MQP-PPM-1234

Flood Mitigation for Quinsigamond Avenue in Worcester, MA

A Major Qualifying Project
Submitted to Faculty of
Worcester Polytechnic Institute

In Partial Fulfillment of the Requirements for the Degree of Bachelor of Science

Submitted by

Joseph Allen

Katherine Mattern

Matthew McCarthy

March, 2013

Professor Suzanne LePage, Co-Advisor

Professor Paul P. Mathisen, Co-Advisor

Abstract

The Quinsigamond Avenue area in Worcester Massachusetts is a highly commercial zone with a historic flooding problem. This project reviews alternative design options for the Quinsigamond Avenue storm drain, which is believed to contribute to these problems. Based upon research of previous reports, this project analyzes improvement scenarios including flap valve installation, sub-surface detention, and combinations of both. Using programs such as GIS and SWMM, simulations of these different scenarios were created and analyzed for their effectiveness.

Acknowledgements

The completion of this project would not have been possible without the help of several people. We would first like to express our gratitude to our advisors Professor Suzanne LePage and Professor Paul Mathisen, for their continued support and guidance. Finally, we would like to thank Mr. Joe Buckley, Mr. Phillip Guerin and Mr. Mark Hollis from the City of Worcester Department of Public Works and Parks. The knowledge and information that they supplied us with throughout the duration of this project was essential to our success.

Table of Authorship

Section	Author
Capstone Design Statement	MM
1.0 Introduction	JA
2.0 Background	ALL
2.1 Site Description	KM
2.2 Combined Sewer Overflow System	KM
2.3 Worcester Storm Water Management History	KM
2.4 Storm Water Controls	KM
2.4.1 Subsurface Detention	MM
2.4.2 Check Valves	JA
2.5 Previous Storm Water Studies Completed in Worcester	KM
2.5.1 Kleinfelder/SEA Report	KM
2.5.2 Phase 1 CSO Long-Term Control Plan Report	KM
2.6 Health and Safety Concerns	JA, KM
2.7 Permits	KM
2.8 Hydrologic Processes in Urban Areas	JA
2.8.1 Storm Water Models	JA
2.8.1.1 Storm Water Management Model (SWMM)	JA
3.0 Methodology	ALL
3.1 Completing Research Regarding Quinsigamond Avenue Flooding	MM
3.1.1 GIS Data	MM
3.1.2 Model Data	MM
3.1.3 Flow Metering Data	MM
3.2 Evaluation of Existing Conditions in Quinsigamond Avenue Area	MM, JA
3.2.1 The Rational Method	MM, JA
3.2.2 Calibration of SWMM Model to Match Existing Conditions	MM
3.3 Generation of Preliminary Design Options	MM
3.3.1 Selection of Flap Valve Model	JA
3.3.2 Introduction to Scenarios	MM
3.3.2.1 Scenario 1 - Flap Valve	MM
3.3.2.2 Scenario 2 - Flap Valve Plus Storage	MM
3.4 Evaluation of Preliminary Design Options' Feasibility	KM
3.5 Defining a Design for a Flap Valve/Storage System	JA
3.6 Providing Recommendations to the City of Worcester	ALL
4.0 Results	JA,MM
4.1 Research of Quinsigamond Avenue Flooding Results	JA, MM
4.1.1 GIS Data	MM
4.1.2 Model Data	MM
4.1.3 Flow Metering Data	MM
4.2 Results for Existing Conditions	MM
4.2.1 Approximate Results for Rational Method	JA
4.2.2 Results for SWMM Model Calibration	MM

4.3 Preliminary Design Alternatives	JA, MM
4.3.1 Flap Valve Selection	JA
4.3.1.1 Series 37	JA
4.3.1.2 Series 35-1	JA
4.3.1.3 Series TF-2	JA
4.3.1.4 Series TF-1	JA
4.3.2 Scenario Results	MM
4.3.2.1 Scenario 1 – Flap Valve	MM
4.3.2.2 Scenario 2 – Flap Valve and Storage	MM
4.3.3 Scenario Comparison	MM
4.4 Feasibility of Scenarios	KM
4.4.1 Economical Feasibility	KM
4.4.2 Political Feasibility	KM
4.4.3 Construction Feasibility	KM
5.0 Conclusions and Recommendations	ALL
5.1 Existing Conditions	JA
5.2 Scenario 1 – Flap Valve	JA, MM
5.3 Scenario 2 – Flap Valve and Storage	JA, MM
6.0 Recommendations for Improvement	JA, MM

Capstone Design Statement

Worcester Polytechnic Institute's Civil and Environmental Engineering program requires students working on their major qualifying project (MQP) to undergo a capstone design experience for its Accreditation Board for Engineering and Technology (ABET)-accredited Bachelor of Science program. The capstone design experience requires students to fulfill Criterion 4 of the ABET. Criterion 4 encourages students to prepare for engineering practice through a major design experience that incorporates engineering standards and constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social and political (WPI, 2002-03).

In order for this MQP to meet capstone design requirements, flood mitigation techniques were applied to reduce flooding in the Quinsigamond Avenue area. Economic, environmental, constructability, ethical, health and safety, social and political constraints were all considered when making recommendations to improve this problem. The following list describes how these constraints were used to select a preferred design option:

Economic

The costs associated with installing a flap valve into a storm drain on Quinsigamond Avenue were determined. In addition to estimating the costs directly associated with installing the flap valve, the project includes the estimation of costs associated with adding subsurface detention in Crompton Park. These costs were determined by using cost estimation booklets designed to provide accurate estimations.

Environment

This project also examined the positive and negative environmental impacts of flooding associated with the Quinsigamond Avenue area. The environmental impacts that were considered include the constraints that affect the flows in the Quinsigamond Avenue storm drain. Also considered is the reduction of storm water runoff impacts because of installation of subsurface detention at Crompton Park.

Constructability

The project investigated the constructability associated with installing a flap valve at the furthest downstream manhole along the Quinsigamond Avenue storm drain and subsurface detention methods at Crompton Park. This included determining what needed to be done in order to install a flap valve and a subsurface storage unit. Considerations for constructability included earthwork, location and time period for the installation process.

Ethical

Ethics are an important consideration with most flooding issues. In some cases, flooding is unavoidable. This project recommended methods to reduce flooding on Quinsigamond Avenue while considering the American Society of Civil Engineer's code of ethics which include the following (ASCE):

1. Using knowledge and skill for the enhancement of human welfare and environment
2. Being honest and impartial and serving with fidelity the public, their employers and clients
3. Striving to increase the competence and prestige of the engineering profession
4. Supporting the professional and technical societies of their disciplines

Health and Safety

Flooding problems lead to several health and safety concerns. One of the main goals of this project was to protect the health and safety of Quinsigamond Avenue residents. This was done by researching what types of health and safety concerns relate to flooding in urban areas such as Worcester, Massachusetts. Waterborne diseases and damage to infrastructure are two examples of the kind of concerns that were considered during the project.

Social

The social impacts of flooding are an important consideration. This project included focusing on how residents of Quinsigamond Avenue are personally affected by flooding in the area. The quality of living for Quinsigamond Avenue residents was a major consideration throughout this project. Displacement of residents and damage to property are two examples of the social impacts that were considered during this project.

Political

All recommendations that this project provides consider regulations set by the Environmental Protection Agency (EPA), The Massachusetts Department of Environmental Protection (MDEP), the City of Worcester's DPW, Worcester's city council and any other organizations having a legal influence in the area. The project included recommendations to existing storm water permits and any other permits directly involved with flooding in the city of Worcester.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

Urban flooding has been an increasingly severe problem in the United States. Floods are the nation's most frequent and dangerous natural hazard, with damages ranging from mold and mildew, to even loss of life (Mileti, 1999). With a significant portion of the United States' flood damage happening to uninsured owners, the prevention of these events is as important as ever (Browne & Hoyt, 2000). Flooding is a major concern in the Quinsigamond Avenue area in Worcester, located in central MA as indicated in Figure 1. The area is part of a low lying, flat neighborhood which makes it a natural location for floods. A major street in the area is Quinsigamond Avenue which is dramatically affected when flooding occurs in the area. Figure 2 displays Quinsigamond Avenue on September 8th, 2011, when one of the worst floods in recent memory hit the area. This storm resulted in massive floods throughout the neighborhood resulting in some residents to refer to the area as "not safe" (Wright, 2012).

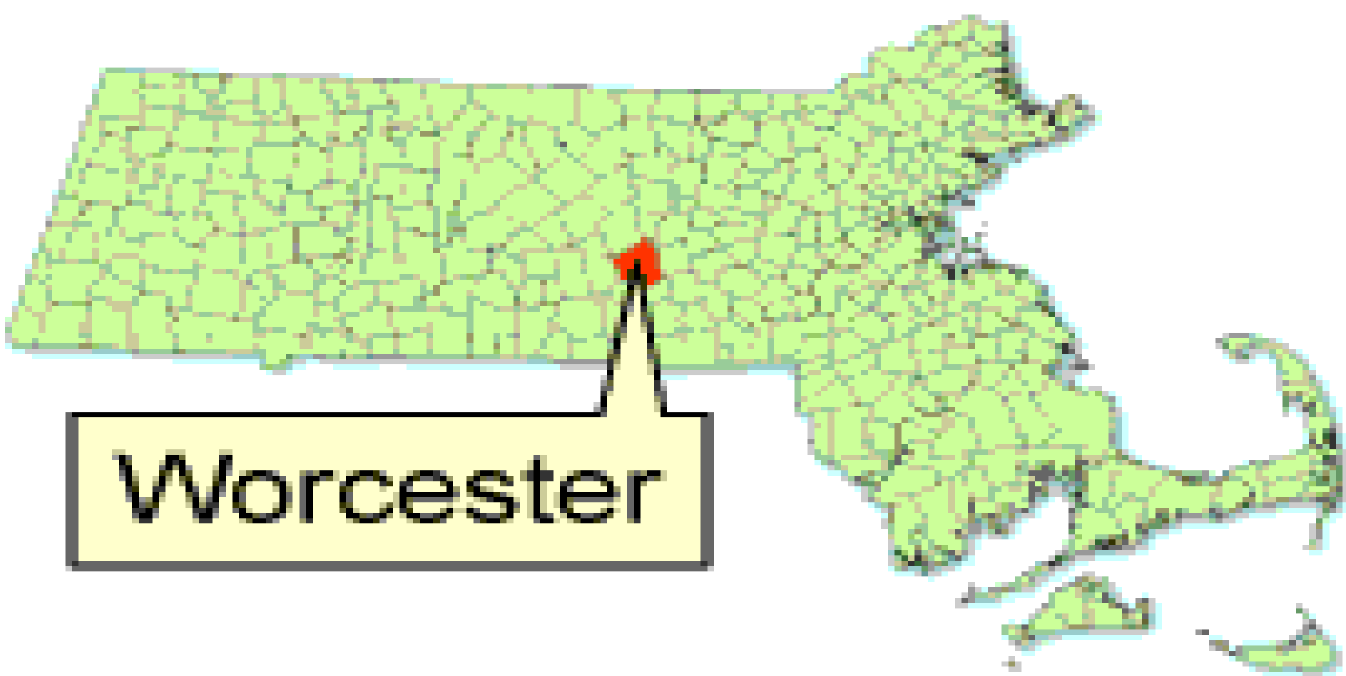


Figure 1: Worcester, MA (State of Massachusetts, 2013)

Figure 2: Quinsigamond Avenue Flood (Corpuz, 2011)

Older cities such as Worcester often operate a combined sewer overflow (CSO) system, which will combine the city's wastewater and storm water for treatment during high rainfall events. Due to capacity issues in Worcester's complex combined sewer system, flooding can often occur along Quinsigamond Avenue. There are many factors that led to the influx of excess water into this location, including heavy rain falls, flood diversion programs, a relatively flat landscape and a high amount of impervious surfaces in the area. During long duration storm events, the city of Worcester is forced to use a flood diversion program to flash treat the storm water received by the Quinsigamond CSO Storage and Treatment Facility. This plan works by reducing the usual treatment the QCSOTF provides to a flash treatment, and releasing these flows directly into the Millbrook Conduit. Figure 3 below provides a schematic of Worcester's CSO system.

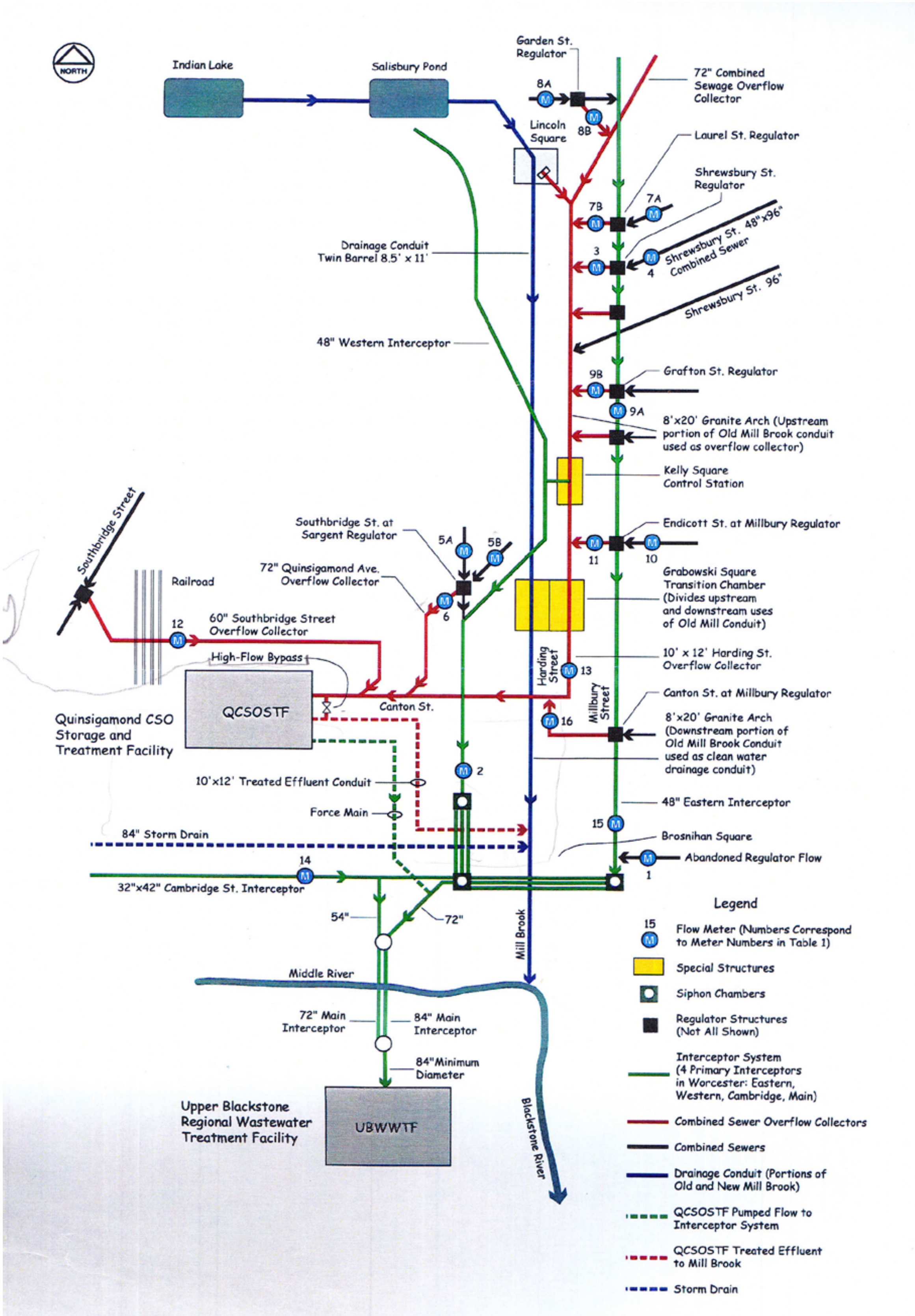


Figure 3: Worcester CSO system (from CDM, 2012)

The “Southbridge Street and Quinsigamond Avenue Area Flood Study” completed by Kleinfelder/S E A Consultants Inc. in 2010, recommended adding a flap valve in a drain manhole along Quinsigamond Avenue. The report mentions that this valve, in conjunction with subsurface detention in Crompton Park, may decrease flooding on Quinsigamond Avenue. However, further analysis of feasibility, level of benefit, and cost still needs to be completed. This project further analyzes this recommendation and determines if this is a practical solution to reduce flooding in the area. Further evaluation of Klienfelder/SEA’s recommendation requires multiple components. These components include gathering data, evaluating existing conditions, evaluating preliminary design options and direct installation cost analysis.

2.0 Background

This chapter provides background information necessary for a more complete understanding of this MQP. These aspects include a site description of the Quinsigamond Avenue area, an overview of Worcester’s CSO system, storm water management history in Worcester, descriptions of subsurface detention and check valves, previous studies associated with the area and permitting restriction relating to the area.

2.1 Site Description

The Quinsigamond Avenue area is located south of Union Station and extends from Southbridge Street to Crompton Park in Worcester, Massachusetts. Figure 4 outlines the street in relation to the green island neighborhood’s boundaries. It is an area that has a great variety of industry, business, and homes. The street is between hills and contains some of the lowest lying areas in Worcester. Quinsigamond Avenue has a high percentage of impervious surfaces surrounding it, such as pavement and buildings. This prevents rainwater from naturally infiltrating, which is a process that is also impeded by the area’s naturally high water table. These features make Quinsigamond Avenue an area especially prone to flooding. The surrounding neighborhoods are very densely populated area and many people travel throughout the area on a daily basis.

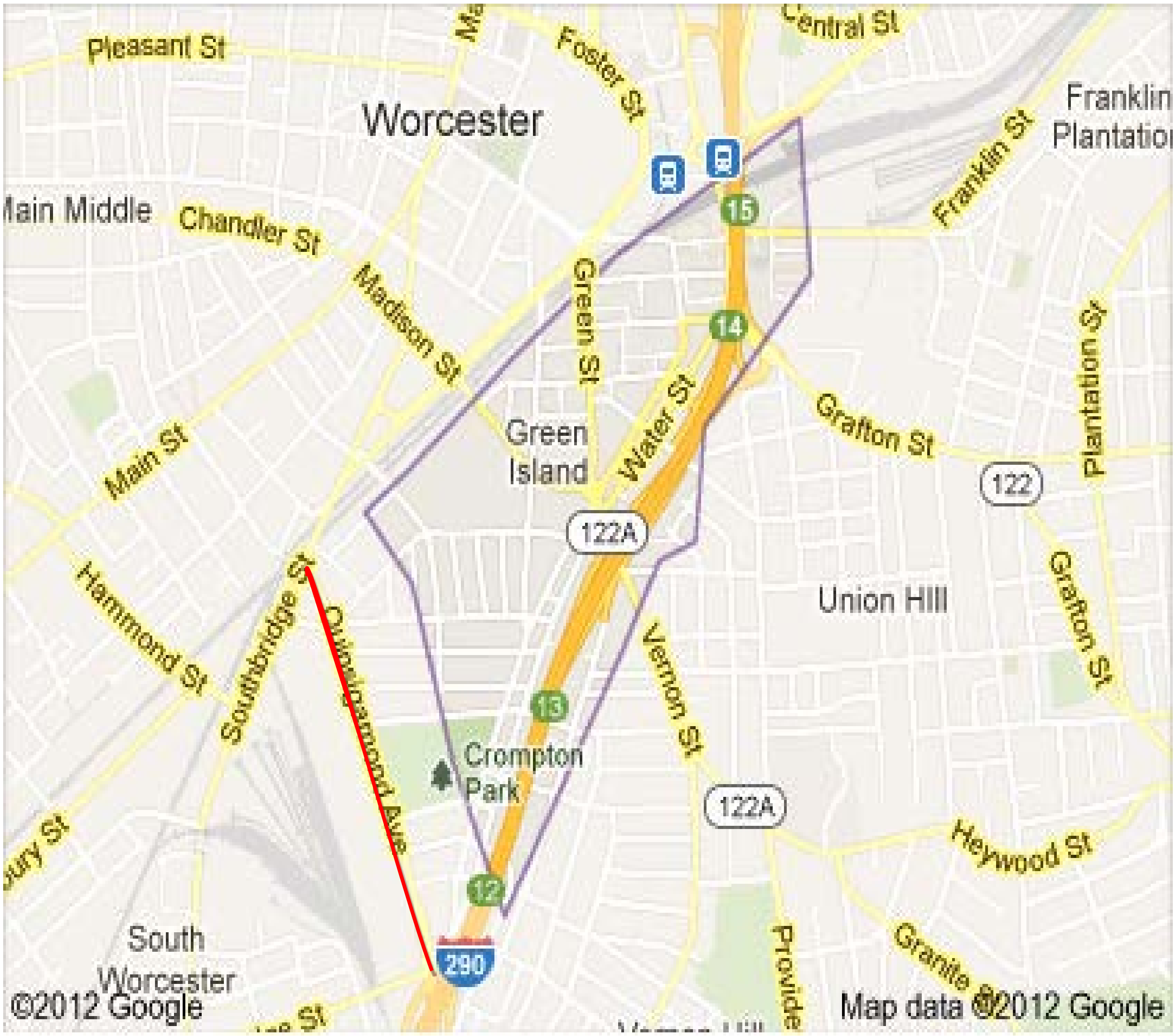


Figure 4: Outline of Quinsigamond Avenue Area

2.2 Combined Sewer Overflow System

Worcester, Massachusetts has had two facility plans prepared for the city's combined sewer system over the past 38 years. The first plan began in 1975 and implemented in 1989. The plan successfully reduced the combined sewer system area by 0.5 square miles and led to the implementation of four large overflow collections. The plan also included a conduit to carry upstream storm water through the combined sewer system, and the construction of the Quinsigamond Avenue Combined Sewer Overflow Treatment Facility (QACSOTF).

The facilities have mitigated the impact of combined sewer overflows (CSO) throughout the city of Worcester. According to CDM's 2002 Long Term Control Plan Report, during a typical five-year period there are no dry weather overflows or untreated bypasses. Treatment at the QACSOTF includes screening, storage, disinfection, and dechlorination, and only occurs during wet weather events. The QACSOTF acts only as a pumping station during dry events, with all of the treating being done at Upper Blackstone Wastewater Treatment Facility. The high volume of water during wet weather conditions requires the QACSOTF to flash treat its inlet, and release the treated effluent into the Blackstone River. Figure 3, found in the introduction of this report, displays a schematic of Worcester's CSO system.

2.3 Worcester Storm Water Management History

Throughout the past 55 years, the city has completed a multitude of projects that alleviate flooding in the area. In 1957, a diversion dam project known as the Worcester Local Protection Program, started in 1957 and was finished in 1960. There were many dams built on major rivers around the south, east, and west of Worcester. A couple of man-made lakes were also built to divert water from overflowing into Webster Square. The entire project allows water that would overflow from the Leesville Pond area to bypass Worcester by directing water into a diversion tunnel that leads to the Blackstone River. This project has been very successful in preventing flooding in Worcester, especially to the Webster Square Area.

In 1985, the city started a Flood Control Project, which had a goal of increasing the system capacity. In 2003, a Southbridge Street Sewer Separation project began which aimed to reduce the frequency and extent of flooding in the Green Island area. The project separated storm water drainage from the combined sewer system and re-directed the storm water to a drain on Cambridge Street. This removed some influence of drainage entering the CSO Facility, which reduced flooding. Observations of this project have shown that storm drain surcharging has been reduced by approximately five feet. However, this project has only impacted flooding on Southbridge Street. In 2007, the Millbrook Conduit was extended to drain downstream to a lower elevation on the Blackstone River. This extension decreased the river flood impact on the drain outfall, resulting in a lower tailwater impact of approximately ten feet.

Recently, there have been many more high intensity storms over short periods of time, which contribute greatly to flooding. Rainfall trend data has been updated since the 1960s and there were changes from previous rainfall trends. Since the 1960s, there has been an increase in the frequency of two-inch rainfall events and storms that were once considered 1- in- 100 year storm events have become more frequent and likely to occur almost twice as often. Because of these changes in rainfall, measures that were taken before and were successful in reducing flooding may not be as effective due to high volumes of water entering the system more and more often (Flooding Presentation, 2011).

2.4 Storm Water Controls

This section expands on specific storm water controls that are often used to prevent surface flooding in urban areas. Examples of these controls include subsurface detention and check valves which are presented and discussed in the next two sections.

2.4.1 Subsurface Detention

Storing excess water in subsurface detention chambers is a practice used by many designers when storm water overflow is deemed to be an issue. Underground storm water detention systems are efficient methods of collecting and storing storm water runoff from surrounding impervious surfaces. Since the systems are below grade they increase the amount of usable land in the area. It is common for parking lots and recreational green areas to be built on top of these types of systems (Underground Storage). Subsurface storm water detention systems usually involve systems of large diameter interconnected storage pipes or chambers. The systems work by storing storm water in these pipes and later releasing the water through an outlet pipe at rates to reduce peak flow conditions. The storm water is either released back into the storm water system or infiltrates to recharge groundwater (Subsurface Detention). Figure 5 displays an example of subsurface detention chambers during the development phase.

Figure 5: Subsurface Detention System

2.4.2 Check Valves

Check valves are often used by developers to help prevent the backflow of fluids within storm drains. A check valve allows flow in only one direction, and closes when flow moves in the reverse direction. This prevention of backflow can often assist in reducing the possibility of overflow and flooding within a storm drain and CSO system. When a combined sewer flow passes through a check valve, it cannot reverse its path back through the pipe. The valves are designed this way by having pressure sensors or manual controls that will open the valve in only one direction, and prevent water from returning from where it came. The water that would reverse through the pipe and often lead to overflow floods could be stored in subsurface detention tanks, where it can be released into the system during low flow times. There are several varieties of check valves, with different material make-up, shape, and sensitivity, all which are useful in the correct scenario. Hinge flap gates are common models that are usually made from stainless steel. Flap valves are another popular model, which are usually made of rubber (Tideflex Technologies, 2012). Figure 6 displays an example of a TF-1 flap valve.

Figure 6: T-1 Flap Valve (Tideflex Technologies, 2012)

A project influenced by an August 2008 flood in the town of Carlow, Ireland involved the implementation of flap valves throughout an entire CSO system. Carlow, Ireland, experienced heavy flooding (some parts of the city were submerged under two meters of water) from the River Barrow after excessive rainfall caused the river burst its banks. (Carlow worst hit by widespread flooding, 2008) Due to extensive flooding, a £18 million flood relief scheme was developed in order to prevent and control future flooding from the river. Over 20 km of new pipelines, storage chambers, pumping stations and pressure lines were installed in order to increase the efficiency of the network that already existed. The Tideflex TF-1 Check Valve was used throughout the project. Using both the valves, the CSO system, the running time, size, and number of pumps required to cope with exceptional rainfall events was decreased. (Technologies, 2011)

2.5 Previous Storm Water Studies Completed in Worcester

The following sections further examine reports completed by Kleinfelder/SEA and CDM. These reports provided background information for the Worcester CSO system and the Quinsigamond Avenue area as it relates to flooding.

2.5.1 Kleinfelder/S E A Report

In 2010, a "Southbridge Street and Quinsigamond Avenue Area Flood Study" was completed by Kleinfelder/S EA consultants Inc. They investigated the Southbridge Street area in order to determine why the area has flooding issues. "...field investigations during wet and dry weather conditions, and performing evaluations of the city's storm drain and sewer systems including analysis using a hydrologic/hydraulic model of those systems," was completed. Southbridge Street, Southgate Street, Cambridge Street, Quinsigamond Avenue, and the Providence & Worcester Facility were the main areas of focus for this study. Sediment accumulation, drain slopes, low elevation of the area, lack of adequate draining, weak pumps, and damage to drains and manholes all contribute to flooding in the Quinsigamond Avenue area.

There was a multitude of recommendations given, including:

- Cleaning sediment from storm drains
- A new catch basin should be installed at a low point on Southbridge Street
- Redirecting catch basins from Southgate St. from the CSO to the storm drain and manholes secured to prevent overflows
- Upgrading pumps in the Cambridge St. drainage pump station to a higher capacity

- Adding a flap valve to a drain manhole on Quinsigamond Avenue in conjunction with adding subsurface detention
- Upgrading the Quinsigamond Avenue Combined Sewer Overflow Treatment Facility

SEA evaluated a number of methods that could potentially decrease the amount of surface flooding in the Quinsigamond Avenue area. First, an evaluation of replacing the 72”x74” trunk drain with a 48 inch diameter pipe from Lamartine Street to the Millbrook Conduit at a higher elevation to allow for greater slope was conducted. Raising the discharge elevation to the Conduit in hopes to decrease the tailwater impacts from the Conduit was also evaluated. In order to alleviate flooding using these measures, drain connections would need to be raised to connect to the replacement drain or flooding on the streets intersection Quinsigamond Avenue would actually increase. Since raising the elevation of the connecting storm drains would result in large costs, SEA determined that this option was not feasible for the city of Worcester.

Another option that was evaluated was adding a subsurface storm water detention system underneath Crompton Park. The hope was that this storage could minimize the volume of overflows from the Quinsigamond Ave storm drain that causes flooding on the surface. Overflowing water would drain to the detention system and then be released back into the drain by gravity when surcharged water conditions decrease. Using a hydrologic/hydraulic model, it was determined that subsurface detention alone would not provide any benefit. Because of the conditions in the Millbrook Conduit, the peak hydraulic grade in the drain was only decreased by half a foot. Both of these two options are not feasible because they would require reconfiguring the Conduit or the QACSOTF which are not realistic options

2.5.2 Phase 1 CSO Long-term Control Plan Report

In 2000, the EPA and the city of Worcester signed a consent order that required the city to develop a two-phase Long-term Control Plan (LTCP). In March of 2002, CDM completed a "Phase 1 CSO Long-term Control Plan Report". This particular report presents Phase I finding of the LTCP "for mitigating the water-quality impacts of its combined sewer system's combined sewer overflows (CSOs)." The report provides information that includes the following:

"Worcester's combined sewer system (CSS), effectiveness of existing facilities, and the CSS's relative impact on the Blackstone River; future planned improvements at the Upper Blackstone Wastewater Treatment Facility (UBWWTF), and how they will further mitigate CSS impacts on the Blackstone River; Evaluation of additional alternatives, beyond UBWWTF improvements, to further minimize CSS impacts; Financial impacts of potential CSS improvements; Regulations affecting the CSS; and Phase II of the LTCP."

CDM researched and developed ways to improve the CSS and found quite a few possible techniques. These improvements include diversion of two ponds out of the CSS; increasing storage in Kelly Square, the Harding Street Overflow Collector; increasing pump capacity at the QACSOTF. Ongoing projects that were already in the process of completion that would improve the CSS were also considered and included in the study. These projects included building a dechlorination facility in order to improve water quality, meet fecal coliform and total residual chlorine permit limits, and upgrades to the UBWWTF. A particularly helpful improvement made to the UBWWTF was that the QACSOTF was able to pump 70 MGD more to the UBWWTF, which allowed the QACSOTF to discharge about once every two months, as opposed to the previous discharge of more than once per month. (Phase I CSO Long-term Control Plan Report, 2002)

2.6 Health and Safety Concerns

With flood waters having the ability to carry bacteria and viruses, flooding in an urban community is a very serious issue. Eating or drinking anything that is been contaminated by flood waters can lead to the contraction of several water-borne diseases (CDC, 2011). If flooding causes a sewage backflow, this introduces many more contaminants in the flood waters. In the case of the Quinsigamond Avenue storm drain, flooding does result in contaminants in the water because of the combined sewer system.

Flood waters can provide insects such as mosquitos with new breeding grounds, which can increase the chance of contracting a mosquito-borne disease. Floods can also force animals, such as snakes and rodents, from their natural habits. Often this can lead to the infestation of these animals into home dwellings and buildings. Mold and mildew can grow in the walls, floors, carpets, toilets, and bathrooms of buildings that have been impacted by floods within 24 to 48 hours. This can lead to upper respiratory diseases and also trigger cold-like systems, such as watery eyes, sore throat, and dizziness. (Minamiguchi, 2013) Flooding can also cause structural damage to building by weakening the walls and foundations, which can pose a safety threat on anyone inside an affected building. Floods pose a serious threat to any urban environment, in terms of both health and safety. (Health and Safety Hazards Arising From Floods, 2002).

2.7 Permits

A major consideration when analyzing solutions to reduce flooding is the issue of permits issued by the Environmental Protection Agency (EPA). The EPA writes and regulates different permits relating to water. There are two treatment plants in the area, the Upper Blackstone Wastewater Treatment Facility (UBWWTF) and the Quinsigamond Avenue Combined Sewer Overflow Treatment Facility (QACSOTF), which each require a permit. There is another city-wide permit that aims to regulate storm water. These permits must be taken into consideration when making any adjustments to the system. Any changes made to the systems must be in compliance with these permits.

However, having to take into account three different permits can cause conflicts. Because the systems are all interconnected, changes or requirements in one permit can have a direct effect on another permit. For example, if a new permit for the QACSOTF increases the amount of flow they are allowed to discharge, and UBWWTF can only accept a certain amount of flow from all the various plants and drains that feed into this plant, the new QACSOTF flow might cause the UBWWTF inlet flow to be exceeded. Not only do any changes made in the system have to be in compliance with the permits, but changes must also be examined to ensure it will not indirectly violate another permit.

2.8 Hydrologic Processes in Urban Watersheds

The urbanization of an area changes the characteristics of a watershed substantially. The hydrologic processes are modified by replacing vegetated land cover with impervious surfaces, and by including above and underground conduits which carry storm water through the natural drainage network (Cuo, Lettenmaier, Mattheussen, Storck, & Wiley, 2008). Urban storm water drainage systems typically consist of two different hydrological elements, surface and subsurface components. Surface components include streets, rooftops, and ditches, whereas subsurface components include pipes and other manmade storm water drainage conduits. These two elements often combine through street curb inlets and manholes, before they are transported to a facility for treatment. Because impervious surfaces reduce infiltration and increase storm water runoff, urbanization essentially increases the peak flows of the hydrological processes.

2.8.1 Storm Water Models

Storm water models are helpful because they allow for the use of known confounding factors to predict urban flooding (Cuo, Lettenmaier, Mattheussen, Storck, & Wiley, 2008). These models simulate the hydrodynamics of overland flow by using GIS and digital elevations to determine surface runoff direction, locations of streets, storm sewer pipes, street inlets and manholes. Models take into account many different variables, such as drainage area, percent of impervious surface, average slope, and other conduit and junction variables. When known factors are entered into the model, an accurate depiction of what the urban watershed acts like can be achieved. If proposed improvements or other changes are to be made to the current watershed, the variables within the model can be adjusted to see how the alterations would affect the urban watershed.

2.8.1.1 Storm Water Management Model (SWMM)

Storm Water Management Model (SWMM) is a free software provided by the EPA. It is used for predicting the effects of changes within a storm water management system. The EPA describes its program with the following statement:

"SWMM operates on a collection of subcatchment areas on which rain falls and runoff is generated. The routing portion of SWMM transports this runoff through a conveyance system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps" (Environmental Protection Agency, 2013).

First developed in 1971, SWMM has been improved upon ever since and is now a leading program in providing hydraulic and water quality simulations. The results of these simulations can be viewed in several different formats, including color-coded drainage maps, time series graphs and tables, profile plots, and statistical frequency analyses.

