WHITWELL AVENUE AREA

Drainage Investigation and Flooding Analysis

Project No. 16-040

CITY OF NEWPORT
Department of Utilities
Water Pollution Control Division

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Table of Contents

List of Figures

List of Tables

Attachments

Funding for this drainage investigation and flooding analysis is funded by sewer rates as part of the Water Pollution Control Division's capital improvement program.

Executive Summary

The Whitwell Avenue project area receives runoff from a 262-acre drainage catchment that eventually discharges through a 48-inch outfall at the northwest corner of the Moat (Figure ES-1). The Moat eventually discharges through a culvert under Memorial Boulevard to the Atlantic Ocean at Easton Beach. The Moat is a nearly flat manmade channel that was constructed as part of the Easton Pond reservoir system to collect runoff from the City's storm drainage system.

During high intensity rain events, significant street and private property flooding occurs in the Whitwell Avenue neighborhood, especially within the few blocks bounded by Bliss Road, Whitwell Avenue, Gibbs Avenue, Eustis Avenue, and Ellery Road. The purpose of this project is to understand causes of flooding in the Whitwell Avenue project area and identify recommendations that could reduce this flooding.

Figure ES-1. Whitwell Avenue Area Drainage Area

The runoff generated in the watershed above and within this neighborhood drains to a trunk storm sewer that consists of a series of 36-inch pipes below Bliss Road, Whitwell Avenue, Taber Avenue, Kay Street, and Eustis Avenue. The 36-inch pipe on Eustis then transitions into a 48-inch pipe at Kay Street through the outfall at the Moat. The Gibbs Avenue and Champlin Place N drainage collects through a series of pipes that discharge along Ellery Road to an 18-inch outfall, which is not connected to the 48-inch pipe that collects drainage from the other areas of the neighborhood.

In order to evaluate flooding and potential solutions, hydrologic and hydraulic models were completed for existing and proposed conditions. Two storm types were evaluated for this system: an actual storm event on August 15, 2012 to both help to calibrate the model as well as observe results for an actual event; and a 10-year, 24 hour duration Type III storm which is a typical standard for new drainage systems.

Several alternative structural improvements to the existing drainage system were assessed to potentially reduce flooding in the project area. These alternatives included:

- **Alternative 1, Increase Pipe Sizes:** Increase the pipe sizes along trunk storm sewer from 36-inch to 48-inch between Bliss Road and Kay Street. The only section of pipe that would not be replaced would be where a privately-owned structure has been built over it where it drains through private property above Taber Street. This would substantially increase capacity for the entire system and reduce flooding. However, it would increase flooding in larger storms at Kay

Street and near the section of 36-inch pipe at Taber Street, which cannot be replaced since a garage is located above it. It would also increase peak flows to the Moat and thereby increase risk of flooding on adjacent properties.

- **Alternative 2, Increase Pipe Sizes and Connect Watson Street with Kay Street:** Increase the pipe sizes as indicted under Alternative 1 and install a new 36-inch drain diverting part of the Whitwell system connecting the drainage system that now terminates at the intersection of Whitwell Avenue and Watson Street with the existing drainage system on Kay Street. While this pipe would reduce flooding along Whitwell Avenue compared to the Existing Conditions and Alternative 1 scenarios, it would increase flooding in the Moat and at the Kay Street and Eustis Avenue intersection. Relying on just connecting Watson Street and Kay Street will not improve flooding in most of the watershed and thereby is not viable as a stand-alone alternative.

- **Alternative 3, Install Subsurface Storage System:** Construct a subsurface storage system (Figure ES-2) above existing trunk storm sewers in order to temporarily store stormwater below grade. This alternative also includes the replacement of the existing 36-inch pipes in the locations proposed for subsurface storage. This would both reduce peak flows downstream of the storage system as well as provide space under the street to store stormwater as opposed to above the streets. This system would eliminate flooding throughout the project area during storms consistent with the August 15, 2012 storm, however, it would not substantially improve flooding for a 10-year storm. It would also reduce peak flows from the watershed to the Moat.

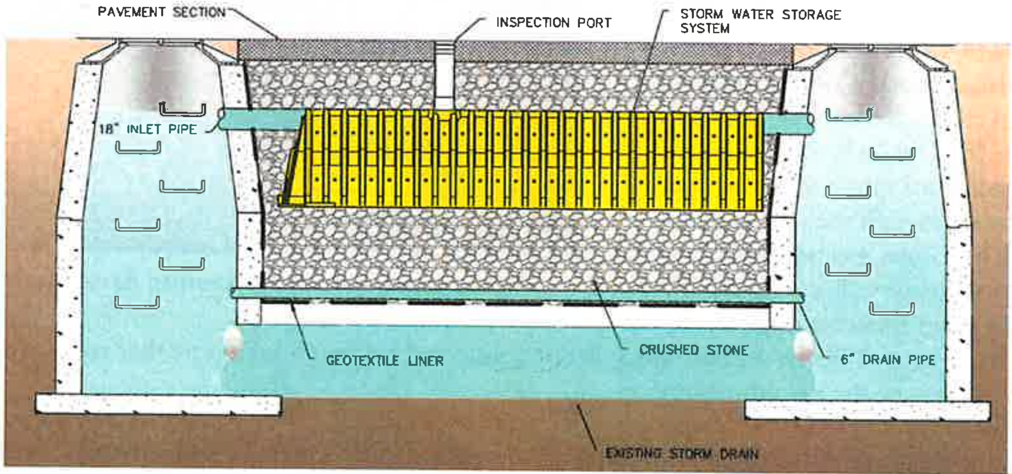


Figure ES-2. Longitudinal Profile of the Storage System Concept

Alternative 3, Install Subsurface Storage System, is the only alternative that would achieve the City's goals for reducing flooding in the Whitwell Avenue project area and not negatively impact downstream flooding, especially in the Moat. As a result, it is the recommended alternative to reduce flooding in the Whitwell Avenue project area. However, there are several potential challenges with installation and maintenance of a system such as this in a densely-developed neighborhood with existing utilities that will need to be addressed during preliminary design.

The opinion of cost to implement this alternative is $3.6 million in 2016 dollars. This system can be installed in smaller segments over time and still provide incremental benefits in order to start with smaller parts of the project first. However, phasing these improvements would increase overall costs as it will be less efficient to construct in separate phases as opposed to one large project.

1 What Is the Purpose of this Project?

This project is focused on addressing existing flooding problems in the Whitwell Avenue neighborhood. This neighborhood is defined as the few blocks bounded by Bliss Road, Whitwell Avenue, Gibbs Avenue, Eustis Avenue, and Ellery Road, herein known as the Whitwell Avenue project area (Figure 1).

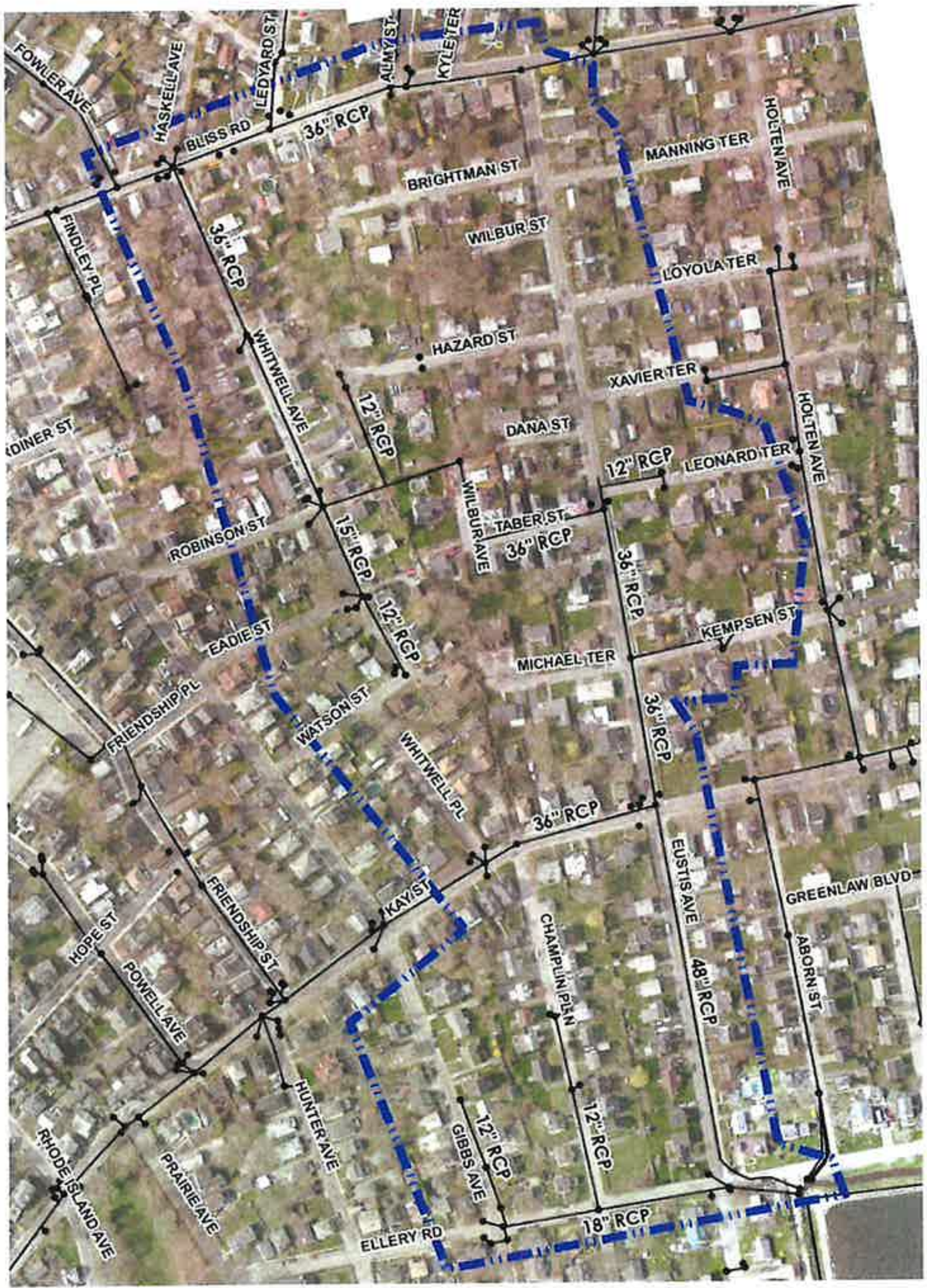


Figure 1. Whitwell Avenue Project Area

A 262-acre catchment drains through a closed storm drainage system buried under the streets in this neighborhood to a 48-inch outfall (Figure 2) at the northwest corner of the Moat that flows around South Easton Pond and eventually discharges to the Atlantic Ocean at Easton Beach.

During high intensity storms, significant street and private property flooding occurs in a number of locations in the Whitwell Avenue project area. The purpose of this project is to understand what is causing the flooding in the Whitwell Avenue project area and identify recommendations that could reduce this flooding.

Figure 2. Drainage Outfall Locations at the Moat

2 Existing Conditions

The Whitwell Avenue area drainage contains primarily high-density residential and some commercial and institutional land uses. The drainage area extends north of Miantonomi Avenue in the vicinity of the Broadway/West Main Street and Admiral Kalbfus Road intersection. The eastern boundary contains a segment of Broadway and several side streets off of Broadway. The southern boundary of the watershed extends south to the area around the intersection of Old Beach Road and Bellevue Avenue. Runoff from this drainage area is collected in a closed drainage system that conveys the stormwater to its outfall on the Moat (Figure 3).

The Whitwell Avenue neighborhood is located in a low area at the bottom of the watershed, receiving all of the drainage from these upgradient areas prior to being discharged to the Moat. Several factors, including high levels of imperviousness and poor soils, exacerbate flooding in this area.

The average impervious percent is currently approximately 54%. The land use within the drainage area is primarily high-density residential, characterized by typical lot sizes between ⅛ and ¼ -acre (Table 1).

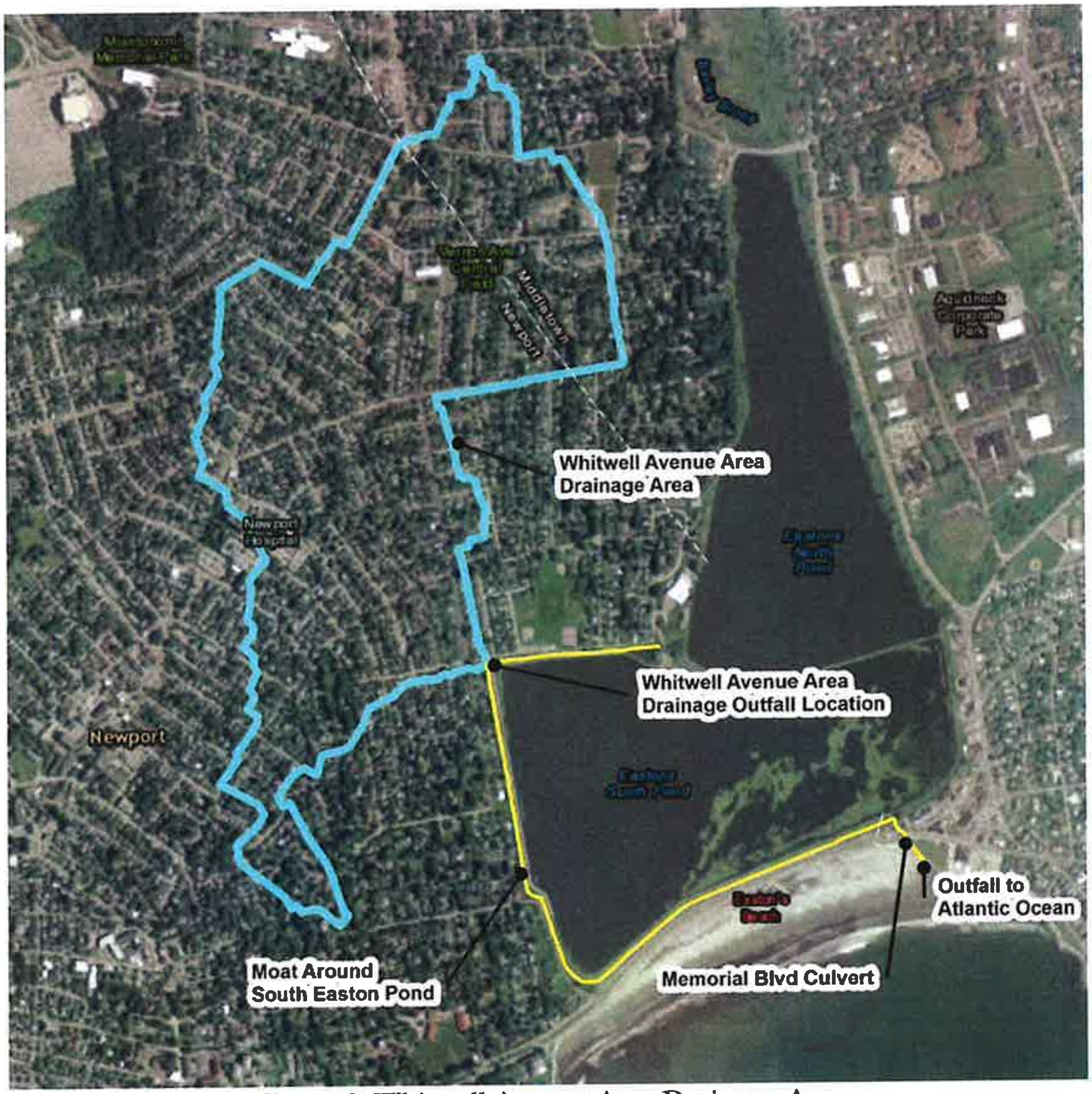


Figure 3. Whitwell Avenue Area Drainage Area

Table 1. Whitwell Avenue Area Drainage Area Facts

Area	262 acres
Outfall Location	Ellery Avenue @ the Moat
Elevation	Highest: 146 ft Lowest: 10 ft
Impervious Cover	53.8 %
Annual Average Precipitation	46 Inches
Length of Storm Drainage (within catchment)	4.4 miles

Existing Drainage System

The existing drainage within the Whitwell Avenue neighborhood generally consists of 12- or 18-inch drainage pipes that connect to 36-inch pipes along Bliss Road, Whitwell Avenue, Taber Avenue, Kay Street, and Eustis Avenue. The 36-inch pipe on Eustis transitions into a 48-inch pipe at Kay Street which flows to the outfall at the Moat. The Gibbs Avenue and Champlin Place N drainage collects through a series of pipes that drain along Ellery Road to a separate 18-inch outfall.

Survey data was collected in June and August 2016 for the detailed portion of the hydraulic model at critical manholes including rim elevations, invert elevations, and pipe diameters. Data was collected for each manhole along the trunk storm sewer through the project area draining to both the 18-inch and 48-inch outfalls. Catch basin data was not collected as it was not required for the modeling completed for this project.

