding in the H1 drainage area. The same trend was also observed for the H4 drainage area.

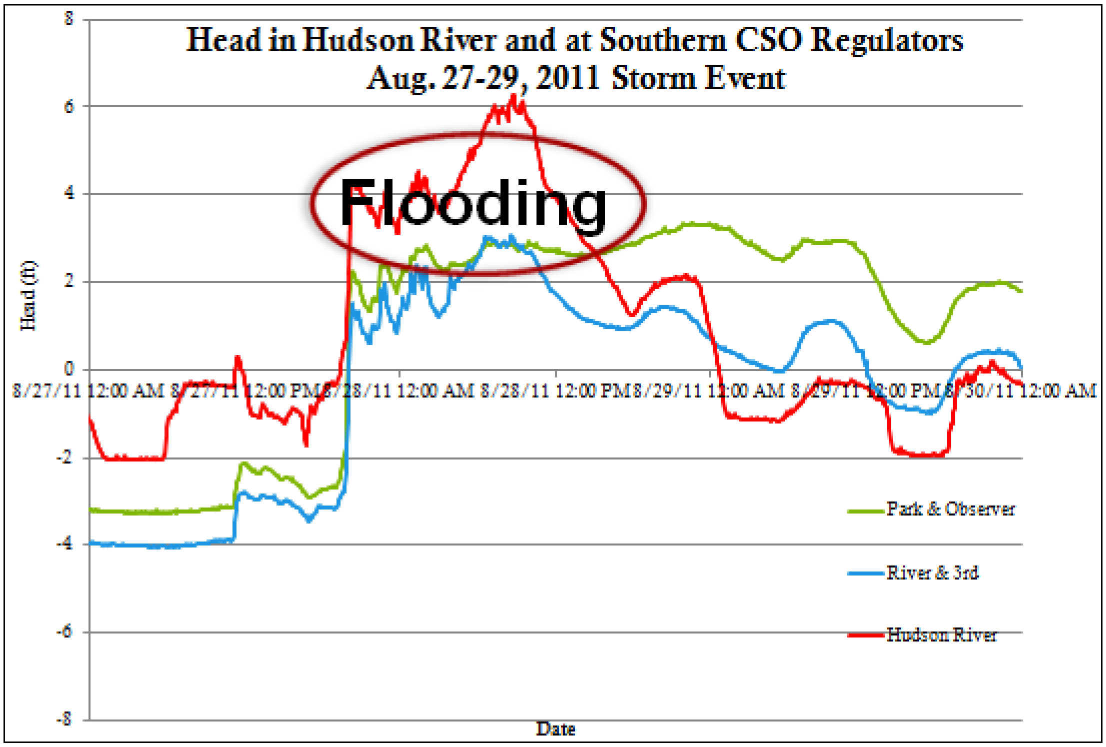


Figure 18. Typical Head Readings for Selected Southern Outfalls During Large Storm Events, Compared Against the Tide Level in the Hudson River

Conversely, the head at the northern regulators stayed above the tide elevation throughout all of the large storm events (see Figure 19). The H6 drainage area did not experience any flooding and was able to overflow during all of the observed events. Based on the observed storm events, this drainage area does not need the assistance of an ejector pump. The H5 drainage area was able to overflow during these storm events, as well. However, this drainage area also experienced flooding at its interconnection points, indicating that this drainage area was not able to overflow sufficient water to prevent flooding. This drainage area, however, was also capable of relieving its excess flows into the H4 and H7 drainage areas. This means that if the H4 and H7 drainage areas use ejector pumps, then any flooding issues in the H5 drainage area can be resolved using these pumps without building an additional ejector pump at the H5 regulator.