3.0 Methodology

The goal of this project was to develop an efficient, feasible alternative design plan to reduce surface flooding problems in the Quinsigamond Avenue area of Worcester, Massachusetts. This plan includes a set of preliminary designs for any structural components associated with the storm water management plan, such as flap valves, or subsurface detention chambers. To accomplish this, our project team completed several tasks that ultimately lead to the completion of this project. These tasks included the following:

1. Completing research regarding Quinsigamond Avenue flooding
2. Evaluating existing conditions in the Quinsigamond Avenue area
3. Generating preliminary design options
4. Evaluating the preliminary design options' feasibility
5. Defining a design for a flap valve/storage system
6. Providing recommendations to the city of Worcester

3.1 Completing Research Regarding Quinsigamond Avenue Flooding

To begin research on flooding issues in the Quinsigamond Avenue area, the project team first focused on past flooding events in recent history that caused significant damage. The various factors that contributed to these flooding events were discussed with Joe Buckley and Philip Guerin of the Worcester Department of Public Works & Parks. The "Southbridge Street and Quinsigamond Avenue Area Flood Study" completed by Kleinfelder/SEA in 2010 was also analyzed. The study focused on five areas in the Southbridge Street area of Green Island in order to obtain a better understanding as to why flooding is such a severe problem in the neighborhood. After presenting the various factors associated with flooding in the area, SEA's report listed conclusions and also provided recommendations for possible solutions that could reduce flooding in the area. These recommendations were reviewed in order to determine which would best provide a desired major qualifying project experience.

An effective and commonly used method for solving flooding issues in large areas is to focus on smaller sections of the area contributing to the problem. When smaller sections are considered, solving a major problem can become easier because a clear step by step approach is being used. After reviewing various recommendations made in the Kleinfelder/SEA report, a specific recommendation was chosen for further analysis. This project focused on a recommendation that includes adding a flap valve to the Quinsigamond Avenue storm drain in conjunction with subsurface detention. The goal of this recommendation is to reduce surface flooding associated with the Quinsigamond Avenue area. This recommendation was chosen based on several factors, including Kleinfelder/SEA's conclusion that it "required further analysis to determine feasibility, level of benefit, and cost." This is an important consideration because one of the goals of this task was to find a project that needed more analysis. The topic was also chosen because it encourages engineering students to use course related knowledge to solve a problem which was an additional consideration for the completion of this task.

A general outline of the flooding issues in the Quinsigamond Avenue area was presented by employees of the Worcester Department of Public Works & Parks. These employees agreed to provide useful information needed for the completion of the project. The Worcester DPW has past studies, technical data, general knowledge about Quinsigamond Avenue and the flooding that occurs in the area, as well as information regarding the combined sewer overflow system. Online research and data gathering from newspaper articles, studies and reports associated with flooding in the area was completed. Technical data provided by the city of Worcester included GIS data and flow metering data. Previously used SWMM models were also provided by CDM.

3.1.1 GIS Data

GIS data provided by the city of Worcester were used to determine pipe/conduit elevation, pipe depth, drainage area, and impervious surface data associated with the Quinsigamond Avenue area. Data layers provided by the city of Worcester included addresses, brooks, streams, buildings, catch basin locations, contour lines, drainage culverts, driveways, lakes, manhole locations, roads, sewer lines, storm lines and combined sewer lines. Further information on how these data were used is presented in Section 3.2

3.1.2 Model Data

A SWMM model of Worcester's combined sewer system that was previously developed was provided by CDM-Smith for academic use at WPI. This model was used by Renaud (2012) to quantify the combined sewer overflows associated with rainfall events that may occur under climate change. The model provided detailed information of other combined sewer lines in the area, but did not include any conduit properties for either the Millbrook conduit or the Quinsigamond Avenue storm drain. However, the existing model was helpful since it included conduit property information on the effluent treatment line leaving the Quinsigamond CSO Storage and Treatment Facility (QCSOSTF) and entering Mill Brook. The effluent treatment line is used when the storage capacity of the QCSOSTF is exceeded. Storage capacity at the QCSOTF is exceeded during long duration storms which require the facility to discharge large amounts of flash treated effluent into the Mill Brook conduit (Kleinfelder/SEA, 2010). This causes tailwater impacts from the Mill Brook conduit to dramatically impact the Quinsigamond Avenue storm drain. Figure 7 is partial schematic showing the original SWMM model.

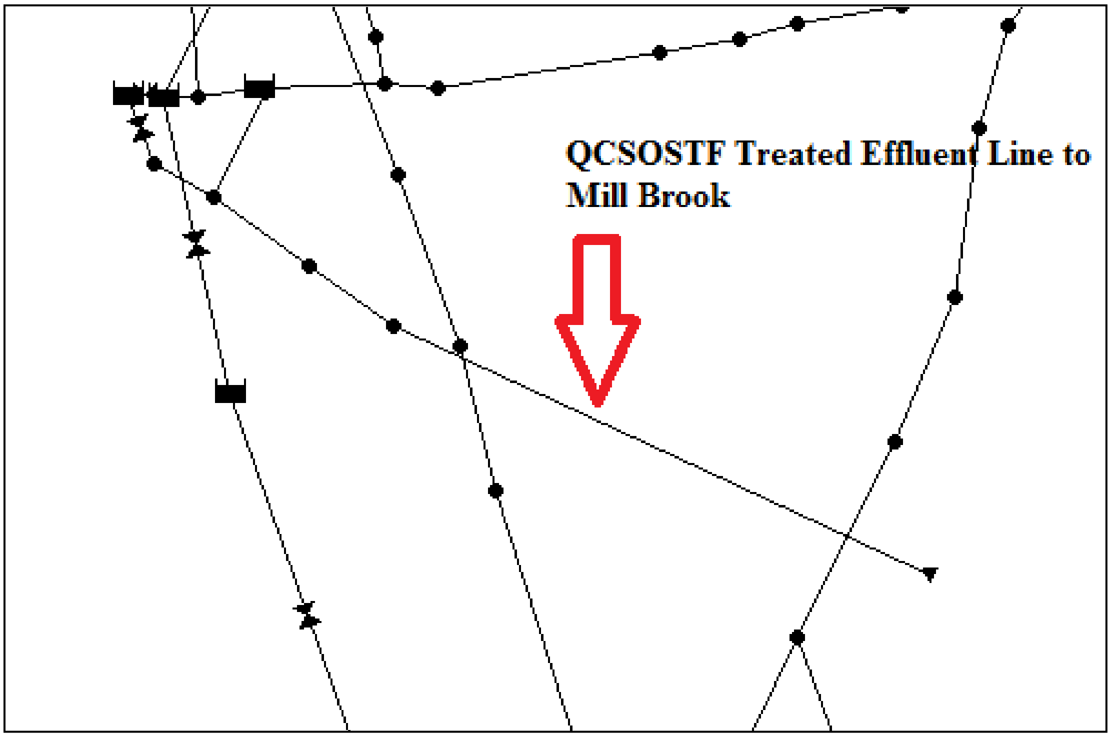


Figure 7: Original SWMM Model

Since the original model already included conduit properties for a treated effluent line that dramatically impacts surface flooding in the Quinsigamond Avenue area, it was determined that the best way to accurately evaluate surface flooding in the area was to manually add the Mill Brook Conduit and the Quinsigamond Avenue storm drain to the existing model. This was completed by using EPA SWMM software and developing junctions and conduits within the original SWMM model such that they had similar properties to the Millbrook conduit and the Quinsigamond Avenue storm drain. Once these junctions and conduits were developed, they were placed in the appropriate locations to provide an accurate representation of the location of the Quinsigamond Avenue storm drain and the Mill Brook conduit in relation to Worcester's CSO system. A subcatchment was also added to include the appropriate rain gages being used in the model. Once an accurate representation of the Quinsigamond Avenue storm drain and the Millbrook conduit was in place, it became possible to evaluate existing conditions in the area. Further information on how existing conditions were evaluated can be found in Section 3.2.

3.1.3 Flow Metering Data

During SEA/Kleinfelder's Southbridge Street and Quinsigamond Avenue Area Flood Study, four metering locations were installed in the Quinsigamond Avenue storm drain by a sub-consultant (Kleinfelder/SEA, 2010). These meters were installed and analyzed from April 23rd, 2010 – June 21st, 2010. Raw data for these flow meters can be found in Appendix A. The flow metering data that were collected contributed to the development of a more accurate SWMM model. This was done by using the standing water elevations in the Quinsigamond Avenue storm drain during dry conditions, as well as the peak flows during wet conditions as a baseline for the model. The locations of the meters 1-4 are displayed in Figure 8, and their recorded standing water elevations displayed in Table 1.

Table 1: Standing Water Elevations for Quinsigamond Avenue Storm Drain during Dry Conditions

	Date	Standing Water Depth (Inches)		Date	Standing Water Elevation (Inches)
Man Hole 3	4/23/2010	6.25	Man Hole 4	5/5/2010	25
	4/28/2010	5.5		5/12/2010	25.87
	5/5/2010	5		5/20/2010	27.5
	5/27/2010	6.4		5/27/2010	26
	6/9/2010	4		6/2/2010	24.75
	6/21/2010	5		6/9/2010	25
	-	-		6/21/2010	24.5

Figure 8: Flow Metering Locations (Kleinfelder/SEA, 2010)

3.2 Evaluating Existing Conditions in the Quinsigamond Avenue Area

The existing conditions in the Quinsigamond Avenue area were evaluated by calibrating a SWMM model using the Rational Method as an approximate approach to check results. The following sections discuss both of these methods.

3.2.1 The Rational Method

The rational method was used to estimate the peak flow calculations in the Quinsigamond Avenue storm drain. The rational method involves using the following variables:

Q = C * I * A
Q = Peak Flow (gpm)
C = Runoff Coefficient
I = Rainfall Intensity (in. /hr.)
A = Area (acres)

How these parameters were determined can be found in Table 2, which characterizes variables used in the SWMM model.

Table 2: Rational Method Variables

Desired Property	Method Used for Property Identification	Significance
Peak Flow	Q = C*i*A	Peak flow within storm drain during rain event.
Runoff Coefficient	Used guideline chart provided by SWMM which identifies coefficients for different land make-ups.	Considers contributing drainage area's make-up and how well water flows on it.
Rainfall Intensity	Amount of rain fall divided by length of storm.	Considers how quickly a specific amount of rain falls onto the drainage area.
Area	Area delineated by interpreting elevation contour data layer in ArcGIS representation for Worcester and using the drawing tool to define the watershed boundary.	Contributing drainage area for all flow draining to subcatchment outlet.

3.2.2 Calibration of SWMM Model to Match Existing Conditions

Existing conditions within conduits in the Quinsigamond Avenue area lead to surface flooding during wet weather. To properly evaluate the flooding issues associated with existing conditions, adjustments were made to an existing SWMM model originally developed by CDM. Previous reports indicated that flooding most likely occurs as a result of capacity issues in the Quinsigamond Avenue storm drain. The capacity issues in the 72" by 74" are believed to be influenced by backflow conditions in the Millbrook conduit (Kleinfelder/SEA, 2010). The updated SWMM model was adjusted to replicate the existing conditions in the area.

This task included analyzing surface flooding in the Quinsigamond Avenue area if no action is taken. In order to properly prepare the SWMM model, flow metering information, GIS data, rainfall intensity information, and previous Worcester SWMM models were all used. All of this information was analyzed to properly adjust the subcatchment, as well as the different conduits and junctions used within the model. In order to accurately depict the impact of storm events corresponding to the Quinsigamond Avenue area, the SWMM model requires specific properties that replicate the subcatchment, conduits, and junctions involved. Tables 3, 4 and 5 display these required properties, and the basis for the determination of properties. These properties are significant for an accurate simulation of the impacts of specific storm events on the Quinsigamond Avenue storm drain and the Millbrook Conduit. Graphics used in determining sucbcatchment properties can be found in Appendix B. Graphics used in determining conduit and junction properties can be found in Appendix C.

Table 3: Subcatchment Properties for Updated SWMM Model

Desired Property	Method Used for Property Identification	Significance
Drainage Area	Area delineated by interpreting elevation contour data layer in ArcGIS representation for Worcester and using the drawing tool to define the watershed boundary.	Contributing drainage area for all flow draining to subcatchment outlet.
Width of Overland Flow Path	In order to determine the width of overland flow path, it was suggested to find the main stream channel length and multiply by a factor of 1.7 (Troidl, 2007).	Considers the width of the overland flow path.
Average Surface Slope	ArcGIS data was used to determine this property. The Mass GIS soil data layer was used to determine the % Slope.	Considers rate of runoff as well as time of concentration.
Percent of Impervious Surface	ArcGIS data was used to determine this property. The Mass GIS impervious surface layer was used to determine this percentage.	Percent of the drainage area that is covered by non-porous material such as asphalt or buildings.
Manning's n for impervious area	Used guideline chart provided by SWMM software.	Considers the impervious portion of the subcatchment and the amount of runoff associated with it.
Manning's n for pervious area	Used guideline chart provided by SWMM model.	Represent the resistance to flood flows within the subcatchment.
Depth of depression storage on impervious surface	Used typical values chart provided by the SWMM software.	Represents rainfall volume that will not reach the storm drain.
Depth of depression storage on pervious surface	Used typical values chart provided by the SWMM software.	Represents areas where storm water may infiltrate, rather than flowing to storm drain.
Percent of impervious area with no depression storage (%)	Used default SWMM setting (Troidl, 2007)	Represents areas where storm water does not infiltrate.

Table 4: Conduit Properties for Updated SWMM Model

Desired Property	Method Used for Property Identification	Significance
Inlet Node	Set automatically based on conduit placement	Allows for proper flow direction in model.
Outlet Node	Set automatically based on conduit placement	Allows for proper flow direction in model.
Shape of Conduit	The shape of all conduits were determined using the pipe size information in the GIS and recorded plans provided by the city of Worcester	The shape of the conduits is significant to the hydraulic process.
Max Depth of Cross Section of the Conduit	Max depth of all conduits were determined using the pipe size information in the GIS and recorded plans provided by the city of Worcester	Dimensions give the capacity of the conduit.
Conduit Length	Length of all conduits were determined using the pipe size information in the GIS and recorded plans provided by the city of Worcester	Dimensions give the capacity of the conduit.
Manning's roughness coefficient	Used typical values provided by SWMM software	Represent the resistance to flood flows within the pipes.
Inlet Offset	Inlet offset was determined based on record plans provided by Worcester's DPW.	Provided the depth or elevation of the conduit invert above the node invert at the inlet end of the conduit.
Outlet Offset	Inlet offset was determined based on average slopes in Millbrook or Quinsigamond Avenue. These average slopes were calculated using record drawings provided by Worcester's DPW.	Provided the depth or elevation of the conduit invert above the node invert at the outlet end of the conduit.
Initial Flow	Determined based on flow metering data provided by the City of Worcester. Was also determined during calibration of the model.	Provided the initial flow in the conduit at the start of a simulation
Flap gate	Used for specific design scenarios simply by turning the option on and off in the appropriate location.	Prevent backflow and acts as a gate to allow flow in one direction, but now in another.

Table 5: Junction Properties for Updated SWMM Model

Desired Property	Method Used for Property Identification	Significance
Inflows	Additional inflows were only considered during the calibration of the model. This was completing by entering a flow value for either dry weather or direct flow.	Inflows can provide a means to properly configure the model and account for any inflows from other areas that may not be considered in the modeling software.
Elevation at Junctions Invert	Elevation at junctions invert was determined using the pipe data layer in the Worcester GIS and recorded plans provided by the city of Worcester.	These elevations were used to determine the slopes from one junction to another.
Maximum Water Depth	The maximum water depth at the junction was determined using rain fall data provided by the city of Worcester.	The maximum water depth was used to determine the amount of water that can be contained within a junction.
Initial Depth	Initial depth was determined by considering the flow metering data while calibrating the SWMM model.	Initial depth made it possible to account for standing water in either Millbrook or Quinsigamond Avenue.
Surcharge Depth	In order to obtain surcharge depth for specific junctions, recorded drawings provided by the city of Worcester were considered. The model was set up so that the junctions representing the flow metering locations. The depths were then used based on the manhole locations where meters were installed.	Surcharge depth is an important consideration because it can reveal when water surcharges from the Quinsigamond Avenue storm drain during various storm simulations in the model.

The next step in calibrating the SWMM model was to differentiate between the different conduits and junctions located within the subcatchment. Figure 9 was developed to identify the specific conduits within the model. Conduit segments numbered 1-4 are located within the

Quinsigamond Avenue storm drain, and conduit segments numbered 5-7 are located within the Millbrook conduit. This numbering system for conduits will be referenced throughout the remainder of this report.

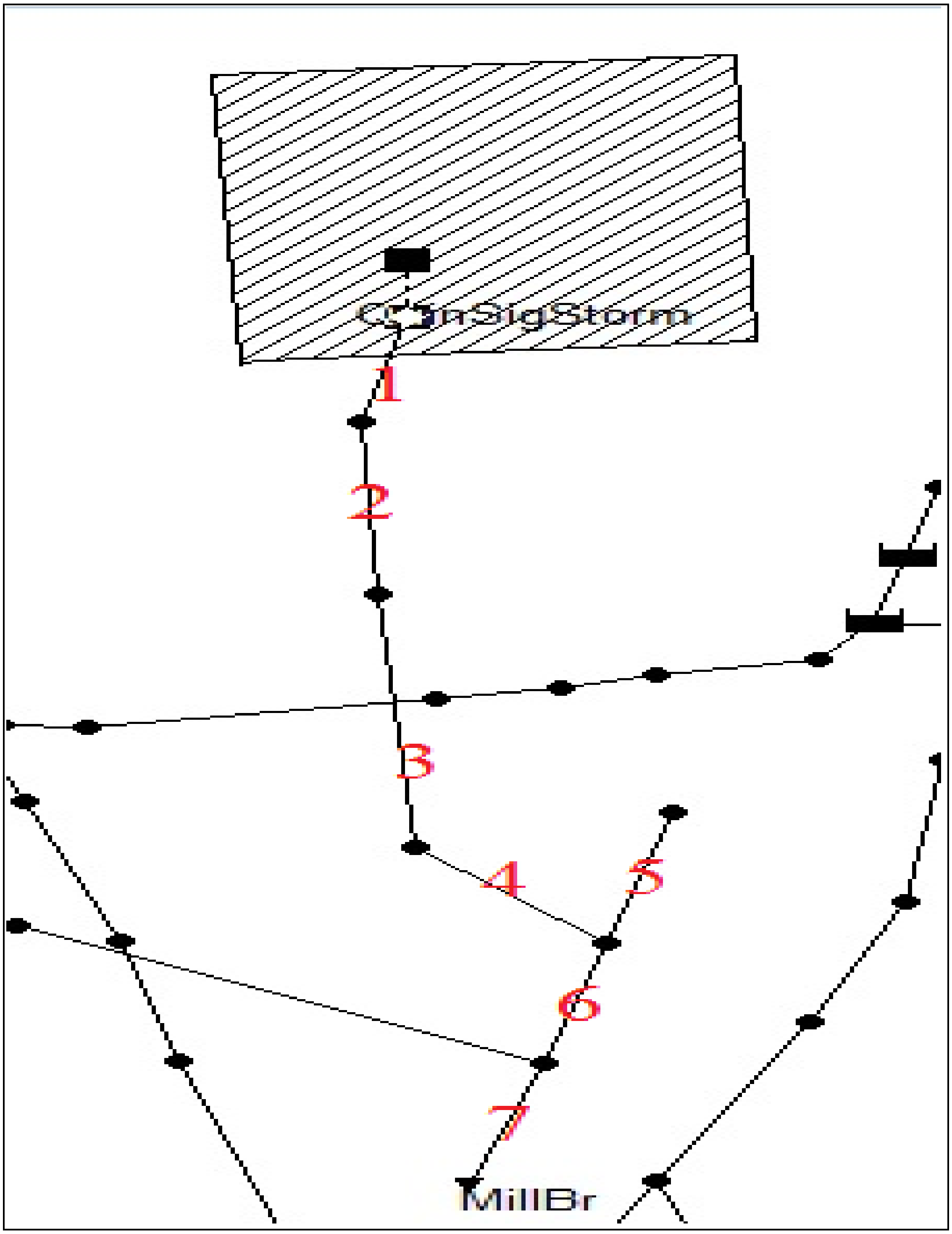


Figure 9: Conduit Labels

Figure 10 was developed to identify the specific junctions within the model. Junctions numbered 1-4 are located within the Quinsigamond Avenue storm drain, and junctions numbered 5-7 located within the Millbrook conduit. This numbering system for junctions will be referenced throughout the remainder of this report.

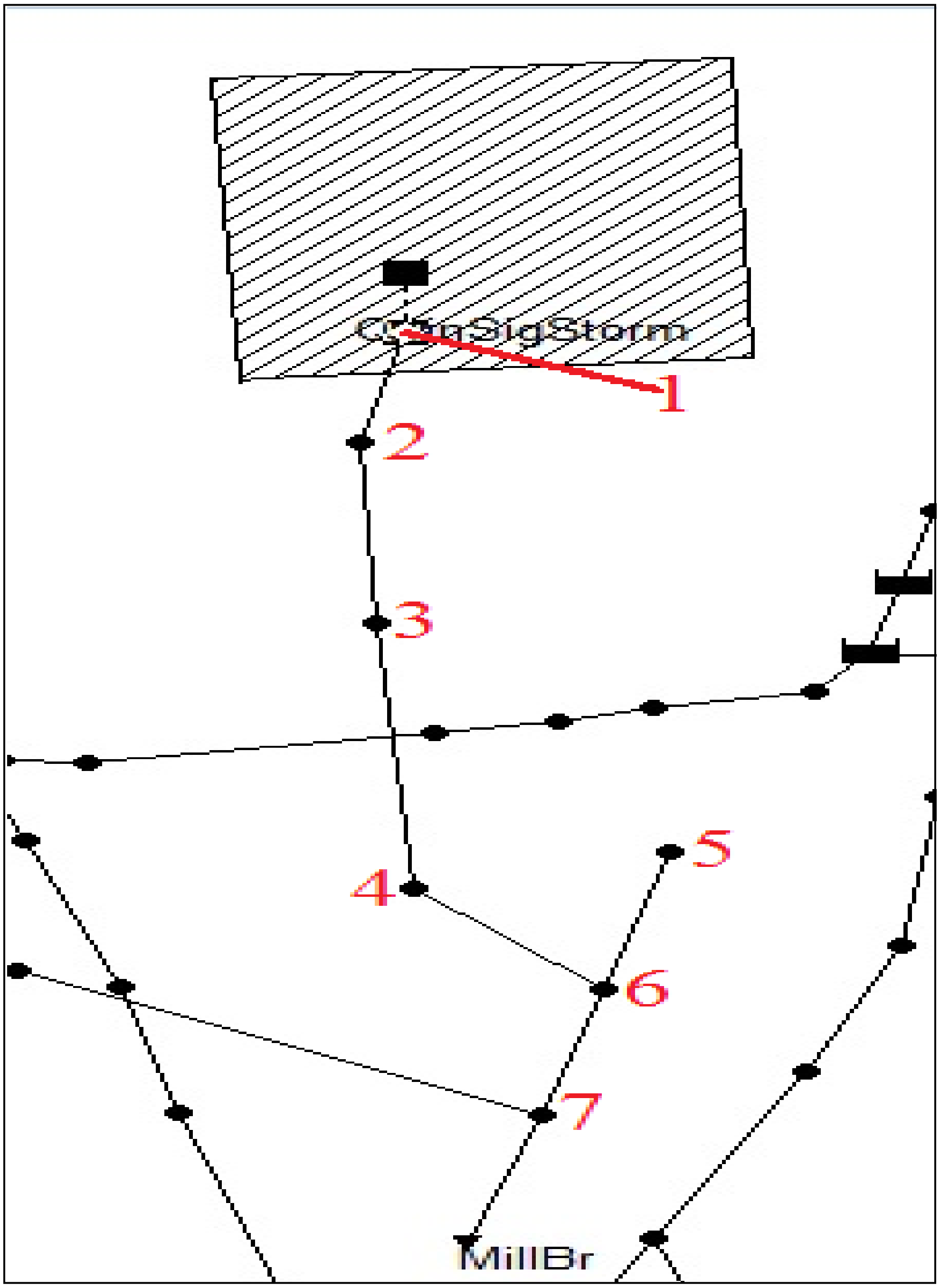


Figure 10: Junction Labels

Using the adjusted subcatchment, junction, and conduit properties, along with the standing water elevations in the storm drain, the model was adjusted to accurately represent existing conditions. To understand the impacts of backflow conditions from the Millbrook conduit on the Quinsigamond Avenue storm drain, dry weather conditions were investigated first. The approach used to investigate whether or not backflow is present in the Quinsigamond Avenue storm drain under dry weather conditions was to analyze the available metering information. Field inspections provided by the City of Worcester indicated that standing water at junctions 3 and 4 existed even when there was no flow in the drain, as previously displayed in Table 1. During dry weather conditions there were about 25.5 inches of standing water at junction 4, and 5.5 inches at junction 3.

Since no flow metering data were provided for the Millbrook conduit, two methods were used in order to account for standing water in the Quinsigamond Avenue storm drain. The first method used involved adding a large dry weather inflow of 675 CFS to maintain flow in Millbrook at Junction 5. This was done in order to provide a downstream water depth that would result in similar standing water elevations to those that were provided in the flow metering data at Junction 3 and Junction 4. The adjustment resulted in standing water depths of 25.39 inches and 13.54 inches for Junctions 4 and 3, respectively. After further analysis of this approach, it was recognized that a dry weather inflow of 675 CFS was far too high to accurately portray existing conditions. A new approach was then generated.

The second approach considered setting a fixed water elevation in the conduit. This was done by changing the fixed stage elevation at Millbrook’s downstream outfall to 432.5 feet. By adjusting this elevation, the water level in Millbrook was maintained such that standing water depths of 25.25 inches at Junction 4 and 12.82 inches at Junction 3. These values matched depths that were provided in conjunction with the flow metering data. Since this method did not include adding an unrealistic amount of dry weather inflow it was used during the calibration of the model. After these adjustments were made, simulated storm events were developed to match flow metering data provided by the city of Worcester. The results for the SWMM model calibration process can be found in Section 4.2.2.

3.3 Generating Preliminary Design Options

In order to prepare an efficient, feasible design plan to reduce surface flooding associated with Quinsigamond Avenue, different scenarios were analyzed. After evaluating various alternatives for flood mitigation in the area, SEA recommended reducing surface flooding by installing a flap valve in the Quinsigamond Avenue storm drain in combination with subsurface detention in Crompton Park. All design alternatives that were evaluated included the flap valve installation part of this recommendation. The scenarios differed based on whether or not subsurface storage was included in the design. If storage was involved, it was determined how much storage would be necessary to control flows in the storm drain. Several different types of flap valves were investigated in order to determine the most effective model.

The design option scenarios were analyzed using the SWMM model which was developed during the completion of Task 3.2. In order to evaluate each scenario for specific storm events, the model was simulated using different rainfall input files. These input files included two storm events that were created using flow metering data provided by the city of Worcester as well as a 3 month, 1 year,10 year , 25 year and a 100 year design storm. These design storms can be found in Appendix D.

3.3.1 Selection of Flap Valve Model

In order to select the proper flap valve to be used to mitigate flooding of the Quinsigamond Avenue area, several different features were considered. Various types of flap valves were researched and 4 different models were selected to be further investigated based on the size of the Quinsigamond Avenue storm drain and the issue of backflow conditions from the Millbrook conduit. The different models of flap valves that were investigated include the Tide Flex TF-1, 35-1, TF-2 and series 37. The features and benefits of these models were taken into consideration when choosing the appropriate flap valve. All of these models are made with a lightweight, all-elastomer design that will not warp or freeze open or shut. All models will not rust or corrode, and are great replacements for flanged flap gates. The hinge pins in flanged flap gates often deteriorate if they are not properly maintained, which allows for unwanted backflow.

3.3.2 Introduction to Scenarios

The following scenarios were developed to provide a practical solution to surface flooding issues in the Quinsigamond Avenue area. These scenarios include different types of storm water BMPs and were analyzed to provide a recommendation to reduce surface flooding while considering both effectiveness and feasibility. These scenarios were analyzed using an EPA SWMM model. The effectiveness of each scenario was measured based on the flows in the Quinsigamond Avenue storm drain in the model.

3.3.2.1 Scenario 1 – Flap Valve

This scenario included analyzing the levels of flooding associated with the Quinsigamond Avenue area after the implementation of a flap valve at the furthest downstream manhole location of the Quinsigamond Avenue storm drain. The model was adjusted to include a flap valve at this location. It was assumed that the backflow conditions in the Quinsigamond Avenue storm drain from the Millbrook conduit are no longer impacting the drain beyond the manhole where the flap valve was placed in the model. The significance of this scenario was to determine the maximum amount of capacity the 72" x 74" storm drain can provide during various storm events. This scenario included evaluating what storm events (if any) resulted in surface flooding with the presence of a flap valve in the storm drain.

3.3.2.2 Scenario 2 - Flap Valve Plus Storage

This scenario included analyzing the levels of flooding associated with the Quinsigamond Avenue area after the implementation of a flap valve at the furthest downstream manhole location of the Quinsigamond Avenue storm drain in combination with subsurface detention in Crompton Park. This task includes the use of results from Scenario 1 and the addition of subsurface storage aimed to decrease surface flooding in the area. Major considerations for this task were determining how much storage will be needed for various storm events and the installation of subsurface detention basins while considering groundwater levels and other constraints. The EPA SWMM model as well as hand calculations were used to evaluate the correct amount of storage.

3.4 Evaluating the Preliminary Design Options' Feasibility

To evaluate the feasibility of the recommendations, the project team will look at the different design options and their financial requirements. These different levels of improvement will require varying levels of financial backing, depending on how intricate the design is. The project team will evaluate what the financial requirements will be for improvement Scenarios 1 and 2. Financial data gathered from online research, the RSMeans Building Construction Cost

Data Book (Reed Construction Data, 2011) and similar projects and studies will be used to evaluate the costs associated with the different scenarios. This task will also include analyzing the installation process for flap valves and subsurface detention. The cost of installation and maintenance of flap valves and subsurface detention will be determined and included in all cost estimations for specific scenarios. Cost data used for feasibly analysis is located in Appendix E.

3.5 Defining a Design for a Flap Valve/Storage System

A final design plan for a flap valve/storage system was created. This design plan was completed using the results gathered after implementing a flap valve while including subsurface detention in the SWMM model. The design was generated by analyzing how these components effectively reduced flooding in the area. In addition to considering effectiveness based on model results, the design also reflected results from feasibility analysis to provide a practical solution.

3.6 Providing Recommendations to the City of Worcester

Based on the effectiveness and the feasibility of the flood mitigation improvement scenarios, a final design recommendation will be presented to the city of Worcester. This recommendation will include a cost effective and efficient flood mitigation design for the Quinsigamond Avenue area that will not have major negative impacts on the rest of Worcester's CSO system. Considering the economic situation alongside the effectiveness of each design scenario will be how the feasibility and overall quality of each recommendation is determined.

4.0 Results

This chapter presents the results obtained from researching the Quinsigamond Avenue area, analyzing existing conditions, reviewing preliminary design options and investigating the feasibility of these design options to provide an overall design for a flap valve and subsurface detention system.

4.1 Research Quinsigamond Avenue Flooding Results

Using data provided by the city of Worcester, a schematic was generated to demonstrate how the Quinsigamond Avenue storm drain functions. Understanding how the flow within the storm water system operates was very important to being able to make useful recommendations to the city of Worcester. Figure 11 displays this schematic.