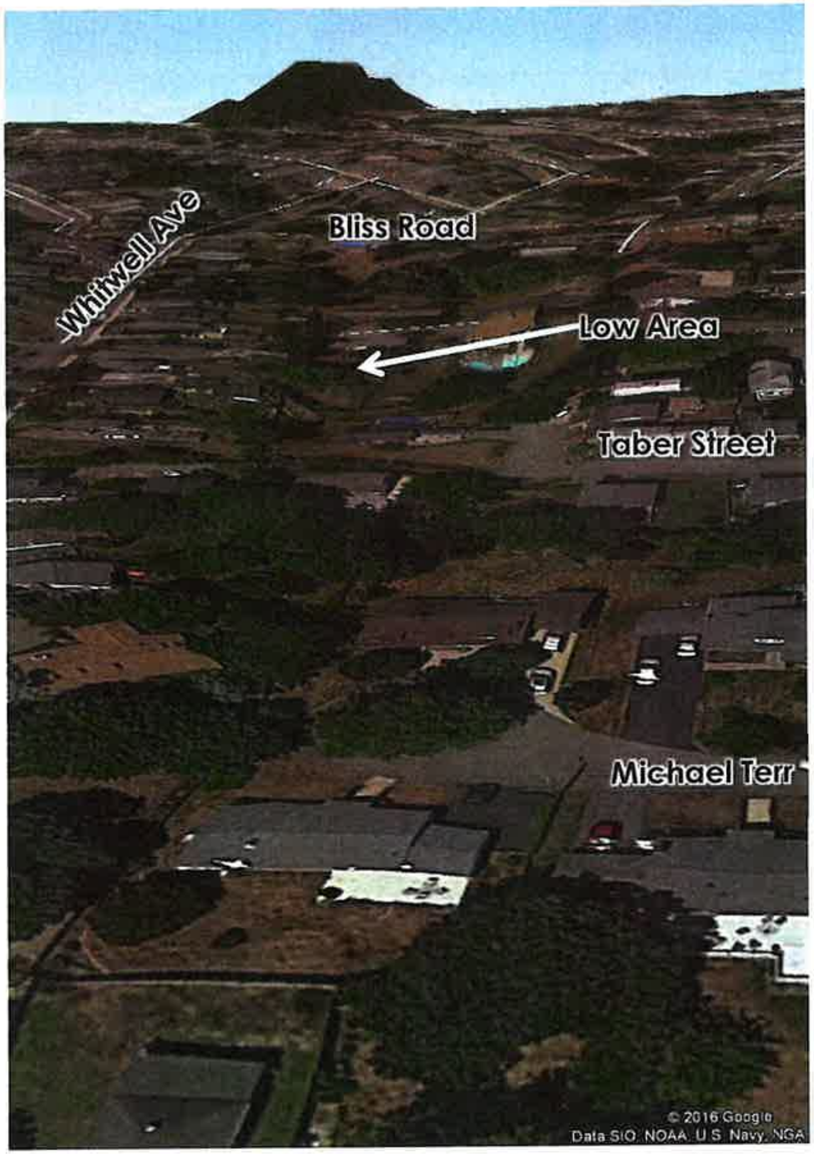
A dye test was conducted in October 2016 that confirmed that the 18-inch reinforced concrete pipe (RCP) along Ellery Road that collects drainage from Gibbs Avenue and Champlin Place N is not connected to the 48-inch outfall, but rather discharges to the 18-inch outfall at the Moat.

The majority of the drainage piping is several decades old. For design purposes, the average service life for most RCP pipe types is about 70 to 100 years. A closed-circuit television (CCTV) inspection of the storm drain system along Whitwell Avenue and Eustis Avenue to the discharge into the Moat was completed in August 2015 with no major defects identified. Several deficiencies observed in the pipes include increased surface roughness and longitudinal fractures which would increase friction but would have a negligible impact on flow capacity.

Topography

The topography of the study area generally slopes from Bliss Road at the northern boundary to the Moat, with water flowing in a north to south direction. One characteristic of the project area is that the topography between Whitwell Avenue and Eustis Avenue is a natural low area that extends to Kay Street (Figure 4). A similar low area exists between Champlin Place N and Eustis Avenue. This low area may reflect a historic watercourse which would also be consistent with the poor soils in this area.

This low area presents a couple of challenges in this watershed. Runoff will naturally want to accumulate in the low area thereby creating exacerbating the volume of water that needs to be managed in these areas. Also, the capacity of the storm drains are limited in these areas because of the lack of available depth for water to surcharge within the system before flooding above the top of a catch basin or manhole. A deeper storm drain will have more capacity because of its ability to become pressurized. In these low areas, the storm drain is shallower and loses its ability to pressurize and convey more flow.



Source: Google Earth

Figure 4. Topography

Soils

The soils in the watershed are mostly classified as Newport-Urban Land Complex, and are characterized as Hydrologic Soil Group (HSG) C, which has slow infiltration capacity. In general, Aquidneck Island soils are characterized primarily as HSG C. In comparison, HSG A and B soils have high to moderate infiltration capacity. The saturated hydraulic conductivity within the watershed could range from between 0.0 to 0.2 inches per hour; however in-situ testing is required to confirm these characterizations. As a result, there is a significant potential for runoff even from unpaved surfaces in this watershed.

Storms and Flooding

There are generally two types of storm events that are observed along the coast of Rhode Island that are also typical for the study area.

- **Large and sustained inland floods -** There are major floods with sustained precipitation. Recent inland floods of this type were the July 28, 2012 storm (3.9 inches), which was close in total rainfall to a 10-year frequency storm (5.0 inches) and the December 22-24, 2015 storm event (2.7 inches). A 10-year frequency storm is a typical standard for the design of "new" drainage systems.

- **Flash Floods –** Flash flooding in the study area is primarily associated with summer thunderstorm systems that are characterized by large, usually isolated, thunderstorm patterns with a high intensity rainfall over a short duration. Examples storms occurred on August 10 and 15, 2012, which had recorded rainfall of 1.58-inches over 5 hours and 1.78-inches over 4 hours, respectively.

What is a "10-Year Storm"?

The ability to drain a 10-year frequency storm is a typical standard for new storm drainage systems. A ten year frequency storm has a total amount of precipitation that has a 10% probability of being equaled or exceeded in any given year. While this storm could happen more than once in a given year, over a long period of record it would be equaled or exceeded on an average of once every ten years.

For Newport, Rhode Island, a total amount of rainfall equaling 5.0-inches over a 24 hour period constitutes the 10-year rainfall amount. The typical rainfall pattern is the majority of the rain would fall within approximately 4 to 6 hour period in the middle of the 24 hour duration storm. The modeled storm events are discussed more in Section 3.

Typically, retrofitting existing systems to reduce flooding will not meet the same 10-year storm standard as what is required for new systems given the cost that is often associated with the scale of improvements to upgrade a system to meet that standard.

Observed Localized Flooding

A public meeting was held on June 1, 2016 at the Pell Elementary School, located in Newport, Rhode Island. The purpose of meeting was to provide information to members of the public about this study and receive public observation and input to the study by requesting testimonials and photographs of past flooding events both during the meeting and following the meeting via email. A publicly announced site visit was also held thereafter to collect additional information from residents.

Photographs and narrative accounts of flooding were received from many residents. These general areas of concern are identified on Figure 5 and generally consist of flooding on residential properties and roadways at:

- Bliss Road & Whitwell Avenue
- Whitwell Avenue at Watson Street
- Cul-de-sac on Hazard Avenue
- Back yard of 29 Wilbur Avenue
- Back yard of 116 Kay Street
- Along Gibbs Avenue and North Champlin Place

The information during these meetings was used in calibrating the SWMM model (See Section 3) which was then used to develop alternatives to mitigate the flooding.

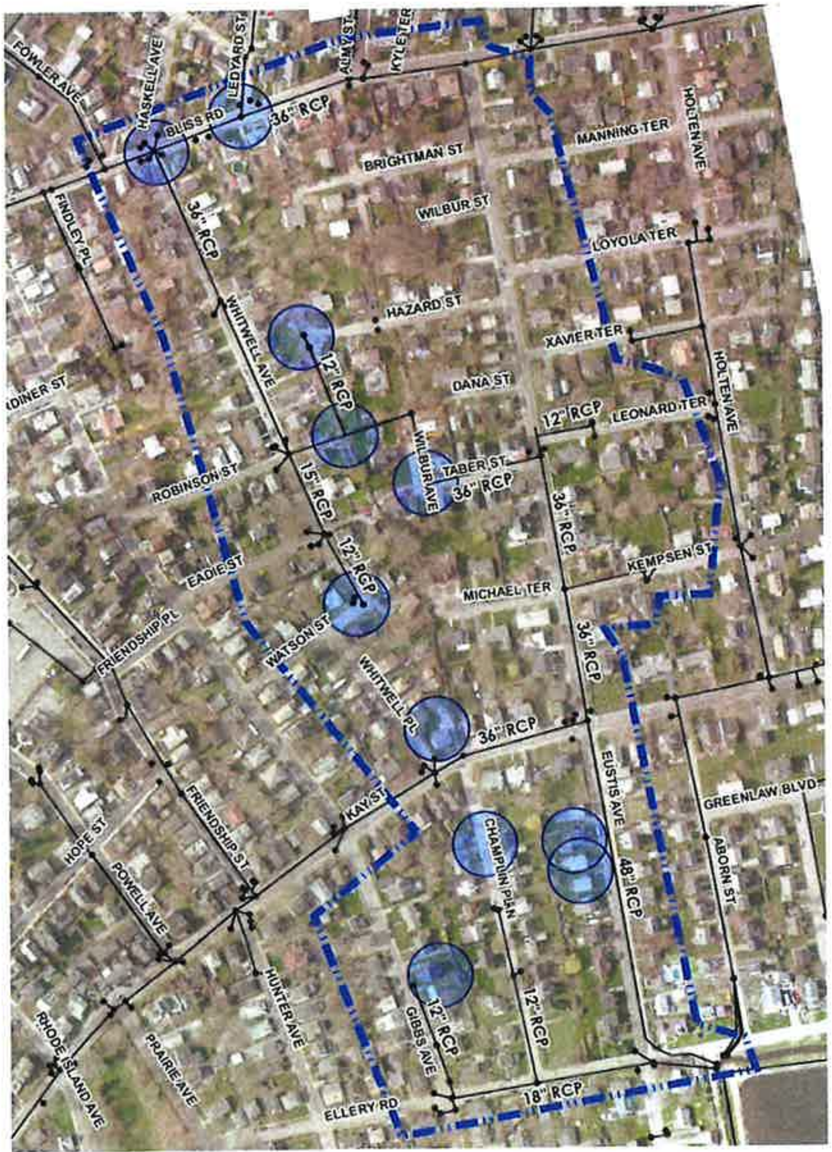


Figure 5. Areas of Observed Routine Flooding Reported by Residents

3 Whitwell Avenue Area Drainage Model

A Storm Water Management Model (SWMM) Version 5.1.010 model was developed using PCSWMM version 6.3, for the 262-acre Whitwell Avenue area drainage area, which include modeling rainfall and runoff for the entire catchment area and detailed hydraulics of the drainage system in the Whitwell Avenue project area.

Data Collection

Survey data was collected in June and August 2016 for the detailed portion of the hydraulic model at critical manholes that connect the storm drain trunk sewers which was used to develop the SWMM model. The survey is included in Attachment A. The surveyed information included rim elevations, invert elevations, and pipe sizes and diameters for manholes and did not include catch basin data.

Manholes were selected as they are located the trunk storm sewer that drains through the project area. The ability for connecting catch basins to drain to these manholes is driven by the hydraulics of the trunk storm sewer. Data was collected within the detailed study area at manhole locations along Bliss Road between Eustis and Whitwell, Eustis Avenue, Whitwell Avenue, Taber Street, Hazard Street, Leonard Terrace, Kempson Street, behind 29 Wilbur Avenue, Kay Street, Champlin Place N, Gibbs Avenue, and Ellery Road. Surveyed manhole locations are named J01 through J26 as shown on the SWMM Model Schematic (Figure 6).

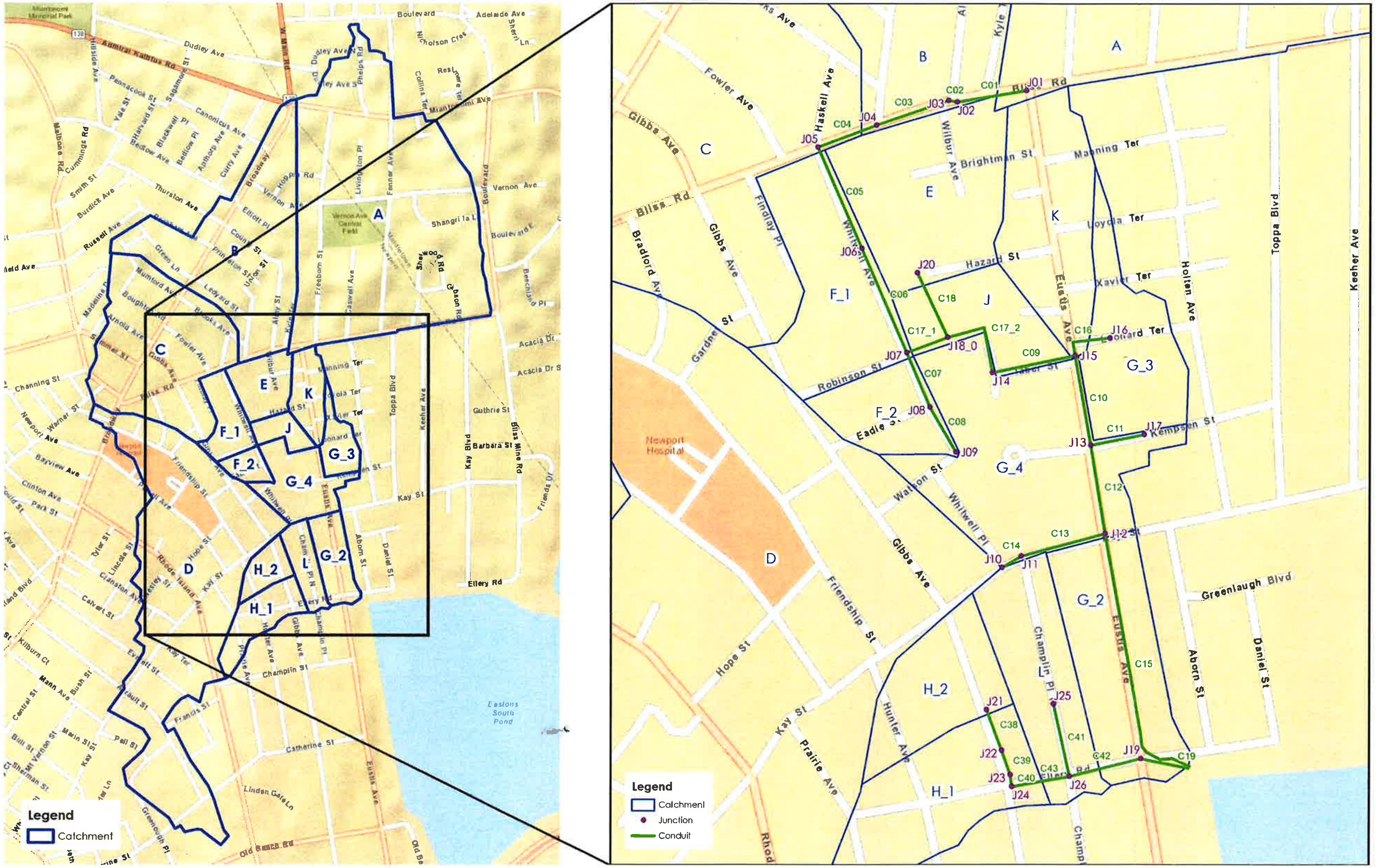


Figure 6. SWMM Model Schematic

Modeling Approach

Subcatchments were delineated and the average slope determined using topographic information obtained fróm the "2011 U.S. Geological Survey Topographic LiDAR for the North East" data set. Subcatchments are named "A" through "L." The percent impervious value is based on the Rhode Island Department of Environmental Management impervious surface raster data layer, with impervious percentages ranging from 36 to 63%. The subcatchment widths were determined based on typical flow paths of approximately 200 feet to reach the storm drain system.

The system was modeled using a combined one and two-dimensional model in which the closed drainage system connects to the land surface to model the depth and extent of flooding from surcharging manholes along the trunk storm sewer. The land surface elevations are discretized at 10 foot intervals.

The Green-Ampt infiltration method was used for this modeling with soils parameters assigned consistent with sandy-loam that exists in this watershed based on the Natural Resources Conservation Service (NRCS) Soil Survey data.

Modeling input is included in Attachment B.

Modeled Storm Events

For the purposes of evaluating the flooding in this watershed, two storms were simulated in SWMM for the existing and proposed conditions. These storms were both the actual storm event during the August 15, 2012 period to reflect an actual case of flooding in the neighborhood as well as the theoretical 10-Year, 24 Hour duration (Type III) storm which is a typical standard for new systems. The storms have similar peak intensities; however, the August 2012 storm had a much shorter duration of 4 hours, consistent with thunderstorm events (Table 2 and Figure 7).

These two storms were selected because the August, 2012 would provide information on short duration storms that mimics routine thunderstorm events while the 10-year frequency storm would reflect a longer duration flooding event.

Table 2. Simulated Storm Events

Storm	Total Rainfall Depth (in)	Duration (hr)	Peak Intensity (in/hr)
August 15, 2012	1.78	4	1.17
10-Year Storm Event	5.02	24	1.26

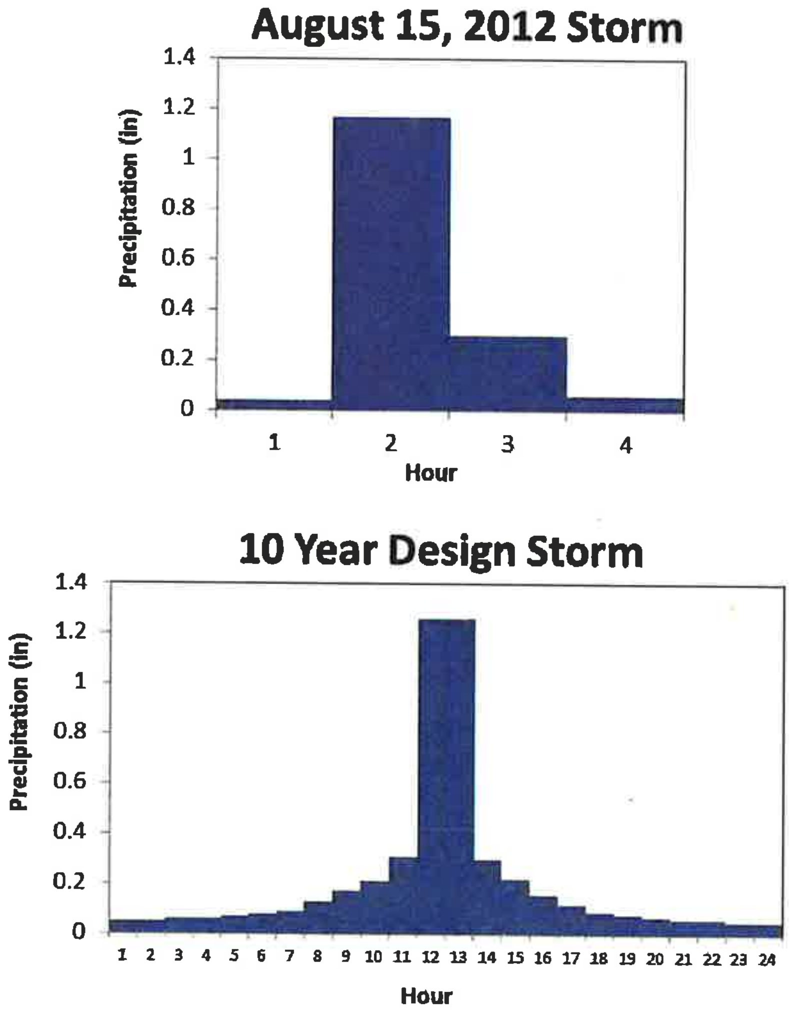


Figure 7. Storm Event Hyetographs Model Input

Model Calibration

The model calibration was checked using two photographs taken during the modeled storm event August 15, 2012. Figure 8 is a photograph of the intersection of Whitwell Avenue and Watson Street showing flooding conditions during storm event. Based on estimating the height of the catch basin to be 6 inches, it can be estimated that there is between 2-3 inches of flooding occurring during this event at this intersection. The simulation model results are 7 inches of maximum flooding depth at this intersection. It is likely that the photograph was not taken at exactly the peak flood depth of the storm, so the model results are slightly higher than the flood depth in the photograph. The average flooding depth during the 3 hour peak precipitation was 3 inches.