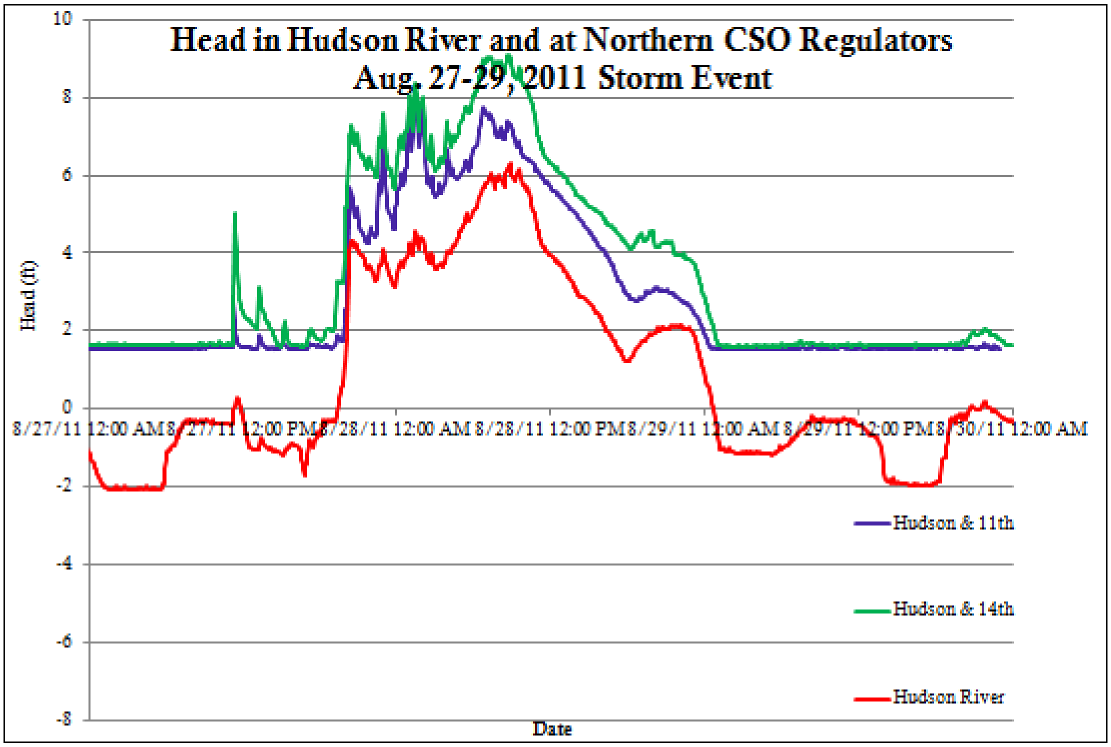


Figure 19. Typical Head Readings for the Northern Outfalls During Large Storm Events, Compared Against the Tide Level in the Hudson River

Since the Grand and Sixteenth area likely flooded during these large storm events and flows from the H5 drainage area entered into this area, the H7 drainage area will likely require an ejector pump in order to prevent flooding. Furthermore, the configuration of the regulator chamber may also allow water from the Hudson River into the H7 drainage area during storm high tide. A tide gate may be required at this location to prevent this inflow during large storm events.

## EXPECTED FLOOD PREVENTION AFTER INSTALLATION OF OBSERVER EJECTOR PUMP

The NHSA has completed the installation of the first ejector pump, located near the Observer Highway (H1) outfall. The pump station has a capacity of 50 MGD and is intended to pump excess water that would overflow during low tide into the Hudson River during high tide storm events. During small and medium storm events, all of the detected flooding was observed in the H1 drainage area. As part of this analysis, the expected impact of the pump was calculated.

For this analysis, the following assumptions were made:

- Due to the impervious nature of Hoboken, 90% of the rain immediately enters the sewer.
- The maximum flow from the H3 drainage area to the H1 drainage area is 1.44 MGD. No flow enters the H1 drainage area from the H4 drainage area.
- The pipes in the H1 drainage area are already full and have no additional capacity to store water before flooding occurs.

Using these assumptions, it was calculated that the maximum rain intensity that the pump station will be able to handle before flooding occurs is 0.30 in/hr, which is approximately equivalent to the peak intensity of a two month storm event.

However, the last assumption is typically not valid. The purpose of the pump station is to prevent the sewer pipes from filling up and surcharging by allowing the excess water to overflow. In actuality, the pipes should only be one half to two thirds full at the peak of the storm event. This means that collection system is able to store a certain amount of water that the pump is not able to handle before flooding begins.

To determine this storage volume, the amount of rain required to increase the depth from the dry weather level to the flooding level at Marshall and First (typically, the first site to flood) was determined for the Aug. 9, 2011 storm event, the Aug. 14, 2011 storm event, and the Aug. 27, 2011 storm event. The amount of rain required to increase the depth from dry weather to flooding ranged from 0.43” to 1.13”. The smallest amount of rain required for this increase was selected for this analysis, since it represents the most conservative value and is the least likely to include rain runoff that was able to overflow by gravity. Assuming that 90% of the rain entered the sewers, it was calculated that the H1 drainage area had approximately 3.0 MG of storage available before flooding occurred.