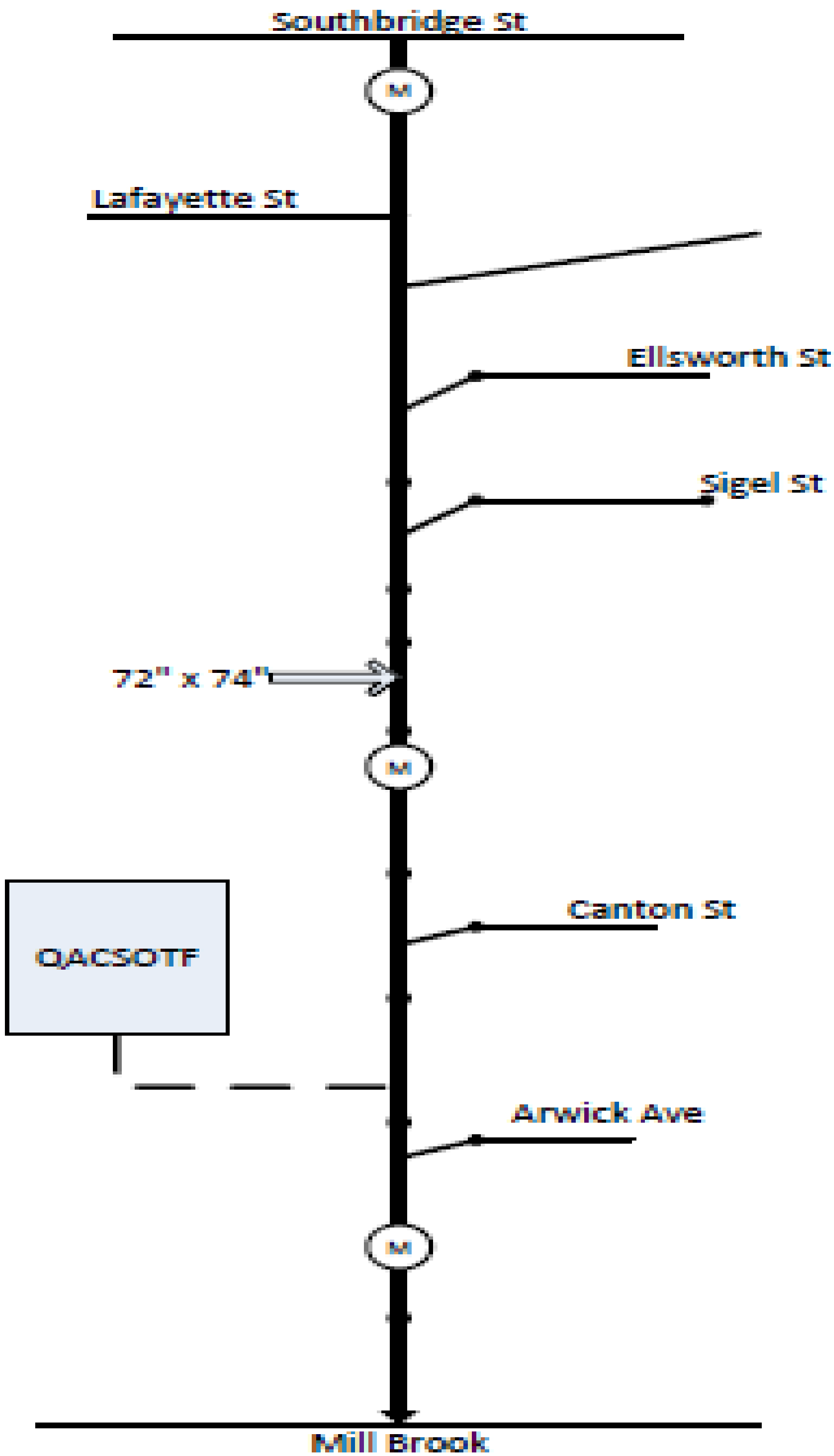


Figure 11: Quinsigamond Avenue Storm Line Schematic

4.1.1 GIS Data

GIS information provided by the city of Worcester was used to generate a base map of the Quinsigamond Avenue Area. Using these provided data, important subcatchment variables such as drainage area, percentage of impervious area, and average slope could be determined for use in the SWMM model development. Also, conduit and junction variables such as elevations, lengths, Manning's Roughness Coefficient, and maximum water depth were determined for use in the SWMM model development. Table 6 lists the properties that were identified using GIS data. Properties for specific pipes and manholes differ. Information regarding a specific pipe or manhole can be found in Section 4.2.2. Figure 12 is a layout view of the base map prepared using the data layers provided by the Worcester DPW

Table 6: GIS Results

Properties	Result
Drainage Area	254 Acres
Surface Slope	0.3%
Percent of Impervious Surface	75%
Quinsigamond Avenue Storm Drain and Mill Brook Shape	Varies Based on Location (Refer to Tables in Section 4.2.2)
Quinsigamond Avenue Storm Drain and Mill Brook Depth of Cross Section	Varies Based on Location (Refer to Tables in Section 4.2.2)
Quinsigamond Avenue Storm Drain and Mill Brook Length (All Pipes/Conduits)	Varies Based on Location (Refer to Tables in Section 4.2.2)
Quinsigamond Avenue Storm Drain Manhole Invert Elevation and Depth (ALL MH)	Varies Based on Location (Refer to Tables in Section 4.2.2)
Quinsigamond Avenue Storm Drain and Mill Brook Surface Elevation (All Pipes/Conduits)	Varies Based on Location (Refer to Tables in Section 4.2.2)

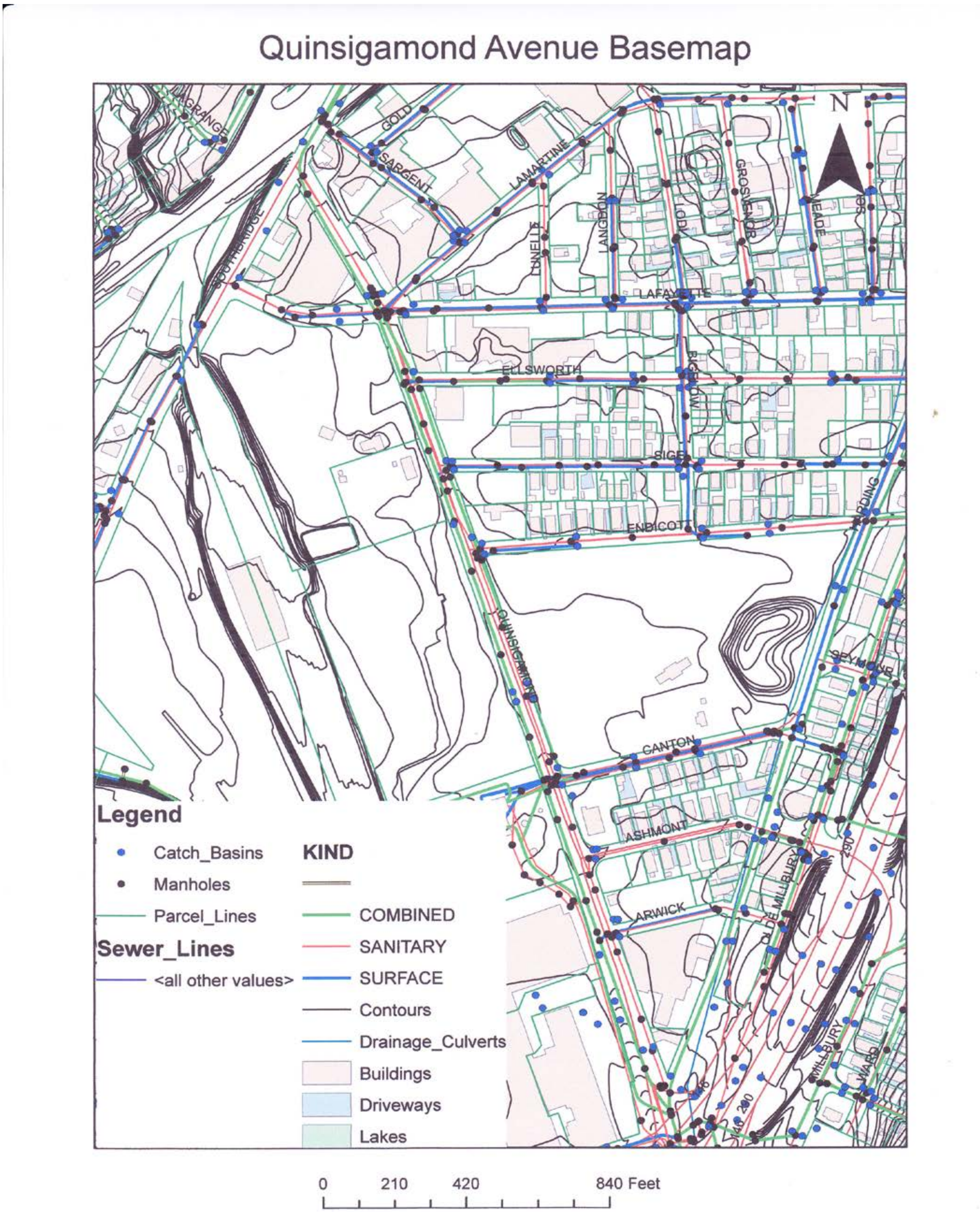


Figure 12: GIS Basemap

4.1.2 Model Data

A SWMM model for the city of Worcester was provided by CDM. This model was used as a basis for representing the Quinsigamond Avenue storm drain and the Mill Brook Conduit. Developing an updated SWMM model made it possible to begin evaluating existing conditions in the Quinsigamond Avenue Area. Figure 13 displays the additional subcatchment, junctions and conduits that were included in this updated SWMM model.

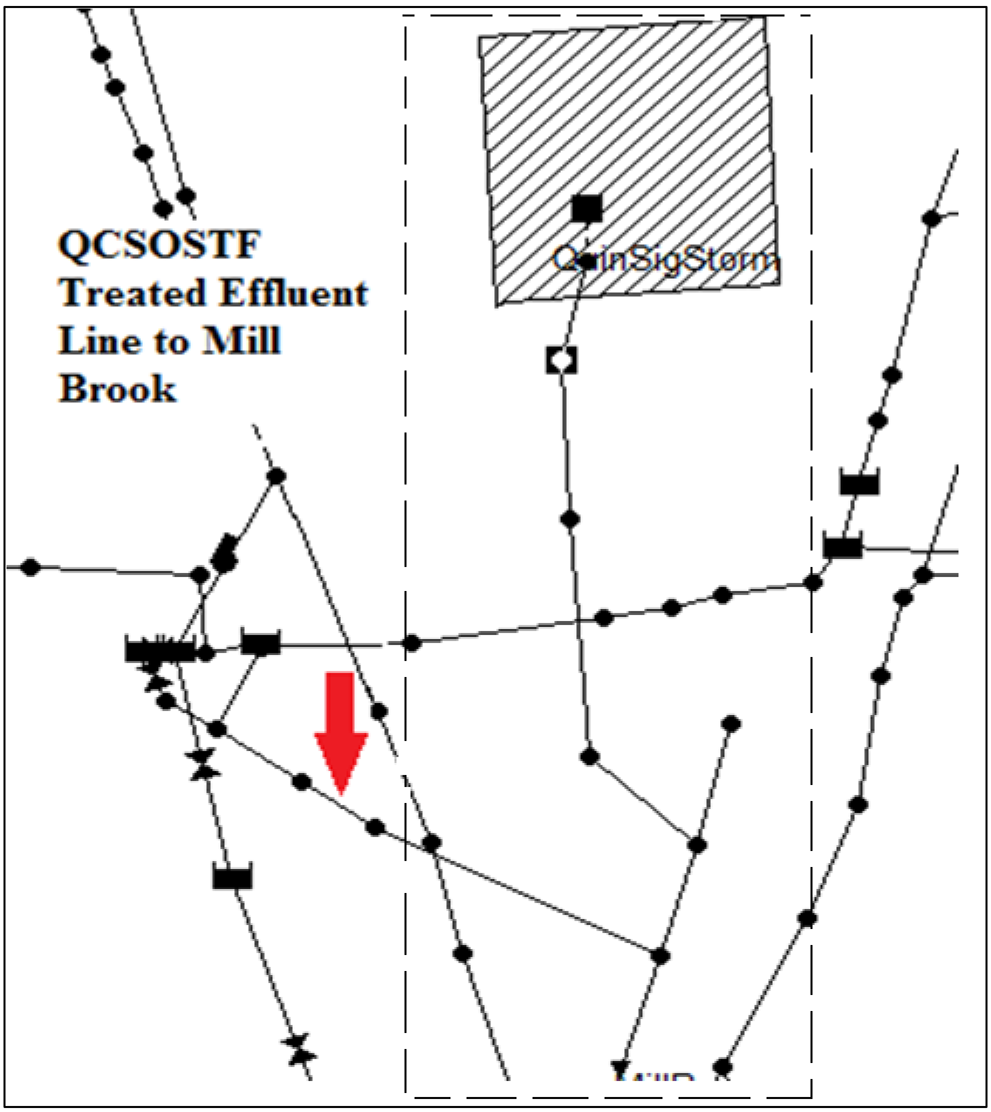


Figure 13: Updated SWMM Model

4.1.3 Flow Metering Data

The flow metering data gathered from the SEA/Kleinfelder report were analyzed and compiled into Tables 7 and 8 (Kleinfelder/SEA, 2010). The data in these tables provided an accurate portrayal of standing water levels in the Quinsigamond Avenue storm drain. Standing water elevations in the Quinsigamond Avenue storm drain provided insight as to the water levels that were present in the storm drain during dry weather conditions. This was a major consideration during model calibration.

Table 7: Standing Water Elevations

	Date	**Standing Water Depth (Inches)**		**Date**	**Standing Water Elevation (Inches)**
Man Hole 3	4/23/2010	6.25	**Man Hole 4**	5/5/2010	25
	4/28/2010	5.5		5/12/2010	25.87
	5/5/2010	5		5/20/2010	27.5
	5/27/2010	6.4		5/27/2010	26
	6/9/2010	4		6/2/2010	24.75
	6/21/2010	5		6/9/2010	25
	-	-		6/21/2010	24.5

Table 8: Average and Peak Flows for Wet Weather Conditions

Storm Date	Average flow (gpm)	Peak Flow (gpm)
5/8/2010	1,120	15,681
6/12/2010	1,000	8,364

4.2 Results for Existing Conditions

Existing conditions were evaluated using results from the Rational Method to obtain an approximant assessment of runoff volume. The calibration of the SWMM model was also used to gain an accurate representation of existing conditions in the area. The following sections provide results from both methods.

4.2.1 Approximate Results for Rational Method

The existing conditions of the Quinsigamond Avenue storm drain were evaluated, mainly to provide a baseline for comparison of Worcester flow metering data and the results for the calibration of the SWMM model. The rational method was used to obtain a rough estimate of flow within the Quinsigamond Avenue storm drain, as well as check the accuracy of the runoff coefficient and drainage area. The results are displayed in Table 9.

Table 9: Hand Calculated Peak Flow Results

Storm Date	Peak Flow (gpm)
5/8/2010	13,805
6/12/2010	8,500

4.2.2 Results for SWMM Model Calibration

Using the updated SWMM model that is displayed in Figure 13 and flow metering data that were provided by the City of Worcester, the SWMM model was calibrated to replicate existing conditions in the Quinsigamond Avenue storm drain. GIS data and record plans were used to adjust the additional subcatchment, junctions, and conduits added to the EPA SWMM model. The results for the subcatchment, conduit, and junction properties are presented in Tables 10, 11, and 12.

Table 10: Subcatchment Properties for Updated SWMM Model Results

Desired Property	Result
Drainage Area	254 acres
Width of Overland Flow Path	5950 ft.
Average Surface Slope	0.3%
Percent of Impervious Surface	75%
Manning's n for impervious area	0.012
Manning's n for pervious area	0.2
Depth of depression storage on impervious surface	0.05
Depth of depression storage on pervious surface	0.20
Percent of impervious area with no depression storage (%)	25 (Default Setting)

Table 11: Conduit Properties for Updated SWMM Model Results

Conduit #	Shape of Conduit	Max Depth of Cross Section (ft)	Manning's Roughness Coefficient	Conduit Length (ft)	Inlet Offset or Outlet Offset	Initial Flow
1	Egg	6	0.011	362.3	N/A	N/A
2	Egg	6	0.011	1583.75	N/A	N/A
3	Egg	6	0.011	1320.51	N/A	N/A
4	Egg	6	0.011	149.28	N/A	N/A
5	Close Rectangle	18	0.011	55	N/A	N/A
6	Closed Rectangle	18	0.011	50	N/A	N/A
7	Closed Rectangle	18	0.011	400	N/A	N/A

Table 12: Junction Properties for Updated SWMM Model Results

Junction #	Elevation at Junction's Invert (ft)	Maximum Water Depth (ft)	Inflows
1	435.99	16.53	No
2	432.58	14.57	No
3	431.47	11.96	No
4	430.45	15.47	No
5	430.1	18	No
6	430	18	No
7	429.5	18	No

Adjusting the model to account for standing water in the storm drain was a major consideration during the model calibration process. This step was mainly required because of the lack of flow metering data for Millbrook. In order to properly calibrate the model for dry weather, the standing water data from Table 1 were analyzed. Using these data, the model was calibrated to have similar dry weather standing elevations. This was done by changing the fixed stage elevation at Millbrook's downstream outfall to 432.5 feet. A profile from the SWMM model showing this comparison can be seen in Figure 14.

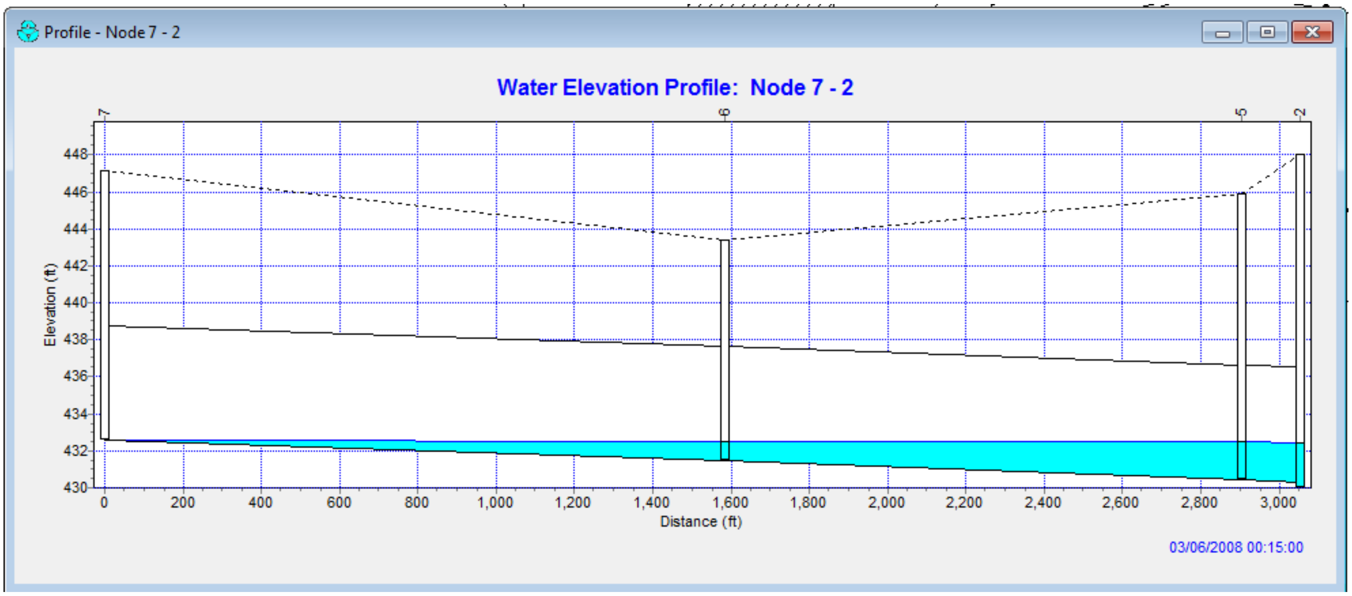


Figure 14: SWMM Plot Showing Quinsigamond Avenue Storm Drain Profile

The two storms that were previously displayed in Table 2 are displayed again in Table 13, alongside the simulations created using the SWMM model. Also displayed in Table 13 are the hand calculations that were used to further check the group's accuracy on peak flows results. The average and peak flows of the SWMM model's simulations were shown to be similar to the design storm data, where the peak flow simulation results were comparable to the hand calculations. These simulations were completed after the properties of the subcatchment, junctions, and conduits were updated.

Table 13: Design Storm Data and Simulation Results

	Design Storm Data		Design Storm Simulation Results		Hand Calculated Storm Results
Storm Date	**Avg. flow (gpm)**	**Peak Flow (gpm)**	**Avg. Flow (gpm)**	**Peak Flow (gpm)**	**Peak Flow (gpm)**
5/8/2010	1120	15681	1223	17437	13,805
6/12/2010	1000	8364	794	8445	8,500

These results were analyzed and percent differences were calculated for average and peak flows. For the 5/8/2010 storm it was calculated that percent difference for the average flow in the drain for the design storm and the design storm simulation was 8.8%. The 6/12/2010 storm was analyzed and it was calculated that percent difference for the average flow in the drain for the design storm and the design storm simulation was 23%. The percent difference for peak flows when comparing the design storm and the design storm simulation resulted in 11%. The percent difference for the design storm simulation and the hand calculations was calculated to be 23%, while the percent difference for the design storm and the hand calculations was equal to 13%. Using these percentages, it was determined that these SWMM model modifications resulted in sufficiently accurate storm simulations. Although the average flows in the model did not exactly match the flow metering data, the properties in the model remained consistent for the remainder of the project. The properties were unchanged mainly because the flow metering data, hand calculations and model results all provided relatively close results for average and peak flows in the drain.

Hydrographs were then generated using the flow metering data and were compared to hydrographs using the data provided by the SWMM model. In addition to displaying similar average and peak flows, the hydrographs revealed that the model and flow metering data had very similar flow trends with respect to time. Figures 15 and 16 display the comparisons of the hydrographs for the 5/8/2010 and the 6/12/2010 storms. These figures show that the predictions matched the observations very well.

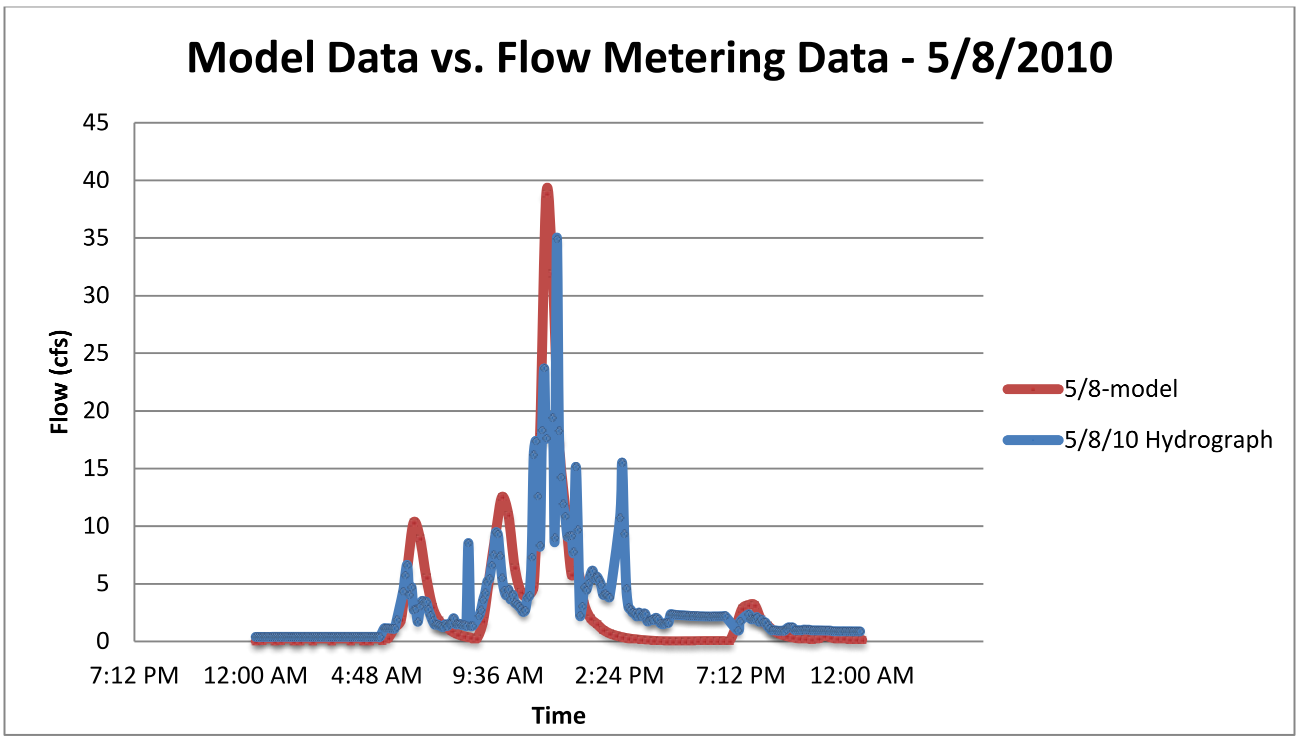


Figure 15: Model Data vs. Flow Metering Data - 5/8/2010

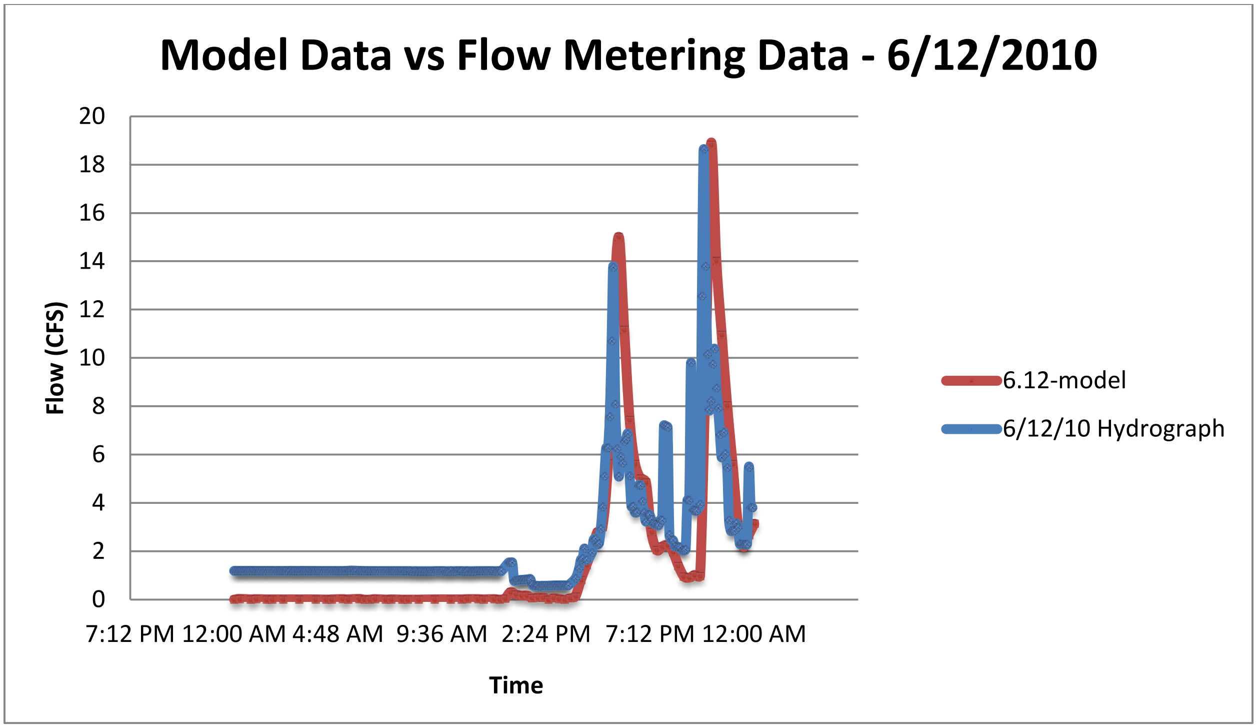


Figure 16: Model Data vs. Flow Metering Data - 6/12/2010

Since the hydrographs in the previous figures matched up well with respect to time, peak flows and statistics, the model was considered to be calibrated sufficiently. The newly calibrated model made it possible to analyze the impacts of 3 month, 1 year, 10 year, 25 year and 100 year – 24 hour storm events on the flows in the storm drain. Hydrographs for these storms are provided in Figures 17-21.

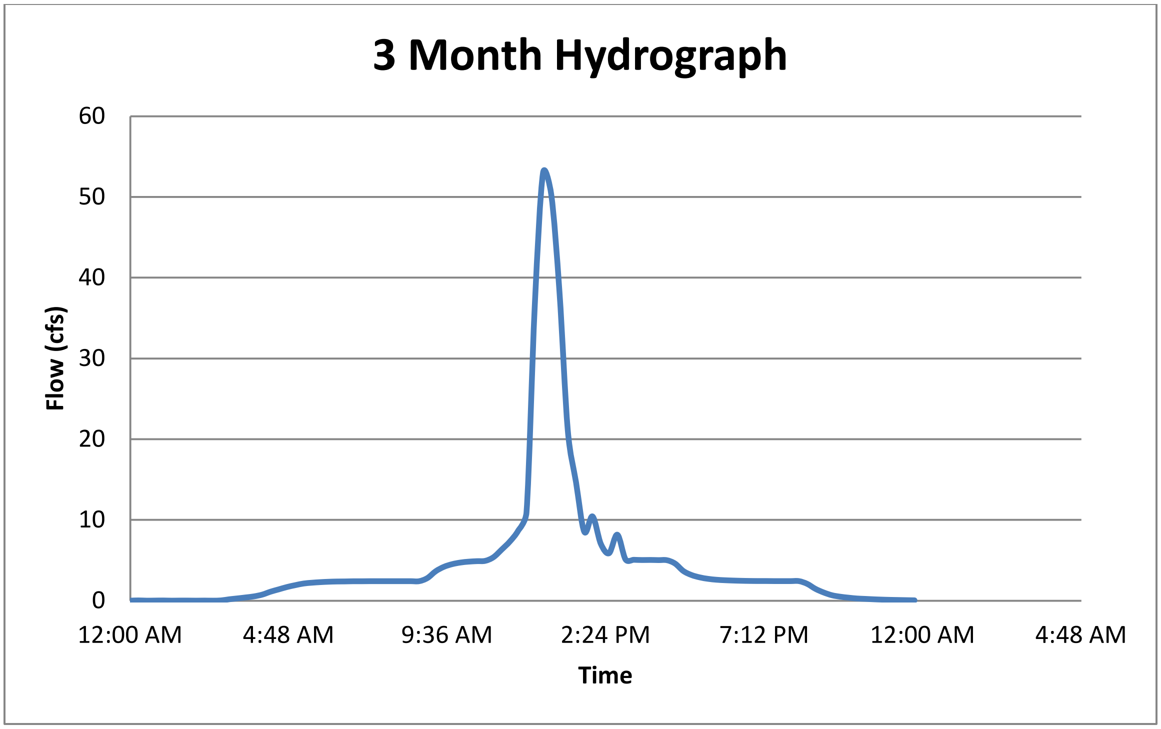


Figure 17: 3 Month Hydrograph

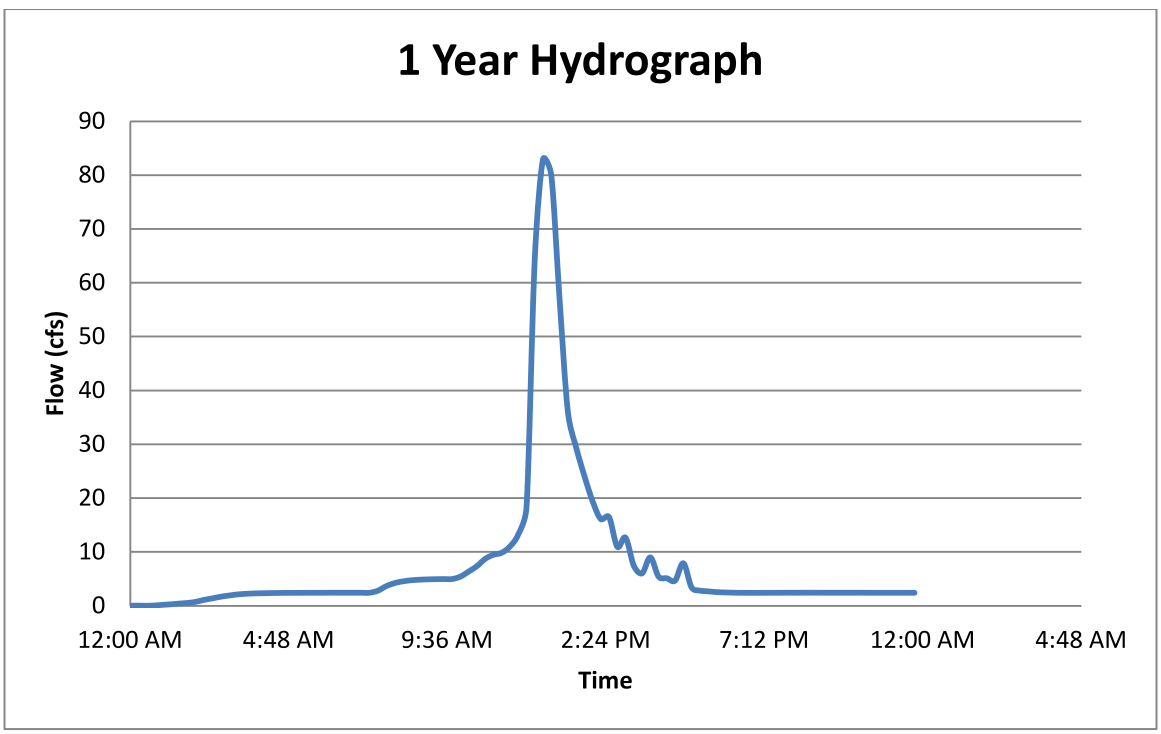


Figure 18: 1 Year Hydrograph

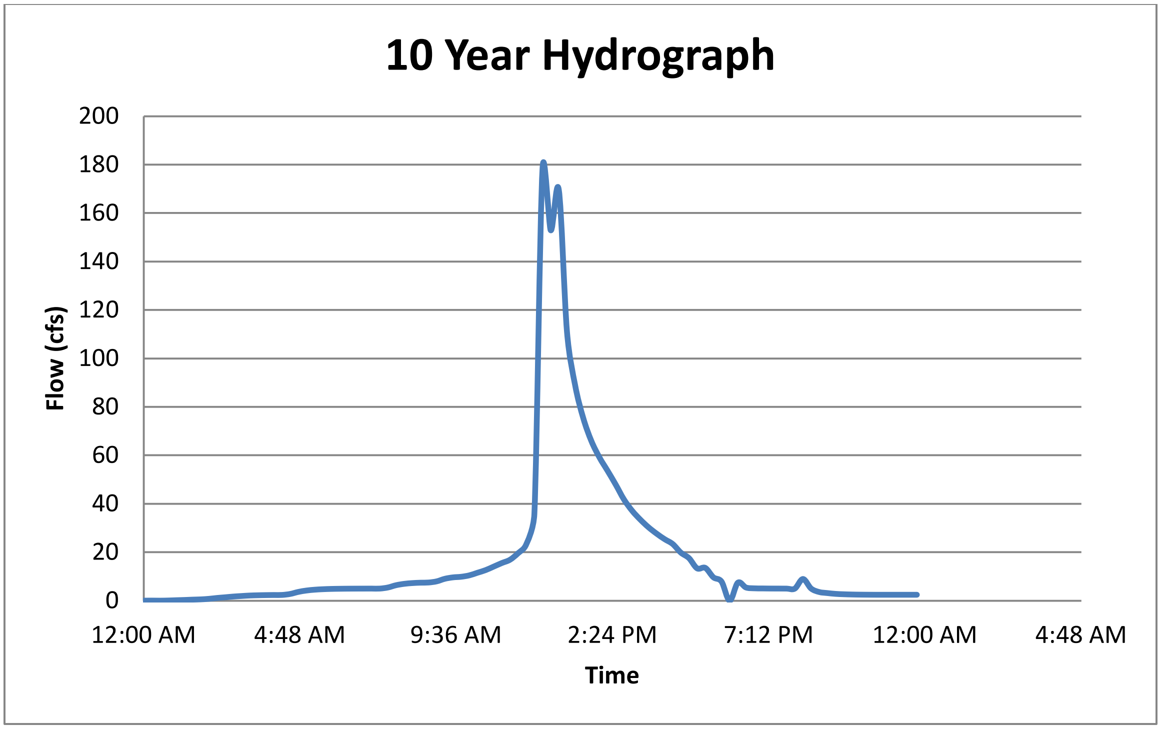


Figure 19: 10 Year Hydrograph

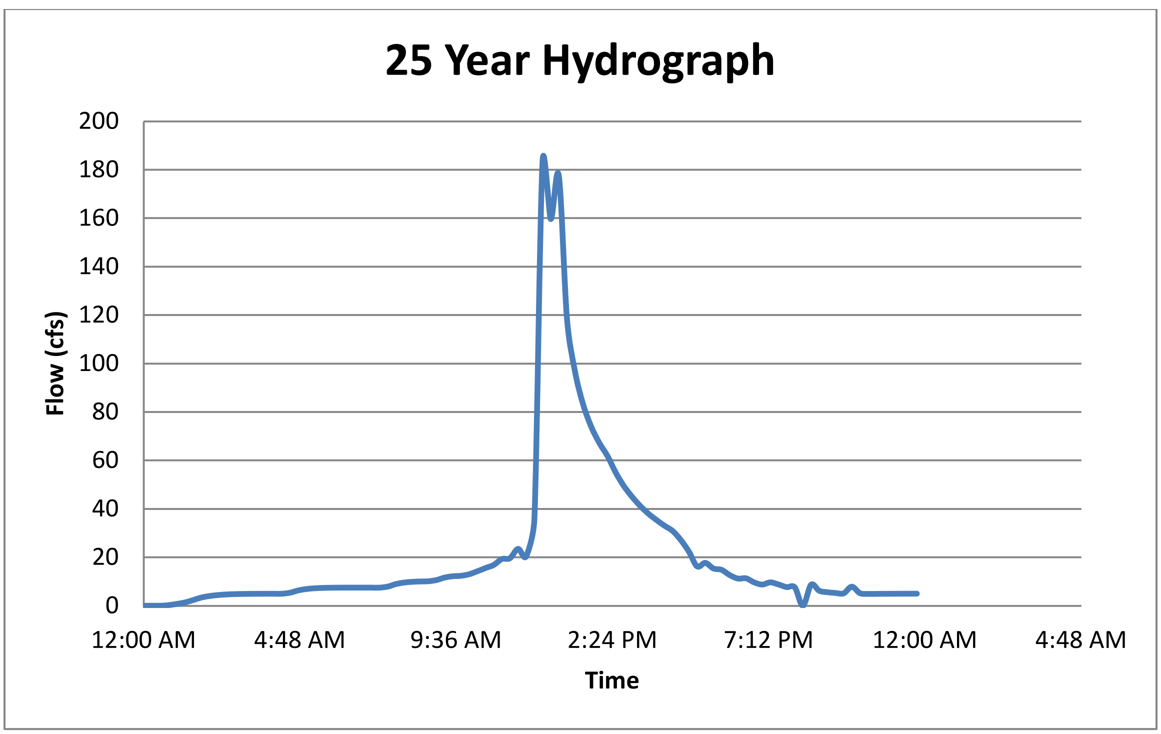


Figure 20: 25 Year Hydrograph

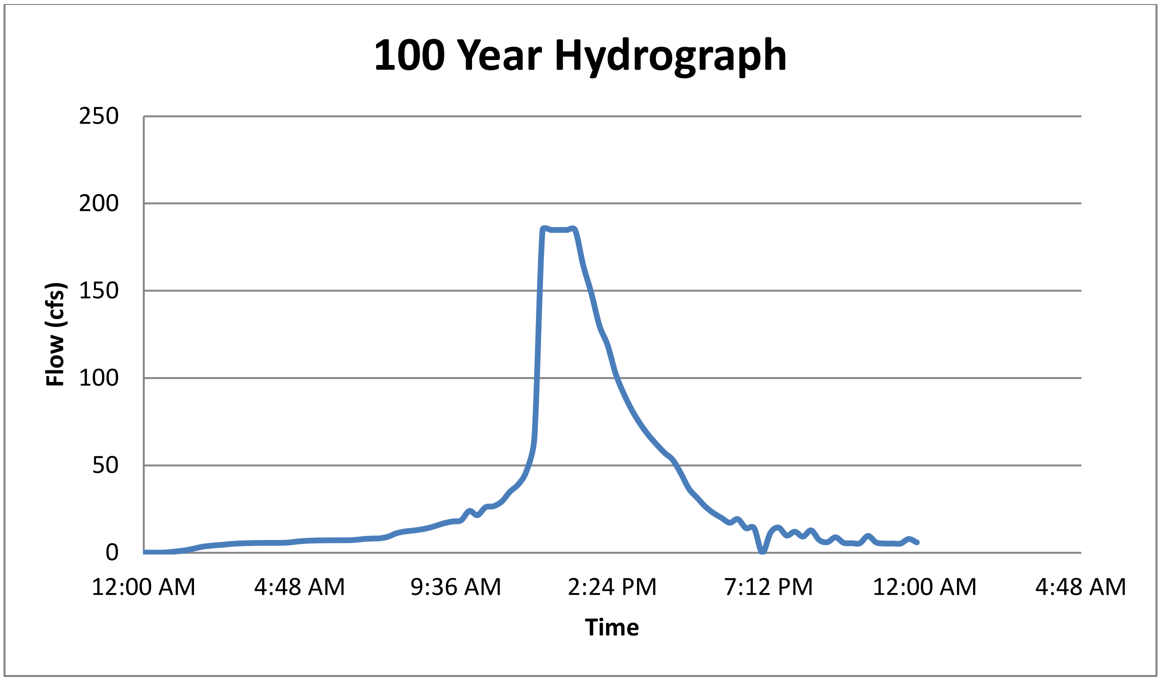


Figure 21: 100 Year Hydrograph

Mean and peak flows varied based on the severity of the storm event. Under existing conditions, the 3 month, 1 year, 10 year, 25 year and 100 year – 24 hour storm events were analyzed. Table 14 summarizes which storm events resulted in flooding under existing conditions.