Figure 8. Intersection of Whitwell Avenue and Watson Street on August 15, 2012

The photograph in Figure 9 depicts the flooding during the August 15, 2012 storm, taken by a local resident at 17 Hazard Street. Based on the bottom white piece of vinyl that is estimated at 12-inches in height, the flood depth in the photo is approximately 10 inches. The simulation model results are 13 inches of maximum flooding depth at this intersection. It is likely that the photo was not taken at exactly the peak flood depth of the storm making this observed depth more consistent with the modeling results.

Figure 9. 17 Hazard Street on August 15, 2012

Existing Conditions Results

The peak flows from the subcatchment areas generally correspond to the relative sizes of the subcatchments, with Subcatchment A having the highest peak flows and the largest land area of 77 acres. Subcatchment F-2 is the smallest subcatchment at 2.2 acres and has the lowest peak flow rates. The modeled peak flow rates within the pipes at critical locations are shown in Table 3.

Table 3. Existing Condition Model Results – Subcatchment Peak Flows

Subcatchment Area (See Figure 6)	Modeled Peak Flow (cfs) August 2012 Storm	10-Year Storm
Catchment A (Bliss Rd & Eustis Ave)	61.9	80.1
Catchment B (Bliss Rd & Almy St)	33.7	40.3
Catchment C (Bliss Rd & Haskell Ave)	27.6	34.9
Catchment D (Kay St & Whitwell Ave)	56.2	68.9
Catchment E (Hazard Ave)	4.0	5.9
Catchment F-1 (Whitwell Ave & Robinson St)	4.0	5.5
Catchment F-2 (Whitwell Ave & Watson St)	1.7	2.3
Catchment G-2 (Ellery Rd & Eustis Ave)	4.0	5.4
Catchment G-3 (Kempson St)	2.8	3.8
Catchment G-4 (Kay St & Eustis Ave)	6.6	9.0
Catchment H-1 (Gibbs Ave & Ellery Rd)	5.5	6.7
Catchment H-2 (Gibbs Ave)	3.0	3.6
Catchment J (Eustis Ave & Taber St)	1.9	2.6
Catchment K (Leonard Ter)	3.8	5.0
Catchment L (Champlin Pl N)	3.3	4.3

Peak flows in the 36-inch pipe that drains from Bliss Road, down Whitwell and over to Eustis Avenue, and then discharges to the Moat through a 48-inch pipe increases more than two-fold between the intersection of Bliss Road at Whitwell Avenue and the outfall location at the Moat, 72 cfs to 189 cfs during the 10-year storm (Table 4). This is primarily due to the contribution of the large subcatchments C and D which discharge into the drainage system at junctions J05 (at Bliss Rd and Whitwell Ave) and J10 (at Kay St and Whitwell Pl), respectively.

The storm drainage system associated with the Gibbs Avenue and Champlin Place N roadways result in a peak August 2012 and 10-year storm flow of approximately 15 cfs and 26 cfs, respectively into the Moat.

Table 4. Existing Condition Model Results –Peak Pipe Flows (cfs) at Critical Locations

SWMM Model Conduit (See Figure 6)	Existing Conditions August 2012 Storm	10-Year Storm
C04 (Bliss Road near Whitwell Ave)	69.9	72.0
C06 (Whitwell Ave, Mid-Block)	90.3	91.3
C08 (Whitwell Ave near Watson St)	2.8	3.2
C09 (Taber St)	110.3	106.5
C15 (Eustis Ave to 48" Outfall)	160.0	189.3
C19 (Ellery Rd; 18" Outfall)	15.3	25.5

Table 5 depicts the modeled surcharge[1] depths at certain manhole locations in the system based on the modeled flows. This represents the depth of flooding above the manhole rim and thereby above ground at that location. Manhole locations that did not surcharge are not shown in the table.

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[1] Surcharging occurs in a manhole or catch basin where the rate of the water entering or flowing through it is greater than the capacity of the pipe under open-channel conditions. As water starts to surcharge above the top of pipe in a manhole or catch basin, the pipe begins to flow under pressure which does increase the pipe's capacity somewhat. The depths provided in the report are the depth of water over the rim of the modeled structure in order to focus more on above ground flooding.

Table 5. Modeled Surcharge Depths under Existing Conditions (Feet above Rim)

Manhole ID (See Figure 6)	Existing Conditions	
	August 15, 2012 Storm	**10-Year Storm**
J03 (Bliss Road & Almy St)	--	0.06
J04 (Bliss Road & Ledyard St)	0.77	1.1
J05 (Bliss Road & Whitwell Ave)	--	0.09
J07 (Whitwell Ave & Robinson St)	--	--
J08 (Whitwell Ave & Eadie St)	--	0.14
J09 (Whitwell Ave & Watson St)	0.57	0.61
J11 (Kay St & Champlin Place N)	--	--
J12 (Kay St & Eustis Ave)	--	--
J14 (Taber St)	0.65	1.37
J17 (Kempsen Street)	--	0.65
J18 (Eustis Ave & Ellery Rd)	2.72	3.07
J20 (Hazard St)	1.79	2.12
J25 (Champlin Place North)	--	0.45
J26 (Champlin Place N & Ellery Rd)	--	0.22

Note: "--" denotes no surcharging occurs at the manhole location during the scenario listed.

As the water surcharges out of the storm drainage system, it begins to flow over the land surface following the topography. Water that flows down the roadways may re-enter the drainage system downstream if the manhole structures lower in the system are not surcharging during that model timestep.

The simulated storm events result in surcharged water along Bliss Road that flows over the curbing on the roadway and begin to flow through residential back yards following the low topography between Eustis Avenue and Whitwell Avenue. This is primarily due to the large percentage of the overall watershed area that is located north of Bliss Road and flowing into the system along Bliss Road. Approximately 56% of the total watershed area is collected in the closed drainage system upgradient from Bliss Road.

The maximum depth of flooding of 3.1 feet occurs in a low area behind 29 Wilbur Avenue for the 10-year storm. This area corresponds to a low point in the topography. A catch basin was reportedly installed in this location several years ago to alleviate ponding water that occurs in this area (Figure 10). Although the flooding in this area is the most severe, there are other areas around the project area that flood, including along Bliss Road, Eustis Avenue, Whitwell Avenue, and several side streets as noted in Table 5.

The August 2012 event resulted in surcharging at several locations within the project area. Similar to the 10-year storm, the area of deepest maximum flooding occurs in the rear of 29 Wilbur Avenue. Figure 11 shows the depth of flooding over time during the August 15, 2012 storm event at ground surface locations in the vicinity of the following manholes:

- J04 (Bliss Road & Ledyard St)
- J09 (Whitwell Ave & Watson St)
- J14 (Taber St)
- J20 (Hazard St)
- J18 (Behind 29 Wilbur Ave)

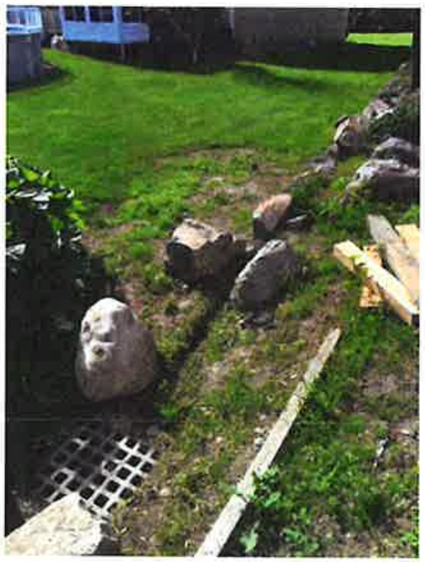

Figure 10. Catch Basin behind 29 Wilbur Avenue

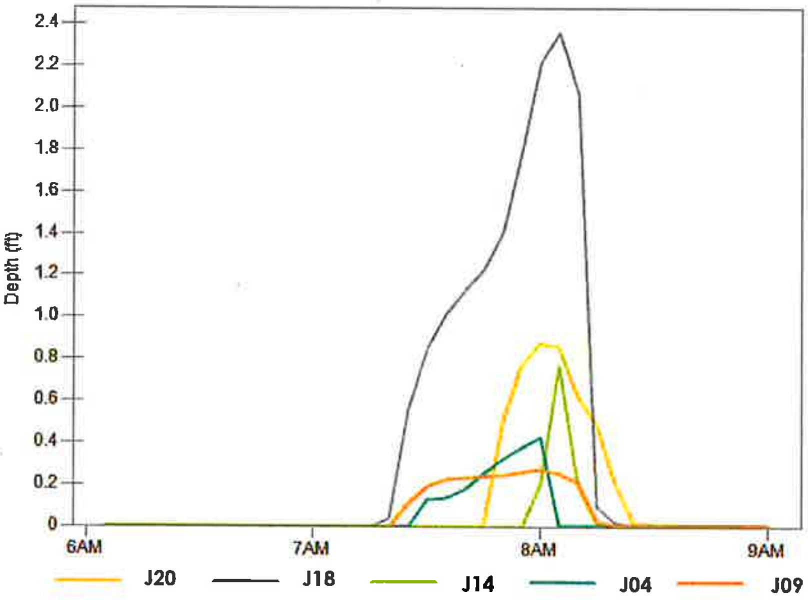

Figure 11. Depth of Surface Flooding at Critical Locations during the August, 15 2012 Event

Figures 12 and 13 depict the maximum simulated flooding depths across the project area for the 10-year frequency storm and the August 2012 event. Some of the flooding shown in roads is runoff draining down existing road gutters to the next downstream catch basins and may not necessarily be visually recognized as "flooding" during a storm event.

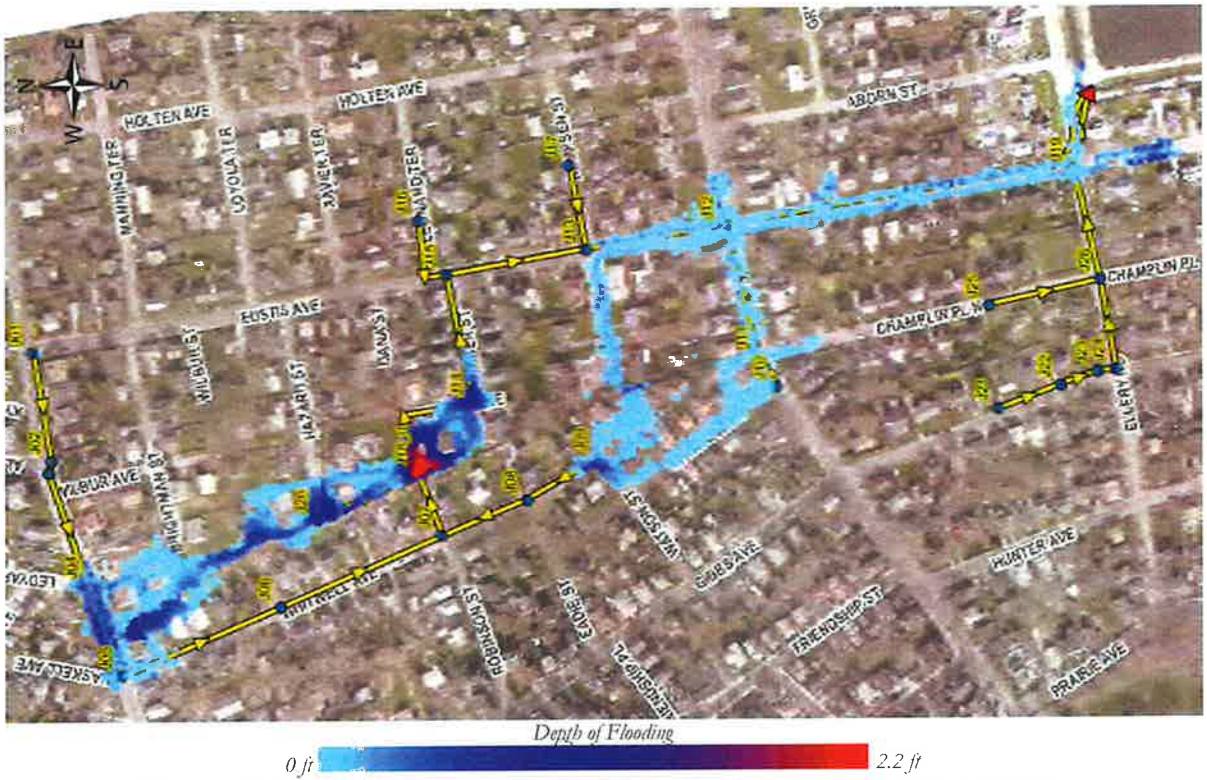

Figure 12. Simulated Peak Flooding Depths under Existing Conditions (August 15, 2012 Storm Event)

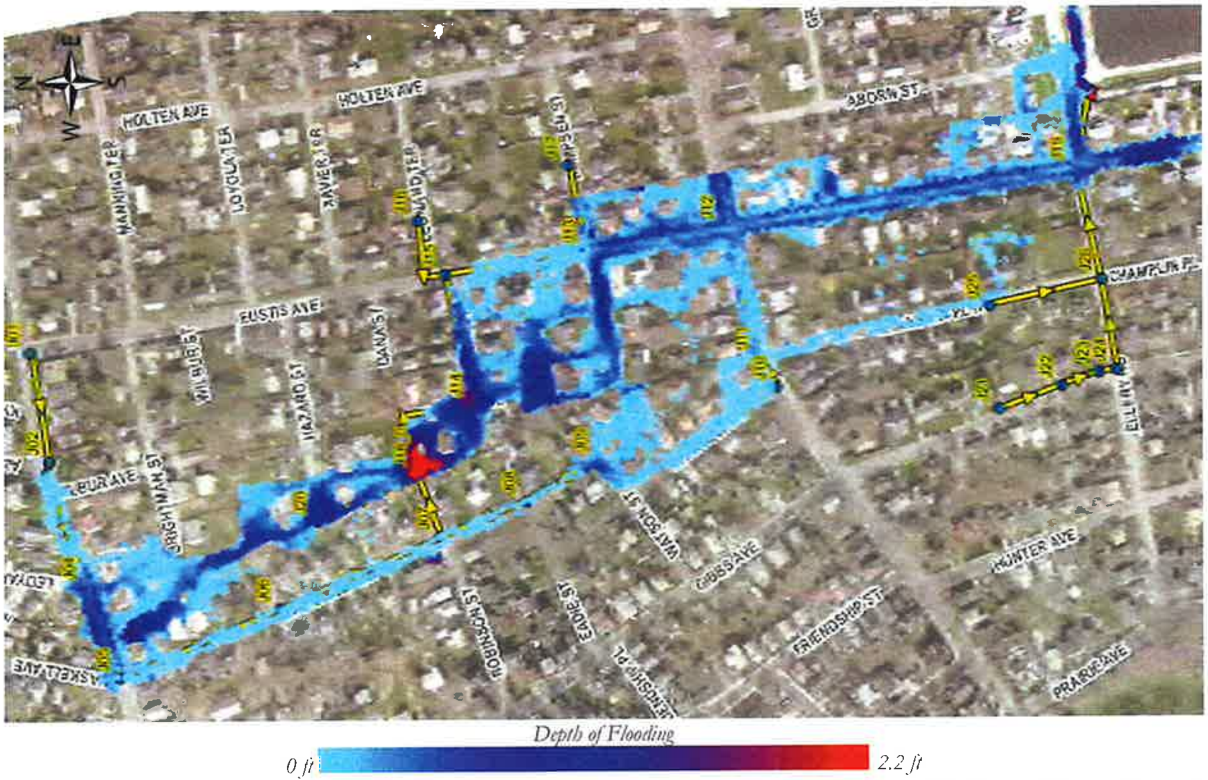

Figure 13. Simulated Peak Flooding Depths under Existing Conditions (10 Year Storm Event)

4 Moat Impacts to Whitwell Avenue Drainage System

The Moat is a man-made drainage channel that collects runoff from the neighborhoods that surround South Easton Pond. The Moat starts near the eastern end of Ellery Road where it drains to the west before it turns south along the western edge of the pond's dam and then east along the southern edge of the pond's dam. Below the dam's spillway it turns south again, draining under Memorial Boulevard before it flows into the ocean.

Significant flooding problems occur along the length of this Moat associated with both storm tides as well as inland flooding events that generate volumes of runoff beyond the capacity of the Moat. Specific historic flooding occurs on sections of the Moat along Memorial Boulevard, Old Beach Road and Ellery Road.

2008 Dam and Moat Study

In 2008, a study was completed by Fuss & O'Neill, the *Dam and Moat Study*, which included a flood study of the Moat to identify potential engineering solutions to reduce flooding. This study evaluated several alternatives. The primary alternatives are summarized in Table 6. The HEC-RAS modeled maximum water elevation in the Moat under the existing conditions 10-year storm is 11.9 feet NAVD88.