By combining the pumping capacity of the ejector pump with the storage capacity in the H1 drainage area, the City of Hoboken will likely be able to withstand a six month storm event before flooding occurs.

By comparison, before the installation of the ejector pump, the H1 drainage area flooded during the April 16-17, 2011 storm event, which had a total rainfall of 1.78” over 13 hours.  Four storm events that were this size or larger, each of which caused flooding, occurred between March 1, 2011 and April 30, 2011 (see Table 2).

# Conclusions

The City of Hoboken installed an extensive sewer monitoring system throughout its collection system in order to further understand the underlying hydraulics of its collection system and how this affects their flooding issue. The monitoring data from a variety of storm events was analyzed, and the following conclusions were made:

*For Medium Storm Events*

- All of the detected flooding during these storm events occurred in the H1 drainage area, and it is expected that the presence of the Observer Highway ejector pump will prevent this type of flooding from happening in the future.
- In the analyzed medium storm events, no flows from other drainage areas entered the H1 drainage area. This may have been due to sediment buildup in the H1/H4 interconnection and blockages in the H1/H3 interconnections. This situation may change after the H1/H4 interconnection is cleaned.
- Flow did enter the H1 drainage area from the H3 drainage area in ensuing storm events. Given the relatively high elevation of the H3 drainage area, it was unlikely that this area would flood if these interconnections are completely closed off. Doing so would decrease the amount of flooding in the H1 drainage area.
- The southern regulators were unable to overflow during the medium storm events, but this only caused flooding in the H1 drainage area.
- The northern regulators were able to overflow during the medium storm events.
- If flooding occurred at Grand and Sixteenth during these storm events, an ejector pump may be necessary to prevent this flooding. This drainage area was able to relieve excess flows into the H5 drainage area during medium storm events, but it was unclear if this would prevent the possible flooding.

*For Large Storm Events*

- Flooding was detected in the H1, H4, and H5 drainage areas during these large storm events. Flooding also likely occurred in the H7 drainage area.
- The southern regulators were unable to overflow during large storm events.
- The northern regulators were able to overflow during large storm events.

- Flows from the H3 drainage area into the H1 drainage area aggravated the H1 flooding problem without providing any benefit to the H3 drainage area.

- Flows out of the H5 drainage area aggravated flooding in the H7 and H4 drainage area.

- The H5 drainage area was able to relieve excess flows into the H4 and H7 drainage areas. If these areas had ejector pumps, then no additional pump would be required to prevent flooding in the H5 area.

- Flow conditions during large storm events in the H1/H4 interconnection and the H4/H5 interconnections could not be determined due to removed or damaged equipment.

- Ejector pumps are necessary to prevent flooding in the H1, H4, and H7 drainage areas.

*Other Conclusions*

- After the completion of the Observer Highway ejector pump, it is expected that H1 drainage area will likely be able to withstand a 6 month storm event before flooding occurs.

- The collection system has the ability to store several million gallons of water before flooding begins.

## Recommendations

The following actions are recommended as future steps:

- Re-analyze the hydraulics of the collection system after the Observer Highway ejector pump is fully operational in order to determine the effectiveness of this pump in preventing flooding. Perform this analysis after each future pump comes online.
- Add additional monitoring points at the following locations:
  - Grand and Sixteenth (for flooding detection)
  - Upstream of the H7 regulator (to detect any inflow from the Hudson River)
  - On the H4 trunkline (to determine if flow is going towards or away from the interconnections)
- Reinstall the flow meter at the H1/H4 interconnection and analyze data from additional storm events in order to determine the impact of the sewer cleaning.
- Install a rain gauge in Hoboken.
- Survey the manhole rim of every monitoring location in order to more accurately compare water elevations.

## Additional Benefits of the Monitoring System

The Hoboken sewer monitoring system is able to provide the following additional benefits to the City:

- Early flood warning system – the monitoring system is typically able to detect the potential for flooding at least two hours before flooding actually begins

- Provide data for further model calibration and improvement, especially with regards to the drainage area interconnections

- Aid with the system characterization portion of the City's future CSO Long Term Control Plan

- Determine the effectiveness of the ejector pumps for flood prevent through pre- and post-construction monitoring

- Coordinate the activation of the ejector pumps with conditions in the collection system so that the in-system storage is more effectively utilized before wastewater overflows. This will minimize the amount of wastewater discharged into the Hudson River without building any new infrastructure.