Table 14: Flooding During Existing Conditions

Storm Event	Average Daily Flow (GPM)	Peak Flow (GPM)	Total Volume (MG)	Flooding
Event Storms				
3 Month – 24 hour storm	2114	23770	3.0	No
1 Year – 24 hour storm	3498	37231	5.0	No
10 year – 24 hour storm	7981	80054	11.5	No
25 year – 24 hour storm	9626	82275	14	Yes
100 year – 24 hour storm	14519	82970	20.5	Yes

4.3 Preliminary Design Alternatives

This section summarizes the results for the selection of the appropriate flap valve for each design alternative, and presents the overall effectiveness of each design option. The calibrated SWMM model was used in order to evaluate all of these alternatives. These results were all considered when providing the city of Worcester with a recommendation to reduce surface flooding in the Quinsigamond Avenue area.

4.3.1 Flap Valve Selection

Various types of flap valves were researched and 4 different models were selected to be further investigated based on the size of the Quinsigamond Avenue storm drain and the issue of backflow conditions from the Millbrook conduit. The different models of flap valves that were investigated include the Tide Flex TF-1, 35-1, TF-2 and series 37. This section includes a brief summary of each flap valve that was evaluated. Then, based on a review of the design alternatives, a specific model was chosen.

4.3.1.1 Series 37

The Series 37 flap valve is made with an extremely simple design, with the maintenance-free rubber check sleeve as the only moving part. Also, the Series 37 requires no outside source of air or electricity, so the operating costs are minimal. This model is designed to be installed between two mating flanges in a connected pipe, which eliminates the need for a valve body.

Figure 22: Series 37 Flap Valve (Tideflex Technologies, 2012)

4.3.1.2 Series 35-1

The Series 35-1 flap valve is constructed with a flat bottom design, and has an all rubber flange. This design comes with galvanized or stainless steel back up rings when installed, and has a lightweight, all-elastomer design. The flange design allows the Series 35-1 to be mounted directly to flanged outfall pipes, or to headwalls where the pipe is flush.

Figure 23: Series 35-1 Flap Valve (Tideflex Technologies, 2012)

4.3.1.3 Series TF-2

The Series TF-2 is Tideflex's revolutionary design in backflow prevention. This design has a very long operational lifespan and requires no maintenance or repairs, resulting in a very cost-effective solution. No outside air or electricity is required for this model, so operating costs are also extremely low. The clearance space needed for the bottom of the Series TF-2 is relatively high, because this model does not feature a flat bottom design. This makes the Series TF-2 more suitable for open ended pipes.

Figure 24: Series TF-2 Flap Valve (Tideflex Technologies, 2012)

4.3.1.4 Series TF-1

The Series TF-1 is the ideal Tideflex model for use inside of a manhole vault. The flat bottom design allows for a very small clearance between the bottom floor of the vault and the bottom of the pipe. As seen if Figure 20, the bottom of the flap valve is very close to the floor, so a flap valve without the Series TF-1's flat bottom design would not be able to fit. The slip-on, all-elastomer rubber design is constructed in one piece, so this model is easily installed and requires virtually no maintenance. The configuration of the Series TF-1 also allows for installation without manhole configuration, which further reduces the initial installation costs.

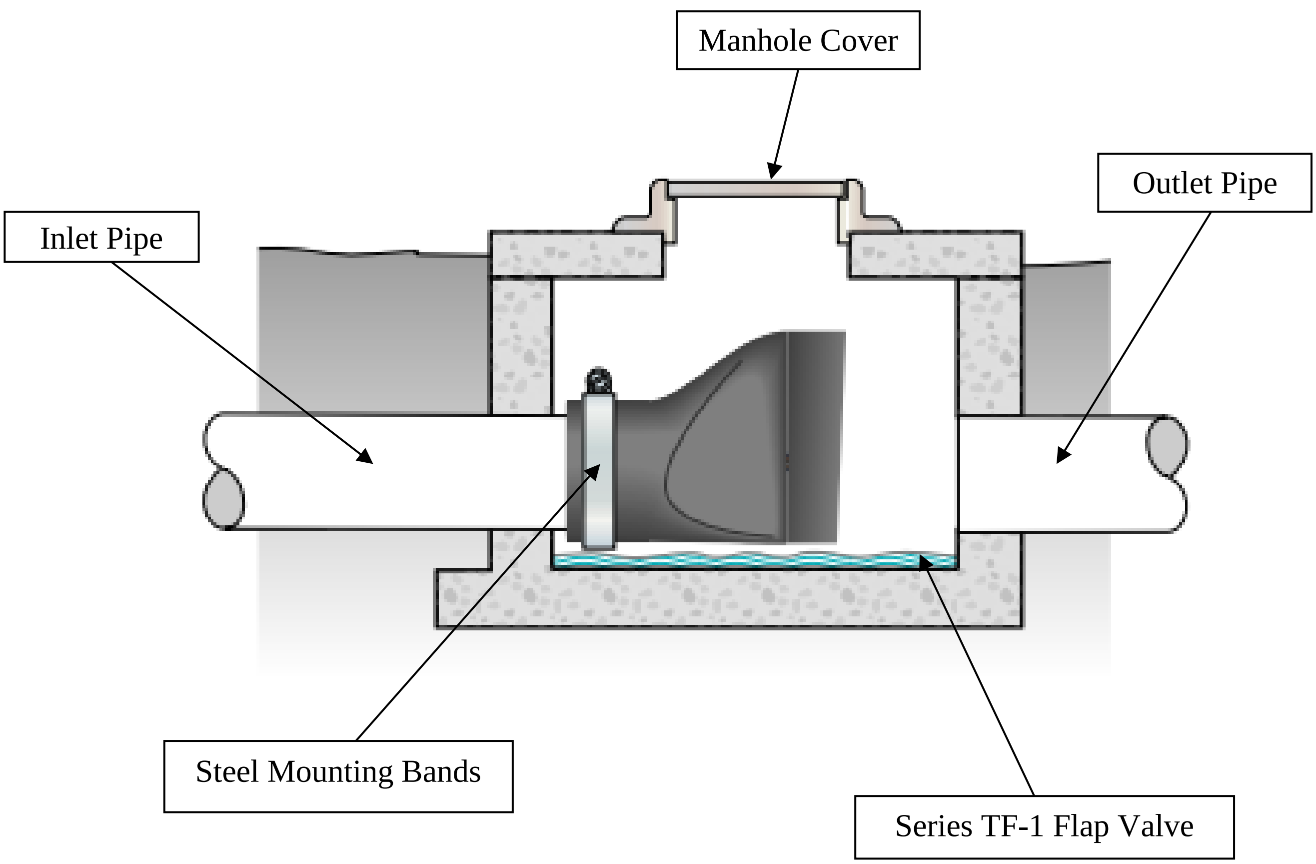


Figure 25: Series TF-1 Flap Valve (Tideflex Technologies, 2012)

Table 15 illustrates the different characteristics in the four Tideflex models that were investigated for the selection of the proper flap valve. Features such as design, maintenance, flanged, and slip on were considered as well as the cost of installation. These benefits and features were used to select the best possible model of flap valve to be used in all of the design scenarios. Based on the results presented in this Table, the TF-1 was chosen as the most suitable flap valve for every preliminary design alternative.

Table 15: Comparison of Different Check Valve Designs

Tideflex Check Valve Model	Eccentric, flat bottom design	Flanged	Slip-on	Cost effective, maintenance free design	Ideal for manhole installations
Series TF-1	✓		✓	✓	✓
Series 35-1	✓	✓			
Series TF-2			✓	✓	
Series 37		✓		✓	

4.3.2 Scenario Results

This section analyzes the effectiveness of each of the following scenarios:

- Existing conditions
- Flap valve
- Flap valve plus storage

These scenarios were evaluated by making adjustments to the SWMM model that was calibrated during Task 3.2. Each scenario was evaluated for 3 month, 1 year, 10 year, 25 year, and 100 year – 24 hour storm events. Table 16 summarizes the total rainfall for each storm event.

Table 16: Simulated Storm Rainfall Totals

Storm Type	Total Rainfall (Inches)
3 Month – 24 hour storm	1.8
1 Year – 24 hour storm	2.6
10 year – 24 hour storm	4.35
25 Year – 24 hour storm	5.30
100 year – 24 hour storm	7.84

4.3.2.1 Scenario 1 – Flap Valve

For Scenario 1, a flap valve was placed at Manhole 4 in Figure 26, which is the furthest downstream manhole on the Quinsigamond Avenue storm drain.

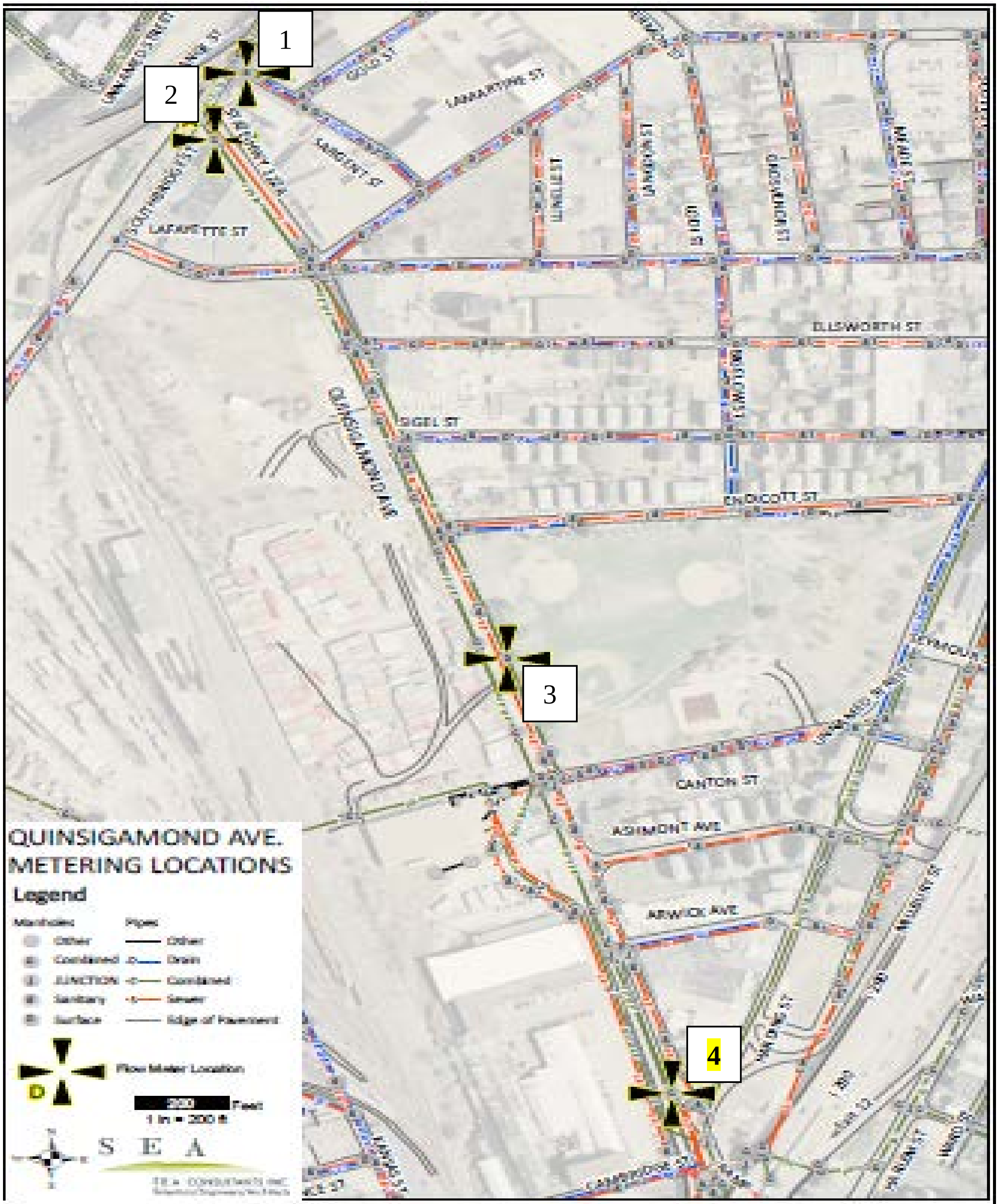


Figure 26: Furthest Downstream Manhole Location

The SWMM model was used to simulate the conditions with this flap valve installed at Manhole 4. The results are displayed in Table 17. Average daily flow, peak flow, total flow, as well as flooding characteristics (i.e. whether or not flooding occurred) were the outcomes of the SWMM model simulation. It was concluded that flooding occurs for storms greater than or equal to the 25 year event.

Table 17: SWMM Model Results with Flap Valve Installation

Storm Event	Average Daily Flow (GPM)	Peak Flow (GPM)	Total Volume (MG)	Flooding
Design Storms				
5/8/2010	1223	17437	1.7	No
6/12/2010	794	8445	1.1	No
Event Storms				
3 Month – 24 hour storm	2114	23770	3.0	No
1 Year – 24 hour storm	3498	37231	5.0	No
10 year – 24 hour storm	7981	80054	11.5	No
25 year – 24 hour storm	9626	82275	14	Yes
100 year – 24 hour storm	14519	82970	20.5	Yes

4.3.2.2 Scenario 2 – Flap Valve and Storage

In order to determine how much storage would be needed to mitigate flooding in the Quinsigamond Avenue area, all storm events that led to surcharging with the installation of a flap valve were further evaluated. The amount of storage needed to mitigate flooding for each event was determined. Placing a flap valve at the furthest downstream manhole on Quinsigamond Avenue as well as subsurface storage beneath Crompton Park led to the SWMM model results shown in Table 18. The average, peak and total flows are displayed, as well as the amount of storage that would be needed to prevent surcharging. It was concluded that for a storm size equal to a 25 year event, 6,000 gallons of subsurface detention would be needed to prevent flooding.

Table 18: SWMM Model Results with Flap Valve and Storage Installation

Storm Event with Surcharging for Flap Valve Scenario	Average Daily Flow (GPM)	Peak Flow (GPM)	Total Volume (MG)	Amount of Storage Needed to Prevent Surcharging
25 year – 24 hour storm	9626	82275	14	6,000 GAL
100 year – 24 hour storm	14519	82970	20.5	>100,000 GAL

4.3.3 Scenario Comparison

Scenario 1 was effective for 3-Month, 1 Year and 10 Year storm events. The evaluation of scenario 1 for the 100 year- 24 Hour storm event resulted in capacity issues in the storm drain and additional subsurface storage had to be used. While running the 100 Year – 24 Hour storm event simulation, it was determined that a 200,000 gallon tank would provide enough storage to mitigate flooding. Since such a large tank would result in high cost and several construction constraints, the 100 Year - 24 Hour storm event was not considered as a reasonable design alternative. A 25 Year – 24 Hour storm event simulation was then developed to further investigate how subsurface detention can further reduce flooding in the Quinsigamond Avenue area. Under Scenario 1, the 25 year storm event resulted in flooding, so subsurface storage was added to the model. It was determined that flooding would not occur during the 25 year event if a flap valve and a 6,000 gallon subsurface detention tank were added to the drain. Further explanation of the design for the addition of a 6,000 gallon subsurface tank to the Quinsigamond Avenue storm drain is described in Section 4.5.

4.4 Feasibility of Scenarios

The feasibility of all the scenarios, in terms of economics, politics, and constructability are explained in the following sections:

4.4.1 Economic Feasibility

Cost estimates had to be completed in order to analyze the economic feasibility of any recommended installations. Costs for the flap valve and subsurface storage tank were estimated using the *RSMeans Building Costs Handbook* (Reed Construction Data, 2011). Values for different parts of the installation process were found in the handbook. The labor hours were determined by dividing the volume or area needed by the daily output (how many units can be installed per day). From there, labor hours were multiplied by hourly costs of each laborer. Then, equipment rental costs were also added and a total cost was found. Table 19 shows the cost for a 72” flap valve.

Table 19: Flap Valve Cost

Item	Price ($)
Flap valve	51,000
Labor for installing valve	500
Maintenance (per year)	600
Total	**52,100**

Table 20 shows details for the cost associated with the storage tank and connecting pipe that is recommended for installation in Crompton Park. The price includes labor and equipment costs.

Table 20: Storage Tank and Pipe Cost

Item	Unit Cost ($)	Total Cost ($)	Explanation
Structural excavation for minor structures, 1 C.Y. bucket hydraulic backhoe	222 /CY	30,000	Needed for excavation required for the installation of storage chamber
Precast concrete tank, 6,000 gallons	Base Cost	65,000	
Labor for installing the tank	167 /hr	1000	
Cost of 100 ft pipe	100 /ft	10,000	
Labor for installing the pipe	125 /hr	5,000	
Backfill with a dozer from existing stockpile	15 /CY	1,500	Used for filling in dirt around the tank.
Finish grading with a grader	77 /SY	5,000	Grading after the storage tank has been placed.
Total		**117,500**	

Combining the costs from the two tables yields a total cost of installing the valve and storage of $169,600. These costs are a rough estimate of the basic costs of installation and do not include other costs such as traffic disruption, detouring, police details, and other external costs associated with construction work. It is emphasized that the costs presented here serve as initial estimates, and a more detailed cost estimate recommended to fully define construction costs associated with installation of a flap valve and storage basin system.

4.4.2 Political Feasibility

Permits would have to be obtained from the city in order to install the check valve and storage tank. Building permits and a permit to partially close the street during the valve installation would be needed. An application with plans for these additions would have to be taken to City of Worcester Planning Board. After a review process, the Board would hopefully give approval to the plan and permits would be granted.

4.4.3 Construction Feasibility

The installation of the Tideflex TF-1 flap valve, connecting pipeline and storage tank presents some construction difficulties. The TF-1 valve has a bill length of approximately 10 feet, as shown in Figure 27. The manhole chamber does not have enough length to support the size of the TF-1, so that particular valve would not physically fit in the current manhole without extensive alterations. One option would be to excavate the area and enlarge the size of the manhole. Figure 28 shows the current manhole, which was built using bricks. Since this manhole is located on Quinsigamond Avenue, the street would have to be blocked off in order for construction to be completed.

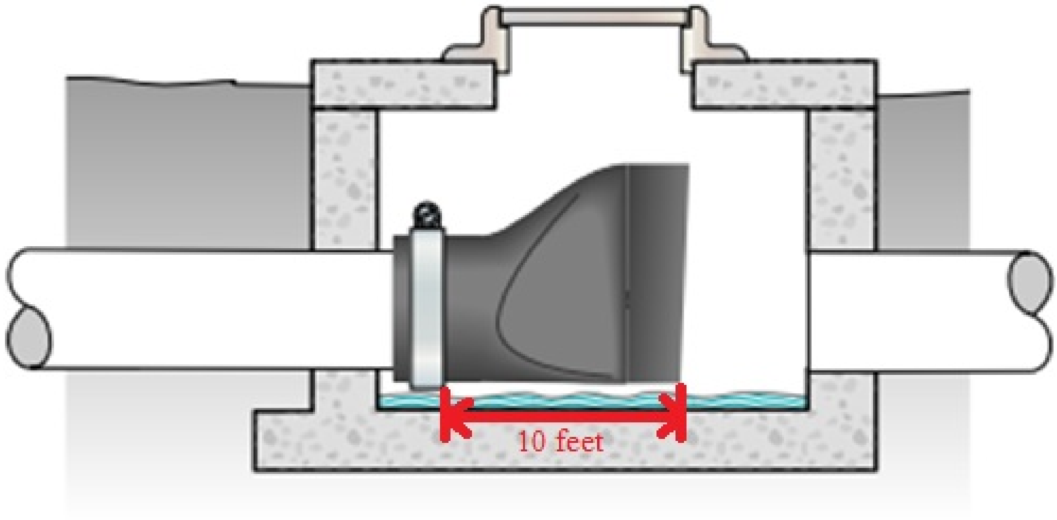


Figure 27: TF-1 Bill Length

Figure 28: Current Manhole Construction

The area of installation for the subsurface storage tank was chosen to be Crompton Park for multiple reasons. One reason was because the park happens to be located at the lowest elevation along Quinsigamond Avenue. By placing the tank at this location, surface flooding in the area would be reduced. Crompton Park was also chosen as the location for the storage tank because of the lack of asphalt and underground piping. Crompton Park is made up entirely of grass and dirt so the excavation process would be easier. An area of Crompton Park would have to be excavated, the tank placed into the hole, and then backfill and grading. The biggest concern for this region is the water table, which could potentially pose a problem. The connecting pipe from Manhole 3 to the storage tank located in Crompton Park would require excavation of Quinsigamond Avenue and Crompton Park, as well as the laying of the pipe and refinishing of the disturbed area.

It was decided to place the flap valve at the lowest downstream manhole location. By placing a flap valve at the furthest downstream manhole location, the capacity of the Quinsigamond Avenue storm drain is increased for stormwater runoff in the area.

4.5 Design for a Flap Valve/Storage System

It was determined through the use of SWMM that installing a flap valve in combination with a 6,000 gallon storage tank would be the most favorable method to control flooding under the evaluated storm events. The tank would be connected to the storm drain using a 100 foot long, 12 inch pipe that exits Manhole 3 in front of Crompton Park. The pipe exits Manhole 3 at elevation 431.97 ft. and enters the 6,000-gallon tank at an elevation of 433 ft. The invert elevation of the tank would be equal to 432 ft. By using this slope, the tank would be able to fill as a result of the pressure from the stormwater in the drain and self-drain when the water pressure is reduced in the drain. The 1-foot offset between the tank's invert elevation and the invert elevation of the inflow/drain pipe would result in minimal standing water in the tank. Figure 29 provides an outline for the proposed design on Quinsigamond Avenue.

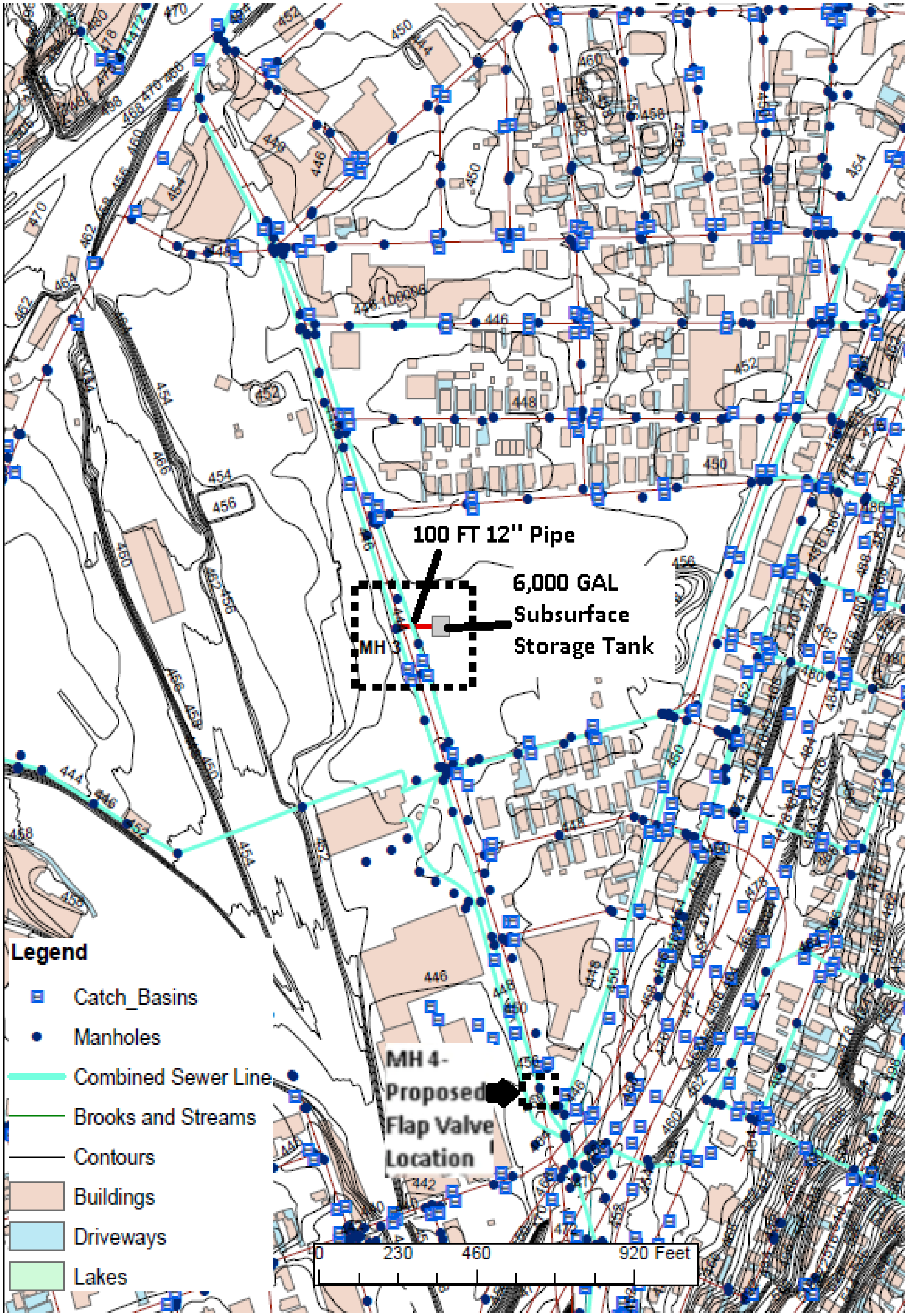


Figure 29: Recommendations for Improvement to Quinsigamond Ave. Storm drain

Figure 30 displays a profile of the Quinsigamond Avenue storm drain with a flap valve installed. At Manhole 3 the additional piping will be connected to include subsurface storage.

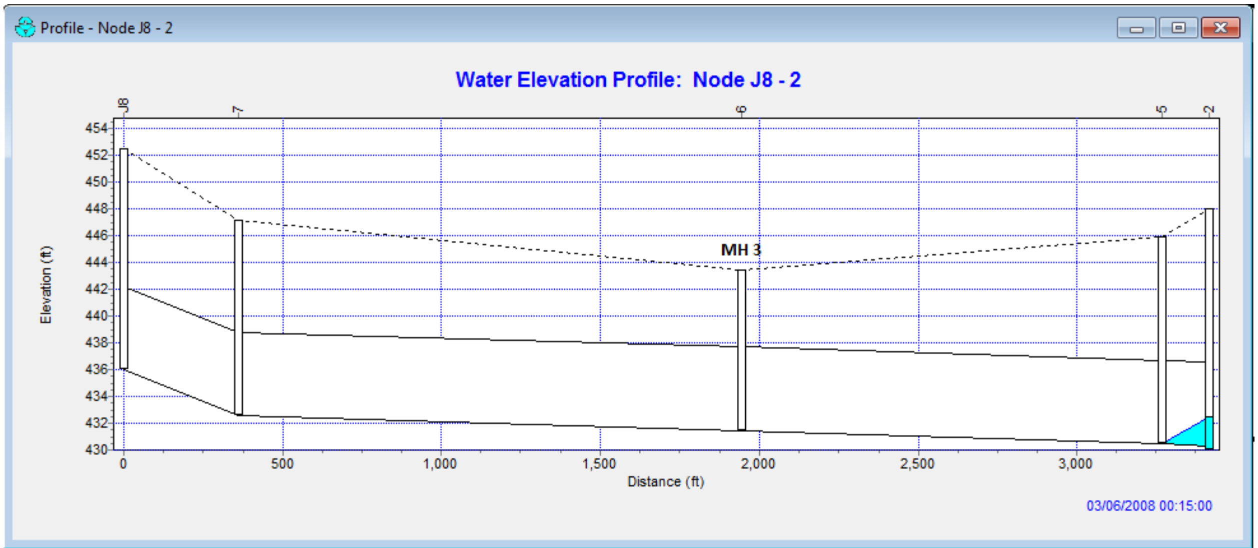


Figure 30: SWMM Plot Showing Profile of Quinsigamond Avenue Storm Drain with Flap Valve Installed

Figure 31 displays the additional piping and storage tank added to the drain from Manhole 3 using the SWMM model.

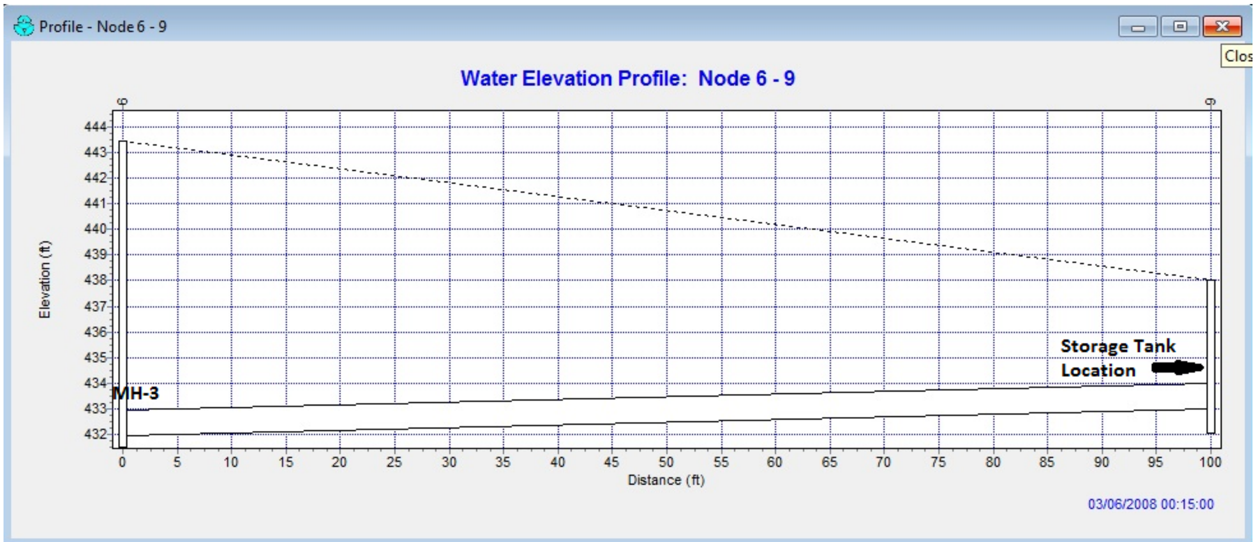


Figure 31: SWMM Plot Showing Profile of Additional Piping and Storage Tank

5.0 Conclusions and Recommendations

The goal of this project was to develop a feasible alternative design plan to reduce flooding problems in the Quinsigamond Avenue area. This section explains the conclusions that were reached based on the results derived in the previous sections. When evaluating the final results, several factors were considered. For both scenario one and two, the effectiveness and cost of the improvements were taking into consideration.

5.1 Existing Conditions

The existing conditions of the Quinsigamond Avenue stormwater drain result in flooding during long duration storms. Currently, Mill Brook conduit causes a backflow effect in the storm drain which results in this flooding problem. The SWMM model developed during the duration of this project provides accurate simulations of the impacts specific storm events have on Quinsigamond Ave.

5.2 Scenario 1 - Flap Valve

The installation of a flap valve was successful in mitigating flooding for every storm simulation. Figures 32 and 33 display how implementing a flap valve instantly increases pipe capacity in the storm drain. Figure 32 shows a profile of the Quinsigamond Avenue storm drain under existing conditions, with a large amount of standing water. Figure 33 shows the same profile of the storm drain, but with a flap valve installed to prevent back flow. The amount of standing water present after the flap valve installation is noticeably less.