Table 6. Summary of Long-Term Flood Management Alternatives for the Moat

Alternative	Order of Magnitude Cost (2008 Dollars)	Reduction in Flooding During 10-Year Storm at Whitwell Outfall
1. Excavate existing channel bottom to provide a uniform channel slope in sections of the Moat that are adjacent to the identified areas of flooding	$1.4 Million	0.2 feet
2: Excavate and widen the Moat channel	$2.5 Million	0.2 feet
3. Replace existing Memorial Boulevard culvert with three 5-foot by10-foot box culverts	$650,000	0.2 feet
4. Install a pump station within southern portion of Moat	$6.5 Million	0.2 feet
5. Install 3-5'x8' box culverts at southwestern corner of Moat (adjacent to Old Beach Road)	$1.4 Million	0.2 feet
6. Provide uniform channel slope and cross-section throughout Moat and line base of channel with concrete	$3.7 Million	1.1 feet

This study concluded that reducing flooding along the Moat would cost several millions of dollars depending on the specific alternative while only reducing flooding by a few tenths of a foot. This is primarily due to the Moat being very long and flat which cannot be significantly overcome by improvements. Because of the length of the Moat, even pumping would not have a significant impact on flooding in the Moat. Figure 3 depicts the Moat location and the Whitwell Avenue outfall.

About the Moat Hydraulic Model

A HEC-RAS model was utilized to model water surface profile elevations in the Moat. HEC-RAS is a US Army Corps of Engineers model specifically developed to model flooding along open channels such as the Moat. This model is documented in detail in the earlier 2008 *Dam and Moat Study*.

Assessment of Moat Impacts to Whitwell Ave Drainage System

In order to assess how water levels in the Moat can impact flooding in the Whitwell Avenue study area, we utilized the 2008 hydraulic modeling. Water surface elevations in the Moat under a 10-year storm event in HEC-RAS were used in the SWMM model to assess impacts to water surface elevations in the Whitwell Avenue drainage system.

According to the Rhode Island Climate Change Collaborative[2], the predicted end-of-century tidal high water would inundate up to an elevation of 4.9 feet NAVD88, which is a 2.3-foot rise in sea level. The projected 4.9 foot sea level elevation is well below the 11.9 foot water surface elevation for a 10-year storm at the Moat as calculated by the HEC-RAS model. As a result, this projected sea level rise elevation will not impact 10-year storm flood elevations in the Moat along Ellery Road given the fact that the 10-year water surface elevations are so much higher the projected sea level rise. The hydraulic distance along the Moat between Ellery Road and the Moat outlet also dampens sea level rise impacts.

Under the 10-year storm scenario where the Moat elevation is at 11.9 feet, the Ellery Road and Eustis Avenue intersection would be inundated by approximately 2 inches. This would cause water in the 48-inch outfall pipe to back up to Kay Street by approximately another 6 inches as compared to the same storm occurring when the Moat is at normal water levels (Moat elevation of 5.5 feet). However, the impacts of the 10-year storm water surface levels in the Moat do not continue north of Kay Street because of the elevations of the drainage system.

The influence of water elevations in the Moat on the hydraulic performance the Whitwell Avenue drainage system is minor. Even with a reduction of water surface elevations in the Moat to 10.8 (a 1.1 foot reduction consistent with Alternative 6 in Table 6) would only yield a 1-inch decrease in water levels at Ellery and Eustis intersection. As a result, investing in improvements to reduce flooding in the Moat is not recommended as part of an overall plan to reduce flooding in the Whitwell Avenue project area.

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[2] http://www.riclimatechange.org/changes_sea_level.php

5 Potential Drainage System Improvements

Several alternative structural improvements to the existing drainage system could reduce flooding in the project area. These alternatives are listed below:

- **Alternative 1, Increase Pipe Sizes:** Increase the pipe sizes along trunk storm sewers within the project area.
- **Alternative 2, Increase Pipe Sizes & Connect Watson Street with Kay Street:** Increase the pipe sizes along trunk storm sewers within the project area and install a new 36-inch storm drain connecting the drainage system that now terminates at the intersection of Whitwell and Watson Street with Kay Street.
- **Alternative 3, Install Subsurface Storage System:** Construct storage units above existing trunk storm sewers and replace the existing trunk storm drains.

Each alternative and corresponding model results are described in the following sections, followed by a discussion of non-structural best management practices. Green infrastructure and offsite storage alternatives were also considered and are described in this section.

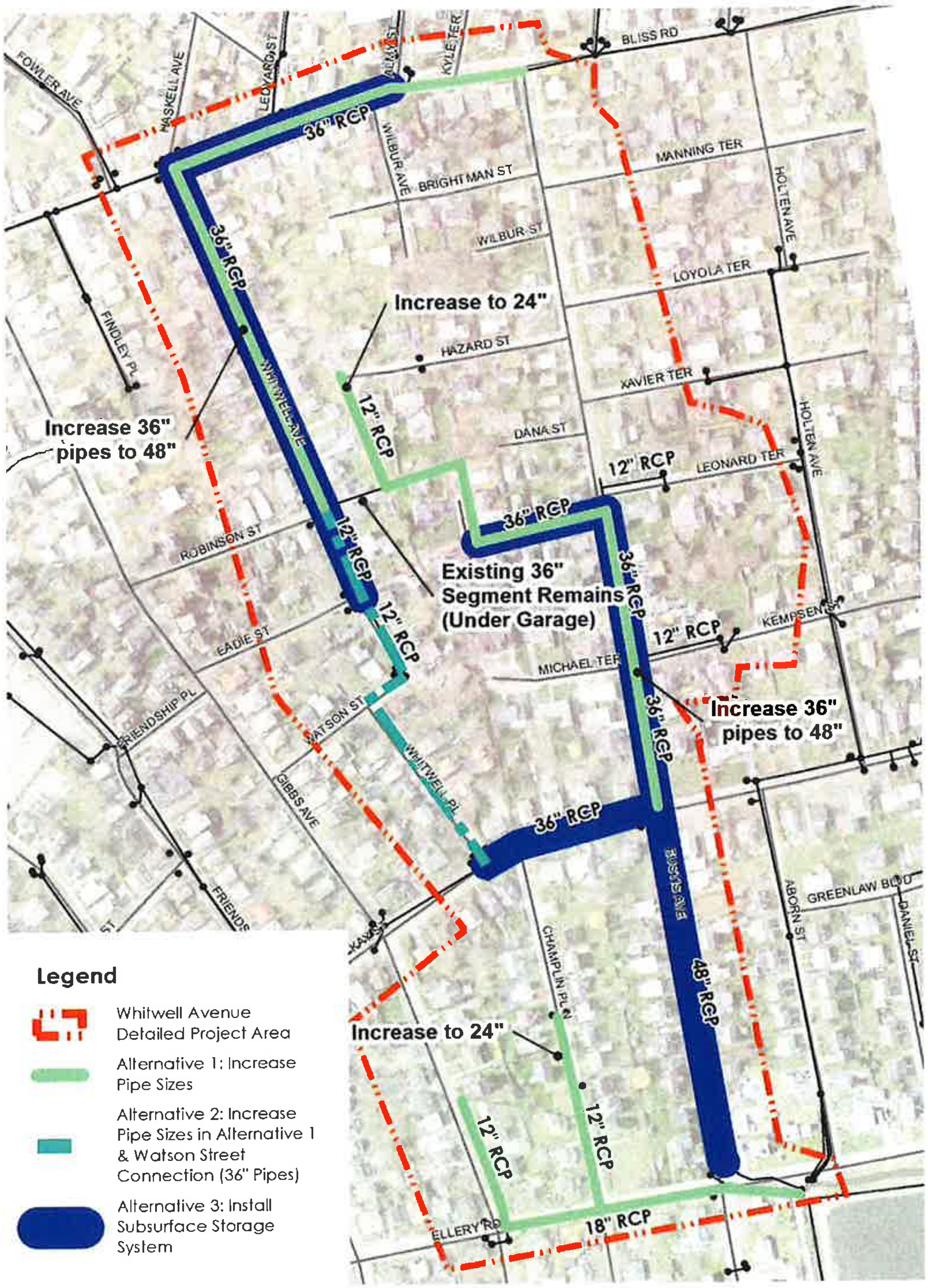

Figure 14. Overview of Alternative Scenarios

Alternative 1: Increase Pipe Sizes

Alternative 1 includes the following drainage system modifications, as shown in Figure 14:

- Increasing the existing 36-inch pipe that runs across Bliss Road, down Whitwell Ave, cross country to Taber Street, and down Bliss Road to the existing 48-inch pipe. Note that the 36-inch connection pipe from Whitwell Avenue at Robinson Street to behind 29 Wilbur Avenue runs underneath an existing garage and therefore, is not proposed to be replaced and would remain a 36-inch pipe.

- Increasing the 12-inch pipe from the cul-de-sac on Hazard Avenue to the connection with the existing Wilbur Avenue cross country 36-inch pipe to a 24-inch pipe.
- Increasing the pipe sizes on Gibbs and Champlin N and Ellery to 24-inch.

Modeling results for this alternative are presented in Tables 7 and 8 and Figures 15 through 18. Based on SWMM modeling, this alternative would eliminate surcharging in the system and surface flooding during the August 15, 2012 storm.

Under the 10-year storm scenario, there would be increased flooding at J07 (Whitwell Ave & Robinson St), J08 (Whitwell Ave & Eadie St), J09 (Whitwell Ave & Watson St), J11 (Kay St & Champlin Place N), and J12 (Kay St & Eustis Ave) compared to the existing conditions. Increased flooding would occur because of the increased storm flows being conveyed from the upper portion of the project area more quickly to the lower areas of the project. Surcharging still occurs in the lower portion of the project area, although improved in most locations from the existing conditions.

The surcharging at J07 near Robinson Street is due to the fact that the pipe segment was left as 36-inch. The surcharging at this location would be reduced if the pipe could also be replaced with a 48-inch.

Table 7. Modeled Surcharge Depths under Alternative 1: Increase Pipe Sizes (Feet above Rim)

	Existing Conditions		Alternative 1: Increase Pipe Sizes	
Manhole ID (See Figure 6)	August 15, 2012 Storm	10-Year Storm	August 15, 2012 Storm	10-Year Storm
J03 (Bliss Road & Almy St)	--	0.06	--	--
J04 (Bliss Road & Ledyard St)	0.77	1.1	--	--
J05 (Bliss Road & Whitwell Ave)	--	0.09	--	--
J07 (Whitwell Ave & Robinson St)	--	--	--	0.59
J08 (Whitwell Ave & Eadie St)	--	0.14	--	0.4
J09 (Whitwell Ave & Watson St)	0.57	0.61	--	0.73
J11 (Kay St & Champlin Place N)	--	--	--	0.35
J12 (Kay St & Eustis Ave)	--	--	--	0.72
J14 (Taber St)	0.65	1.37	--	--
J17 (Kempsen Street)	--	0.65	--	0.46
J18 (Eustis Ave & Ellery Rd)	2.72	3.07	--	0.39
J20 (Hazard St)	1.79	2.12	--	--
J25 (Champlin Place North)	--	0.45	--	0.43
J26 (Champlin Place N & Ellery Rd)	--	0.22	--	--

Note: "--" denotes no surcharging occurs at the manhole location during the scenario listed.

Although this alternative eliminates surcharging under the August 2012 storm scenario, the peak flows discharged to the Moat would increase substantially as shown in Table 8. For the August 2012 storm event the existing peak flow at the outfall is 160 cfs and this alternative is predicted to increase the peak flow at the outfall to 189 cfs, an 18% increase. Similarly for the 10-Year Event, the peak flow is simulated to increase from 189 cfs to 196 cfs, a 3% increase. Increasing peak flows in the Moat is unacceptable due to the downstream flooding impacts to residents in the low-lying areas around the Moat.

Table 8. Modeled Peak Outfall Flows (cfs) for Existing Conditions vs. Alternative 1: Increase Pipe Sizes

SWMM Model Conduit	Existing Conditions		Alternative 1: Increase Pipe Sizes	
(See Figure 6)	**August 2012 Storm**	**10-Year Storm**	**August 2012 Storm**	**10-Year Storm**
C15 (Eustis Ave to 48" Outfall)	160.0	189.3	188.9	196.1
C19 (Ellery Rd; 18" Outfall)	15.1	25.5	15.6	24.4

The construction of this alternative will have to address utility conflicts within the roadway, including water, sewer, gas, electric, and telecommunications lines that are below ground. Some of these utilities may laterally conflict with increasing the pipes from 36-inch to 48-inch. Service connections over the trench will also complicate installation. Further details on the exact locations of these utilities through site survey will be required to determine the exact extent of potential utility conflicts.

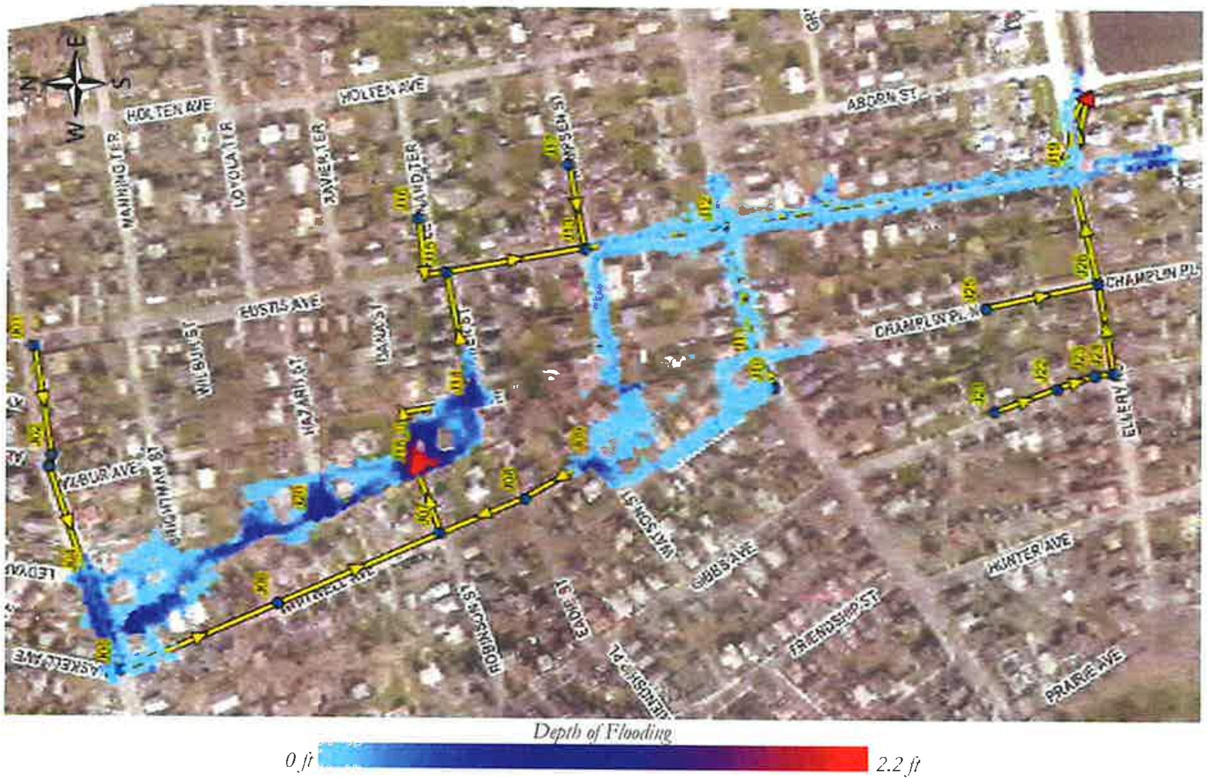

Figure 15. Simulated Peak Flooding Depths under Existing Conditions (August 15, 2012 Storm Event)

No Flooding

Figure 16. Simulated Peak Flooding Depths under Alternative 1: Increase Pipe Sizes (August 2012 Storm Event)

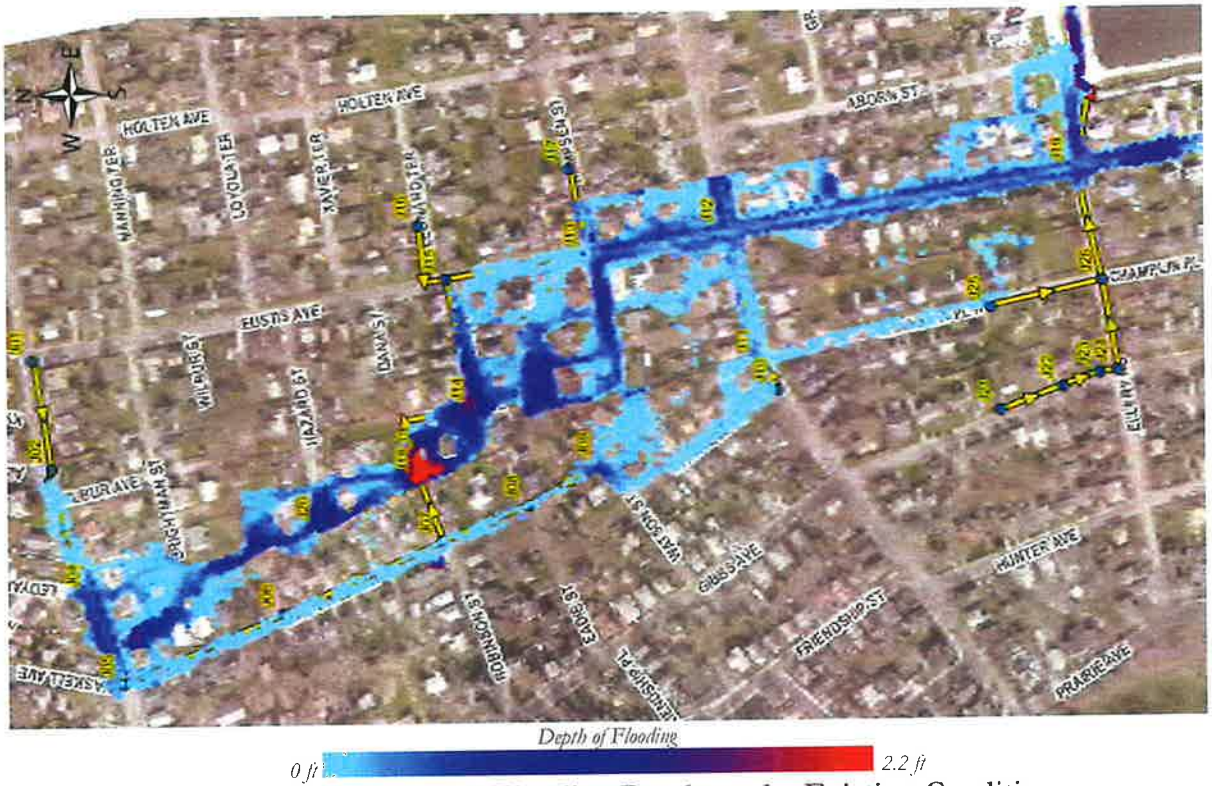

Figure 17. Simulated Peak Flooding Depths under Existing Conditions (10 Year Storm Event)