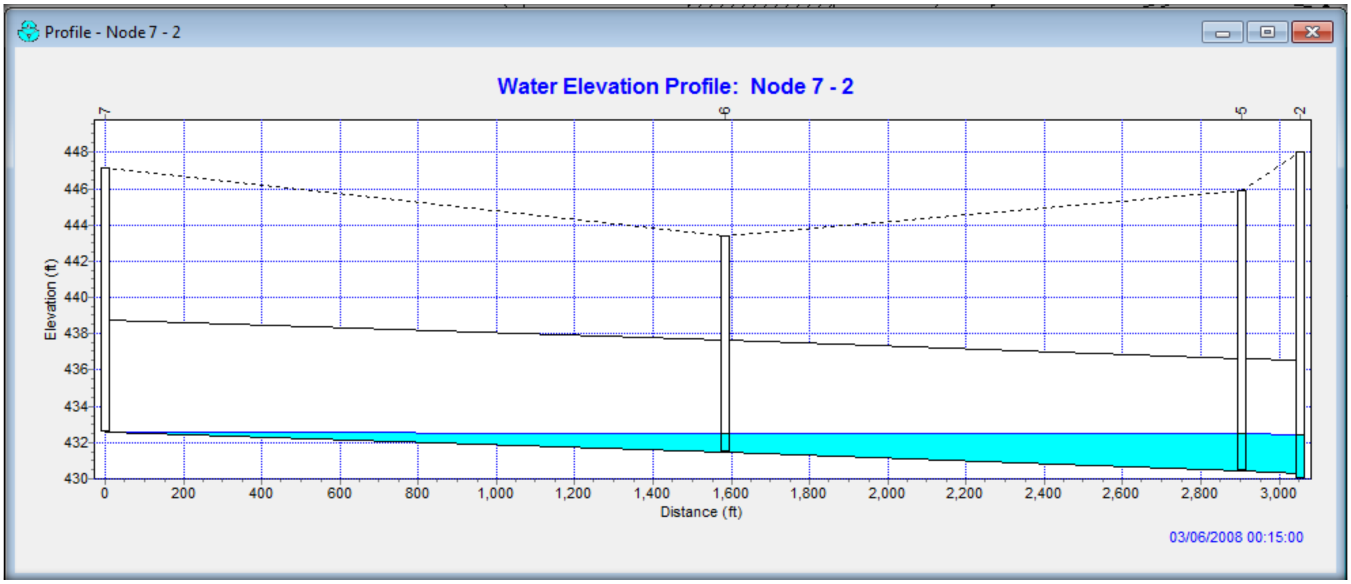


Figure 32: SWMM Plot Showing Standing Water in Quinsigamond Avenue Storm Drain Under Existing Conditions

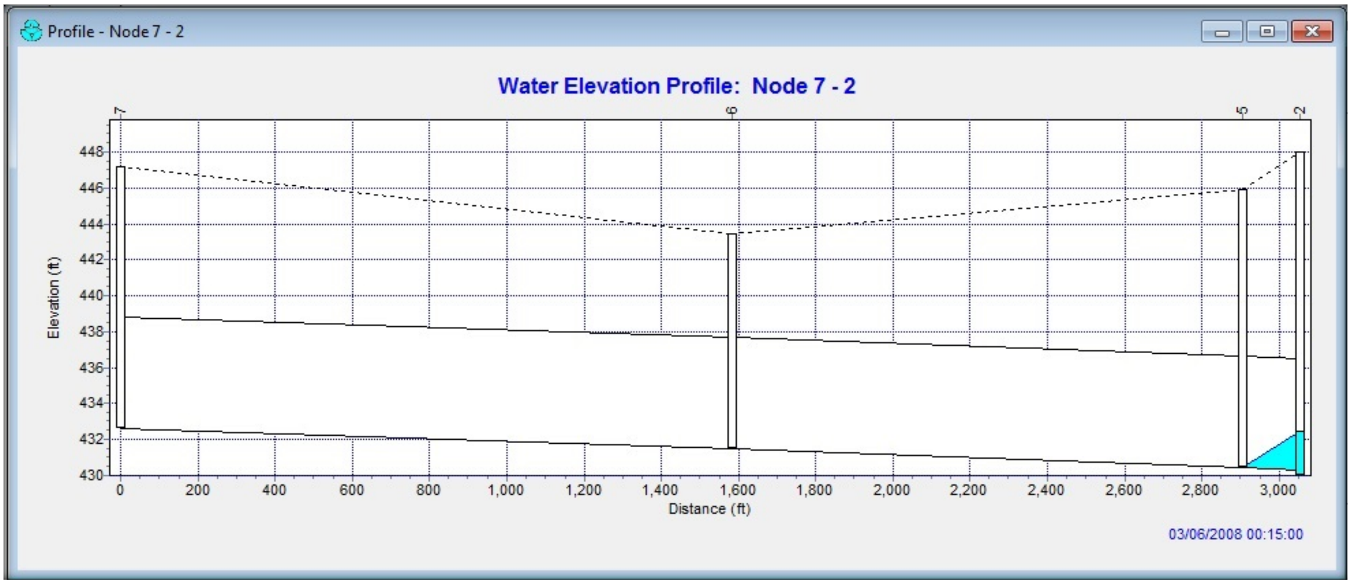


Figure 33: SWMM Plot Showing Standing Water in Quinsigamond Avenue Storm Drain with Flap Valve Installed

For 3-month, 1-year, and 10-year 24-hour storm events, the installation of a flap valve eliminated all flooding in the area. But for 25-year and 100-year 24-hour storm events, the flooding was only reduced, requiring storage for the excess.

5.3 Scenario 2 - Flap Valve and Storage

The use of sub-surface storage was unnecessary for 3-month, 1-year, and 10-year 24-hour storm events because of the effectiveness of the flap valve in these situations. For the 100-year storm event, the use of sub-surface storage was not feasible because of the volume of excess water associated with this storm. But for a 25-year, 24-hour storm, the flap valve would reduce the total flooding to an amount that could be contained using a 6,000 gallon sub-surface storage tank located in Crompton Park.

6.0 Recommendations for Improvement

These recommendations were intended to provide plausible, realistic solutions using the gathered and generated data. Based on the analysis, it is recommended that a flap valve be installed at Manhole 4 in the Quinsigamond Avenue storm drain, in order to reduce backflow from the Mill Brook conduit. Also, it is recommended that this flap valve be used in conjunction with a subsurface storage tank with a volume of 6000 gallons, to be installed beneath Crompton Park. This storage tank should be connected to the Quinsigamond Avenue storm drain at Manhole 3, with a slope of 0.021. Figure 29 displays where the flap valve and the subsurface detention will be placed along Quinsigamond Avenue. It is further recommended that the City of Worcester install a flow metering system at points upstream, as well as downstream of the Millbrook conduit. This would enhance the accuracy of the SWMM model by providing realistic flows as opposed to just standing water elevations.

Further recommendations for student projects could include investigating implementing best management practices to reduce flooding in the Quinsigamond Avenue area. Students could also further investigate methods to prevent capacity issues at the QACSOTF. By preventing these capacity issues, the impact of backflow conditions in the Millbrook conduit will decrease.

Works Cited

Health and Safety Hazards Arising From Floods. (2002, January). Retrieved January 14, 2013, from NPS: http://www.nps.gov/museum/publications/conserveogram/21-01.pdf

(2002). *Phase I CSO Long-term Control Plan Report.* CDM.

Carlow worst hit by widespread flooding. (2008, August 18). Retrieved January 14, 2013, from RTE: http://www.rte.ie/news/2008/0818/floods.html

Green Island Area Flooding Presentation. (2011, October 19). 29. Worcester, MA: City of Worcester.

Green Island. (2012). Retrieved September 2012, from Google: http://maps.google.com/maps?hl=en&bav=on.2,or.r_gc.r_pw.r_qf.&biw=1231&bih=612&q=green+island,+worcester&um=1&ie=UTF-8&hq=&hnear=0x89e4067a80fb3ea9:0xe3802d5b104104ee,Green+Island,+Worcester,+MA&gl=us&sa=X&ei=yrtsUOKCAq6p0AHvjYGIDw&ved=0CFoQtgM

Browne, M. J., & Hoyt, R. E. (2000). The Demand for Flood Insurance: Emperical Evidence. *Journal of Risk and Uncertainty*, 291-306.

CDC. (2011, May 11). *Flood Waters or Standing Water*. Retrieved January 14, 2013, from Center for Disease Control: http://www.cdc.gov/healthywater/emergency/flood/standing.html

City Data. (2011). *Green Island Neighborhood City Data*. Retrieved October 9, 2012, from City Data Web Site: http://www.city-data.com/neighborhood/Green-Island-Worcester-MA.html

Corpuz, B. (2011 йил 8-September). *CBS Boston*. Retrieved 2012 йил 1-November from CBS Boston Website: http://boston.cbslocal.com/2011/09/08/heavy-rains-cause-significant-flooding-in0-worcester/

Cuo, L., Lettenmaier, D. P., Mattheussen, B. V., Storck, P., & Wiley, M. (2008). *Hydrologic Prediction for Urban Watercheds with the Distributed Hydrology-Soil-Vegitation Model.* www.interscience.wiley.com: Wiley InterScience.

Environmental Protection Agency. (2013). *Storm Water Management Model*. Retrieved from http://www.epa.gov/athens/wwqtsc/SWMM.pdf

Kleinfelder/SEA. (2010). *Southbridge Street and Quinsigamond Avenue Area Flood Study.* Worcester : Kleinfelder/SEA.

Lerner, K. L., & Lerner, B. W. (2008). *Flooding* (Vol. 3). Detroit: The Gale Group, Inc.

Mileti, D. (1999). *Disasters by Design: A Reassessment of Natural Hazards in the United States.* Washington D.C.: John Henry Press.

Minamiguchi, N. (2013). *Health Risk and Hazards caused by floods*. Retrieved January 14, 2013, from SSI: http://www.ssi.dk/Smitteberedskab/Infektionshygiejne/Retningslinjer/~/media/Indhold/DK%20-%20dansk/Smitteberedskab/Infektionshygiejne/PDF/Oversvommelse/Health%20risks%20and%20hazards%20caused%20by%20floods.ashx

Reed Construction. (2010). *RSMeans Building Construction Cost Data.* Reed Construction.

Reed Construction Data. (2011). *RSMeans Building Construction Cost Data.* RSMeans.

State of Massachusetts. (2013). *Smart Growth/Smart Energy Toolkit*. Retrieved February 25, 2013, from mass.gov: http://www.mass.gov/envir/smart_growth_toolkit/pages/CS-tif-worcester.html

Struzziery, J. J. (n.d.). *Southbridge Street and Quinsignamond Avenue Area Flood Study Draft Technical Memorandum.* Kleinfelder/S E A Consultants Inc.

Subsurface Detention. (n.d.). Retrieved October 2012, from A & M Contractors: http://www.am-contractors.com/index.php?option=com_content&view=article&id=60&Itemid=68

Technologies, T. (2011). *Series TF-1 check valve protects residents of irish town from flood prone river*. Retrieved January 14, 2013, from TideFlex: http://www.redvalve.com/rv/documents/multilingual/irish/Carlow-Ireland.pdf?phpMyAdmin=be41330fb396fd34b0af4503bda1ca16

Tideflex Technologies. (2012). *Tideflex Technologies*. Retrieved October 3, 2012, from Tideflex Technologies Web Site: http://www.tideflex.com/tf/index.php/content/view/228/368/

Troidl, J. (2007). *A Storm Water Management Model to Predict Runoff and Streamflow in the Pennichuck Brook Watershed.* Cornell University .

Underground Storage. (n.d.). Retrieved 10 2012, from Lake Superior Streams: http://www.lakesuperiorstreams.org/stormwater/toolkit/underground.html

WPI. (2002-03). WPI CEE DEPARTMENT 30-DAY REPORT. *CAPSTONE DESIGN*.

Wright, M. (2012, 9 27). Flooding Makes Green Island Earn Its Name, Property Owners Say. *Worcester Telegram & Gazette*.

Appendix A: Flow Metering Raw Data

Site Name	Loc-D	Loc-D	Loc-D
Isco Quantity	Level	Velocity	Flow Rate
Label	Level	Velocity	Flow Rate
Units	in	ft/s	gpm
Resolution	0.1	0.1	0.1
Significant Digits	0	0	0
5/8/2010 0:00	24.44	0.051	175.44
5/8/2010 0:05	24.457	0.051	175.628
5/8/2010 0:10	24.45	0.051	175.547
5/8/2010 0:15	24.445	0.051	175.492
5/8/2010 0:20	24.449	0.051	175.542
5/8/2010 0:25	24.443	0.051	175.476
5/8/2010 0:30	24.441	0.051	175.449
5/8/2010 0:35	24.436	0.051	175.404
5/8/2010 0:40	24.689	0.051	178.167
5/8/2010 0:45	24.691	0.051	178.193
5/8/2010 0:50	24.692	0.051	178.198
5/8/2010 0:55	24.686	0.051	178.136
5/8/2010 1:00	24.69	0.051	178.174
5/8/2010 1:05	24.689	0.051	178.169
5/8/2010 1:10	24.691	0.051	178.186
5/8/2010 1:15	24.69	0.051	178.177
5/8/2010 1:20	24.691	0.051	178.189
5/8/2010 1:25	24.689	0.051	178.172
5/8/2010 1:30	24.691	0.051	178.193
5/8/2010 1:35	24.691	0.051	178.196
5/8/2010 1:40	24.693	0.051	178.207
5/8/2010 1:45	24.69	0.051	178.182
5/8/2010 1:50	24.69	0.051	178.179
5/8/2010 1:55	24.692	0.051	178.199
5/8/2010 2:00	24.693	0.051	178.209
5/8/2010 2:05	24.691	0.051	178.191
5/8/2010 2:10	24.692	0.051	178.205
5/8/2010 2:15	24.692	0.051	178.207
5/8/2010 2:20	24.693	0.051	178.209
5/8/2010 2:25	24.695	0.051	178.237

5/8/2010 2:30	24.691	0.051	178.187
5/8/2010 2:35	24.691	0.051	178.187
5/8/2010 2:40	24.69	0.051	178.182
5/8/2010 2:45	24.695	0.051	178.233
5/8/2010 2:50	24.688	0.051	178.157
5/8/2010 2:55	24.693	0.051	178.209
5/8/2010 3:00	24.694	0.051	178.225
5/8/2010 3:05	24.691	0.051	178.195
5/8/2010 3:10	24.693	0.051	178.208
5/8/2010 3:15	24.693	0.051	178.217
5/8/2010 3:20	24.692	0.051	178.203
5/8/2010 3:25	24.692	0.051	178.203
5/8/2010 3:30	24.692	0.051	178.205
5/8/2010 3:35	24.692	0.051	178.202
5/8/2010 3:40	24.692	0.051	178.204
5/8/2010 3:45	24.692	0.051	178.201
5/8/2010 3:50	24.694	0.051	178.227
5/8/2010 3:55	24.693	0.051	178.217
5/8/2010 4:00	24.693	0.051	178.213
5/8/2010 4:05	24.692	0.051	178.198
5/8/2010 4:10	24.692	0.051	178.205
5/8/2010 4:15	24.694	0.051	178.22
5/8/2010 4:20	24.689	0.051	178.165
5/8/2010 4:25	24.693	0.051	178.215
5/8/2010 4:30	24.692	0.051	178.206
5/8/2010 4:35	24.695	0.051	178.239
5/8/2010 4:40	24.694	0.051	178.224
5/8/2010 4:45	24.69	0.051	178.183
5/8/2010 4:50	24.694	0.051	178.219
5/8/2010 4:55	24.693	0.051	178.207
5/8/2010 5:00	24.74	-0.49	-1701.02
5/8/2010 5:05	25.13	0.142	504.341
5/8/2010 5:10	25.275	0.142	508.73
5/8/2010 5:15	25.331	0.142	510.433
5/8/2010 5:20	25.623	0.135	495.465
5/8/2010 5:25	25.667	0.136	498.639
5/8/2010 5:30	25.799	0.136	502.519
5/8/2010 5:35	26.165	0.222	838.775
5/8/2010 5:40	26.524	-0.157	-606.666
5/8/2010 5:45	27.229	-0.368	-

			1474.72
5/8/2010 5:50	28.267	0.459	1945.26
5/8/2010 5:55	29.191	0.58	2573.66
5/8/2010 6:00	30.455	0.626	2956.84
5/8/2010 6:05	32.962	0.346	1827.68
5/8/2010 6:10	35.545	0.361	2112.99
5/8/2010 6:15	37.258	0.196	1226.09
5/8/2010 6:20	38.336	0.196	1273.59
5/8/2010 6:25	38.677	0.116	762.392
5/8/2010 6:30	38.731	0.206	1355.7
5/8/2010 6:35	38.141	0.244	1571.82
5/8/2010 6:40	37.682	0.244	1547.22
5/8/2010 6:45	37.101	0.247	1534.69
5/8/2010 6:50	36.68	0.204	1246.33
5/8/2010 6:55	36.536	0.167	1014.99
5/8/2010 7:00	36.402	0.132	799.813
5/8/2010 7:05	36.366	0.108	654.189
5/8/2010 7:10	36.491	0.11	667.51
5/8/2010 7:15	36.488	0.103	626.875
5/8/2010 7:20	36.557	0.096	586.658
5/8/2010 7:25	36.44	0.092	555.248
5/8/2010 7:30	36.428	0.11	663.591
5/8/2010 7:35	36.129	0.1	599.727
5/8/2010 7:40	36.051	0.117	700.959
5/8/2010 7:45	35.864	0.12	714.255
5/8/2010 7:50	35.593	0.154	902.409
5/8/2010 7:55	35.476	0.115	673.347
5/8/2010 8:00	35.179	0.115	665.917
5/8/2010 8:05	35.025	0.119	684.879
5/8/2010 8:10	34.764	0.112	638.48
5/8/2010 8:15	34.548	0.116	656.271
5/8/2010 8:20	34.393	0.108	606.597
5/8/2010 8:25	34.183	0.69	3831.95
5/8/2010 8:30	34.037	0.111	614.048
5/8/2010 8:35	33.73	0.11	599.037
5/8/2010 8:40	33.575	-0.215	-1166.5
5/8/2010 8:45	33.642	-0.223	-1212.08
5/8/2010 8:50	33.427	0.185	994.372
5/8/2010 8:55	33.498	0.227	1224.94
5/8/2010 9:00	33.856	0.295	1616.22

5/8/2010 9:05	33.904	0.346	1900.73
5/8/2010 9:10	34.404	0.415	2324.79
5/8/2010 9:15	34.979	0.428	2453.4
5/8/2010 9:20	36.121	0.493	2951.81
5/8/2010 9:25	37.418	0.538	3380.16
5/8/2010 9:30	38.489	0.651	4240.71
5/8/2010 9:35	39.18	0.625	4167.61
5/8/2010 9:40	39.369	0.497	3334.23
5/8/2010 9:45	39.383	0.367	2465.61
5/8/2010 9:50	39.269	0.297	1989.08
5/8/2010 9:55	39	0.27	1793.73
5/8/2010 10:00	38.535	0.31	2025.27
5/8/2010 10:05	38.1	0.254	1630.85
5/8/2010 10:10	37.659	0.288	1820.65
5/8/2010 10:15	37.12	0.244	1512.93
5/8/2010 10:20	36.773	0.236	1446.87
5/8/2010 10:25	36.509	0.224	1358.7
5/8/2010 10:30	36.268	0.211	1272.29
5/8/2010 10:35	36.206	0.191	1145.27
5/8/2010 10:40	36.376	0.2	1208.62
5/8/2010 10:45	36.703	0.277	1692.18
5/8/2010 10:50	37.168	0.29	1801.65
5/8/2010 10:55	38.633	0.501	3282.81
5/8/2010 11:00	42.115	0.993	7274.64
5/8/2010 11:05	45.811	0.958	7794.9
5/8/2010 11:10	52.381	0.594	5647.69
5/8/2010 11:15	58.715	0.35	3746.92
5/8/2010 11:20	62.205	0.731	8236.98
5/8/2010 11:25	62.936	0.935	10634.8
5/8/2010 11:30	61.975	0.704	7911.91
5/8/2010 11:35	77.152	-1.448	-17822.9
5/8/2010 11:40	85.791	-0.928	-11421.2
5/8/2010 11:45	85.892	0.708	8708.6
5/8/2010 11:50	83.113	0.327	4028.32
5/8/2010 11:55	75.602	1.274	15681.2
5/8/2010 12:00	72.247	0.667	8208.24
5/8/2010 12:05	69.533	0.525	6389.71
5/8/2010 12:10	67.862	0.446	5353.33
5/8/2010 12:15	66.729	0.41	4872.66
5/8/2010 12:20	65.012	0.35	4080.97

5/8/2010 12:25	63.401	0.36	4122.89
5/8/2010 12:30	61.946	0.366	4113.56
5/8/2010 12:35	60.808	0.316	3496.34
5/8/2010 12:40	57.153	0.652	6793.09
5/8/2010 12:45	55.902	0.426	4338.42
5/8/2010 12:50	54.691	0.102	1017.61
5/8/2010 12:55	54.21	0.139	1373.71
5/8/2010 13:00	53.791	0.215	2101.6
5/8/2010 13:05	53.411	0.206	1999.14
5/8/2010 13:10	52.677	0.238	2276.91
5/8/2010 13:15	52.22	0.275	2602.22
5/8/2010 13:20	51.73	0.294	2755.41
5/8/2010 13:25	51.096	0.267	2465.77
5/8/2010 13:30	50.447	0.277	2524.93
5/8/2010 13:35	49.74	0.267	2389.57
5/8/2010 13:40	49.306	0.248	2197.27
5/8/2010 13:45	48.723	0.208	1816.51
5/8/2010 13:50	48.163	0.214	1850.76
5/8/2010 13:55	47.674	0.209	1785.73
5/8/2010 14:00	47.032	0.205	1721.03
5/8/2010 14:05	49.425	-0.363	-3231.11
5/8/2010 14:10	49.278	-0.174	-1546.61
5/8/2010 14:15	48.668	0.578	5049.23
5/8/2010 14:20	48.92	0.151	1330.48
5/8/2010 14:25	46.113	0.588	4816.63
5/8/2010 14:30	43.445	0.914	6962.07
5/8/2010 14:35	41.51	0.583	4191.57
5/8/2010 14:40	40.092	0.3	2063.03
5/8/2010 14:45	39.139	0.2	1332.67
5/8/2010 14:50	38.444	0.191	1241.59
5/8/2010 14:55	38.027	0.175	1120.62
5/8/2010 15:00	37.652	0.171	1080.78
5/8/2010 15:05	37.292	0.156	975.207
5/8/2010 15:10	37.043	0.181	1124.03
5/8/2010 15:15	36.726	0.16	978.091
5/8/2010 15:20	36.46	0.178	1078.03
5/8/2010 15:25	36.25	0.178	1069.63
5/8/2010 15:30	35.992	0.132	783.68
5/8/2010 15:35	35.696	0.138	815.711
5/8/2010 15:40	35.582	0.144	843.754

5/8/2010 15:45	35.358	0.144	836.517
5/8/2010 15:50	34.984	0.16	919.565
5/8/2010 15:55	34.893	0.151	864.839
5/8/2010 16:00	34.784	0.126	718.304
5/8/2010 16:05	34.463	0.119	670.272
5/8/2010 16:10	34.272	0.122	680.088
5/8/2010 16:15	34.085	0.132	731.633
5/8/2010 16:20	34.009	0.131	724.009
5/8/2010 16:25	33.685	0.193	1052.12
5/8/2010 16:30	33.605	0.193	1048.64
5/8/2010 16:35	33.387	0.193	1039.2
5/8/2010 16:40	33.202	0.193	1031.18
5/8/2010 16:45	33.128	0.193	1027.98
5/8/2010 16:50	32.964	0.193	1020.89
5/8/2010 16:55	32.848	0.193	1015.9
5/8/2010 17:00	32.663	0.193	1007.89
5/8/2010 17:05	32.573	0.193	1003.99
5/8/2010 17:10	32.424	0.193	997.555
5/8/2010 17:15	32.285	0.193	991.579
5/8/2010 17:20	32.317	0.193	992.927
5/8/2010 17:25	32.179	0.193	987.004
5/8/2010 17:30	32.096	0.193	983.418
5/8/2010 17:35	31.974	0.193	978.136
5/8/2010 17:40	31.936	0.193	976.487
5/8/2010 17:45	31.836	0.193	972.18
5/8/2010 17:50	31.793	0.193	970.335
5/8/2010 17:55	31.789	0.193	970.149
5/8/2010 18:00	31.747	0.193	968.361
5/8/2010 18:05	31.821	0.193	971.562
5/8/2010 18:10	31.842	0.193	972.444
5/8/2010 18:15	31.842	0.193	972.441
5/8/2010 18:20	31.863	0.193	973.344
5/8/2010 18:25	31.995	0.193	979.058
5/8/2010 18:30	31.971	0.193	977.996
5/8/2010 18:35	32.068	0.193	982.18
5/8/2010 18:40	32.139	-0.232	-1181.98
5/8/2010 18:45	32.384	-0.169	-868.078
5/8/2010 18:50	32.461	-0.169	-870.998
5/8/2010 18:55	32.572	-0.169	-

			875.183
5/8/2010 19:00	32.576	-0.169	-875.314
5/8/2010 19:05	32.606	0.081	422.209
5/8/2010 19:10	32.564	0.148	769.96
5/8/2010 19:15	32.736	-0.207	-1082.11
5/8/2010 19:20	32.943	-0.114	-600.489
5/8/2010 19:25	33.064	-0.114	-603.563
5/8/2010 19:30	33.132	0.198	1053.05
5/8/2010 19:35	33.155	0.166	883.487
5/8/2010 19:40	33.128	0.162	858.79
5/8/2010 19:45	32.998	0.167	881.236
5/8/2010 19:50	32.963	0.179	943.057
5/8/2010 19:55	32.898	0.146	766.284
5/8/2010 20:00	32.737	0.162	849.541
5/8/2010 20:05	32.546	0.145	750.619
5/8/2010 20:10	32.483	0.143	739.474
5/8/2010 20:15	32.382	0.117	602.35
5/8/2010 20:20	32.227	0.1	512.659
5/8/2010 20:25	32.295	0.084	433.079
5/8/2010 20:30	32.301	0.084	433.197
5/8/2010 20:35	32.345	0.083	426.229
5/8/2010 20:40	32.348	0.081	416.15
5/8/2010 20:45	32.25	0.081	414.372
5/8/2010 20:50	32.215	0.082	417.814
5/8/2010 20:55	32.093	0.082	415.586
5/8/2010 21:00	32.037	0.096	489.147
5/8/2010 21:05	31.887	0.108	546.097
5/8/2010 21:10	31.757	0.108	542.963
5/8/2010 21:15	31.727	0.108	542.22
5/8/2010 21:20	31.6	0.089	440.265
5/8/2010 21:25	31.515	0.089	438.577
5/8/2010 21:30	31.49	0.089	438.083
5/8/2010 21:35	31.322	0.089	434.783
5/8/2010 21:40	31.251	0.093	456.676
5/8/2010 21:45	31.242	0.093	456.484
5/8/2010 21:50	31.149	0.093	454.541
5/8/2010 21:55	31.026	0.094	453.519
5/8/2010 22:00	30.972	0.089	430.591

5/8/2010 22:05	30.902	0.089	429.207
5/8/2010 22:10	30.811	0.089	427.392
5/8/2010 22:15	30.8	0.089	427.186
5/8/2010 22:20	30.723	0.089	425.657
5/8/2010 22:25	30.646	0.089	424.132
5/8/2010 22:30	30.523	0.089	421.701
5/8/2010 22:35	30.487	0.089	420.988
5/8/2010 22:40	30.453	0.089	420.321
5/8/2010 22:45	30.37	0.089	418.685
5/8/2010 22:50	30.285	0.085	399.539
5/8/2010 22:55	30.173	0.085	397.426
5/8/2010 23:00	30.061	0.085	395.321
5/8/2010 23:05	29.975	0.085	393.689
5/8/2010 23:10	29.915	0.085	392.549
5/8/2010 23:15	29.877	0.086	395.071
5/8/2010 23:20	29.747	0.086	392.609
5/8/2010 23:25	29.755	0.086	392.764
5/8/2010 23:30	29.75	0.086	392.654
5/8/2010 23:35	29.634	0.086	390.464
5/8/2010 23:40	29.549	0.086	388.838
5/8/2010 23:45	29.583	0.086	389.484
5/8/2010 23:50	29.532	0.086	388.512
5/8/2010 23:55	29.522	0.086	388.337
6/12/2010 0:00	25.318	0.149	534.276
6/12/2010 0:05	25.326	0.149	534.524
6/12/2010 0:10	25.325	0.149	534.496
6/12/2010 0:15	25.331	0.149	534.684
6/12/2010 0:20	25.324	0.149	534.471
6/12/2010 0:25	25.321	0.149	534.366
6/12/2010 0:30	25.318	0.149	534.295
6/12/2010 0:35	25.319	0.149	534.316
6/12/2010 0:40	25.321	0.149	534.373
6/12/2010 0:45	25.32	0.149	534.359
6/12/2010 0:50	25.308	0.149	533.957
6/12/2010 0:55	25.305	0.149	533.882
6/12/2010 1:00	25.305	0.149	533.873
6/12/2010 1:05	25.291	0.149	533.436
6/12/2010 1:10	25.289	0.149	533.348
6/12/2010 1:15	25.289	0.149	533.349
6/12/2010 1:20	25.287	0.149	533.293
6/12/2010 1:25	25.285	0.149	533.238

6/12/2010 1:30	25.284	0.149	533.21
6/12/2010 1:35	25.277	0.149	532.974
6/12/2010 1:40	25.271	0.149	532.773
6/12/2010 1:45	25.284	0.149	533.202
6/12/2010 1:50	25.272	0.149	532.821
6/12/2010 1:55	25.252	0.149	532.18
6/12/2010 2:00	25.274	0.149	532.877
6/12/2010 2:05	25.268	0.149	532.679
6/12/2010 2:10	25.266	0.149	532.646
6/12/2010 2:15	25.257	0.149	532.346
6/12/2010 2:20	25.263	0.149	532.543
6/12/2010 2:25	25.268	0.149	532.707
6/12/2010 2:30	25.276	0.149	532.933
6/12/2010 2:35	25.345	0.149	535.158
6/12/2010 2:40	25.29	0.149	533.399
6/12/2010 2:45	25.303	0.149	533.817
6/12/2010 2:50	25.301	0.149	533.734
6/12/2010 2:55	25.293	0.149	533.496
6/12/2010 3:00	25.291	0.149	533.415
6/12/2010 3:05	25.306	0.149	533.907
6/12/2010 3:10	25.307	0.149	533.934
6/12/2010 3:15	25.302	0.149	533.781
6/12/2010 3:20	25.301	0.149	533.756
6/12/2010 3:25	25.289	0.149	533.367
6/12/2010 3:30	25.283	0.149	533.17
6/12/2010 3:35	25.28	0.149	533.063
6/12/2010 3:40	25.268	0.149	532.694
6/12/2010 3:45	25.261	0.149	532.459
6/12/2010 3:50	25.265	0.149	532.596
6/12/2010 3:55	25.25	0.149	532.137
6/12/2010 4:00	25.247	0.149	532.041
6/12/2010 4:05	25.24	0.149	531.804
6/12/2010 4:10	25.243	0.149	531.886
6/12/2010 4:15	25.237	0.149	531.698
6/12/2010 4:20	25.228	0.149	531.425
6/12/2010 4:25	25.234	0.149	531.606
6/12/2010 4:30	25.227	0.149	531.405
6/12/2010 4:35	25.233	0.149	531.592
6/12/2010 4:40	25.237	0.149	531.71
6/12/2010 4:45	25.241	0.149	531.841
6/12/2010 4:50	25.244	0.149	531.933

6/12/2010 4:55	25.239	0.149	531.772
6/12/2010 5:00	25.253	0.149	532.214
6/12/2010 5:05	25.274	0.149	532.899
6/12/2010 5:10	25.316	0.149	534.224
6/12/2010 5:15	25.375	0.149	536.096
6/12/2010 5:20	25.452	0.149	538.546
6/12/2010 5:25	25.478	0.149	539.371
6/12/2010 5:30	25.452	0.149	538.56
6/12/2010 5:35	25.428	0.149	537.78
6/12/2010 5:40	25.369	0.149	535.908
6/12/2010 5:45	25.331	0.149	534.695
6/12/2010 5:50	25.287	0.149	533.295
6/12/2010 5:55	25.26	0.149	532.428
6/12/2010 6:00	25.231	0.149	531.52
6/12/2010 6:05	25.215	0.149	530.994
6/12/2010 6:10	25.218	0.149	531.1
6/12/2010 6:15	25.208	0.149	530.779
6/12/2010 6:20	25.196	0.149	530.412
6/12/2010 6:25	25.191	0.149	530.233
6/12/2010 6:30	25.19	0.149	530.205
6/12/2010 6:35	25.182	0.149	529.943
6/12/2010 6:40	25.175	0.149	529.749
6/12/2010 6:45	25.175	0.149	529.723
6/12/2010 6:50	25.18	0.149	529.896
6/12/2010 6:55	25.163	0.149	529.357
6/12/2010 7:00	25.172	0.149	529.65
6/12/2010 7:05	25.173	0.149	529.67
6/12/2010 7:10	25.161	0.149	529.303
6/12/2010 7:15	25.155	0.149	529.095
6/12/2010 7:20	25.158	0.149	529.199
6/12/2010 7:25	25.159	0.149	529.241
6/12/2010 7:30	25.156	0.149	529.131
6/12/2010 7:35	25.162	0.149	529.324
6/12/2010 7:40	25.166	0.149	529.463
6/12/2010 7:45	25.157	0.149	529.165
6/12/2010 7:50	25.174	0.149	529.705
6/12/2010 7:55	25.168	0.149	529.525
6/12/2010 8:00	25.158	0.149	529.194
6/12/2010 8:05	25.159	0.149	529.228
6/12/2010 8:10	25.147	0.149	528.86
6/12/2010 8:15	25.139	0.149	528.59

6/12/2010 8:20	25.154	0.149	529.081
6/12/2010 8:25	25.135	0.149	528.465
6/12/2010 8:30	25.135	0.149	528.477
6/12/2010 8:35	25.142	0.149	528.685
6/12/2010 8:40	25.133	0.149	528.415
6/12/2010 8:45	25.128	0.149	528.24
6/12/2010 8:50	25.129	0.149	528.275
6/12/2010 8:55	25.139	0.149	528.58
6/12/2010 9:00	25.146	0.149	528.807
6/12/2010 9:05	25.138	0.149	528.572
6/12/2010 9:10	25.147	0.149	528.849
6/12/2010 9:15	25.153	0.149	529.03
6/12/2010 9:20	25.151	0.149	528.975
6/12/2010 9:25	25.153	0.149	529.028
6/12/2010 9:30	25.191	0.149	530.259
6/12/2010 9:35	25.164	0.149	529.379
6/12/2010 9:40	25.167	0.149	529.478
6/12/2010 9:45	25.147	0.149	528.845
6/12/2010 9:50	25.143	0.149	528.733
6/12/2010 9:55	25.131	0.149	528.325
6/12/2010 10:00	25.153	0.149	529.037
6/12/2010 10:05	25.147	0.149	528.843
6/12/2010 10:10	25.148	0.149	528.872
6/12/2010 10:15	25.154	0.149	529.066
6/12/2010 10:20	25.155	0.149	529.099
6/12/2010 10:25	25.158	0.149	529.195
6/12/2010 10:30	25.17	0.149	529.59
6/12/2010 10:35	25.146	0.149	528.827
6/12/2010 10:40	25.145	0.149	528.77
6/12/2010 10:45	25.152	0.149	529.019
6/12/2010 10:50	25.149	0.149	528.902
6/12/2010 10:55	25.147	0.149	528.846
6/12/2010 11:00	25.136	0.149	528.507
6/12/2010 11:05	25.148	0.149	528.881
6/12/2010 11:10	25.163	0.149	529.343
6/12/2010 11:15	25.163	0.149	529.352
6/12/2010 11:20	25.156	0.149	529.123
6/12/2010 11:25	25.157	0.149	529.176
6/12/2010 11:30	25.161	0.149	529.306
6/12/2010 11:35	25.159	0.149	529.228
6/12/2010 11:40	25.171	0.149	529.61

6/12/2010 11:45	25.163	0.149	529.355
6/12/2010 11:50	25.161	0.149	529.297
6/12/2010 11:55	25.156	0.149	529.12
6/12/2010 12:00	25.147	0.149	528.838
6/12/2010 12:05	25.148	0.149	528.893
6/12/2010 12:10	25.177	0.149	529.801
6/12/2010 12:15	25.19	0.149	530.208
6/12/2010 12:20	25.177	0.149	529.788
6/12/2010 12:25	25.182	-0.16	-571.381
6/12/2010 12:30	25.264	-0.16	-574.192
6/12/2010 12:35	25.324	-0.16	-576.263
6/12/2010 12:40	25.356	0.191	687.003
6/12/2010 12:45	25.331	0.191	685.994
6/12/2010 12:50	25.382	0.191	688.066
6/12/2010 12:55	25.419	0.097	351.463
6/12/2010 13:00	25.438	0.099	357.993
6/12/2010 13:05	25.481	0.1	362.291
6/12/2010 13:10	25.526	0.1	363.262
6/12/2010 13:15	25.632	0.1	365.527
6/12/2010 13:20	25.773	0.1	368.541
6/12/2010 13:25	25.925	0.1	371.818
6/12/2010 13:30	26.063	0.1	374.785
6/12/2010 13:35	26.179	0.1	377.276
6/12/2010 13:40	26.27	0.1	379.229
6/12/2010 13:45	26.308	0.074	280.551
6/12/2010 13:50	26.309	0.067	257.227
6/12/2010 13:55	26.28	0.067	256.8
6/12/2010 14:00	26.232	0.067	256.108
6/12/2010 14:05	26.192	0.066	248.139
6/12/2010 14:10	26.15	0.068	257.075
6/12/2010 14:15	26.144	0.068	256.987
6/12/2010 14:20	26.153	0.068	257.113
6/12/2010 14:25	26.189	0.068	257.644
6/12/2010 14:30	26.28	0.068	258.979
6/12/2010 14:35	26.383	0.068	260.502
6/12/2010 14:40	26.475	0.068	261.847
6/12/2010 14:45	26.54	0.068	262.807
6/12/2010 14:50	26.612	0.068	263.869
6/12/2010 14:55	26.641	0.068	264.294

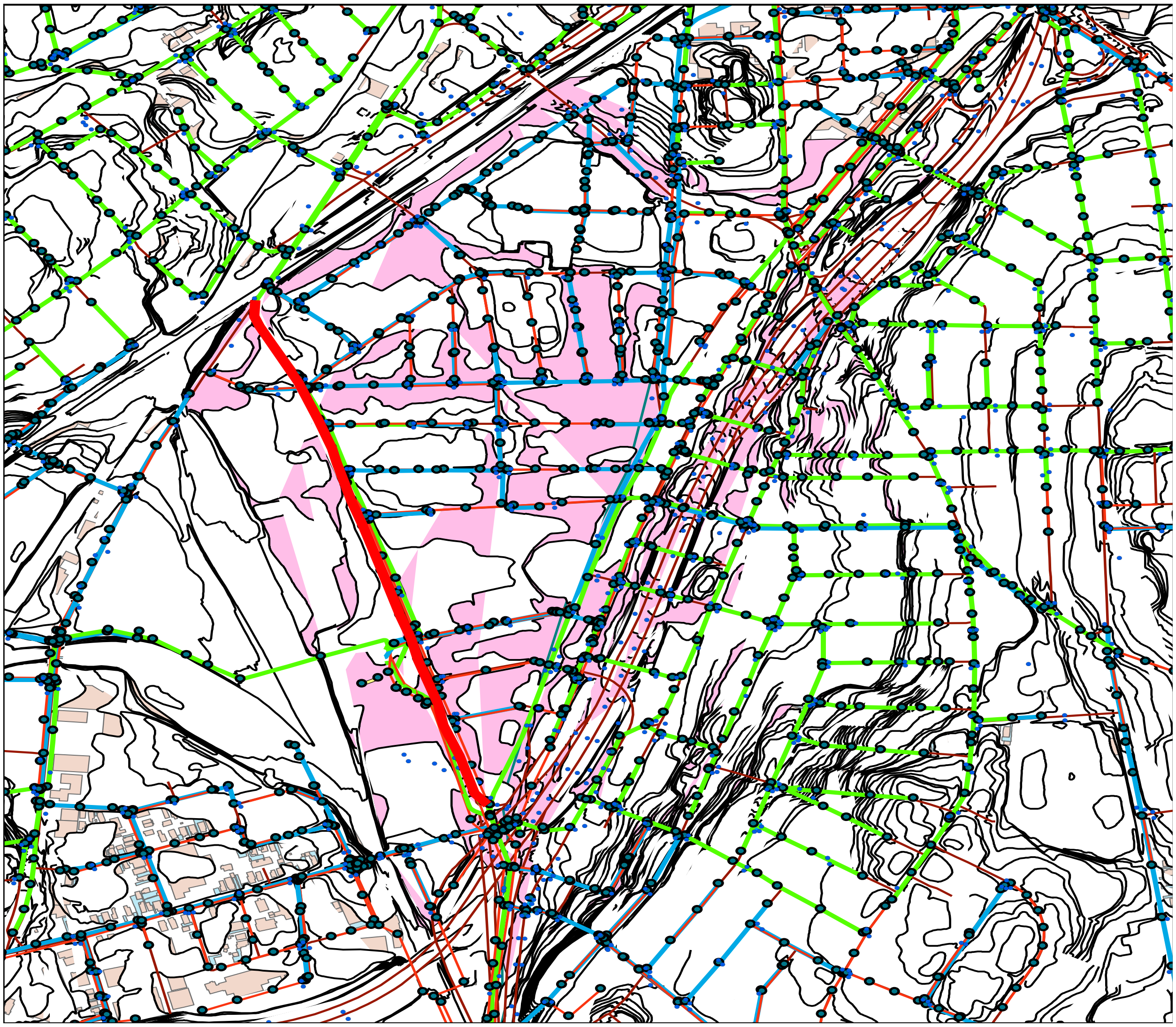
6/12/2010 15:00	26.688	0.068	264.998
6/12/2010 15:05	26.691	0.068	265.04
6/12/2010 15:10	26.706	0.068	265.253
6/12/2010 15:15	26.721	0.068	265.476
6/12/2010 15:20	26.704	0.068	265.223
6/12/2010 15:25	26.723	0.068	265.501
6/12/2010 15:30	26.729	-0.193	-754.283
6/12/2010 15:35	26.786	-0.201	-785.572
6/12/2010 15:40	26.848	-0.111	-437.945
6/12/2010 15:45	26.888	0.1	395.361
6/12/2010 15:50	26.987	-0.194	-766.863
6/12/2010 15:55	27.136	0.145	578.869
6/12/2010 16:00	27.291	0.184	742.361
6/12/2010 16:05	27.498	0.187	761.735
6/12/2010 16:10	27.801	0.23	950.051
6/12/2010 16:15	28.394	0.173	738.037
6/12/2010 16:20	29.449	-0.228	-1026.37
6/12/2010 16:25	30.733	-0.228	-1091.24
6/12/2010 16:30	31.551	0.175	870.958
6/12/2010 16:35	32.11	0.218	1107.02
6/12/2010 16:40	32.652	0.218	1133.37
6/12/2010 16:45	32.796	0.195	1022.35
6/12/2010 16:50	32.724	0.2	1045.5
6/12/2010 16:55	32.954	0.248	1310.11
6/12/2010 17:00	33.265	0.322	1720.94
6/12/2010 17:05	33.661	0.422	2294.02
6/12/2010 17:10	34.437	0.502	2816.9
6/12/2010 17:15	35.435	0.484	2821.7
6/12/2010 17:20	37.005	0.548	3392.28
6/12/2010 17:25	38.395	0.739	4802.22
6/12/2010 17:30	39.728	0.908	6169.51
6/12/2010 17:35	41.15	0.511	3630.35
6/12/2010 17:40	42.441	0.379	2803.84
6/12/2010 17:45	43.239	0.302	2284.39
6/12/2010 17:50	43.682	0.346	2654.89
6/12/2010 17:55	43.397	0.334	2537.75

6/12/2010 18:00	43.051	0.389	2932.37
6/12/2010 18:05	42.835	0.398	2976.32
6/12/2010 18:10	42.477	0.415	3074.88
6/12/2010 18:15	42.285	0.312	2300.71
6/12/2010 18:20	42.249	0.235	1729.99
6/12/2010 18:25	42.274	0.235	1731.31
6/12/2010 18:30	42.445	0.218	1616.32
6/12/2010 18:35	42.596	0.218	1623.61
6/12/2010 18:40	42.685	0.285	2121.82
6/12/2010 18:45	42.657	0.285	2122.73
6/12/2010 18:50	42.454	0.247	1828.52
6/12/2010 18:55	42.424	0.219	1620.29
6/12/2010 19:00	42.198	0.197	1448.45
6/12/2010 19:05	42.122	0.216	1582.85
6/12/2010 19:10	41.515	0.219	1577.31
6/12/2010 19:15	41.279	0.209	1488.85
6/12/2010 19:20	41.014	0.2	1417.09
6/12/2010 19:25	40.675	0.2	1402.03
6/12/2010 19:30	40.425	0.2	1390.85
6/12/2010 19:35	40.187	0.2	1380.28
6/12/2010 19:40	40.003	0.216	1481.08
6/12/2010 19:45	39.754	0.216	1469.09
6/12/2010 19:50	39.622	0.478	3234.67
6/12/2010 19:55	39.478	0.478	3219.33
6/12/2010 20:00	39.324	0.478	3202.82
6/12/2010 20:05	38.974	0.182	1204.32
6/12/2010 20:10	38.813	0.168	1108.2
6/12/2010 20:15	38.604	0.168	1100.34
6/12/2010 20:20	38.341	0.153	991.578
6/12/2010 20:25	38.022	0.153	980.66
6/12/2010 20:30	37.883	0.153	975.898
6/12/2010 20:35	37.652	0.153	967.976
6/12/2010 20:40	37.448	0.146	916.706
6/12/2010 20:45	37.24	0.146	909.911
6/12/2010 20:50	37.047	0.151	933.122
6/12/2010 20:55	36.804	0.301	1848.32
6/12/2010 21:00	36.722	0.301	1842.79
6/12/2010 21:05	36.499	0.725	4402.45
6/12/2010 21:10	36.374	0.276	1665.94
6/12/2010 21:15	36.253	0.276	1658.47
6/12/2010 21:20	36.081	0.276	1647.86

6/12/2010 21:25	36.091	-0.279	- 1670.91
6/12/2010 21:30	36.703	0.291	1777.08
6/12/2010 21:35	38.264	0.872	5639.62
6/12/2010 21:40	39.874	1.225	8363.57
6/12/2010 21:45	41.369	0.865	6196.21
6/12/2010 21:50	43.319	0.6	4555.62
6/12/2010 21:55	44.492	0.45	3529.22
6/12/2010 22:00	44.867	0.465	3689.51
6/12/2010 22:05	44.832	0.551	4366.21
6/12/2010 22:10	44.443	0.593	4650.74
6/12/2010 22:15	43.986	0.507	3925.49
6/12/2010 22:20	43.345	0.469	3560.93
6/12/2010 22:25	43.11	0.407	3067.05
6/12/2010 22:30	42.838	0.353	2639.02
6/12/2010 22:35	42.599	0.418	3109.75
6/12/2010 22:40	42.368	0.367	2707.74
6/12/2010 22:45	42.131	0.335	2452.77
6/12/2010 22:50	42.209	0.201	1478.64
6/12/2010 22:55	42.312	0.173	1275.25
6/12/2010 23:00	42.5	0.173	1280.32
6/12/2010 23:05	42.375	0.173	1275.56
6/12/2010 23:10	42.023	0.194	1417.24
6/12/2010 23:15	42.002	0.184	1340.33
6/12/2010 23:20	41.825	0.142	1034.65
6/12/2010 23:25	41.65	0.142	1029.14
6/12/2010 23:30	41.602	0.142	1027.62
6/12/2010 23:35	41.63	0.142	1028.48
6/12/2010 23:40	41.673	0.142	1029.85
6/12/2010 23:45	41.498	0.342	2461.38
6/12/2010 23:50	41.468	0.239	1718.34
6/12/2010 23:55	41.315	0.239	1710.22

Appendix B: Subcatchment Property Graphics

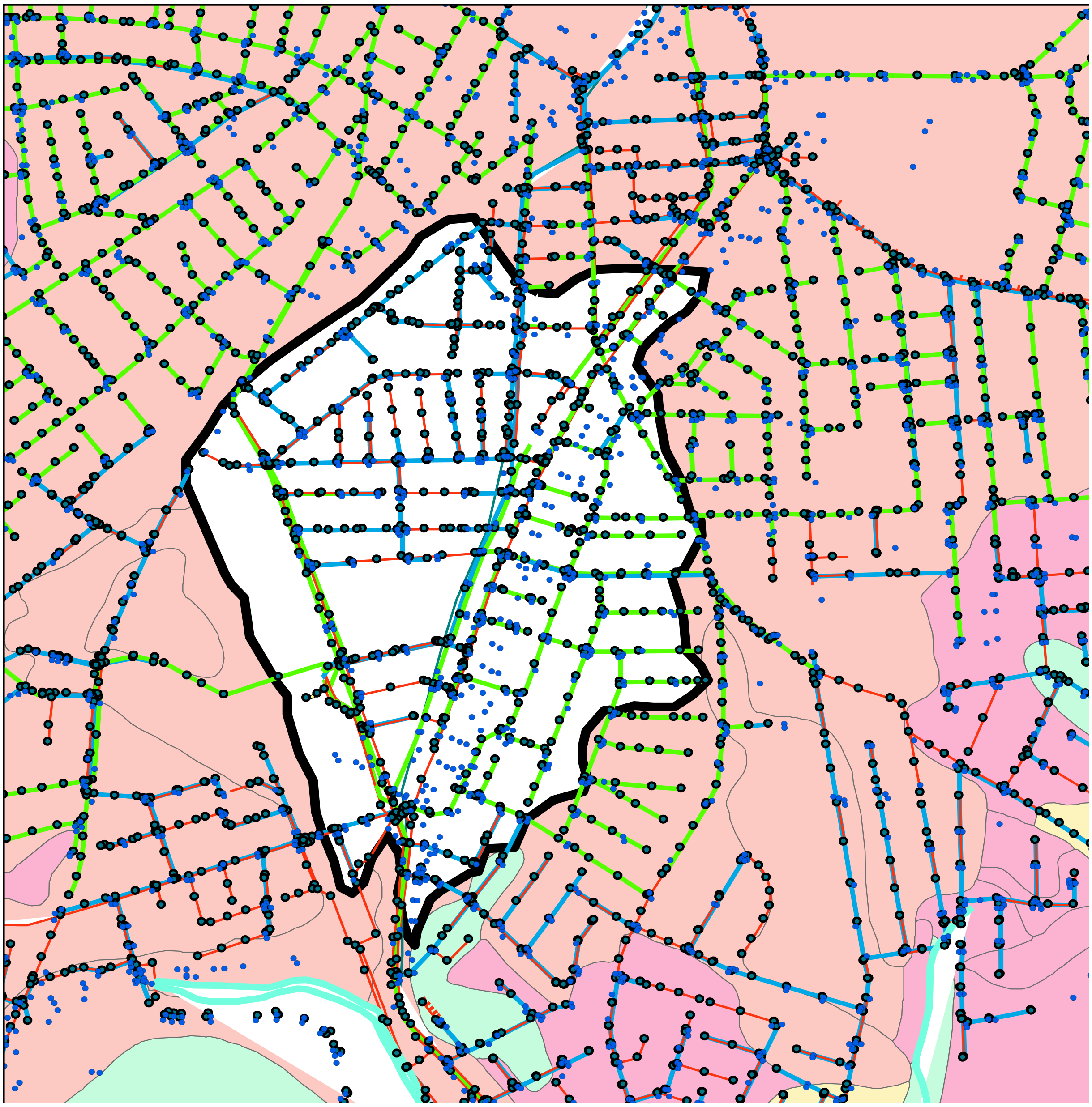
Drainage Area and Width of Overland Flow Path



- Drainage Area

- Width of Overland Flow Path = L x 1.7 = 3500’ x 1.7 = 5950’

Average Surface Slope of Drainage Area



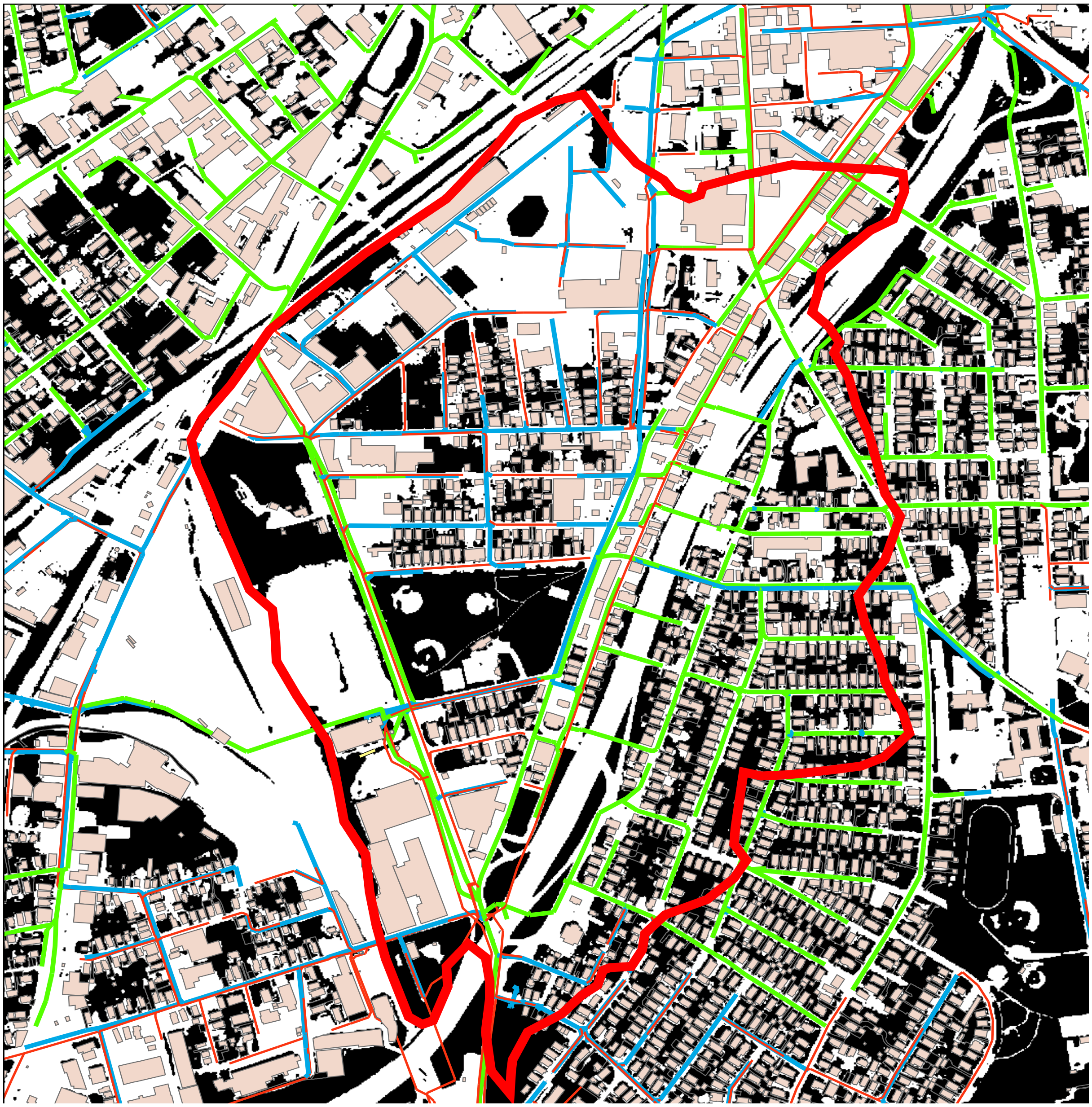
Legend

Slope of Soils **Slope Percentages**

0-3%
8-15%
25-35%
Waterbody
0%
3-8%
15-25%

Outline of Drainage Area

Percent of Impervious Surface in Drainage Area



(red line)	Outline of drainage area
(white box)	Impervious Surface
(tan box)	Building
(green line)	Combined Sewer Line

Manning's N for Impervious and Pervious Surfaces

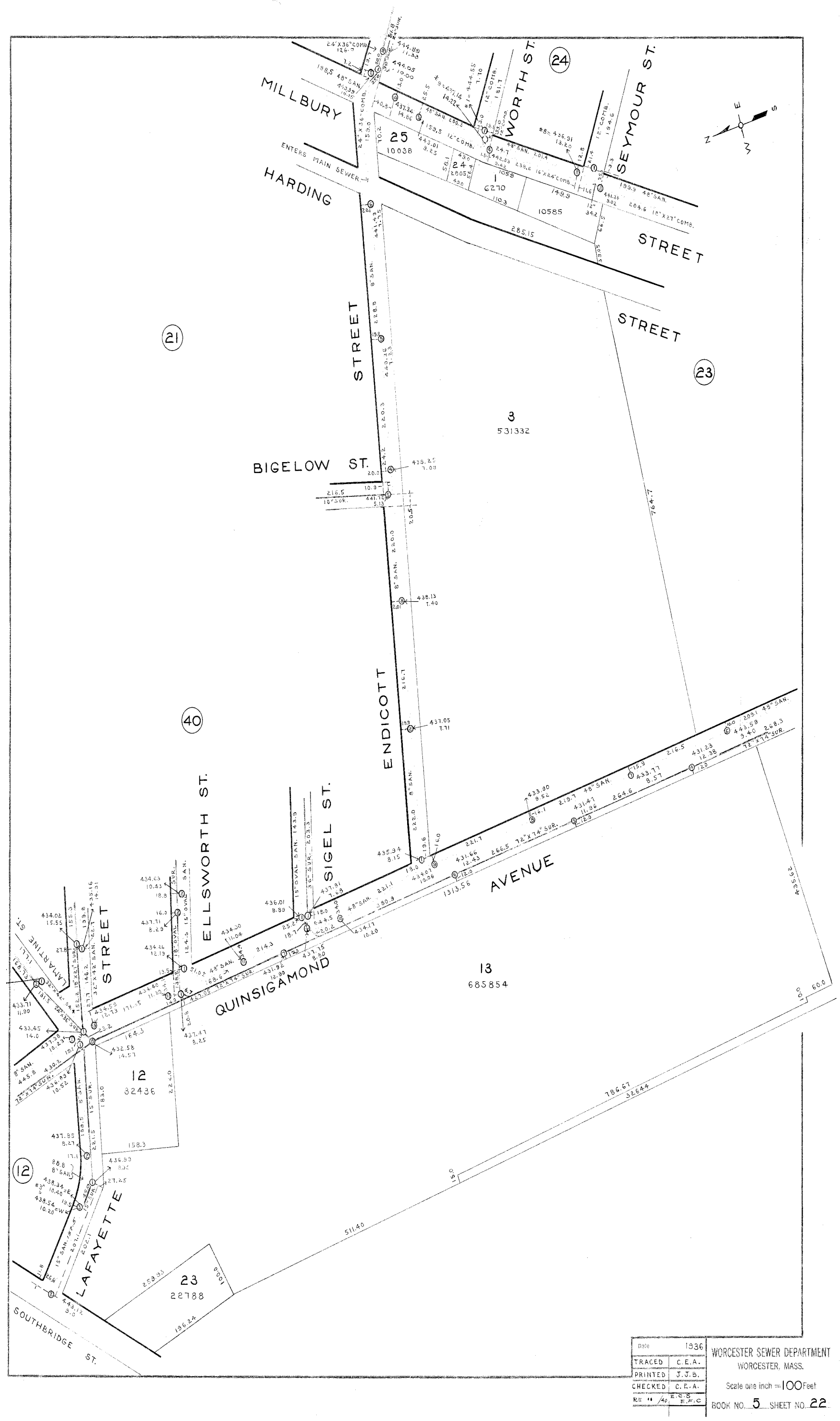
Manning’s N for Impervious Surfaces	Surface	n
	Smooth Asphalt	0.011
	Smooth Concrete	0.012
	Ordinary Concrete Lining	0.013
	Good Wood	0.014
	Brick with Cement Mortar	0.014
	Vitrified clay	0.015
	Cast Iron	0.015
	Corrugated Metal Pipes	0.024
	Cement Rubble Surface	0.024
	Fallow Soils (no residue)	0.05
	Cultivated Soils -Residue cover < 20% -Residue cover > 20%	 0.06 0.17
	Range (natural)	0.13
	Grass -Short, prairie -Dense -Bermuda grass	 0.15 0.24 0.41
	Woods -Light underbrush -Dense underbrush	 0.40 0.80

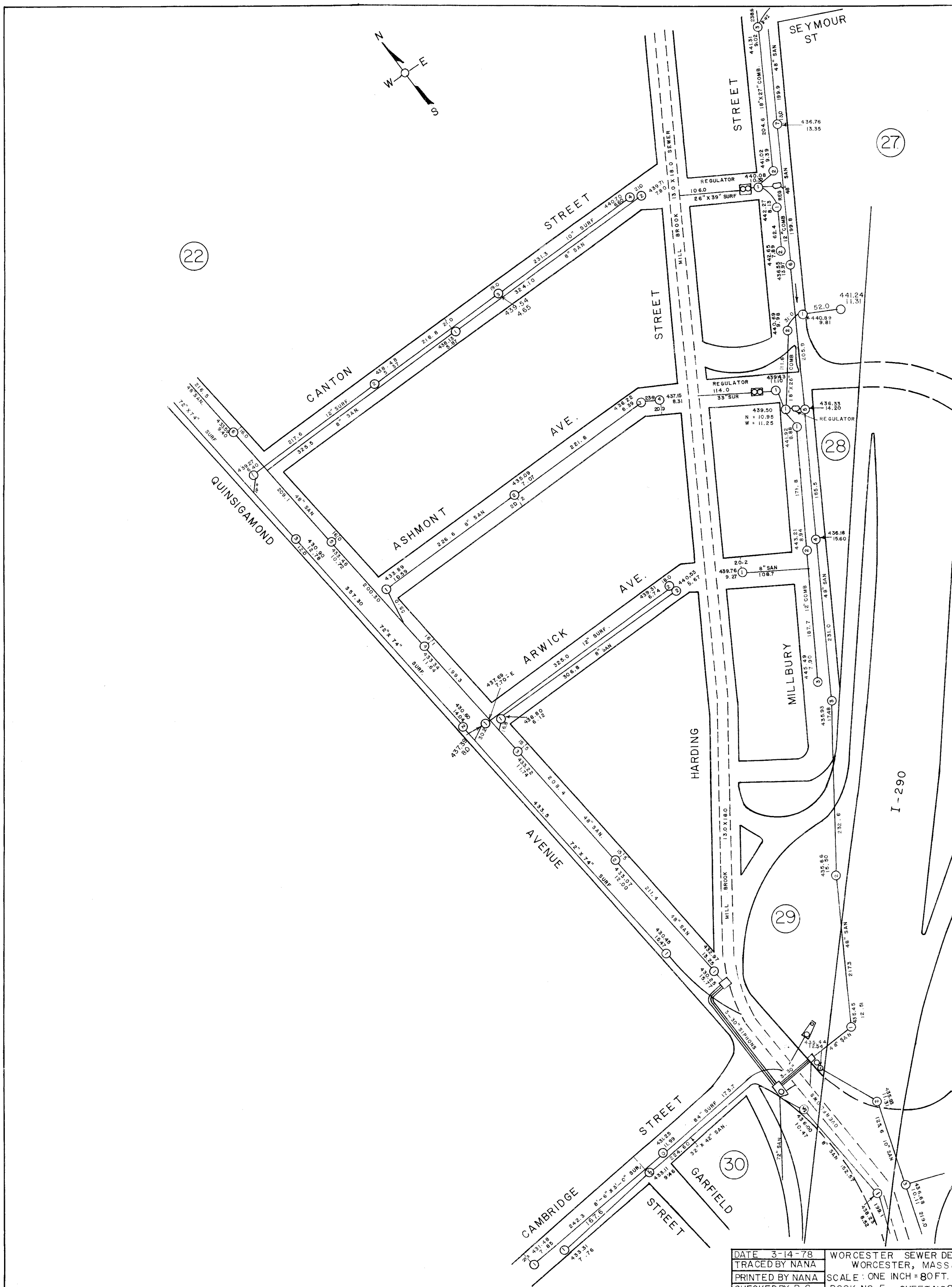
Depth of Depression Storage on Impervious or Pervious Surface

Depth of Depression Storage on Impervious and Pervious Surfaces	Surface	Depth of Depression
	Impervious	0.05 – 0.10 inches
	Lawns	0.10 – 0.20 inches
	Pasture	0.20 inches
	Forest Litter	0.30 inches

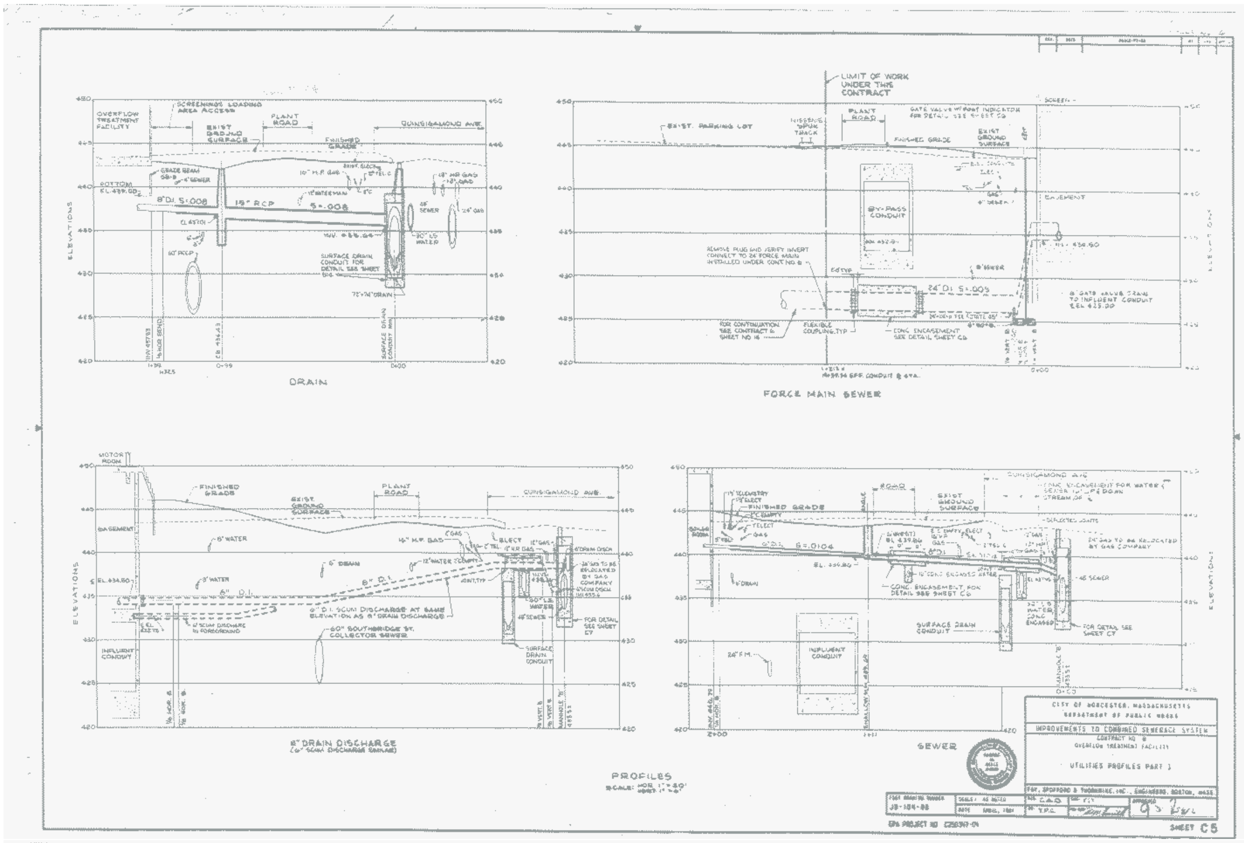
Appendix C: Conduit and Junction Property Graphics

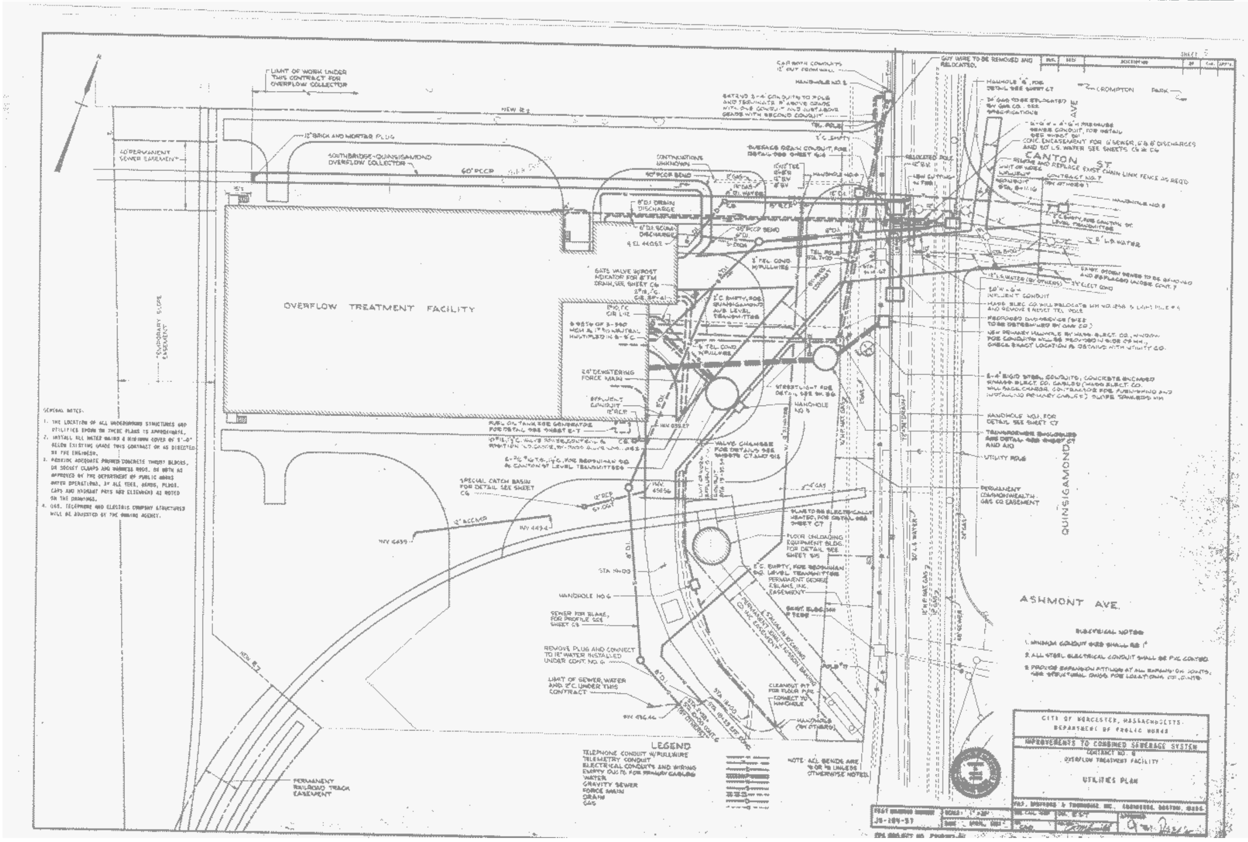
Max Depth of Cross section, length, and shape of the Conduit





SEYMOUR ST
MILLBURY STREET
MILL BROOK 13.0 X 18.0 SEWER
CANTON STREET
ASHMONT AVE.
ARWICK AVE.
QUINSIGAMOND AVENUE
HARDING STREET
CAMBRIDGE STREET
GARFIELD STREET
I-290
REGULATOR
22
27
28
29
30
DATE 3-14-78
TRACED BY NANA
PRINTED BY NANA
CHECKED BY P.C.
WORCESTER SEWER DEPT
WORCESTER, MASS.
SCALE: ONE INCH = 80 FT.
BOOK NO. 5 SHEET NO. 23
C.E.T.A. PROJECT VI