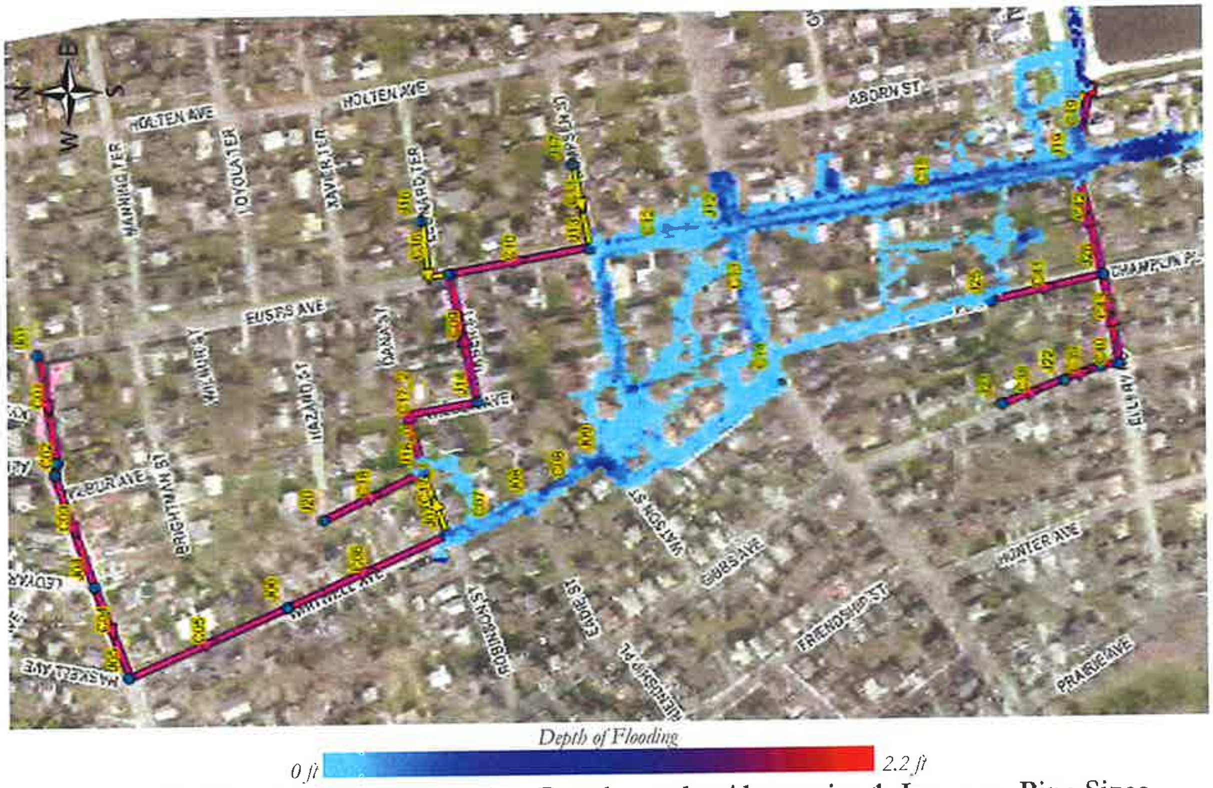

Figure 18. Simulated Peak Flooding Depths under Alternative 1: Increase Pipe Sizes (10 Year Storm Event)

Alternative 2: Increase Pipe Sizes and Connect Watson Street with Kay Street

Alternative 2 involves upgrading all the pipes as described in Alternative 1 and, in addition, replacing the 12-inch RCP pipe along Whitwell Avenue from Robinson Street to Watson Avenue with a 36-inch pipe (Figure 19). The inverts of the pipes from Robinson Street to Watson Avenue would be reset so that the pipes would be sloped north to south instead of south to north as they are currently. The new 36-inch pipe would also be extended to continue down Whitwell Place to the intersection with Kay Street.

Initially, this evaluation only consisted of installing a 36-inch connection between Watson Street and Kay Street. However, modeling results showed that this would only solve flooding problems along Whitwell Avenue to Watson Street and would exacerbate flooding at the Whitwell Place intersection with Kay Street. As shown in Table 9, there would be surcharging at J10 and J11 under both modeled scenarios, where there is none under the existing conditions, and the flooding in other areas of the project area are not reduced significantly. As a result, we combined this alterantive with Alternative 1 to reduce the potential for flooding in other neighborhoods.

Table 9. Modeled Surcharge Depths under Watson Street Connection Only (Feet above Rim)

	Existing Conditions		**Connect Watson Street with Kay Street Only**	
Manhole ID (See Figure 6)	**August 15, 2012 Storm**	**10-Year Storm**	**August 15, 2012 Storm**	**10-Year Storm**
J03 (Bliss Road & Almy St)	--	0.06	--	0.02
J04 (Bliss Road & Ledyard St)	0.77	1.1	0.52	1.02
J05 (Bliss Road & Whitwell Ave)	--	0.09	--	--
J07 (Whitwell Ave & Robinson St)	--	--	--	--
J08 (Whitwell Ave & Eadie St)	--	0.14	--	--
J09 (Whitwell Ave & Watson St)	0.57	0.61	--	--
J10 (Whitwell Place & Kay St)	--	--	0.35	1.00
J11 (Kay St & Champlin Place N)	--	--	0.33	0.82
J12 (Kay St & Eustis Ave)	--	--	--	--
J14 (Taber St)	0.65	1.37	--	0.95
J17 (Kempsen Street)	--	0.65	--	0.41
J18 (Eustis Ave & Ellery Rd)	2.72	3.07	--	2.21
J20 (Hazard St)	1.79	2.12	1.17	2.06
J25 (Champlin Place North)	--	0.45	--	0.52
J26 (Champlin Place N & Ellery Rd)	--	0.22	--	0.48

As shown on Table 10 and Figures 20 through 23, this alternative decreases flooding along Whitwell Avenue by providing a secondary pipe to convey stormwater from the Robinson Street intersection. However, flooding increases significantly on Kay Street at Eustis Avenue due to the new connection from Watson Avenue area. Figure 24 provides a hydraulic profile that shows water elevations at the peak of the 10-year storm. As shown, water surface elevations would decrease above Kay Street but increase at Kay Street.

Figure 19. Watson Street Drainage Connection to Kay Street

Figure 20. Simulated Peak Flooding Depths under Existing Conditions (August 15, 2012 Storm Event)

Figure 21. Simulated Peak Flooding Depths under Alternative 2: Increase Pipe Sizes and Watson Street Connection (August 15, 2012 Storm Event)

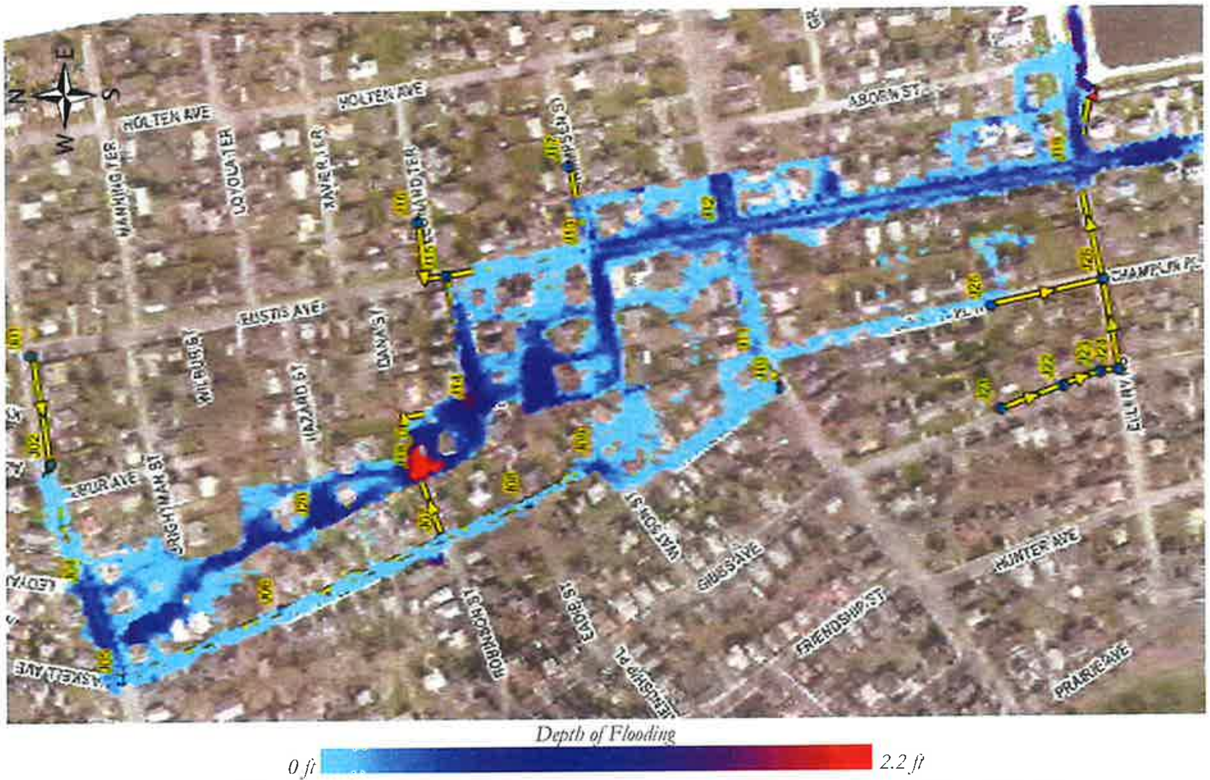

Figure 22. Simulated Peak Flooding Depths under Existing Conditions (10 Year Storm Event)

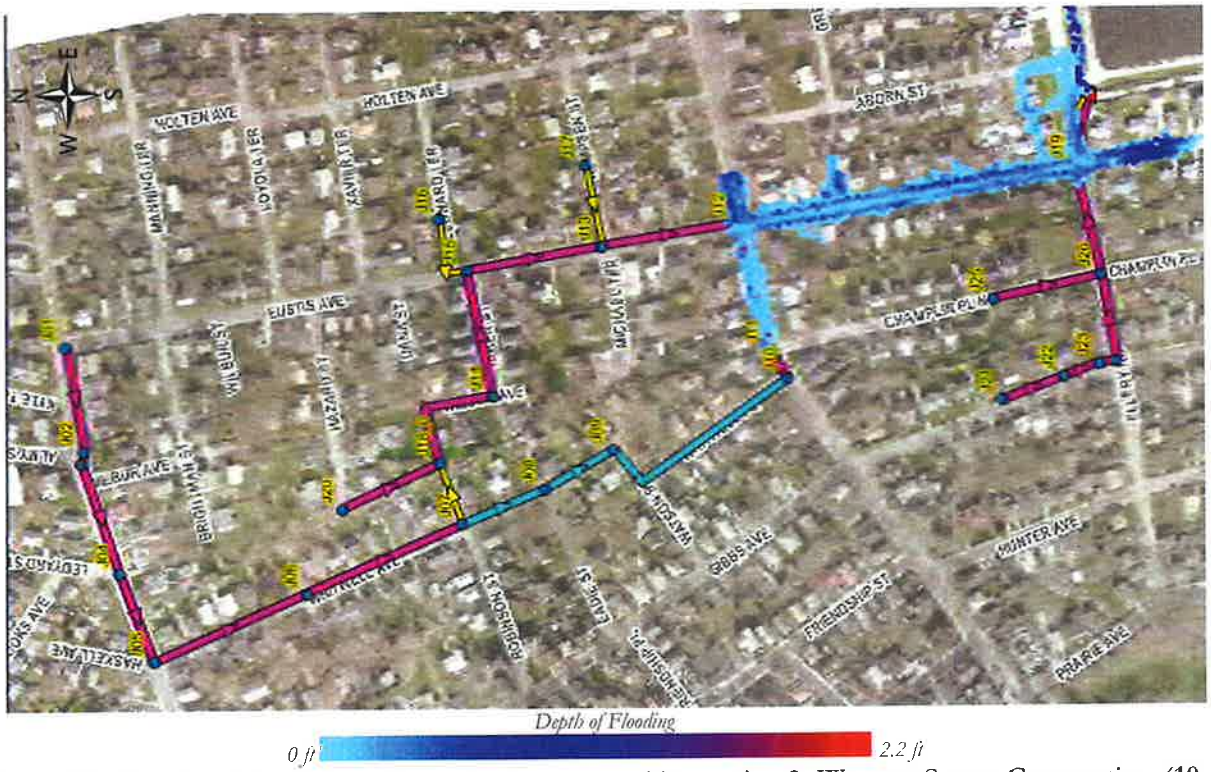

Figure 23. Simulated Peak Flooding Depths under Alternative 2: Watson Street Connection (10 Year Storm Event)

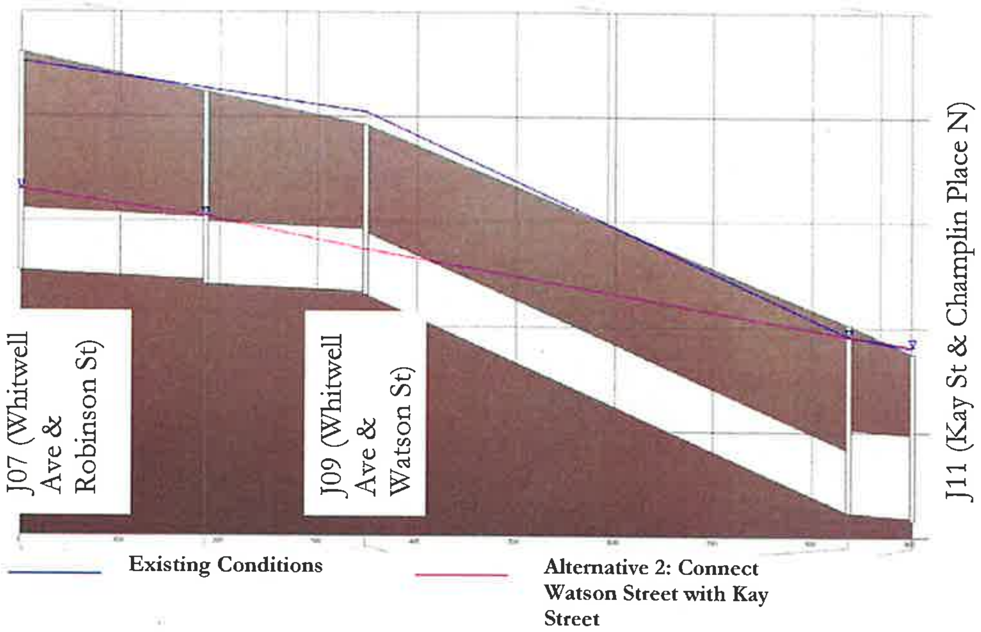

Figure 24. Hydraulic Profile from Robinson Street to Kay Street for Alternative 2 (10-Year Storm)

Table 10. Modeled Surcharge Depths under Alternative 2: Increase Pipe Sizes and Connect Watson Street with Kay Street (Feet above Rim)

	Existing Conditions		**Alternative 2: Increase Pipe Sizes and Connect Watson Street with Kay Street**	
Manhole ID (See Figure 6)	**August 15, 2012 Storm**	**10-Year Storm**	**August 15, 2012 Storm**	**10-Year Storm**
J03 (Bliss Road & Almy St)	--	0.06	--	--
J04 (Bliss Road & Ledyard St)	0.77	1.1	--	--
J05 (Bliss Road & Whitwell Ave)	--	0.09	--	--
J07 (Whitwell Ave & Robinson St)	--	--	--	--
J08 (Whitwell Ave & Eadie St)	--	0.14	--	--
J09 (Whitwell Ave & Watson St)	0.57	0.61	--	--
J11 (Kay St & Champlin Place N)	--	--	--	0.26
J12 (Kay St & Eustis Ave)	--	--	--	0.91
J14 (Taber St)	--	--	--	--
J17 (Kempsen Street)	0.65	1.37	--	0.12
J18 (Eustis Ave & Ellery Rd)	--	0.65	--	--
J19 (Eustis Ave & Ellery Rd)	2.72	3.07	--	--
J20 (Hazard St)	1.79	2.12	--	--
J25 (Champlin Place North)	--	0.45	--	--
J26 (Champlin Place N & Ellery Rd)	--	0.22	--	--

Note: "--" denotes no surcharging occurs at the manhole location during the scenario listed.

The peak flows at the outfalls for this alternative will increase. At the 48-inch outfall peak flow for the August 2012 storm event for this alternative is 190 cfs compared to the existing condition flow of 160 cfs (Table 11). The most significant difference in peak flows over the existing conditions is at the intersection of Whitwell Avenue and Watson Street, where the flows through the manhole increases more than 10 fold due to the additional connection to Kay Street. Increasing peak flows in the Moat and at this intersection is unacceptable due to the potential that increased peak flows would increase downstream flooding to residents in the low-lying areas around the Moat.

Table 11. Modeled Peak Flows (cfs) for Existing Conditions vs. Alternative 2: Watson Street Connection

SWMM Model Conduit	**Existing Conditions**		**Alternative 2: Watson Street Connection**	
(See Figure 6)	**August 2012 Storm**	**10-Year Storm**	**August 2012 Storm**	**10-Year Storm**
C08 (Whitwell Ave near Watson St)	2.8	3.2	46.8	60.3
C15 (Eustis Ave to 48" Outfall)	160.0	189.3	190.3	197.0
C19 (Ellery Rd; 18" Outfall)	15.3	25.5	15.6	24.7

This alternative would have many of the construction challenges that were identified under Alternative 1, including the installation of larger diameter pipes that may present conflicts with existing utilities or utility laterals. In addition, a new stormwater drainage pipe would need to be installed down Watson Street and Whitwell Place, where one does not currently exist, which will have significant potential for new utility conflicts.