DRAIN
FORCE MAIN SEWER
6" DRAIN DISCHARGE
SEWER
PROFILES
CITY OF WORCESTER, MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS
IMPROVEMENTS TO COMBINED SEWERAGE SYSTEM
OVERFLOW TREATMENT FACILITY
UTILITIES PROFILES PART 1
SHEET C5


OVERFLOW TREATMENT FACILITY
CANTON ST
QUINSIGAMOND AVE
ASHMONT AVE.
LEGEND
CITY OF WORCESTER, MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS
IMPROVEMENTS TO COMBINED SEWERAGE SYSTEM
OVERFLOW TREATMENT FACILITY
UTILITIES PLAN

Appendix D: Design Storms

5/8/2010 Design Storm						
ID	Year	Month	Day	Hour	Minute	Rainfall (in)
1	2008	3	6	0	0	0
1	2008	3	6	0	15	0
1	2008	3	6	0	30	0
1	2008	3	6	0	45	0
1	2008	3	6	1	0	0
1	2008	3	6	1	15	0
1	2008	3	6	1	30	0
1	2008	3	6	1	45	0
1	2008	3	6	2	0	0
1	2008	3	6	2	15	0
1	2008	3	6	2	30	0
1	2008	3	6	2	45	0
1	2008	3	6	3	0	0
1	2008	3	6	3	15	0
1	2008	3	6	3	30	0
1	2008	3	6	3	45	0
1	2008	3	6	4	0	0
1	2008	3	6	4	15	0
1	2008	3	6	4	30	0
1	2008	3	6	4	45	0
1	2008	3	6	5	0	0
1	2008	3	6	5	15	0
1	2008	3	6	5	30	0
1	2008	3	6	5	45	0
1	2008	3	6	6	0	0
1	2008	3	6	6	15	0
1	2008	3	6	6	30	0
1	2008	3	6	6	45	0
1	2008	3	6	7	0	0
1	2008	3	6	7	15	0
1	2008	3	6	7	30	0
1	2008	3	6	7	45	0
1	2008	3	6	8	0	0

1	2008	3	6	8	15	0
1	2008	3	6	8	30	0
1	2008	3	6	8	45	0
1	2008	3	6	9	0	0
1	2008	3	6	9	15	0
1	2008	3	6	9	30	0
1	2008	3	6	9	45	0
1	2008	3	6	10	0	0
1	2008	3	6	10	15	0
1	2008	3	6	10	30	0
1	2008	3	6	10	45	0
1	2008	3	6	11	0	0
1	2008	3	6	11	15	0
1	2008	3	6	11	30	0
1	2008	3	6	11	45	0
1	2008	3	6	12	0	0
1	2008	3	6	12	15	0
1	2008	3	6	12	30	0
1	2008	3	6	12	45	0
1	2008	3	6	13	0	0
1	2008	3	6	13	15	0
1	2008	3	6	13	30	0
1	2008	3	6	13	45	0
1	2008	3	6	14	0	0
1	2008	3	6	14	15	0
1	2008	3	6	14	30	0
1	2008	3	6	14	45	0
1	2008	3	6	15	0	0
1	2008	3	6	15	15	0
1	2008	3	6	15	30	0
1	2008	3	6	15	45	0
1	2008	3	6	16	0	0
1	2008	3	6	16	15	0
1	2008	3	6	16	30	0
1	2008	3	6	16	45	0
1	2008	3	6	17	0	0
1	2008	3	6	17	15	0
1	2008	3	6	17	30	0
1	2008	3	6	17	45	0

1	2008	3	6	18	0	0
1	2008	3	6	18	15	0
1	2008	3	6	18	30	0
1	2008	3	6	18	45	0
1	2008	3	6	19	0	0
1	2008	3	6	19	15	0
1	2008	3	6	19	30	0
1	2008	3	6	19	45	0
1	2008	3	6	20	0	0
1	2008	3	6	20	15	0
1	2008	3	6	20	30	0
1	2008	3	6	20	45	0
1	2008	3	6	21	0	0
1	2008	3	6	21	15	0
1	2008	3	6	21	30	0
1	2008	3	6	21	45	0
1	2008	3	6	22	0	0
1	2008	3	6	22	15	0
1	2008	3	6	22	30	0
1	2008	3	6	22	45	0
1	2008	3	6	23	0	0
1	2008	3	6	23	15	0
1	2008	3	6	23	30	0
1	2008	3	6	23	45	0
1	2008	3	6	24	0	0
11	2008	3	7	0	15	0
1	2008	3	7	0	30	0
1	2008	3	7	0	45	0
1	2008	3	7	1	0	0
1	2008	3	7	1	15	0
1	2008	3	7	1	30	0
1	2008	3	7	1	45	0
1	2008	3	7	2	0	0
1	2008	3	7	2	15	0
1	2008	3	7	2	30	0
1	2008	3	7	2	45	0
1	2008	3	7	3	0	0
1	2008	3	7	3	15	0
1	2008	3	7	3	30	0

1	2008	3	7	3	45	0
1	2008	3	7	4	0	0
1	2008	3	7	4	15	0
1	2008	3	7	4	30	0
1	2008	3	7	4	45	0
1	2008	3	7	5	0	0.06
1	2008	3	7	5	15	0
1	2008	3	7	5	30	0.04
1	2008	3	7	5	45	0.07
1	2008	3	7	6	0	0.04
1	2008	3	7	6	15	0.01
1	2008	3	7	6	30	0
1	2008	3	7	6	45	0
1	2008	3	7	7	0	0
1	2008	3	7	7	15	0
1	2008	3	7	7	30	0
1	2008	3	7	7	45	0
1	2008	3	7	8	0	0
1	2008	3	7	8	15	0
1	2008	3	7	8	30	0
1	2008	3	7	8	45	0.05
1	2008	3	7	9	0	0.05
1	2008	3	7	9	15	0.06
1	2008	3	7	9	30	0.06
1	2008	3	7	9	45	0
1	2008	3	7	10	0	0.01
1	2008	3	7	10	15	0.01
1	2008	3	7	10	30	0.02
1	2008	3	7	10	45	0.03
1	2008	3	7	11	0	0.2
1	2008	3	7	11	15	0.18
1	2008	3	7	11	30	0.05
1	2008	3	7	11	45	0.02
1	2008	3	7	12	0	0.03
1	2008	3	7	12	15	0
1	2008	3	7	12	30	0.01
1	2008	3	7	12	45	0
1	2008	3	7	13	0	0
1	2008	3	7	13	15	0

1	2008	3	7	13	30	0
1	2008	3	7	13	45	0
1	2008	3	7	14	0	0
1	2008	3	7	14	15	0
1	2008	3	7	14	30	0
1	2008	3	7	14	45	0
1	2008	3	7	15	0	0
1	2008	3	7	15	15	0
1	2008	3	7	15	30	0
1	2008	3	7	15	45	0
1	2008	3	7	16	0	0
1	2008	3	7	16	15	0
1	2008	3	7	16	30	0
1	2008	3	7	16	45	0
1	2008	3	7	17	0	0
1	2008	3	7	17	15	0
1	2008	3	7	17	30	0
1	2008	3	7	17	45	0
1	2008	3	7	18	0	0
1	2008	3	7	18	15	0
1	2008	3	7	18	30	0.01
1	2008	3	7	18	45	0.04
1	2008	3	7	19	0	0.01
1	2008	3	7	19	15	0.02
1	2008	3	7	19	30	0
1	2008	3	7	19	45	0
1	2008	3	7	20	0	0
1	2008	3	7	20	15	0
1	2008	3	7	20	30	0
1	2008	3	7	20	45	0
1	2008	3	7	21	0	0
1	2008	3	7	21	15	0
1	2008	3	7	21	30	0
1	2008	3	7	21	45	0
1	2008	3	7	22	0	0.01
1	2008	3	7	22	15	0
1	2008	3	7	22	30	0
1	2008	3	7	22	45	0
1	2008	3	7	23	0	0

1	2008	3	7	23	15	0
1	2008	3	7	23	30	0
1	2008	3	7	23	45	0
1	2008	3	7	24	0	0
1	2008	3	8	0	15	0.00
1	2008	3	8	0	30	0.00
1	2008	3	8	0	45	0.00
1	2008	3	8	1	0	0.00
1	2008	3	8	1	15	0.00
1	2008	3	8	1	30	0.00
1	2008	3	8	1	45	0.00
1	2008	3	8	2	0	0.00
1	2008	3	8	2	15	0.00
1	2008	3	8	2	30	0.00
1	2008	3	8	2	45	0.00
1	2008	3	8	3	0	0.00
1	2008	3	8	3	15	0.00
1	2008	3	8	3	30	0.00
1	2008	3	8	3	45	0.00
1	2008	3	8	4	0	0.00
1	2008	3	8	4	15	0.00
1	2008	3	8	4	30	0.00
1	2008	3	8	4	45	0.00
1	2008	3	8	5	0	0.00
1	2008	3	8	5	15	0.00
1	2008	3	8	5	30	0.00
1	2008	3	8	5	45	0.00
1	2008	3	8	6	0	0.00
1	2008	3	8	6	15	0.00
1	2008	3	8	6	30	0.00
1	2008	3	8	6	45	0.00
1	2008	3	8	7	0	0.00
1	2008	3	8	7	15	0.00
1	2008	3	8	7	30	0.00
1	2008	3	8	7	45	0.00
1	2008	3	8	8	0	0.00
1	2008	3	8	8	15	0.00
1	2008	3	8	8	30	0.00
1	2008	3	8	8	45	0.00

	1	2008	3	8	9	0	0.00
	1	2008	3	8	9	15	0.00
	1	2008	3	8	9	30	0.00
	1	2008	3	8	9	45	0.00
	1	2008	3	8	10	0	0.00
	1	2008	3	8	10	15	0.00
	1	2008	3	8	10	30	0.00
	1	2008	3	8	10	45	0.00
	1	2008	3	8	11	0	0.00
	1	2008	3	8	11	15	0.00
	1	2008	3	8	11	30	0.00
	1	2008	3	8	11	45	0.00
	1	2008	3	8	12	0	0.00
	1	2008	3	8	12	15	0.00
	1	2008	3	8	12	30	0.00
	1	2008	3	8	12	45	0.00
	1	2008	3	8	13	0	0.00
	1	2008	3	8	13	15	0.00
	1	2008	3	8	13	30	0.00
	1	2008	3	8	13	45	0.00
	1	2008	3	8	14	0	0.00
	1	2008	3	8	14	15	0.00
	1	2008	3	8	14	30	0.00
	1	2008	3	8	14	45	0.00
	1	2008	3	8	15	0	0.00
	1	2008	3	8	15	15	0.00
	1	2008	3	8	15	30	0.00
	1	2008	3	8	15	45	0.00
	1	2008	3	8	16	0	0.00
	1	2008	3	8	16	15	0.00
	1	2008	3	8	16	30	0.00
	1	2008	3	8	16	45	0.00
	1	2008	3	8	17	0	0.00
	1	2008	3	8	17	15	0.00
	1	2008	3	8	17	30	0.00
	1	2008	3	8	17	45	0.00
	1	2008	3	8	18	0	0.00
	1	2008	3	8	18	15	0.00
	1	2008	3	8	18	30	0.00

1	2008	3	8	18	45	0.00
1	2008	3	8	19	0	0.00
1	2008	3	8	19	15	0.00
1	2008	3	8	19	30	0.00
1	2008	3	8	19	45	0.00
1	2008	3	8	20	0	0.00
1	2008	3	8	20	15	0.00
1	2008	3	8	20	30	0.00
1	2008	3	8	20	45	0.00
1	2008	3	8	21	0	0.00
1	2008	3	8	21	15	0.00
1	2008	3	8	21	30	0.00
1	2008	3	8	21	45	0.00
1	2008	3	8	22	0	0.00
1	2008	3	8	22	15	0.00
1	2008	3	8	22	30	0.00
1	2008	3	8	22	45	0.00
1	2008	3	8	23	0	0.00
1	2008	3	8	23	15	0.00
1	2008	3	8	23	30	0.00
1	2008	3	8	23	45	0.00
1	2008	3	8	24	0	0.00

6/12/2010 Design Storm

ID	Year	Month	Day	Hour	Minute	Rainfall (in)
1	2008	3	6	0	0	0
1	2008	3	6	0	15	0
1	2008	3	6	0	30	0
1	2008	3	6	0	45	0
1	2008	3	6	1	0	0
1	2008	3	6	1	15	0
1	2008	3	6	1	30	0
1	2008	3	6	1	45	0
1	2008	3	6	2	0	0
1	2008	3	6	2	15	0
1	2008	3	6	2	30	0

	1	2008	3	6	2	45	0
	1	2008	3	6	3	0	0
	1	2008	3	6	3	15	0
	1	2008	3	6	3	30	0
	1	2008	3	6	3	45	0
	1	2008	3	6	4	0	0
	1	2008	3	6	4	15	0
	1	2008	3	6	4	30	0
	1	2008	3	6	4	45	0
	1	2008	3	6	5	0	0
	1	2008	3	6	5	15	0
	1	2008	3	6	5	30	0
	1	2008	3	6	5	45	0
	1	2008	3	6	6	0	0
	1	2008	3	6	6	15	0
	1	2008	3	6	6	30	0
	1	2008	3	6	6	45	0
	1	2008	3	6	7	0	0
	1	2008	3	6	7	15	0
	1	2008	3	6	7	30	0
	1	2008	3	6	7	45	0
	1	2008	3	6	8	0	0
	1	2008	3	6	8	15	0
	1	2008	3	6	8	30	0
	1	2008	3	6	8	45	0
	1	2008	3	6	9	0	0
	1	2008	3	6	9	15	0
	1	2008	3	6	9	30	0
	1	2008	3	6	9	45	0
	1	2008	3	6	10	0	0
	1	2008	3	6	10	15	0
	1	2008	3	6	10	30	0
	1	2008	3	6	10	45	0
	1	2008	3	6	11	0	0
	1	2008	3	6	11	15	0
	1	2008	3	6	11	30	0
	1	2008	3	6	11	45	0
	1	2008	3	6	12	0	0
	1	2008	3	6	12	15	0

1	2008	3	6	12	30	0
1	2008	3	6	12	45	0
1	2008	3	6	13	0	0
1	2008	3	6	13	15	0
1	2008	3	6	13	30	0
1	2008	3	6	13	45	0
1	2008	3	6	14	0	0
1	2008	3	6	14	15	0
1	2008	3	6	14	30	0
1	2008	3	6	14	45	0
1	2008	3	6	15	0	0
1	2008	3	6	15	15	0
1	2008	3	6	15	30	0
1	2008	3	6	15	45	0
1	2008	3	6	16	0	0
1	2008	3	6	16	15	0
1	2008	3	6	16	30	0
1	2008	3	6	16	45	0
1	2008	3	6	17	0	0
1	2008	3	6	17	15	0
1	2008	3	6	17	30	0
1	2008	3	6	17	45	0
1	2008	3	6	18	0	0
1	2008	3	6	18	15	0
1	2008	3	6	18	30	0
1	2008	3	6	18	45	0
1	2008	3	6	19	0	0
1	2008	3	6	19	15	0
1	2008	3	6	19	30	0
1	2008	3	6	19	45	0
1	2008	3	6	20	0	0
1	2008	3	6	20	15	0
1	2008	3	6	20	30	0
1	2008	3	6	20	45	0
1	2008	3	6	21	0	0
1	2008	3	6	21	15	0
1	2008	3	6	21	30	0
1	2008	3	6	21	45	0
1	2008	3	6	22	0	0

1	2008	3	6	22	15	0
1	2008	3	6	22	30	0
1	2008	3	6	22	45	0
1	2008	3	6	23	0	0
1	2008	3	6	23	15	0
1	2008	3	6	23	30	0
1	2008	3	6	23	45	0
1	2008	3	6	24	0	0
1	2008	3	7	0	15	0
1	2008	3	7	0	30	0
1	2008	3	7	0	45	0
1	2008	3	7	1	0	0
1	2008	3	7	1	15	0
1	2008	3	7	1	30	0
1	2008	3	7	1	45	0
1	2008	3	7	2	0	0
1	2008	3	7	2	15	0
1	2008	3	7	2	30	0
1	2008	3	7	2	45	0
1	2008	3	7	3	0	0
1	2008	3	7	3	15	0
1	2008	3	7	3	30	0
1	2008	3	7	3	45	0
1	2008	3	7	4	0	0
1	2008	3	7	4	15	0
1	2008	3	7	4	30	0
1	2008	3	7	4	45	0
1	2008	3	7	5	0	0
1	2008	3	7	5	15	0
1	2008	3	7	5	30	0
1	2008	3	7	5	45	0
1	2008	3	7	6	0	0
1	2008	3	7	6	15	0
1	2008	3	7	6	30	0
1	2008	3	7	6	45	0
1	2008	3	7	7	0	0
1	2008	3	7	7	15	0
1	2008	3	7	7	30	0
1	2008	3	7	7	45	0

1	2008	3	7	8	0	0
1	2008	3	7	8	15	0
1	2008	3	7	8	30	0
1	2008	3	7	8	45	0
1	2008	3	7	9	0	0
1	2008	3	7	9	15	0
1	2008	3	7	9	30	0
1	2008	3	7	9	45	0
1	2008	3	7	10	0	0
1	2008	3	7	10	15	0
1	2008	3	7	10	30	0
1	2008	3	7	10	45	0
1	2008	3	7	11	0	0
1	2008	3	7	11	15	0
1	2008	3	7	11	30	0
1	2008	3	7	11	45	0
1	2008	3	7	12	0	0
1	2008	3	7	12	15	0.03
1	2008	3	7	12	30	0
1	2008	3	7	12	45	0
1	2008	3	7	13	0	0
1	2008	3	7	13	15	0
1	2008	3	7	13	30	0
1	2008	3	7	13	45	0
1	2008	3	7	14	0	0
1	2008	3	7	14	15	0
1	2008	3	7	14	30	0
1	2008	3	7	14	45	0
1	2008	3	7	15	0	0
1	2008	3	7	15	15	0.01
1	2008	3	7	15	30	0.02
1	2008	3	7	15	45	0.02
1	2008	3	7	16	0	0.01
1	2008	3	7	16	15	0.02
1	2008	3	7	16	30	0.01
1	2008	3	7	16	45	0.02
1	2008	3	7	17	0	0.06
1	2008	3	7	17	15	0.09
1	2008	3	7	17	30	0.04

1	2008	3	7	17	45	0.01
1	2008	3	7	18	0	0.02
1	2008	3	7	18	15	0.01
1	2008	3	7	18	30	0.03
1	2008	3	7	18	45	0
1	2008	3	7	19	0	0
1	2008	3	7	19	15	0.01
1	2008	3	7	19	30	0.01
1	2008	3	7	19	45	0.01
1	2008	3	7	20	0	0
1	2008	3	7	20	15	0
1	2008	3	7	20	30	0
1	2008	3	7	20	45	0.01
1	2008	3	7	21	0	0
1	2008	3	7	21	15	0.01
1	2008	3	7	21	30	0.16
1	2008	3	7	21	45	0.04
1	2008	3	7	22	0	0.04
1	2008	3	7	22	15	0.02
1	2008	3	7	22	30	0.02
1	2008	3	7	22	45	0
1	2008	3	7	23	0	0
1	2008	3	7	23	15	0.01
1	2008	3	7	23	30	0.02
1	2008	3	7	23	45	0.01
1	2008	3	7	24	0	0
1	2008	3	8	0	15	0.00
1	2008	3	8	0	30	0.00
1	2008	3	8	0	45	0.00
1	2008	3	8	1	0	0.00
1	2008	3	8	1	15	0.00
1	2008	3	8	1	30	0.00
1	2008	3	8	1	45	0.00
1	2008	3	8	2	0	0.00
1	2008	3	8	2	15	0.00
1	2008	3	8	2	30	0.00
1	2008	3	8	2	45	0.00
1	2008	3	8	3	0	0.00
1	2008	3	8	3	15	0.00

	1	2008	3	8	3	30	0.00
	1	2008	3	8	3	45	0.00
	1	2008	3	8	4	0	0.00
	1	2008	3	8	4	15	0.00
	1	2008	3	8	4	30	0.00
	1	2008	3	8	4	45	0.00
	1	2008	3	8	5	0	0.00
	1	2008	3	8	5	15	0.00
	1	2008	3	8	5	30	0.00
	1	2008	3	8	5	45	0.00
	1	2008	3	8	6	0	0.00
	1	2008	3	8	6	15	0.00
	1	2008	3	8	6	30	0.00
	1	2008	3	8	6	45	0.00
	1	2008	3	8	7	0	0.00
	1	2008	3	8	7	15	0.00
	1	2008	3	8	7	30	0.00
	1	2008	3	8	7	45	0.00
	1	2008	3	8	8	0	0.00
	1	2008	3	8	8	15	0.00
	1	2008	3	8	8	30	0.00
	1	2008	3	8	8	45	0.00
	1	2008	3	8	9	0	0.00
	1	2008	3	8	9	15	0.00
	1	2008	3	8	9	30	0.00
	1	2008	3	8	9	45	0.00
	1	2008	3	8	10	0	0.00
	1	2008	3	8	10	15	0.00
	1	2008	3	8	10	30	0.00
	1	2008	3	8	10	45	0.00
	1	2008	3	8	11	0	0.00
	1	2008	3	8	11	15	0.00
	1	2008	3	8	11	30	0.00
	1	2008	3	8	11	45	0.00
	1	2008	3	8	12	0	0.00
	1	2008	3	8	12	15	0.00
	1	2008	3	8	12	30	0.00
	1	2008	3	8	12	45	0.00
	1	2008	3	8	13	0	0.00

	1	2008	3	8	13	15	0.00
	1	2008	3	8	13	30	0.00
	1	2008	3	8	13	45	0.00
	1	2008	3	8	14	0	0.00
	1	2008	3	8	14	15	0.00
	1	2008	3	8	14	30	0.00
	1	2008	3	8	14	45	0.00
	1	2008	3	8	15	0	0.00
	1	2008	3	8	15	15	0.00
	1	2008	3	8	15	30	0.00
	1	2008	3	8	15	45	0.00
	1	2008	3	8	16	0	0.00
	1	2008	3	8	16	15	0.00
	1	2008	3	8	16	30	0.00
	1	2008	3	8	16	45	0.00
	1	2008	3	8	17	0	0.00
	1	2008	3	8	17	15	0.00
	1	2008	3	8	17	30	0.00
	1	2008	3	8	17	45	0.00
	1	2008	3	8	18	0	0.00
	1	2008	3	8	18	15	0.00
	1	2008	3	8	18	30	0.00
	1	2008	3	8	18	45	0.00
	1	2008	3	8	19	0	0.00
	1	2008	3	8	19	15	0.00
	1	2008	3	8	19	30	0.00
	1	2008	3	8	19	45	0.00
	1	2008	3	8	20	0	0.00
	1	2008	3	8	20	15	0.00
	1	2008	3	8	20	30	0.00
	1	2008	3	8	20	45	0.00
	1	2008	3	8	21	0	0.00
	1	2008	3	8	21	15	0.00
	1	2008	3	8	21	30	0.00
	1	2008	3	8	21	45	0.00
	1	2008	3	8	22	0	0.00
	1	2008	3	8	22	15	0.00
	1	2008	3	8	22	30	0.00
	1	2008	3	8	22	45	0.00

1	2008	3	8	23	0	0.00
1	2008	3	8	23	15	0.00
1	2008	3	8	23	30	0.00
1	2008	3	8	23	45	0.00
1	2008	3	8	24	0	0.00

3 Month – 24 Hour Storm

ID	Year	Month	Day	Hour	Minute	Rainfall (in)
1	2008	3	6	0	0	0
1	2008	3	6	0	15	0
1	2008	3	6	0	30	0
1	2008	3	6	0	45	0
1	2008	3	6	1	0	0
1	2008	3	6	1	15	0
1	2008	3	6	1	30	0
1	2008	3	6	1	45	0
1	2008	3	6	2	0	0
1	2008	3	6	2	15	0
1	2008	3	6	2	30	0
1	2008	3	6	2	45	0
1	2008	3	6	3	0	0
1	2008	3	6	3	15	0
1	2008	3	6	3	30	0
1	2008	3	6	3	45	0
1	2008	3	6	4	0	0
1	2008	3	6	4	15	0
1	2008	3	6	4	30	0
1	2008	3	6	4	45	0
1	2008	3	6	5	0	0
1	2008	3	6	5	15	0
1	2008	3	6	5	30	0
1	2008	3	6	5	45	0
1	2008	3	6	6	0	0
1	2008	3	6	6	15	0
1	2008	3	6	6	30	0
1	2008	3	6	6	45	0
1	2008	3	6	7	0	0
1	2008	3	6	7	15	0
1	2008	3	6	7	30	0
1	2008	3	6	7	45	0
1	2008	3	6	8	0	0
1	2008	3	6	8	15	0

1	2008	3	6	8	30	0
1	2008	3	6	8	45	0
1	2008	3	6	9	0	0
1	2008	3	6	9	15	0
1	2008	3	6	9	30	0
1	2008	3	6	9	45	0
1	2008	3	6	10	0	0
1	2008	3	6	10	15	0
1	2008	3	6	10	30	0
1	2008	3	6	10	45	0
1	2008	3	6	11	0	0
1	2008	3	6	11	15	0
1	2008	3	6	11	30	0
1	2008	3	6	11	45	0
1	2008	3	6	12	0	0
1	2008	3	6	12	15	0
1	2008	3	6	12	30	0
1	2008	3	6	12	45	0
1	2008	3	6	13	0	0
1	2008	3	6	13	15	0
1	2008	3	6	13	30	0
1	2008	3	6	13	45	0
1	2008	3	6	14	0	0
1	2008	3	6	14	15	0
1	2008	3	6	14	30	0
1	2008	3	6	14	45	0
1	2008	3	6	15	0	0
1	2008	3	6	15	15	0
1	2008	3	6	15	30	0
1	2008	3	6	15	45	0
1	2008	3	6	16	0	0
1	2008	3	6	16	15	0
1	2008	3	6	16	30	0
1	2008	3	6	16	45	0
1	2008	3	6	17	0	0
1	2008	3	6	17	15	0
1	2008	3	6	17	30	0
1	2008	3	6	17	45	0
1	2008	3	6	18	0	0
1	2008	3	6	18	15	0
1	2008	3	6	18	30	0
1	2008	3	6	18	45	0
1	2008	3	6	19	0	0
1	2008	3	6	19	15	0
1	2008	3	6	19	30	0
1	2008	3	6	19	45	0
1	2008	3	6	20	0	0

1	2008	3	6	20	15	0
1	2008	3	6	20	30	0
1	2008	3	6	20	45	0
1	2008	3	6	21	0	0
1	2008	3	6	21	15	0
1	2008	3	6	21	30	0
1	2008	3	6	21	45	0
1	2008	3	6	22	0	0
1	2008	3	6	22	15	0
1	2008	3	6	22	30	0
1	2008	3	6	22	45	0
1	2008	3	6	23	0	0
1	2008	3	6	23	15	0
1	2008	3	6	23	30	0
1	2008	3	6	23	45	0
1	2008	3	6	24	0	0
1	2008	3	7	0	15	0.00
1	2008	3	7	0	30	0.00
1	2008	3	7	0	45	0.00
1	2008	3	7	1	0	0.00
1	2008	3	7	1	15	0.00
1	2008	3	7	1	30	0.00
1	2008	3	7	1	45	0.00
1	2008	3	7	2	0	0.00
1	2008	3	7	2	15	0.01
1	2008	3	7	2	30	0.01
1	2008	3	7	2	45	0.01
1	2008	3	7	3	0	0.01
1	2008	3	7	3	15	0.01
1	2008	3	7	3	30	0.01
1	2008	3	7	3	45	0.01
1	2008	3	7	4	0	0.01
1	2008	3	7	4	15	0.01
1	2008	3	7	4	30	0.01
1	2008	3	7	4	45	0.01
1	2008	3	7	5	0	0.01
1	2008	3	7	5	15	0.01
1	2008	3	7	5	30	0.01
1	2008	3	7	5	45	0.01
1	2008	3	7	6	0	0.01
1	2008	3	7	6	15	0.01
1	2008	3	7	6	30	0.01
1	2008	3	7	6	45	0.01
1	2008	3	7	7	0	0.01
1	2008	3	7	7	15	0.01
1	2008	3	7	7	30	0.01
1	2008	3	7	7	45	0.01

	1	2008	3	7	8	0	0.01
	1	2008	3	7	8	15	0.01
	1	2008	3	7	8	30	0.01
	1	2008	3	7	8	45	0.02
	1	2008	3	7	9	0	0.02
	1	2008	3	7	9	15	0.02
	1	2008	3	7	9	30	0.02
	1	2008	3	7	9	45	0.02
	1	2008	3	7	10	0	0.02
	1	2008	3	7	10	15	0.02
	1	2008	3	7	10	30	0.02
	1	2008	3	7	10	45	0.03
	1	2008	3	7	11	0	0.03
	1	2008	3	7	11	15	0.04
	1	2008	3	7	11	30	0.04
	1	2008	3	7	11	45	0.07
	1	2008	3	7	12	0	0.29
	1	2008	3	7	12	15	0.18
	1	2008	3	7	12	30	0.18
	1	2008	3	7	12	45	0.04
	1	2008	3	7	13	0	0.04
	1	2008	3	7	13	15	0.03
	1	2008	3	7	13	30	0.03
	1	2008	3	7	13	45	0.02
	1	2008	3	7	14	0	0.02
	1	2008	3	7	14	15	0.02
	1	2008	3	7	14	30	0.02
	1	2008	3	7	14	45	0.02
	1	2008	3	7	15	0	0.02
	1	2008	3	7	15	15	0.02
	1	2008	3	7	15	30	0.02
	1	2008	3	7	15	45	0.02
	1	2008	3	7	16	0	0.02
	1	2008	3	7	16	15	0.01
	1	2008	3	7	16	30	0.01
	1	2008	3	7	16	45	0.01
	1	2008	3	7	17	0	0.01
	1	2008	3	7	17	15	0.01
	1	2008	3	7	17	30	0.01
	1	2008	3	7	17	45	0.01
	1	2008	3	7	18	0	0.01
	1	2008	3	7	18	15	0.01
	1	2008	3	7	18	30	0.01
	1	2008	3	7	18	45	0.01
	1	2008	3	7	19	0	0.01
	1	2008	3	7	19	15	0.01
	1	2008	3	7	19	30	0.01

1	2008	3	7	19	45	0.01
1	2008	3	7	20	0	0.01
1	2008	3	7	20	15	0.00
1	2008	3	7	20	30	0.00
1	2008	3	7	20	45	0.00
1	2008	3	7	21	0	0.00
1	2008	3	7	21	15	0.00
1	2008	3	7	21	30	0.00
1	2008	3	7	21	45	0.00
1	2008	3	7	22	0	0.00
1	2008	3	7	22	15	0.00
1	2008	3	7	22	30	0.00
1	2008	3	7	22	45	0.00
1	2008	3	7	23	0	0.00
1	2008	3	7	23	15	0.00
1	2008	3	7	23	30	0.00
1	2008	3	7	23	45	0.00
1	2008	3	7	24	0	0.00
1	2008	3	8	0	15	0.00
1	2008	3	8	0	30	0.00
1	2008	3	8	0	45	0.00
1	2008	3	8	1	0	0.00
1	2008	3	8	1	15	0.00
1	2008	3	8	1	30	0.00
1	2008	3	8	1	45	0.00
1	2008	3	8	2	0	0.00
1	2008	3	8	2	15	0.00
1	2008	3	8	2	30	0.00
1	2008	3	8	2	45	0.00
1	2008	3	8	3	0	0.00
1	2008	3	8	3	15	0.00
1	2008	3	8	3	30	0.00
1	2008	3	8	3	45	0.00
1	2008	3	8	4	0	0.00
1	2008	3	8	4	15	0.00
1	2008	3	8	4	30	0.00
1	2008	3	8	4	45	0.00
1	2008	3	8	5	0	0.00
1	2008	3	8	5	15	0.00
1	2008	3	8	5	30	0.00
1	2008	3	8	5	45	0.00
1	2008	3	8	6	0	0.00
1	2008	3	8	6	15	0.00
1	2008	3	8	6	30	0.00
1	2008	3	8	6	45	0.00
1	2008	3	8	7	0	0.00
1	2008	3	8	7	15	0.00

1	2008	3	8	7	30	0.00
1	2008	3	8	7	45	0.00
1	2008	3	8	8	0	0.00
1	2008	3	8	8	15	0.00
1	2008	3	8	8	30	0.00
1	2008	3	8	8	45	0.00
1	2008	3	8	9	0	0.00
1	2008	3	8	9	15	0.00
1	2008	3	8	9	30	0.00
1	2008	3	8	9	45	0.00
1	2008	3	8	10	0	0.00
1	2008	3	8	10	15	0.00
1	2008	3	8	10	30	0.00
1	2008	3	8	10	45	0.00
1	2008	3	8	11	0	0.00
1	2008	3	8	11	15	0.00
1	2008	3	8	11	30	0.00
1	2008	3	8	11	45	0.00
1	2008	3	8	12	0	0.00
1	2008	3	8	12	15	0.00
1	2008	3	8	12	30	0.00
1	2008	3	8	12	45	0.00
1	2008	3	8	13	0	0.00
1	2008	3	8	13	15	0.00
1	2008	3	8	13	30	0.00
1	2008	3	8	13	45	0.00
1	2008	3	8	14	0	0.00
1	2008	3	8	14	15	0.00
1	2008	3	8	14	30	0.00
1	2008	3	8	14	45	0.00
1	2008	3	8	15	0	0.00
1	2008	3	8	15	15	0.00
1	2008	3	8	15	30	0.00
1	2008	3	8	15	45	0.00
1	2008	3	8	16	0	0.00
1	2008	3	8	16	15	0.00
1	2008	3	8	16	30	0.00
1	2008	3	8	16	45	0.00
1	2008	3	8	17	0	0.00
1	2008	3	8	17	15	0.00
1	2008	3	8	17	30	0.00
1	2008	3	8	17	45	0.00
1	2008	3	8	18	0	0.00
1	2008	3	8	18	15	0.00
1	2008	3	8	18	30	0.00
1	2008	3	8	18	45	0.00
1	2008	3	8	19	0	0.00

1	2008	3	8	19	15	0.00
1	2008	3	8	19	30	0.00
1	2008	3	8	19	45	0.00
1	2008	3	8	20	0	0.00
1	2008	3	8	20	15	0.00
1	2008	3	8	20	30	0.00
1	2008	3	8	20	45	0.00
1	2008	3	8	21	0	0.00
1	2008	3	8	21	15	0.00
1	2008	3	8	21	30	0.00
1	2008	3	8	21	45	0.00
1	2008	3	8	22	0	0.00
1	2008	3	8	22	15	0.00
1	2008	3	8	22	30	0.00
1	2008	3	8	22	45	0.00
1	2008	3	8	23	0	0.00
1	2008	3	8	23	15	0.00
1	2008	3	8	23	30	0.00
1	2008	3	8	23	45	0.00
1	2008	3	8	24	0	0.00

1 Year – 24 Hour Storm

ID	Year	Month	Day	Hour	Minute	Rainfall (in)
1	2008	3	6	0	0	0
1	2008	3	6	0	15	0
1	2008	3	6	0	30	0
1	2008	3	6	0	45	0
1	2008	3	6	1	0	0
1	2008	3	6	1	15	0
1	2008	3	6	1	30	0
1	2008	3	6	1	45	0
1	2008	3	6	2	0	0
1	2008	3	6	2	15	0
1	2008	3	6	2	30	0
1	2008	3	6	2	45	0
1	2008	3	6	3	0	0
1	2008	3	6	3	15	0
1	2008	3	6	3	30	0
1	2008	3	6	3	45	0
1	2008	3	6	4	0	0
1	2008	3	6	4	15	0