Alternative 3: Install Subsurface Storage System

The objective of this alternative is to provide storage in order to temporarily detain peak flood flows within the drainage system, thereby reducing downstream peak flows and surcharging in existing drainage structures. Since there is no space within the watershed to install detention basins or other more common above-ground storage facilities, this alternative involves installing storage units below-grade above the existing 36-inch pipes where enough vertical space exists. This alternative would install 11 separate segments of this system that will act as storage units for the stormwater. Each segment consists of a system that would be placed between two existing manholes. The aging pipes underneath the areas proposed for storage units would be replaced under this alternative, along with manholes, catch basins, and lateral storm piping.

These storage units would consist of a manufactured chamber-type stormwater system with crushed stone backfill. Stone backfill will be placed up to the road subgrade. These storage units will be set level and will have 18-inch inlet and outlet pipes. The system would also have two 6-inch underdrains at the base of the stone to drain the unit following the peak flows.

The 6-inch underdrains would also serve to lower the groundwater table permanently in the vicinity of the storage units and thereby preserve the capacity in the storage system to store stormwater runoff instead of being filled by groundwater. While this system will prevent groundwater from filling the storage unit, the actual extent of the cone of depression in the surrounding soils will depend on the hydraulic conductivity of the soils, which would need to be determined prior to designing the systems. Some of the stormwater stored in the system will infiltrate into the surrounding soils but that positive benefit was not included in the modeling in order to make a more conservative assessment.

The concept for such storage units are shown in Figures 25 and 26. Based on NRCS soils data, the groundwater within the project area is believed to be around 23 to 24 inches below ground surface. A geomembrane liner could also be placed in the trench to keep groundwater out of the trench. However, that option would be expensive and difficult to construct. Penetrations for drains and utility connections will also be difficult with a geomembrane liner. A liner would also substantially complicate future maintenance. As a result, it was decided to rely on an underdrain system to keep groundwater from consuming storage capacity in these systems.

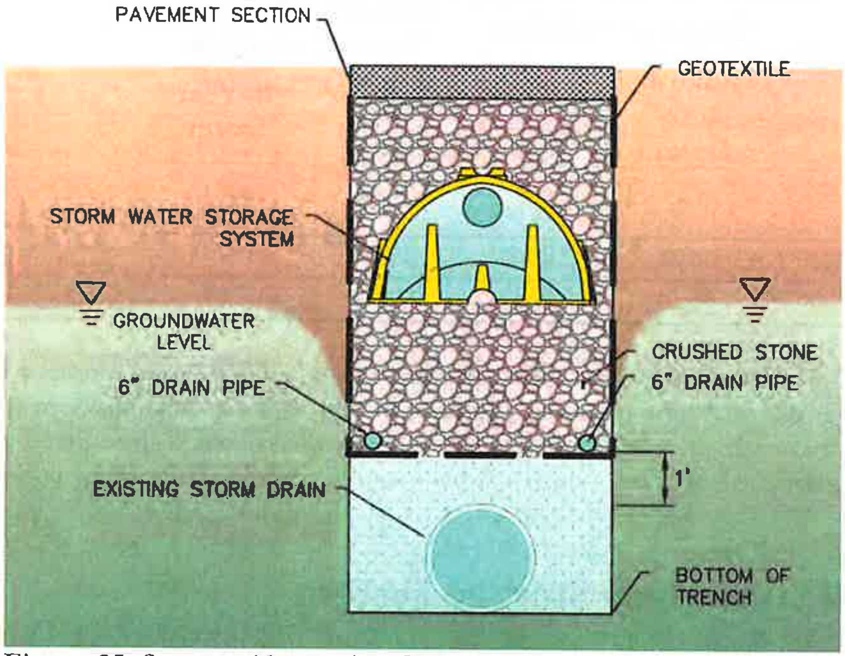

Figure 25. Storage Alternative Cross-Section

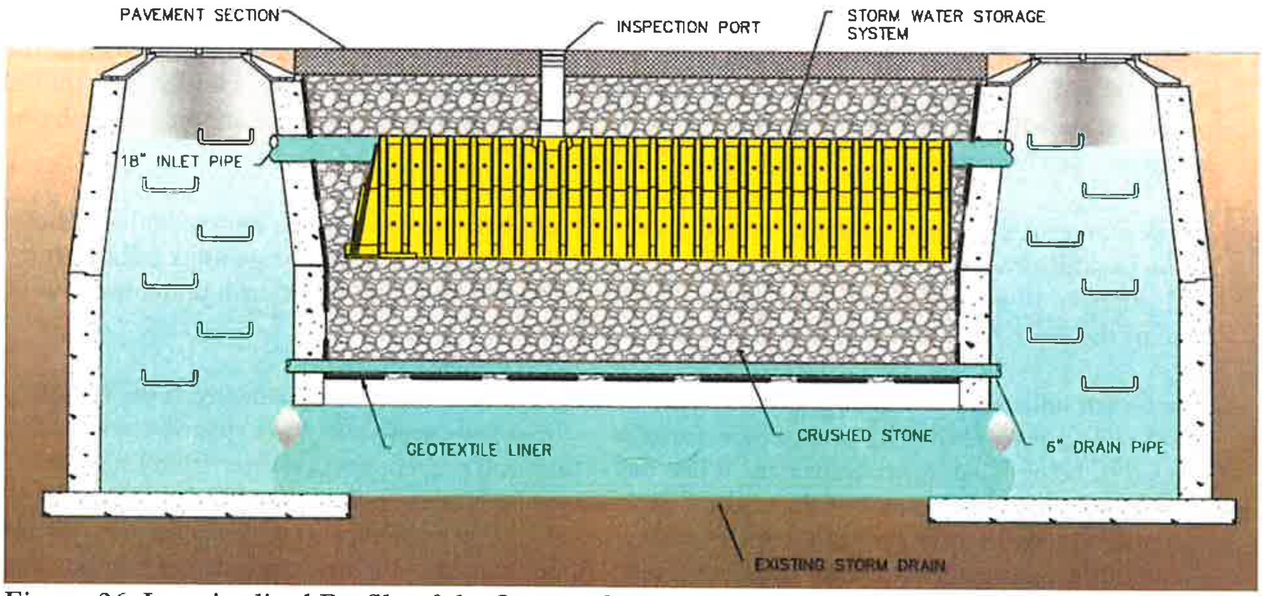

Figure 26. Longitudinal Profile of the Storage System Concept

The modeling results for this alternative are presented in Tables 12 and 13 and Figures 27 through 30. With this alternative, all surcharging was eliminated under the August 2012 storm event; however, there is only limited improvement of the surcharging under the 10-year storm. If desired, additional subsurface detention structures could be installed upstream of the watershed to increase storm capacity.

The outfall peak flows for the 48-inch pipe remain the same for each scenario, and thereby will not increase risk of increased downstream flooding.

Table 12. Modeled Peak Outfall Flows (cfs) for Existing Conditions vs. Alternative 3: Install Subsurface Storage System

SWMM Model Conduit	**Existing Conditions**		**Alternative 3: Install Subsurface Storage System**	
(see Figure 6)	**August 2012 Storm**	**10-Year Storm**	**August 2012 Storm**	**10-Year Storm**
C15 (Eustis Ave to 48" Outfall)	160.0	189.3	160.0	189.3
C19 (Ellery Rd; 18" Outfall)	15.3	25.5	15.3	25.5

Table 13. Modeled Surcharge Depths under Alternative 3: Install Subsurface Storage System (Feet above Rim)

	Existing Conditions		**Alternative 3: Install Subsurface Storage System**	
Manhole ID (see Figure 6)	**August 15, 2012 Storm**	**10-Year Storm**	**August 15, 2012 Storm**	**10-Year Storm**
J03 (Bliss Road & Almy St)	--	0.06	--	--
J04 (Bliss Road & Ledyard St)	0.77	1.1	--	0.98
J05 (Bliss Road & Whitwell Ave)	--	0.09	--	--
J07 (Whitwell Ave & Robinson St)	--	--	--	--
J08 (Whitwell Ave & Eadie St)	--	0.14	--	0.14
J09 (Whitwell Ave & Watson St)	0.57	0.61	--	0.61
J11 (Kay St & Champlin Place N)	--	--	--	--
J12 (Kay St & Eustis Ave)	--	--	--	--
J14 (Taber St)	0.65	1.37	--	1.37
J17 (Kempsen Street)	--	0.65	--	0.65
J18 (Eustis Ave & Ellery Rd)	2.72	3.07	--	2.81
J20 (Hazard St)	1.79	2.12	--	2.05
J25 (Champlin Place North)	--	0.45	--	--
J26 (Champlin Place N & Ellery Rd)	--	0.22	--	--

Note: "--" denotes no surcharging occurs at the manhole location during the scenario listed.

Figure 27. Simulated Peak Flooding Depths under Existing Conditions (August 15, 2012 Storm Event)

[No Flooding]

Figure 28. Simulated Peak Flooding Depths under the Storage Alternative (August 2012 Storm Event)

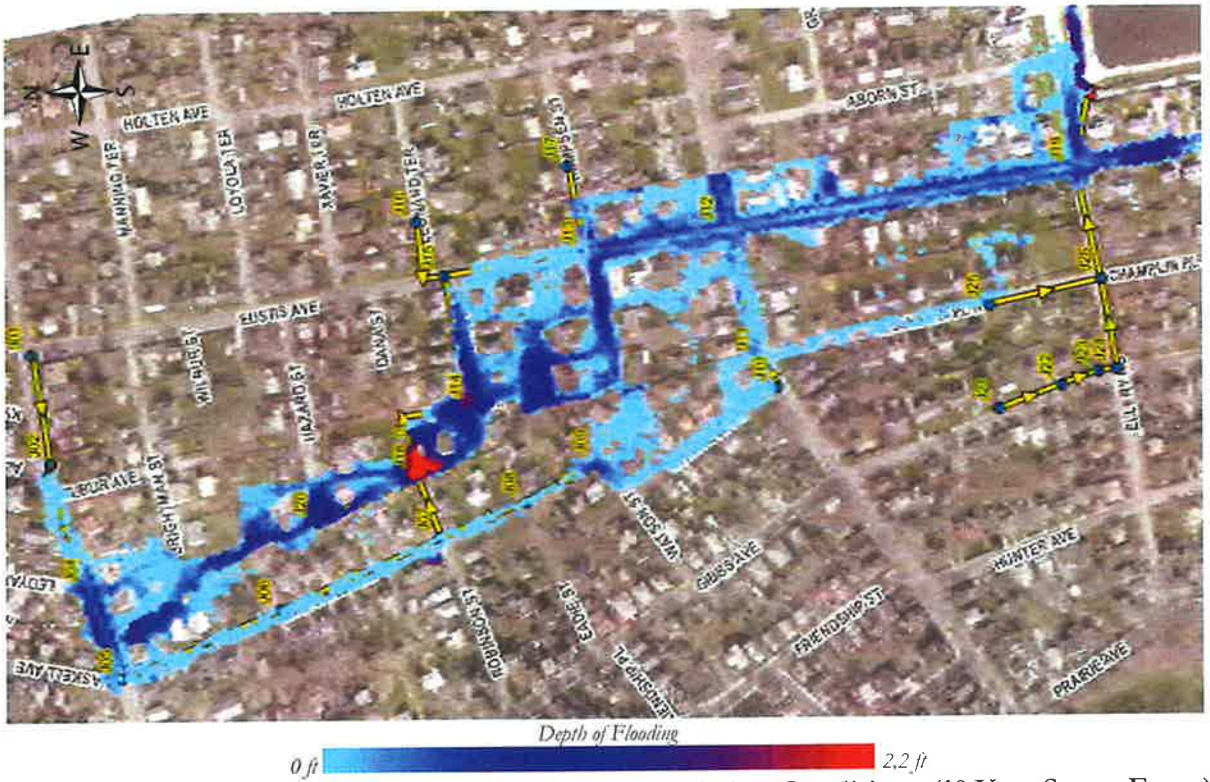

Figure 29. Simulated Peak Flooding Depths under Existing Conditions (10 Year Storm Event)

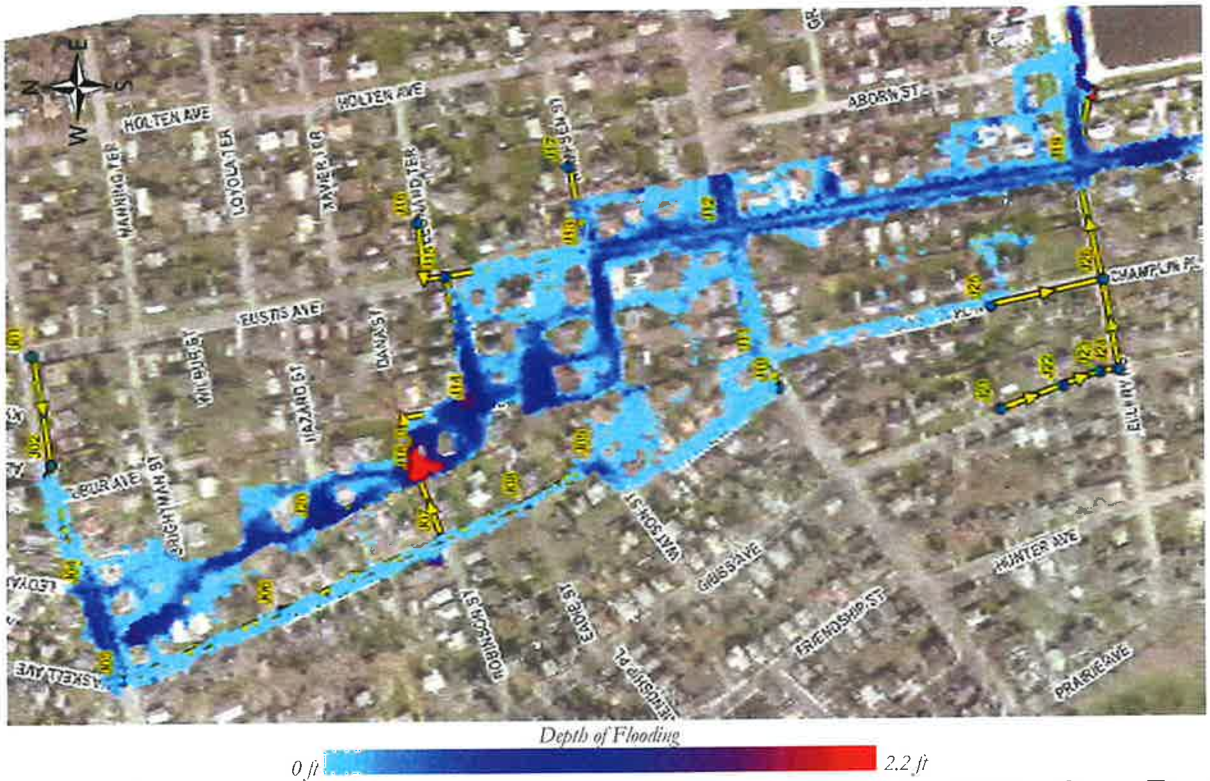

Figure 30. Simulated Peak Flooding Depths under the Storage Alternative (10 Year Storm Event)

There are several construction and long-term maintenance challenges with this alternative. The construction of the underground storage units will be complicated due to the existing utilities and the utility laterals in the roadway. The installation of the geotextile filter around the unit will be important in order to prevent migration of soils outside the trench into the storage unit and thereby creating sink holes.

Future replacement or installation of utility services to houses that cross the subsurface storage system will be more complicated than today because of the need to repair the geotextile filter for the storage system. Proper construction oversight will be required to ensure proper repair of the geotextile filter. In addition, the cost of future storm drainage repairs or replacement would be more costly since the storage system would be located above the existing storm drainage system piping.

Other Alternatives Considered

Green Infrastructure

Implementation of green infrastructure within the drainage area was considered as a potential project alternative. Green infrastructure consists of practices such as bioretention basins, infiltration trenches, permeable pavement, and dry swales that would temporarily store and infiltrate stormwater, removing that runoff from the storm drainage system. However, there are a number of physical limitations in the watershed that prevent green infrastructure from being effective including high groundwater and poor hydraulic capacity of underlying soils that prevent the ability to infiltrate any substantial volume of runoff as described earlier in this report.:

Because of the inability of underlying soils to infiltrate significant volumes of runoff, significant amount of land would be needed to store stormwater to make an impact on flooding. The only available land are areas along road Rights-of Way which are largely homeowner's lawns, Vernon Park/Cottrell Field. In order to eliminate flooding for the August 15, 2012 storm, it is estimated that up to 37 acres of bioretention installations (nearly 15% of the watershed) would be required. This assumes the bioretention facilities are sized to store one foot of water because of high groundwater conditions. This is nearly impossible in this watershed with 54% impervious cover and primarily privately-owned land.

Offline Storage

An alternative that was considered and determined to be infeasible was installing a large storage facility beneath publicly-owned property that could be connected to the existing drainage system. Two potential locations were considered:

- Vernon Park/Cottrell Field was considered, but is located too far upstream in the watershed to have a significant impact on peak flow reductions within the project area.

- Offline storage at Braga Field, which is located downgradient and adjacent to the watershed, would involve the installation of chamber-type storage beneath the playing field to store the peak flood volume prior to releasing it by gravity back into the Moat. However, this alternative was determined not to be feasible because the field elevation is too low and tailwater from the Moat would be above the invert of the storage units underneath the field. The water would not have enough hydraulic head to leave the system via gravity and would likely cause inundation of the field and surrounding neighborhood.

Summary of Costs

A budget-level opinion of construction cost was developed for each of the three alternatives that were assessed. A more detailed optinion of cost should be developed as part of a preliminary design which will allow issues such as utility conflicts and constructability to be better assessed.

Alternative 1: Increase Pipe Sizes

The opinion of cost for this alternative includes several major items of work as follows:

- Replacing 2,471 linear feet of 36-inch storm drain with 48-inch storm drain. The only 36-inch storm drain in the project area that would not be replaced would be the section located at Robinson Street to Taber Street, where the pipe is believed to cross underneath an existing garage.
- Replacing all 60 publicly-owned catch basins with deep sump catch basins. Many of the existing catch basins are old and should be replaced as part of this project.
- Replacing all 13 manholes along the trunk storm drain because of the increase in storm drain size.
- Completing pavement milling and overlay over the full-width of the portions of road where new storm drain and structures are placed.

Costs were also included for replacing 887 linear feet of 12-inch and 18-inch RCP storm drain in the project area with 24-inch RCP storm drain principally within the Gibbs Avenue/Champlin Place drainage system as this drainage system does not surcharge during the evaluated August 2012 storm but does surcharge during a 10-year frequency storm.

Alternative 2: Increase Pipe Sizes and Connect Watson Street with Kay Street

The opinion of cost for this alternative includes the components of Alternative 1 with several additional items of work to connect Watson Street drainage to Kay Street as follows:

- Install 828 linear feet of 36-inch RCP storm drain from Watson Street to Kay Street.
- Replacing 887 linear feet of 12-inch and 18-inch RCP storm drain in the project area with 24-inch RCP storm drain.
- Replacing all 14 publicly-owned catch basins with deep sump catch basins within the area where new pipe is proposed. Many of the existing catch basins are old and should be replaced as part of this project.
- Installing 5 manholes along the trunk storm drain to replace existing manholes and install new manhole along the new trunk storm sewer.
- Completing pavement milling and overlay over the full-width of the portions of road where new storm drain and structures are placed.

Alternative 3: Install Subsurface Storage System

The opinion of cost for this alternative includes several major items of work as follows:

- Install 2,937 linear feet of subsurface storage system including recharge structure, stone, geotextile and underdrain.
- Replace 2,937 linear feet of existing 36-inch RCP below the proposed subsurface storage system.

- Replacing all 60 publicly-owned catch basins with deep sump catch basins within the area where new pipe is proposed. Many of the existing catch basins are old and should be replaced as part of this project.
- Replacing all 13 manholes along the trunk storm drain because of the increase in storm drain size.
- Completing pavement milling and overlay over the full-width of the portions of road where new storm drain and structures are placed.
- Hauling and disposing 2,081 cubic yards of trench spoils off-site.

Table 14 summarizes the opinions of cost to implement each of these alternatives:

Table 14. Summary of Alternative Opinions of Costs (2016 dollars)

Item of Work	**Alternatives**		
	1. Increase Pipe Sizes	**2. Increase Pipe Sizes & Connect Watson and Kay Streets**	**3. Install Subsurface Storage**
Site Prep[(1)]	$190,000	$280,000	$230,000
Water Control[(1)]	$65,000	$98,000	$70,000
Earthwork[(1)]	$380,000	$520,000	$550,000
Site Restoration[(1)]	$570,000	$710,000	$480,000
Drainage Improvements[(1)]	$1,600,000	$2,000,000	$1,600,000
Miscellaneous (e.g. engineering, insurance, etc.)[(2)]	$850,000	$1,100,000	$890,000
Subtotal (To Nearest $100,000)	$3,700,000	$4,700,000	$3,800,000

Notes:
1 – Assumes contingency of 30%
2 – Miscellaneous costs include the following: mobilization and demobilization (5%), survey, construction stakeout ($10,000), bonds and insurance (5%), engineering (20%) of the base cost plus contingency

6 Summary of Alternatives

Table 15 summarizes each of the alternatives in Section 5.

Table 15. Summary of Alternatives

Alternative	Advantages	Challenges	Opinion of Cost to Implement
1: Increase Pipe Sizes	Eliminate flooding above the City's storm drainage system for the modeled August 2012 storm.	Increase peak flows and volume of water discharged downstream and to Moat. This will increase risk of flooding to downstream facilities and properties. This alternative would also increase flooding during the 10-year storm at Kay Street and above the 36" restriction at Whitwell Ave. and Robinson Street. Installing new 48-inch pipe in a trench originally built for a 36-inch pipe increases potential for utility conflicts. Existing service connections will complicate construction.	$3,700,000
2: Increase Pipe Sizes & Connect Watson Street with Kay Street	Eliminates flooding above the City's storm drainage system for the modeled August 2012 storm. Eliminates flooding along Whitwell Avenue during the 10-year storm.	Increase peak flows and volume of water discharged downstream and to Moat. This will increase risk of flooding to downstream facilities and properties. Increases flooding at some locations, specifically at Kay Street and Eustis Avenue.Same installation challenges as Alternative 1. Installing new storm drain through Whitwell Place will also have to address utility conflicts.	$4,700,000

Alternative	Advantages	Challenges	Opinion of Cost to Implement
3: Install Subsurface Storage	Eliminates flooding above the City's storm drain system for the modeled August 2012 storm. Does not increase peak flows to the Moat and therefore does not increase risk of flooding to downstream properties. Storage system can be installed in phases based on available budget. Each phase would reduce downstream flooding.	Would cover the existing storm drainage system with the subsurface storage system. As a result, accessing drainage system for repairs would be more costly. Does not eliminate flooding for the 10-year storm. Unconventional design approach. Recommend to install in phases and assess performance after each phase. Existing utility that cross the excavated trench will complicate construction. It will be important to ensure proper installation of the geotextile filter to prevent infiltration of soils. Future replacement of utility services will require careful repair of the geotextile filter which will increase the costs for that replacement.	$3,800,000

7 Non-Structural Improvements

The structural improvements discussed in Section 5 are focused within the lower portion of the catchment which experiences the most significant flooding issues. However, the runoff from the upper portions of the watershed, north of Bliss Road and west of Whitwell Avenue and Gibbs Avenue contribute to the high flows along Bliss and at the northern end of Whitwell Avenue. Implementing non-structural controls across the watershed could further reduce flooding risk in the project area.

Some catchment-wide implementation strategies may include:

- **Reduce infill development impacts within the watershed.** Where infill development is allowed, ensure that appropriate controls are implemented to ensure that the total volume of runoff and post- development peak flow rates do not increase.
- **Disconnecting Roof Downspouts.** Residences generate significant quantities of rooftop runoff within the project area and rooftop disconnection practices can be implemented by homeowners on individual residential lots.
- **Installation of Rain Gardens.** The installation of infiltration practices, like rain gardens or bioretention areas, will decrease the total volume of runoff and reduce the peak floods. Localized soil conditions may vary and soil should be tested for infiltration capacity prior to installation. A rain garden/bioretention installation workshop within the study area may help generate interest and promote participation.
- **Workshop and Give-Away Programs.** Rain barrel workshops for homeowners that provide a free rain barrel to each participating household, along with training on how to install and maintain the rain barrel could be undertaken.

Disconnecting Roof Downspouts

Disconnecting roof downspouts is one of the easiest things homeowners can do to help reduce stormwater runoff. Disconnecting downspouts will reroute the runoff into rain barrels or permeable areas like lawns or rain garden instead of directly to the storm drain. http://reducerunoff.org/downspout.htm (Save the Sound).

Reroute your downspout so your yard or rain garden absorbs and filters the runoff from your roof.

Disconnecting your downspout is a simple and effective way of reducing stormwater runoff. (Photo from grandbuilding.ca)

8 Recommended Plan

The subsurface storage system is the only alternative that would achieve the City's goals for reducing flooding in the Whitwell Avenue project area and not negatively impact downstream flooding, especially in the Moat. In summary, this alternative would eliminate flooding in the project area for more frequent, intense storms such as the August 15, 2012 event. Less frequent, larger events such as a 10-year frequency storm will still result in flooding.

Increasing pipe sizes in the trunk storm sewer from 36" to 48" would also eliminate flooding for storms consistent with the August 15, 2012 storm but would increase flooding during larger storms such as the 10-year storm at locations such as above Robinson Street and below Kay Street. It would also increase peak flows and volumes of stormwater discharged to the Moat increasing the potential of downstream flooding which is unacceptable and thereby is not recommended.

Installing a new storm drain between Watson Street and Kay Street in conjunction with the increase in pipe sizes to 48-inch, is also a less desirable alternative compared to installing subsurface storage. It too increases flooding in the Moat. In addition, it only has a positive incremental impact on flooding in limited areas of the watershed while actually increasing flooding on Kay Street. As a result, this alternative is also not recommended as compared to the subsurface storage alternative which better meets the City's goals of reducing flooding as well as not increasing risk of flooding in downstream areas.

Before the City moves forward with implementing the subsurface storage system alternative, it is recommended that a preliminary design be first completed in order to confirm the conclusions described in this report that were based strictly on limited data and a conceptual design. The purpose of a preliminary design will be to collect data and advance the design to a point where assumptions and conclusions made in this report can be confirmed and allow the City to make a more informed decision as to whether the subsurface storage system is viable. This would include confirming modeling results as well as overall project costs. The preliminary design would also allow critical questions to be answered such as how to manage the future repair and or replacement of utility services that cross this system.

The recommended elements of a preliminary design would include:

- Complete topographic survey within the right-of-way where the subsurface system is proposed. This topographic survey will provide more detailed elevation data but more importantly, the location of potential conflicts to the construction of these improvements. This would include locating subsurface utilities.

- Conduct geotechnical investigation to collect data on both depth to groundwater as well as hydraulic conductivity. This would include test pits (that can also be used to confirm depths to representative utility services), micro-wells to monitor depth to groundwater over a period of time and slug testing of several wells. This data can then be used to confirm the design of the underdrains for the proposed system and determine whether collected stormwater can be recharged into surrounding soils.

- Develop engineering alternatives to improve ability to maintain and replace utility services in the future. This would include assessing the costs for these alternatives as well as the cost differential to home owners compared to existing conditions.

- Update SWMM model for the proposed system to reflect the collected survey and geotechnical data. This updated model will be used to confirm system performance (i.e. ability to manage 8/15/12 storm) as well as identify modifications to maximize system performance without increasing the overall scale of the project. This updated model will also be used to identify a recommended phasing plan based on overall efficiency of individual segments of the proposed system.

- Meet with RIDEM and CRMC regulators to confirm regulatory approach for this proposed system and potential required pretreatment. This is an unconventional design which will not have been seen by state regulators in the past. Issues such as the need for certain permits (e.g. an Underground Injection Permit) and the need for pretreatment will need to be addressed with them.

- Develop preliminary design drawings (30% complete), advancing the conceptual designs to reflect the additional information collected during this phase of the project. This would be completed for the entire system in order to better understand potential issues and costs to fully implement the program.

- Update opinions of construction costs based on the updated preliminary design.

- Identify future operation and maintenance requirements and confirm ability of existing resources to complete this maintenance.

A budget of $120,000 to $140,000 is recommended to complete the preliminary design phase, which is about 3.5% of projected final costs for this alternative.

If this approach is determined to still be viable after the preliminary design phase is completed, final design and permitting of a single segment of the system would be recommended. There are a total of eleven segments proposed for this system and a segment is defined as a reach between two manholes. Installing the system in segments will allow the City to assess its performance and make adjustments in design after only making a limited investment. This approach will minimize risk and maximize potential overall performance of the system.

It is recommended that the segments at the top of the project area, closer to Bliss Road, are started first and then proceed downstream to maximize the benefits of completed segments. While installing the entire system will be required to recognize all of the benefits presented in this report, the system can be installed in segments over time and does not have to be installed at once to start to make a difference.

References

Computational Hydraulics International. PCSWMM Professional 2D Version: 6.3.2220.

Fuss & O'Neill, Inc. Final Report, Easton Pond Dam and Moat Study, City of Newport, September 2007.

National Surveyors-Developers Inc. June 2016. Survey of Whitwell Avenue Area Newport, Rhode Island.

Rossman, Lewis A. (2010). Storm Water Management Model User's Manual; Version 5.0. EPA/600/R-05/040 Revised July 2010.

U.S. Geological Survey, 2011. Topographic LiDAR for the North East.

Attachment A

Survey

18" ID @ Outfall to Moat

FUSS & O'NEILL
WHITWELL AVENUE AREA
NEWPORT, RHODE ISLAND

DRAINAGE LOCATION
1" = 80'

DRAWN BY: J.E.S.	CHECKED BY: N.A.T.	FIELD BY: D.M.&S.K.
JUNE 2016	JOB No. 2016-122	SHEET 1 OF 1

Attachment B

SWMM Model Input

```
[TITLE]
EXISTING CONDITIONS

[OPTIONS]
;;Options              Value
;;------------------ ------------
FLOW_UNITS           CFS
INFILTRATION         GREEN_AMPT
FLOW_ROUTING         DYNWAVE
START_DATE           01/01/2016
START_TIME           11:00:00
REPORT_START_DATE    01/01/2016
REPORT_START_TIME    11:00:00
END_DATE             01/01/2016
END_TIME             15:00:00
SWEEP_START          01/01
SWEEP_END            12/31
DRY_DAYS             0
REPORT_STEP          00:05:00
WET_STEP             00:01:00
DRY_STEP             00:05:00
ROUTING_STEP         0.5
ALLOW_PONDING        YES
INERTIAL_DAMPING     FULL
VARIABLE_STEP        0
LENGTHENING_STEP     0
MIN_SURFAREA         1
NORMAL_FLOW_LIMITED  BOTH
SKIP_STEADY_STATE    NO
FORCE_MAIN_EQUATION  H-W
LINK_OFFSETS         DEPTH
MIN_SLOPE            0
MAX_TRIALS           8
HEAD_TOLERANCE       0.005
SYS_FLOW_TOL         5
LAT_FLOW_TOL         5
MINIMUM_STEP         0.5
THREADS              8

[EVAPORATION]
;;Type          Parameters
;;------------- ----------
CONSTANT      0.0
DRY_ONLY      NO

[RAINGAGES]
;;                Rain      Time   Snow   Data
;;Name            Type      Intrvl Catch  Source
;;--------------- --------- ------ ------ ----------
RAINGAGE          VOLUME    1:00   1.0    TIMESERIES DATA

[SUBCATCHMENTS]
;;                                                  Total    Pcnt.             Pcnt.    Curb     Snow
;;Name            Raingage         Outlet           Area     Imperv   Width    Slope    Length   Pack
;;--------------- ---------------- ---------------- -------- -------- -------- -------- --------
--------
A                 RAINGAGE         J01              77.6     49       16901.28 1.8      0
B                 RAINGAGE         J04              36.7     63       7993.26  1.5      0
C                 RAINGAGE         J05              32.6     57       7100.28  1        0
D                 RAINGAGE         J10              64       58       13939.2  1.7      0
E                 RAINGAGE         J20              6.1      38       1328.58  1        0
F_1               RAINGAGE         J07              5.35493  47       1166.304 1.1      0
F_2               RAINGAGE         J09              2.24507  47       488.976  1.1      0
G_2               RAINGAGE         J19              5.328747 46       1160.601 1.1      0
G_3               RAINGAGE         J17              3.772834 46       821.723  1.1      0
G_4               RAINGAGE         J12              8.898419 46       1938.076 1.1      0
H_1               RAINGAGE         J24              6.221534 57       1355.05  2        0
```

```
H_2              RAINGAGE         J21              3.378466 57       735.83   2        0
J                RAINGAGE         J14              2.7      36       588.06   2.7      0
K                RAINGAGE         J15              4.9      48       1067.22  1.2      0
L                RAINGAGE         J25              4.1      53       892.98   1        0

[SUBAREAS]
;;Subcatchment   N-Imperv   N-Perv     S-Imperv   S-Perv     PctZero    RouteTo    PctRouted
;;-------------- ---------- ---------- ---------- ---------- ---------- ---------- ----------
A                0.011      0.15       0.07       0.15       25         OUTLET
B                0.011      0.15       0.07       0.15       25         OUTLET
C                0.011      0.15       0.07       0.15       25         OUTLET
D                0.011      0.15       0.07       0.15       25         OUTLET
E                0.011      0.15       0.07       0.15       25         OUTLET
F_1              0.011      0.15       0.07       0.15       25         OUTLET
F_2              0.011      0.15       0.07       0.15       25         OUTLET
G_2              0.011      0.15       0.07       0.15       25         OUTLET
G_3              0.011      0.15       0.07       0.15       25         OUTLET
G_4              0.011      0.15       0.07       0.15       25         OUTLET
H_1              0.011      0.15       0.07       0.15       25         OUTLET
H_2              0.011      0.15       0.07       0.15       25         OUTLET
J                0.011      0.15       0.07       0.15       25         OUTLET
K                0.011      0.15       0.07       0.15       25         OUTLET
L                0.011      0.15       0.07       0.15       25         OUTLET

[INFILTRATION]
;;Subcatchment   Suction    HydCon     IMDmax
;;-------------- ---------- ---------- ----------
A                6.69       0.26       0.135
B                6.69       0.26       0.135
C                6.69       0.26       0.135
D                6.69       0.26       0.135
E                6.69       0.26       0.135
F_1              6.69       0.26       0.135
F_2              6.69       0.26       0.135
G_2              6.69       0.26       0.135
G_3              6.69       0.26       0.135
G_4              6.69       0.26       0.135
H_1              6.69       0.26       0.135
H_2              6.69       0.26       0.135
J                6.69       0.26       0.135
K                6.69       0.26       0.135
L                6.69       0.26       0.135

[JUNCTIONS]
;;               Invert     Max.       Init.      Surcharge  Ponded
;;Name           Elev.      Depth      Depth      Depth      Area
;;-------------- ---------- ---------- ---------- ---------- ----------
J01              50.35      7.9        0          0          5000
J02              45.81      7.2        0          30         0
J03              42.34      9.85       0          30         0
J04              39.14      9.1        0          30         0
J05              35.98      12.2       0          30         0
J06              31.8       12.15      0          30         0
J07              27.63      10.45      0          30         0
J08              29.13      7.05       0          30         0
J09              29.67      4.95       0          30         0
J10              16.14      8.8        0          30         0
J11              15.8       7.9        0          30         0
J12              11.27      9.9        0          30         0
J13              15.43      10.6       0          30         0
J14              22.98      9.5        0          30         0
J15              19.92      14.7       0          30         0
J16              30.5       3.5        0          30         0
J17              18.9       6.5        0          0          5000
J18_0            26         6.16       0          30         0
J19              8.04       4.4        0          30         0
J20              32.7       3.85       0          30         0
J21              24.94      1.9        0          30         0
J22              24.6       2.7        0          30         0
J23              23.92      3.7        0          30         0
J24              23.89      3.87       0          30         0
J25              11.96      7.45       0          30         0
J26              9.74       8.9        0          30         0
```

```
[OUTFALLS]
;;               Invert     Outfall    Stage/Table      Tide
;;Name           Elev.      Type       Time Series      Gate Route To
;;-------------- ---------- ---------- ---------------- ---- ----------------
O1               4.47       FIXED      5.5              NO
O2               4.47       FIXED      5.5              NO

[CONDUITS]
;;               Inlet            Outlet                      Manning    Inlet      Outlet     Init.
  Max.
;;Name           Node             Node             Length     N          Offset     Offset     Flow
  Flow
;;-------------- ---------------- ---------------- ---------- ---------- ---------- ---------- ----------
---------- ----------
C01              J01              J02              222        0.012      0          0.25       0
  0
C02              J02              J03              19         0.012      0          1.75       0
  0
C03              J03              J04              241        0.012      0          0.05       0
  0
C04              J04              J05              198        0.012      0          0.1        0
  0
C05              J05              J06              354        0.012      0          0.1        0
  0
C06              J06              J07              363        0.012      0          0.2        0
  0
C07              J08              J07              186        0.012      0          0.2        0
  0
C08              J09              J08              162        0.012      0          0.15       0
  0
C09              J14              J15              269        0.012      0          0.1        0
  0
C10              J15              J13              290        0.012      0          0.8        0
  0
C11              J17              J13              285        0.012      0          2.6        0
  0
C12              J13              J12              171        0.013      0          0.1        0
  0
C13              J11              J12              280        0.012      0          0.1        0
  0
C14              J10              J11              64         0.012      0          0.1        0
  0
C16              J16              J15              167        0.013      0          0.1        0
  0
C17_1            J07              J18_0            151.367    0.012      0          0          0
  0
C17_2            J18_0            J14              291.633    0.012      0          0.04       0
  0
C18              J20              J18_0            474        0.012      0          0.04       0
  0
C19              J19              O2               50         0.012      0          0          0
  0
C38              J21              J22              138        0.012      0          0.2        0
  0
C39              J22              J23              80         0.012      0          0.1        0
  0
C40              J23              J24              7          0.012      0          0.02       0
  0
C41              J25              J26              249        0.012      0          0.3        0
  0
C42              J26              J19              217        0.012      0          0          0
  0
C43              J24              J26              196        0.012      0          0.3        0
  0

[ORIFICES]
;;               Inlet            Outlet           Orifice      Crest      Disch.     Flap Open/Close
;;Name           Node             Node             Type         Height     Coeff.     Gate Time
;;-------------- ---------------- ---------------- ------------ ---------- ---------- ---- ----------
OR1              J02              J329             BOTTOM       7.2        0.65       NO   0
OR10             J14              J5771            BOTTOM       9.736      0.65       NO   0
OR11             J15              J5373            BOTTOM       14.811     0.65       NO   0
OR12             J16              J4885            BOTTOM       3.568      0.65       NO   0
OR13             J13              J7623            BOTTOM       10.714     0.65       NO   0
OR14             J12              J10004           BOTTOM       9.9        0.65       NO   0
OR15             J10              J10800           BOTTOM       8.978      0.65       NO   0
OR16             J11              J10512           BOTTOM       7.942      0.65       NO   0
OR17             J19              J15865           BOTTOM       4.4        0.65       NO   0
OR18             J26              J16416           BOTTOM       9.341      0.65       NO   0
```

```
OR19             J25              J13450           BOTTOM     7.744      0.65       NO    0
OR2              J03              J282             BOTTOM     9.85       0.65       NO    0
OR20             J21              J13695           BOTTOM     1.9        0.65       NO    0
OR21             J22              J15454           BOTTOM     2.816      0.65       NO    0
OR22             J23              J16334           BOTTOM     3.7        0.65       NO    0
OR23             J24              J16660           BOTTOM     4.118      0.65       NO    0
OR24             J18_0            J4836            BOTTOM     6.17       0.65       NO    0
OR3              J04              J690             BOTTOM     9.143      0.65       NO    0
OR4              J05              J1200            BOTTOM     12.363     0.65       NO    0
OR5              J06              J3216            BOTTOM     12.269     0.65       NO    0
OR6              J20              J3663            BOTTOM     4.728      0.65       NO    0
OR7              J07              J5260            BOTTOM     10.45      0.65       NO    0
OR8              J08              J6710            BOTTOM     7.181      0.65       NO    0
OR9              J09              J7790            BOTTOM     5.165      0.65       NO    0

[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels
;;-------------- ------------ ---------------- ---------- ---------- ---------- ----------
C01              CIRCULAR     3                0          0          0          1
C02              CIRCULAR     3                0          0          0          1
C03              CIRCULAR     3                0          0          0          1
C04              CIRCULAR     3                0          0          0          1
C05              CIRCULAR     3                0          0          0          1
C06              CIRCULAR     3                0          0          0          1
C07              CIRCULAR     1                0          0          0          1
C08              CIRCULAR     1                0          0          0          1
C09              CIRCULAR     3                0          0          0          1
C10              CIRCULAR     3                0          0          0          1
C11              CIRCULAR     1                0          0          0          1
C12              CIRCULAR     3                0          0          0          1
C13              CIRCULAR     3                0          0          0          1
C14              CIRCULAR     3                0          0          0          1
C15              CIRCULAR     4                0          0          0          1
C16              CIRCULAR     1                0          0          0          1
C17_1            CIRCULAR     3                0          0          0          1
C17_2            CIRCULAR     3                0          0          0          1
C18              CIRCULAR     1                0          0          0          1
C19              CIRCULAR     1.5              0          0          0          1
C38              CIRCULAR     1                0          0          0          1
C39              CIRCULAR     1                0          0          0          1
C40              CIRCULAR     1                0          0          0          1
C41              CIRCULAR     1                0          0          0          1
C42              CIRCULAR     1.5              0          0          0          1
C43              CIRCULAR     1.5              0          0          0          1
OR1              RECT_CLOSED  30               10         0          0
OR10             RECT_CLOSED  30               10         0          0
OR11             RECT_CLOSED  30               10         0          0
OR12             RECT_CLOSED  30               10         0          0
OR13             RECT_CLOSED  30               10         0          0
OR14             RECT_CLOSED  30               10         0          0
OR15             RECT_CLOSED  30               10         0          0
OR16             RECT_CLOSED  30               10         0          0
OR17             RECT_CLOSED  30               10         0          0
OR18             RECT_CLOSED  30               10         0          0
OR19             RECT_CLOSED  30               10         0          0
OR2              RECT_CLOSED  30               10         0          0
OR20             RECT_CLOSED  30               10         0          0
OR21             RECT_CLOSED  30               10         0          0
OR22             RECT_CLOSED  30               10         0          0
OR23             RECT_CLOSED  30               10         0          0
OR24             RECT_CLOSED  30               10         0          0
OR3              RECT_CLOSED  30               10         0          0
OR4              RECT_CLOSED  30               10         0          0
OR5              RECT_CLOSED  30               10         0          0
OR6              RECT_CLOSED  30               10         0          0
OR7              RECT_CLOSED  30               10         0          0
OR8              RECT_CLOSED  30               10         0          0
OR9              RECT_CLOSED  30               10         0          0

[LOSSES]
;;Link           Inlet      Outlet     Average    Flap Gate  SeepageRate
;;-------------- ---------- ---------- ---------- ---------- ----------

[TIMESERIES]
;;Name           Date       Time       Value
;;-------------- ---------- ---------- ----------
DATA             1/1/2016   0          0.05
DATA             1/1/2016   1          0.05
DATA             1/1/2016   2          0.06
```

```
DATA              1/1/2016   3          0.06
DATA              1/1/2016   4          0.07
DATA              1/1/2016   5          0.08
DATA              1/1/2016   6          0.09
DATA              1/1/2016   7          0.13
DATA              1/1/2016   8          0.17
DATA              1/1/2016   9          0.21
DATA              1/1/2016   10         0.31
DATA              1/1/2016   11         1.26
DATA              1/1/2016   12         1.26
DATA              1/1/2016   13         0.30
DATA              1/1/2016   14         0.22
DATA              1/1/2016   15         0.16
DATA              1/1/2016   16         0.12
DATA              1/1/2016   17         0.09
DATA              1/1/2016   18         0.08
DATA              1/1/2016   19         0.07
DATA              1/1/2016   20         0.06
DATA              1/1/2016   21         0.06
DATA              1/1/2016   22         0.05
DATA              1/1/2016   23         0.05
DATA              1/2/2016   0          0
DATA              1/2/2016   6          0.04
DATA              1/2/2016   7          1.17
DATA              1/2/2016   8          0.3
DATA              1/2/2016   9          0.06
DATA              1/2/2016   10         0
DATA              1/2/2016   20         0.05
DATA              1/2/2016   21         0.14
DATA              1/2/2016   22         0.02

[REPORT]
INPUT      NO
CONTROLS   NO
SUBCATCHMENTS ALL
NODES ALL
LINKS ALL



[CHANGES FOR ALTERNATIVE 1: INCREASE PIPE SIZES]


[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels
;;-------------- ------------ ---------------- ---------- ---------- ---------- ----------
C01              CIRCULAR     4                0          0          0          1
C02              CIRCULAR     4                0          0          0          1
C03              CIRCULAR     4                0          0          0          1
C04              CIRCULAR     4                0          0          0          1
C05              CIRCULAR     4                0          0          0          1
C06              CIRCULAR     4                0          0          0          1
C09              CIRCULAR     4                0          0          0          1
C10              CIRCULAR     4                0          0          0          1
C12              CIRCULAR     4                0          0          0          1
C17_1            CIRCULAR     3                0          0          0          1
C17_2            CIRCULAR     4                0          0          0          1
C18              CIRCULAR     2                0          0          0          1
C19              CIRCULAR     2                0          0          0          1
C38              CIRCULAR     2                0          0          0          1
C39              CIRCULAR     2                0          0          0          1
C40              CIRCULAR     2                0          0          0          1
C41              CIRCULAR     2                0          0          0          1
C42              CIRCULAR     2                0          0          0          1
C43              CIRCULAR     2                0          0          0          1


[CHANGES FOR ALTERNATIVE 2: CONNECT WATSON STREET TO KAY STREET]


[JUNCTIONS]
;;               Invert     Max.       Init.      Surcharge  Ponded
;;Name           Elev.      Depth      Depth      Depth      Area
;;-------------- ---------- ---------- ---------- ---------- ----------
J08              27         9.18       0          30         0
```

```
J09              26.5       8.12       0          30         0

[CONDUITS]
;;               Inlet            Outlet                      Manning    Inlet      Outlet     Init.
   Max.
;;Name           Node             Node             Length     N          Offset     Offset     Flow
   Flow
;;-------------- ---------------- ---------------- ---------- ---------- ---------- ---------- ----------
---------- ----------
C07              J07              J08              186        0.012      0          0.2        0
   0
C08              J08              J09              162        0.012      0          0.15       0
   0
WATSONPIPE       J09              J10              489        0.012      0          0          0
   0

[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels
;;-------------- ------------ ---------------- ---------- ---------- ---------- ----------
C07              CIRCULAR     3                0          0          0          1
C08              CIRCULAR     3                0          0          0          1
WATSONPIPE       CIRCULAR     3                0          0          0          1


[CHANGES FOR ALTERNATIVE 3: INSTALL SUBSURFACE STORAGE SYSTEMS]

[STORAGE]
;;               Invert   Max.     Init.    Storage    Curve                                Ponded   Evap.
;;Name           Elev.    Depth    Depth    Curve      Params                               Area     Frac.
Infiltration parameters
;;-------------- -------- -------- -------- ---------- -------- -------- -------- -------- --------
------------------------
BLISS2           42.52    32.72    0        FUNCTIONAL 740      0        0        0        0
BLISS3           41.21    33.97    0        FUNCTIONAL 1248     0        0        0        0
EUSTIS1          20.56    32.47    0        FUNCTIONAL 853      0        0        0        0
EUSTIS2          15.7     32.47    0        FUNCTIONAL 503      0        0        0        0
EUSTIS3          11.27    36.9     0        FUNCTIONAL 1605     0        0        0        0
KAY1             19.23    31.47    0        FUNCTIONAL 107      0        0        0        0
KAY2             15.8     34.9     0        FUNCTIONAL 688      0        0        0        0
TABER            24.35    35.13    0        FUNCTIONAL 654      0        0        0        0
WHITWELL1        36.23    34.72    0        FUNCTIONAL 878      0        0        0        0
WHITWELL2        32.16    32.92    0        FUNCTIONAL 1021     0        0        0        0
WHITWELL3        29.67    33.51    0        FUNCTIONAL 750      0        0        0        0

[ORIFICES]
;;               Inlet            Outlet           Orifice      Crest      Disch.     Flap Open/Close
;;Name           Node             Node             Type         Height     Coeff.     Gate Time
;;-------------- ---------------- ---------------- ------------ ---------- ---------- ---- ----------
BLISS2a          J03              BLISS2           SIDE         2.9        0.61       NO   0
BLISS2b          BLISS2           J04              SIDE         1.72       0.61       NO   0
BLISS2c          BLISS2           J04              SIDE         0          0.61       NO   0
BLISS3a          J04              BLISS3           SIDE         6.04       0.61       NO   0
BLISS3b          BLISS3           J05              SIDE         2.97       0.61       NO   0
BLISS3c          BLISS3           J05              SIDE         0          0.61       NO   0
EUSTIS1a         J15              EUSTIS1          SIDE         3.11       0.61       NO   0
EUSTIS1b         EUSTIS1          J13              SIDE         2.47       0.61       NO   0
EUSTIS1c         EUSTIS1          J13              SIDE         0          0.61       NO   0
EUSTIS2a         J13              EUSTIS2          SIDE         2.74       0.61       NO   0
EUSTIS2b         EUSTIS2          J12              SIDE         2.47       0.61       NO   0
EUSTIS2c         EUSTIS2          J12              SIDE         0          0.61       NO   0
EUSTIS3a         J12              EUSTIS3          SIDE         6.9        0.61       NO   0
EUSTIS3b         EUSTIS3          J18_0            SIDE         8.84       0.61       NO   0
EUSTIS3c         EUSTIS3          J18_0            SIDE         0          0.61       NO   0
KAY1a            J10              KAY1             SIDE         4.56       0.61       NO   0
KAY1b            KAY1             J11              SIDE         1.47       0.61       NO   0
KAY1c            KAY1             J11              SIDE         0          0.61       NO   0
KAY2a            J11              KAY2             SIDE         4.9        0.61       NO   0
KAY2b            KAY2             J12              SIDE         5          0.61       NO   0
KAY2c            KAY2             J12              SIDE         0          0.61       NO   0
TABER1a          J14              TABER            SIDE         6.5        0.61       NO   0
TABER1b          TABER            J15              SIDE         5.13       0.61       NO   0
TABER1c          TABER            J15              SIDE         0          0.61       NO   0
WHITWELL1a       J05              WHITWELL1        SIDE         4.97       0.61       NO   0
WHITWELL1b       WHITWELL1        J06              SIDE         4.72       0.61       NO   0
WHITWELL1c       WHITWELL1        J06              SIDE         0          0.61       NO   0
WHITWELL2a       J06              WHITWELL2        SIDE         3.28       0.61       NO   0
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WHITWELL2b       WHITWELL2        J07              SIDE         2.92       0.61       NO    0
WHITWELL2c       WHITWELL2        J07              SIDE         0          0.61       NO    0
WHITWELL3a       J07              WHITWELL3        SIDE         5.55       0.61       NO    0
WHITWELL3b       WHITWELL3        J08              SIDE         0.57       0.61       NO    0
WHITWELL3c       WHITWELL3        J08              SIDE         0          0.61       NO    0

[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels
;;-------------- ------------ ---------------- ---------- ---------- ---------- ----------
BLISS2a          CIRCULAR     1.5              0          0          0
BLISS2b          CIRCULAR     1.5              0          0          0
BLISS2c          CIRCULAR     0.33             0          0          0
BLISS3a          CIRCULAR     1.5              0          0          0
BLISS3b          CIRCULAR     1.5              0          0          0
BLISS3c          CIRCULAR     0.33             0          0          0
EUSTIS1a         CIRCULAR     1.5              0          0          0
EUSTIS1b         CIRCULAR     1.5              0          0          0
EUSTIS1c         CIRCULAR     0.33             0          0          0
EUSTIS2a         CIRCULAR     1.5              0          0          0
EUSTIS2b         CIRCULAR     1.5              0          0          0
EUSTIS2c         CIRCULAR     0.33             0          0          0
EUSTIS3a         CIRCULAR     1.5              0          0          0
EUSTIS3b         CIRCULAR     1.5              0          0          0
EUSTIS3c         CIRCULAR     0.33             0          0          0
KAY1a            CIRCULAR     1.5              0          0          0
KAY1b            CIRCULAR     1.5              0          0          0
KAY1c            CIRCULAR     0.33             0          0          0
KAY2a            CIRCULAR     1.5              0          0          0
KAY2b            CIRCULAR     1.5              0          0          0
KAY2c            CIRCULAR     0.33             0          0          0
TABER1a          CIRCULAR     1.5              0          0          0
TABER1b          CIRCULAR     1.5              0          0          0
TABER1c          CIRCULAR     0.33             0          0          0
WHITWELL1a       CIRCULAR     1.5              0          0          0
WHITWELL1b       CIRCULAR     1.5              0          0          0
WHITWELL1c       CIRCULAR     0.33             0          0          0
WHITWELL2a       CIRCULAR     1.5              0          0          0
WHITWELL2b       CIRCULAR     1.5              0          0          0
WHITWELL2c       CIRCULAR     0.33             0          0          0
WHITWELL3a       CIRCULAR     1.5              0          0          0
WHITWELL3b       CIRCULAR     1.5              0          0          0
WHITWELL3c       CIRCULAR     0.33             0          0          0
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City of Newport
Department of Utilities
Water Pollution Control Division