	1	2008	3	6	4	30	0	
	1	2008	3	6	4	45	0	
	1	2008	3	6	5	0	0	
	1	2008	3	6	5	15	0	
	1	2008	3	6	5	30	0	
	1	2008	3	6	5	45	0	
	1	2008	3	6	6	0	0	
	1	2008	3	6	6	15	0	
	1	2008	3	6	6	30	0	
	1	2008	3	6	6	45	0	
	1	2008	3	6	7	0	0	
	1	2008	3	6	7	15	0	
	1	2008	3	6	7	30	0	
	1	2008	3	6	7	45	0	
	1	2008	3	6	8	0	0	
	1	2008	3	6	8	15	0	
	1	2008	3	6	8	30	0	
	1	2008	3	6	8	45	0	
	1	2008	3	6	9	0	0	
	1	2008	3	6	9	15	0	
	1	2008	3	6	9	30	0	
	1	2008	3	6	9	45	0	
	1	2008	3	6	10	0	0	
	1	2008	3	6	10	15	0	
	1	2008	3	6	10	30	0	
	1	2008	3	6	10	45	0	
	1	2008	3	6	11	0	0	
	1	2008	3	6	11	15	0	
	1	2008	3	6	11	30	0	
	1	2008	3	6	11	45	0	
	1	2008	3	6	12	0	0	
	1	2008	3	6	12	15	0	
	1	2008	3	6	12	30	0	
	1	2008	3	6	12	45	0	
	1	2008	3	6	13	0	0	
	1	2008	3	6	13	15	0	
	1	2008	3	6	13	30	0	
	1	2008	3	6	13	45	0	
	1	2008	3	6	14	0	0	
	1	2008	3	6	14	15	0	
	1	2008	3	6	14	30	0	
	1	2008	3	6	14	45	0	
	1	2008	3	6	15	0	0	
	1	2008	3	6	15	15	0	
	1	2008	3	6	15	30	0	
	1	2008	3	6	15	45	0	
	1	2008	3	6	16	0	0	

1	2008	3	6	16	15	0
1	2008	3	6	16	30	0
1	2008	3	6	16	45	0
1	2008	3	6	17	0	0
1	2008	3	6	17	15	0
1	2008	3	6	17	30	0
1	2008	3	6	17	45	0
1	2008	3	6	18	0	0
1	2008	3	6	18	15	0
1	2008	3	6	18	30	0
1	2008	3	6	18	45	0
1	2008	3	6	19	0	0
1	2008	3	6	19	15	0
1	2008	3	6	19	30	0
1	2008	3	6	19	45	0
1	2008	3	6	20	0	0
1	2008	3	6	20	15	0
1	2008	3	6	20	30	0
1	2008	3	6	20	45	0
1	2008	3	6	21	0	0
1	2008	3	6	21	15	0
1	2008	3	6	21	30	0
1	2008	3	6	21	45	0
1	2008	3	6	22	0	0
1	2008	3	6	22	15	0
1	2008	3	6	22	30	0
1	2008	3	6	22	45	0
1	2008	3	6	23	0	0
1	2008	3	6	23	15	0
1	2008	3	6	23	30	0
1	2008	3	6	23	45	0
1	2008	3	6	24	0	0
1	2008	3	7	0	15	0.01
1	2008	3	7	0	30	0.01
1	2008	3	7	0	45	0.01
1	2008	3	7	1	0	0.01
1	2008	3	7	1	15	0.01
1	2008	3	7	1	30	0.01
1	2008	3	7	1	45	0.01
1	2008	3	7	2	0	0.01
1	2008	3	7	2	15	0.01
1	2008	3	7	2	30	0.01
1	2008	3	7	2	45	0.01
1	2008	3	7	3	0	0.01
1	2008	3	7	3	15	0.01
1	2008	3	7	3	30	0.01
1	2008	3	7	3	45	0.01

1	2008	3	7	4	0	0.01
1	2008	3	7	4	15	0.01
1	2008	3	7	4	30	0.01
1	2008	3	7	4	45	0.01
1	2008	3	7	5	0	0.01
1	2008	3	7	5	15	0.01
1	2008	3	7	5	30	0.01
1	2008	3	7	5	45	0.01
1	2008	3	7	6	0	0.01
1	2008	3	7	6	15	0.01
1	2008	3	7	6	30	0.01
1	2008	3	7	6	45	0.01
1	2008	3	7	7	0	0.01
1	2008	3	7	7	15	0.02
1	2008	3	7	7	30	0.02
1	2008	3	7	7	45	0.02
1	2008	3	7	8	0	0.02
1	2008	3	7	8	15	0.02
1	2008	3	7	8	30	0.02
1	2008	3	7	8	45	0.02
1	2008	3	7	9	0	0.02
1	2008	3	7	9	15	0.02
1	2008	3	7	9	30	0.02
1	2008	3	7	9	45	0.03
1	2008	3	7	10	0	0.03
1	2008	3	7	10	15	0.04
1	2008	3	7	10	30	0.04
1	2008	3	7	10	45	0.04
1	2008	3	7	11	0	0.04
1	2008	3	7	11	15	0.06
1	2008	3	7	11	30	0.06
1	2008	3	7	11	45	0.11
1	2008	3	7	12	0	0.42
1	2008	3	7	12	15	0.26
1	2008	3	7	12	30	0.26
1	2008	3	7	12	45	0.06
1	2008	3	7	13	0	0.06
1	2008	3	7	13	15	0.04
1	2008	3	7	13	30	0.04
1	2008	3	7	13	45	0.03
1	2008	3	7	14	0	0.03
1	2008	3	7	14	15	0.02
1	2008	3	7	14	30	0.02
1	2008	3	7	14	45	0.02
1	2008	3	7	15	0	0.02
1	2008	3	7	15	15	0.02
1	2008	3	7	15	30	0.02

1	2008	3	7	15	45	0.02
1	2008	3	7	16	0	0.02
1	2008	3	7	16	15	0.01
1	2008	3	7	16	30	0.01
1	2008	3	7	16	45	0.01
1	2008	3	7	17	0	0.01
1	2008	3	7	17	15	0.01
1	2008	3	7	17	30	0.01
1	2008	3	7	17	45	0.01
1	2008	3	7	18	0	0.01
1	2008	3	7	18	15	0.01
1	2008	3	7	18	30	0.01
1	2008	3	7	18	45	0.01
1	2008	3	7	19	0	0.01
1	2008	3	7	19	15	0.01
1	2008	3	7	19	30	0.01
1	2008	3	7	19	45	0.01
1	2008	3	7	20	0	0.01
1	2008	3	7	20	15	0.01
1	2008	3	7	20	30	0.01
1	2008	3	7	20	45	0.01
1	2008	3	7	21	0	0.01
1	2008	3	7	21	15	0.01
1	2008	3	7	21	30	0.01
1	2008	3	7	21	45	0.01
1	2008	3	7	22	0	0.01
1	2008	3	7	22	15	0.01
1	2008	3	7	22	30	0.01
1	2008	3	7	22	45	0.01
1	2008	3	7	23	0	0.01
1	2008	3	7	23	15	0.01
1	2008	3	7	23	30	0.01
1	2008	3	7	23	45	0.01
1	2008	3	7	24	0	0.01
1	2008	3	8	0	15	0.00
1	2008	3	8	0	30	0.00
1	2008	3	8	0	45	0.00
1	2008	3	8	1	0	0.00
1	2008	3	8	1	15	0.00
1	2008	3	8	1	30	0.00
1	2008	3	8	1	45	0.00
1	2008	3	8	2	0	0.00
1	2008	3	8	2	15	0.00
1	2008	3	8	2	30	0.00
1	2008	3	8	2	45	0.00
1	2008	3	8	3	0	0.00
1	2008	3	8	3	15	0.00

1	2008	3	8	3	30	0.00
1	2008	3	8	3	45	0.00
1	2008	3	8	4	0	0.00
1	2008	3	8	4	15	0.00
1	2008	3	8	4	30	0.00
1	2008	3	8	4	45	0.00
1	2008	3	8	5	0	0.00
1	2008	3	8	5	15	0.00
1	2008	3	8	5	30	0.00
1	2008	3	8	5	45	0.00
1	2008	3	8	6	0	0.00
1	2008	3	8	6	15	0.00
1	2008	3	8	6	30	0.00
1	2008	3	8	6	45	0.00
1	2008	3	8	7	0	0.00
1	2008	3	8	7	15	0.00
1	2008	3	8	7	30	0.00
1	2008	3	8	7	45	0.00
1	2008	3	8	8	0	0.00
1	2008	3	8	8	15	0.00
1	2008	3	8	8	30	0.00
1	2008	3	8	8	45	0.00
1	2008	3	8	9	0	0.00
1	2008	3	8	9	15	0.00
1	2008	3	8	9	30	0.00
1	2008	3	8	9	45	0.00
1	2008	3	8	10	0	0.00
1	2008	3	8	10	15	0.00
1	2008	3	8	10	30	0.00
1	2008	3	8	10	45	0.00
1	2008	3	8	11	0	0.00
1	2008	3	8	11	15	0.00
1	2008	3	8	11	30	0.00
1	2008	3	8	11	45	0.00
1	2008	3	8	12	0	0.00
1	2008	3	8	12	15	0.00
1	2008	3	8	12	30	0.00
1	2008	3	8	12	45	0.00
1	2008	3	8	13	0	0.00
1	2008	3	8	13	15	0.00
1	2008	3	8	13	30	0.00
1	2008	3	8	13	45	0.00
1	2008	3	8	14	0	0.00
1	2008	3	8	14	15	0.00
1	2008	3	8	14	30	0.00
1	2008	3	8	14	45	0.00
1	2008	3	8	15	0	0.00

1	2008	3	8	15	15	0.00
1	2008	3	8	15	30	0.00
1	2008	3	8	15	45	0.00
1	2008	3	8	16	0	0.00
1	2008	3	8	16	15	0.00
1	2008	3	8	16	30	0.00
1	2008	3	8	16	45	0.00
1	2008	3	8	17	0	0.00
1	2008	3	8	17	15	0.00
1	2008	3	8	17	30	0.00
1	2008	3	8	17	45	0.00
1	2008	3	8	18	0	0.00
1	2008	3	8	18	15	0.00
1	2008	3	8	18	30	0.00
1	2008	3	8	18	45	0.00
1	2008	3	8	19	0	0.00
1	2008	3	8	19	15	0.00
1	2008	3	8	19	30	0.00
1	2008	3	8	19	45	0.00
1	2008	3	8	20	0	0.00
1	2008	3	8	20	15	0.00
1	2008	3	8	20	30	0.00
1	2008	3	8	20	45	0.00
1	2008	3	8	21	0	0.00
1	2008	3	8	21	15	0.00
1	2008	3	8	21	30	0.00
1	2008	3	8	21	45	0.00
1	2008	3	8	22	0	0.00
1	2008	3	8	22	15	0.00
1	2008	3	8	22	30	0.00
1	2008	3	8	22	45	0.00
1	2008	3	8	23	0	0.00
1	2008	3	8	23	15	0.00
1	2008	3	8	23	30	0.00
1	2008	3	8	23	45	0.00
1	2008	3	8	24	0	0.00

10 Year – 24 Hour Storm

ID	Year	Month	Day	Hour	Minute	Rainfall (in)
1	2008	3	06	0	0.	0.0000
1	2008	3	06	0	15.	0.0000

	1	2008	3	06	0	30.	0.0000
	1	2008	3	06	0	45.	0.0000
	1	2008	3	06	1	0.	0.0000
	1	2008	3	06	1	15.	0.0000
	1	2008	3	06	1	30.	0.0000
	1	2008	3	06	1	45.	0.0000
	1	2008	3	06	2	0.	0.0000
	1	2008	3	06	2	15.	0.0000
	1	2008	3	06	2	30.	0.0000
	1	2008	3	06	2	45.	0.0000
	1	2008	3	06	3	0.	0.0000
	1	2008	3	06	3	15.	0.0000
	1	2008	3	06	3	30.	0.0000
	1	2008	3	06	3	45.	0.0000
	1	2008	3	06	4	0.	0.0000
	1	2008	3	06	4	15.	0.0000
	1	2008	3	06	4	30.	0.0000
	1	2008	3	06	4	45.	0.0000
	1	2008	3	06	5	0.	0.0000
	1	2008	3	06	5	15.	0.0000
	1	2008	3	06	5	30.	0.0000
	1	2008	3	06	5	45.	0.0000
	1	2008	3	06	6	0.	0.0000
	1	2008	3	06	6	15.	0.0000
	1	2008	3	06	6	30.	0.0000
	1	2008	3	06	6	45.	0.0000
	1	2008	3	06	7	0.	0.0000
	1	2008	3	06	7	15.	0.0000
	1	2008	3	06	7	30.	0.0000
	1	2008	3	06	7	45.	0.0000
	1	2008	3	06	8	0.	0.0000
	1	2008	3	06	8	15.	0.0000
	1	2008	3	06	8	30.	0.0000
	1	2008	3	06	8	45.	0.0000
	1	2008	3	06	9	0.	0.0000
	1	2008	3	06	9	15.	0.0000
	1	2008	3	06	9	30.	0.0000
	1	2008	3	06	9	45.	0.0000
	1	2008	3	06	10	0.	0.0000

	1	2008	3	06	10	15.	0.0000
	1	2008	3	06	10	30.	0.0000
	1	2008	3	06	10	45.	0.0000
	1	2008	3	06	11	0.	0.0000
	1	2008	3	06	11	15.	0.0000
	1	2008	3	06	11	30.	0.0000
	1	2008	3	06	11	45.	0.0000
	1	2008	3	06	12	0.	0.0000
	1	2008	3	06	12	15.	0.0000
	1	2008	3	06	12	30.	0.0000
	1	2008	3	06	12	45.	0.0000
	1	2008	3	06	13	0.	0.0000
	1	2008	3	06	13	15.	0.0000
	1	2008	3	06	13	30.	0.0000
	1	2008	3	06	13	45.	0.0000
	1	2008	3	06	14	0.	0.0000
	1	2008	3	06	14	15.	0.0000
	1	2008	3	06	14	30.	0.0000
	1	2008	3	06	14	45.	0.0000
	1	2008	3	06	15	0.	0.0000
	1	2008	3	06	15	15.	0.0000
	1	2008	3	06	15	30.	0.0000
	1	2008	3	06	15	45.	0.0000
	1	2008	3	06	16	0.	0.0000
	1	2008	3	06	16	15.	0.0000
	1	2008	3	06	16	30.	0.0000
	1	2008	3	06	16	45.	0.0000
	1	2008	3	06	17	0.	0.0000
	1	2008	3	06	17	15.	0.0000
	1	2008	3	06	17	30.	0.0000
	1	2008	3	06	17	45.	0.0000
	1	2008	3	06	18	0.	0.0000
	1	2008	3	06	18	15.	0.0000
	1	2008	3	06	18	30.	0.0000
	1	2008	3	06	18	45.	0.0000
	1	2008	3	06	19	0.	0.0000
	1	2008	3	06	19	15.	0.0000
	1	2008	3	06	19	30.	0.0000
	1	2008	3	06	19	45.	0.0000

	1	2008	3	06	20	0.	0.0000
	1	2008	3	06	20	15.	0.0000
	1	2008	3	06	20	30.	0.0000
	1	2008	3	06	20	45.	0.0000
	1	2008	3	06	21	0.	0.0000
	1	2008	3	06	21	15.	0.0000
	1	2008	3	06	21	30.	0.0000
	1	2008	3	06	21	45.	0.0000
	1	2008	3	06	22	0.	0.0000
	1	2008	3	06	22	15.	0.0000
	1	2008	3	06	22	30.	0.0000
	1	2008	3	06	22	45.	0.0000
	1	2008	3	06	23	0.	0.0000
	1	2008	3	06	23	15.	0.0000
	1	2008	3	06	23	30.	0.0000
	1	2008	3	06	23	45.	0.0000
	1	2008	3	06	24	0.	0.0000
	1	2008	3	07	0	0.	0.0000
	1	2008	3	07	0	15.	0.0109
	1	2008	3	07	0	30.	0.0109
	1	2008	3	07	0	45.	0.0109
	1	2008	3	07	1	0.	0.0109
	1	2008	3	07	1	15.	0.0109
	1	2008	3	07	1	30.	0.0109
	1	2008	3	07	1	45.	0.0109
	1	2008	3	07	2	0.	0.0109
	1	2008	3	07	2	15.	0.0125
	1	2008	3	07	2	30.	0.0125
	1	2008	3	07	2	45.	0.0125
	1	2008	3	07	3	0.	0.0125
	1	2008	3	07	3	15.	0.0125
	1	2008	3	07	3	30.	0.0125
	1	2008	3	07	3	45.	0.0125
	1	2008	3	07	4	0.	0.0125
	1	2008	3	07	4	15.	0.0158
	1	2008	3	07	4	30.	0.0158
	1	2008	3	07	4	45.	0.0158
	1	2008	3	07	5	0.	0.0158
	1	2008	3	07	5	15.	0.0158

	1	2008	3	07	5	30.	0.0158
	1	2008	3	07	5	45.	0.0158
	1	2008	3	07	6	0.	0.0158
	1	2008	3	07	6	15.	0.0185
	1	2008	3	07	6	30.	0.0185
	1	2008	3	07	6	45.	0.0185
	1	2008	3	07	7	0.	0.0185
	1	2008	3	07	7	15.	0.0283
	1	2008	3	07	7	30.	0.0283
	1	2008	3	07	7	45.	0.0283
	1	2008	3	07	8	0.	0.0283
	1	2008	3	07	8	15.	0.0326
	1	2008	3	07	8	30.	0.0326
	1	2008	3	07	8	45.	0.0392
	1	2008	3	07	9	0.	0.0392
	1	2008	3	07	9	15.	0.0413
	1	2008	3	07	9	30.	0.0413
	1	2008	3	07	9	45.	0.0478
	1	2008	3	07	10	0.	0.0479
	1	2008	3	07	10	15.	0.0587
	1	2008	3	07	10	30.	0.0587
	1	2008	3	07	10	45.	0.0740
	1	2008	3	07	11	0.	0.0739
	1	2008	3	07	11	15.	0.1044
	1	2008	3	07	11	30.	0.1044
	1	2008	3	07	11	45.	0.1784
	1	2008	3	07	12	0.	0.7004
	1	2008	3	07	12	15.	0.4394
	1	2008	3	07	12	30.	0.4394
	1	2008	3	07	12	45.	0.1066
	1	2008	3	07	13	0.	0.1066
	1	2008	3	07	13	15.	0.0740
	1	2008	3	07	13	30.	0.0740
	1	2008	3	07	13	45.	0.0565
	1	2008	3	07	14	0.	0.0566
	1	2008	3	07	14	15.	0.0408
	1	2008	3	07	14	30.	0.0408
	1	2008	3	07	14	45.	0.0408
	1	2008	3	07	15	0.	0.0408

	1	2008	3	07	15	15.	0.0408
	1	2008	3	07	15	30.	0.0408
	1	2008	3	07	15	45.	0.0408
	1	2008	3	07	16	0.	0.0408
	1	2008	3	07	16	15.	0.0193
	1	2008	3	07	16	30.	0.0193
	1	2008	3	07	16	45.	0.0193
	1	2008	3	07	17	0.	0.0193
	1	2008	3	07	17	15.	0.0193
	1	2008	3	07	17	30.	0.0193
	1	2008	3	07	17	45.	0.0193
	1	2008	3	07	18	0.	0.0193
	1	2008	3	07	18	15.	0.0193
	1	2008	3	07	18	30.	0.0193
	1	2008	3	07	18	45.	0.0193
	1	2008	3	07	19	0.	0.0193
	1	2008	3	07	19	15.	0.0193
	1	2008	3	07	19	30.	0.0193
	1	2008	3	07	19	45.	0.0193
	1	2008	3	07	20	0.	0.0193
	1	2008	3	07	20	15.	0.0117
	1	2008	3	07	20	30.	0.0117
	1	2008	3	07	20	45.	0.0117
	1	2008	3	07	21	0.	0.0117
	1	2008	3	07	21	15.	0.0117
	1	2008	3	07	21	30.	0.0117
	1	2008	3	07	21	45.	0.0117
	1	2008	3	07	22	0.	0.0117
	1	2008	3	07	22	15.	0.0117
	1	2008	3	07	22	30.	0.0117
	1	2008	3	07	22	45.	0.0117
	1	2008	3	07	23	0.	0.0117
	1	2008	3	07	23	15.	0.0117
	1	2008	3	07	23	30.	0.0117
	1	2008	3	07	23	45.	0.0117
	1	2008	3	07	24	0.	0.0117
	1	2008	3	08	0	0.	0.0000
	1	2008	3	08	0	15.	0.0000
	1	2008	3	08	0	30.	0.0000

	1	2008	3	08	0	45.	0.0000
	1	2008	3	08	1	0.	0.0000
	1	2008	3	08	1	15.	0.0000
	1	2008	3	08	1	30.	0.0000
	1	2008	3	08	1	45.	0.0000
	1	2008	3	08	2	0.	0.0000
	1	2008	3	08	2	15.	0.0000
	1	2008	3	08	2	30.	0.0000
	1	2008	3	08	2	45.	0.0000
	1	2008	3	08	3	0.	0.0000
	1	2008	3	08	3	15.	0.0000
	1	2008	3	08	3	30.	0.0000
	1	2008	3	08	3	45.	0.0000
	1	2008	3	08	4	0.	0.0000
	1	2008	3	08	4	15.	0.0000
	1	2008	3	08	4	30.	0.0000
	1	2008	3	08	4	45.	0.0000
	1	2008	3	08	5	0.	0.0000
	1	2008	3	08	5	15.	0.0000
	1	2008	3	08	5	30.	0.0000
	1	2008	3	08	5	45.	0.0000
	1	2008	3	08	6	0.	0.0000
	1	2008	3	08	6	15.	0.0000
	1	2008	3	08	6	30.	0.0000
	1	2008	3	08	6	45.	0.0000
	1	2008	3	08	7	0.	0.0000
	1	2008	3	08	7	15.	0.0000
	1	2008	3	08	7	30.	0.0000
	1	2008	3	08	7	45.	0.0000
	1	2008	3	08	8	0.	0.0000
	1	2008	3	08	8	15.	0.0000
	1	2008	3	08	8	30.	0.0000
	1	2008	3	08	8	45.	0.0000
	1	2008	3	08	9	0.	0.0000
	1	2008	3	08	9	15.	0.0000
	1	2008	3	08	9	30.	0.0000
	1	2008	3	08	9	45.	0.0000
	1	2008	3	08	10	0.	0.0000
	1	2008	3	08	10	15.	0.0000

	1	2008	3	08	10	30.	0.0000
	1	2008	3	08	10	45.	0.0000
	1	2008	3	08	11	0.	0.0000
	1	2008	3	08	11	15.	0.0000
	1	2008	3	08	11	30.	0.0000
	1	2008	3	08	11	45.	0.0000
	1	2008	3	08	12	0.	0.0000
	1	2008	3	08	12	15.	0.0000
	1	2008	3	08	12	30.	0.0000
	1	2008	3	08	12	45.	0.0000
	1	2008	3	08	13	0.	0.0000
	1	2008	3	08	13	15.	0.0000
	1	2008	3	08	13	30.	0.0000
	1	2008	3	08	13	45.	0.0000
	1	2008	3	08	14	0.	0.0000
	1	2008	3	08	14	15.	0.0000
	1	2008	3	08	14	30.	0.0000
	1	2008	3	08	14	45.	0.0000
	1	2008	3	08	15	0.	0.0000
	1	2008	3	08	15	15.	0.0000
	1	2008	3	08	15	30.	0.0000
	1	2008	3	08	15	45.	0.0000
	1	2008	3	08	16	0.	0.0000
	1	2008	3	08	16	15.	0.0000
	1	2008	3	08	16	30.	0.0000
	1	2008	3	08	16	45.	0.0000
	1	2008	3	08	17	0.	0.0000
	1	2008	3	08	17	15.	0.0000
	1	2008	3	08	17	30.	0.0000
	1	2008	3	08	17	45.	0.0000
	1	2008	3	08	18	0.	0.0000
	1	2008	3	08	18	15.	0.0000
	1	2008	3	08	18	30.	0.0000
	1	2008	3	08	18	45.	0.0000
	1	2008	3	08	19	0.	0.0000
	1	2008	3	08	19	15.	0.0000
	1	2008	3	08	19	30.	0.0000
	1	2008	3	08	19	45.	0.0000
	1	2008	3	08	20	0.	0.0000

1	2008	3	08	20	15.	0.0000
1	2008	3	08	20	30.	0.0000
1	2008	3	08	20	45.	0.0000
1	2008	3	08	21	0.	0.0000
1	2008	3	08	21	15.	0.0000
1	2008	3	08	21	30.	0.0000
1	2008	3	08	21	45.	0.0000
1	2008	3	08	22	0.	0.0000
1	2008	3	08	22	15.	0.0000
1	2008	3	08	22	30.	0.0000
1	2008	3	08	22	45.	0.0000
1	2008	3	08	23	0.	0.0000
1	2008	3	08	23	15.	0.0000
1	2008	3	08	23	30.	0.0000
1	2008	3	08	23	45.	0.0000
1	2008	3	08	24	0.	0.0000

25 Year – 24 Hour Storm

ID	Year	Month	Day	Hour	Minute	Rainfall (in)
1	2008	3	6	0	0	0
1	2008	3	6	0	15	0
1	2008	3	6	0	30	0
1	2008	3	6	0	45	0
1	2008	3	6	1	0	0
1	2008	3	6	1	15	0
1	2008	3	6	1	30	0
1	2008	3	6	1	45	0
1	2008	3	6	2	0	0
1	2008	3	6	2	15	0
1	2008	3	6	2	30	0
1	2008	3	6	2	45	0
1	2008	3	6	3	0	0
1	2008	3	6	3	15	0
1	2008	3	6	3	30	0
1	2008	3	6	3	45	0
1	2008	3	6	4	0	0

	1	2008	3	6	4	15	0
	1	2008	3	6	4	30	0
	1	2008	3	6	4	45	0
	1	2008	3	6	5	0	0
	1	2008	3	6	5	15	0
	1	2008	3	6	5	30	0
	1	2008	3	6	5	45	0
	1	2008	3	6	6	0	0
	1	2008	3	6	6	15	0
	1	2008	3	6	6	30	0
	1	2008	3	6	6	45	0
	1	2008	3	6	7	0	0
	1	2008	3	6	7	15	0
	1	2008	3	6	7	30	0
	1	2008	3	6	7	45	0
	1	2008	3	6	8	0	0
	1	2008	3	6	8	15	0
	1	2008	3	6	8	30	0
	1	2008	3	6	8	45	0
	1	2008	3	6	9	0	0
	1	2008	3	6	9	15	0
	1	2008	3	6	9	30	0
	1	2008	3	6	9	45	0
	1	2008	3	6	10	0	0
	1	2008	3	6	10	15	0
	1	2008	3	6	10	30	0
	1	2008	3	6	10	45	0
	1	2008	3	6	11	0	0
	1	2008	3	6	11	15	0
	1	2008	3	6	11	30	0
	1	2008	3	6	11	45	0
	1	2008	3	6	12	0	0
	1	2008	3	6	12	15	0
	1	2008	3	6	12	30	0
	1	2008	3	6	12	45	0
	1	2008	3	6	13	0	0
	1	2008	3	6	13	15	0
	1	2008	3	6	13	30	0
	1	2008	3	6	13	45	0

	1	2008	3	6	14	0	0
	1	2008	3	6	14	15	0
	1	2008	3	6	14	30	0
	1	2008	3	6	14	45	0
	1	2008	3	6	15	0	0
	1	2008	3	6	15	15	0
	1	2008	3	6	15	30	0
	1	2008	3	6	15	45	0
	1	2008	3	6	16	0	0
	1	2008	3	6	16	15	0
	1	2008	3	6	16	30	0
	1	2008	3	6	16	45	0
	1	2008	3	6	17	0	0
	1	2008	3	6	17	15	0
	1	2008	3	6	17	30	0
	1	2008	3	6	17	45	0
	1	2008	3	6	18	0	0
	1	2008	3	6	18	15	0
	1	2008	3	6	18	30	0
	1	2008	3	6	18	45	0
	1	2008	3	6	19	0	0
	1	2008	3	6	19	15	0
	1	2008	3	6	19	30	0
	1	2008	3	6	19	45	0
	1	2008	3	6	20	0	0
	1	2008	3	6	20	15	0
	1	2008	3	6	20	30	0
	1	2008	3	6	20	45	0
	1	2008	3	6	21	0	0
	1	2008	3	6	21	15	0
	1	2008	3	6	21	30	0
	1	2008	3	6	21	45	0
	1	2008	3	6	22	0	0
	1	2008	3	6	22	15	0
	1	2008	3	6	22	30	0
	1	2008	3	6	22	45	0
	1	2008	3	6	23	0	0
	1	2008	3	6	23	15	0
	1	2008	3	6	23	30	0

1	2008	3	6	23	45	0
1	2008	3	6	24	0	0
1	2008	3	7	0	15	0.02
1	2008	3	7	0	30	0.02
1	2008	3	7	0	45	0.02
1	2008	3	7	1	0	0.02
1	2008	3	7	1	15	0.02
1	2008	3	7	1	30	0.02
1	2008	3	7	1	45	0.02
1	2008	3	7	2	0	0.02
1	2008	3	7	2	15	0.02
1	2008	3	7	2	30	0.02
1	2008	3	7	2	45	0.02
1	2008	3	7	3	0	0.02
1	2008	3	7	3	15	0.02
1	2008	3	7	3	30	0.02
1	2008	3	7	3	45	0.02
1	2008	3	7	4	0	0.02
1	2008	3	7	4	15	0.03
1	2008	3	7	4	30	0.03
1	2008	3	7	4	45	0.03
1	2008	3	7	5	0	0.03
1	2008	3	7	5	15	0.03
1	2008	3	7	5	30	0.03
1	2008	3	7	5	45	0.03
1	2008	3	7	6	0	0.03
1	2008	3	7	6	15	0.03
1	2008	3	7	6	30	0.03
1	2008	3	7	6	45	0.03
1	2008	3	7	7	0	0.03
1	2008	3	7	7	15	0.04
1	2008	3	7	7	30	0.04
1	2008	3	7	7	45	0.04
1	2008	3	7	8	0	0.04
1	2008	3	7	8	15	0.04
1	2008	3	7	8	30	0.04
1	2008	3	7	8	45	0.05
1	2008	3	7	9	0	0.05
1	2008	3	7	9	15	0.05

	1	2008	3	7	9	30	0.05
	1	2008	3	7	9	45	0.06
	1	2008	3	7	10	0	0.06
	1	2008	3	7	10	15	0.07
	1	2008	3	7	10	30	0.07
	1	2008	3	7	10	45	0.08
	1	2008	3	7	11	0	0.08
	1	2008	3	7	11	15	0.11
	1	2008	3	7	11	30	0.11
	1	2008	3	7	11	45	0.19
	1	2008	3	7	12	0	0.71
	1	2008	3	7	12	15	0.45
	1	2008	3	7	12	30	0.45
	1	2008	3	7	12	45	0.12
	1	2008	3	7	13	0	0.12
	1	2008	3	7	13	15	0.08
	1	2008	3	7	13	30	0.08
	1	2008	3	7	13	45	0.07
	1	2008	3	7	14	0	0.07
	1	2008	3	7	14	15	0.05
	1	2008	3	7	14	30	0.05
	1	2008	3	7	14	45	0.05
	1	2008	3	7	15	0	0.05
	1	2008	3	7	15	15	0.05
	1	2008	3	7	15	30	0.05
	1	2008	3	7	15	45	0.05
	1	2008	3	7	16	0	0.05
	1	2008	3	7	16	15	0.03
	1	2008	3	7	16	30	0.03
	1	2008	3	7	16	45	0.03
	1	2008	3	7	17	0	0.03
	1	2008	3	7	17	15	0.03
	1	2008	3	7	17	30	0.03
	1	2008	3	7	17	45	0.03
	1	2008	3	7	18	0	0.03
	1	2008	3	7	18	15	0.03
	1	2008	3	7	18	30	0.03
	1	2008	3	7	18	45	0.03
	1	2008	3	7	19	0	0.03

1	2008	3	7	19	15	0.03
1	2008	3	7	19	30	0.03
1	2008	3	7	19	45	0.03
1	2008	3	7	20	0	0.03
1	2008	3	7	20	15	0.02
1	2008	3	7	20	30	0.02
1	2008	3	7	20	45	0.02
1	2008	3	7	21	0	0.02
1	2008	3	7	21	15	0.02
1	2008	3	7	21	30	0.02
1	2008	3	7	21	45	0.02
1	2008	3	7	22	0	0.02
1	2008	3	7	22	15	0.02
1	2008	3	7	22	30	0.02
1	2008	3	7	22	45	0.02
1	2008	3	7	23	0	0.02
1	2008	3	7	23	15	0.02
1	2008	3	7	23	30	0.02
1	2008	3	7	23	45	0.02
1	2008	3	7	24	0	0.02
1	2008	3	8	0	15	0
1	2008	3	8	0	30	0
1	2008	3	8	0	45	0
1	2008	3	8	1	0	0
1	2008	3	8	1	15	0
1	2008	3	8	1	30	0
1	2008	3	8	1	45	0
1	2008	3	8	2	0	0
1	2008	3	8	2	15	0
1	2008	3	8	2	30	0
1	2008	3	8	2	45	0
1	2008	3	8	3	0	0
1	2008	3	8	3	15	0
1	2008	3	8	3	30	0
1	2008	3	8	3	45	0
1	2008	3	8	4	0	0
1	2008	3	8	4	15	0
1	2008	3	8	4	30	0
1	2008	3	8	4	45	0

	1	2008	3	8	5	0	0
	1	2008	3	8	5	15	0
	1	2008	3	8	5	30	0
	1	2008	3	8	5	45	0
	1	2008	3	8	6	0	0
	1	2008	3	8	6	15	0
	1	2008	3	8	6	30	0
	1	2008	3	8	6	45	0
	1	2008	3	8	7	0	0
	1	2008	3	8	7	15	0
	1	2008	3	8	7	30	0
	1	2008	3	8	7	45	0
	1	2008	3	8	8	0	0
	1	2008	3	8	8	15	0
	1	2008	3	8	8	30	0
	1	2008	3	8	8	45	0
	1	2008	3	8	9	0	0
	1	2008	3	8	9	15	0
	1	2008	3	8	9	30	0
	1	2008	3	8	9	45	0
	1	2008	3	8	10	0	0
	1	2008	3	8	10	15	0
	1	2008	3	8	10	30	0
	1	2008	3	8	10	45	0
	1	2008	3	8	11	0	0
	1	2008	3	8	11	15	0
	1	2008	3	8	11	30	0
	1	2008	3	8	11	45	0
	1	2008	3	8	12	0	0
	1	2008	3	8	12	15	0
	1	2008	3	8	12	30	0
	1	2008	3	8	12	45	0
	1	2008	3	8	13	0	0
	1	2008	3	8	13	15	0
	1	2008	3	8	13	30	0
	1	2008	3	8	13	45	0
	1	2008	3	8	14	0	0
	1	2008	3	8	14	15	0
	1	2008	3	8	14	30	0

	1	2008	3	8	14	45	0
	1	2008	3	8	15	0	0
	1	2008	3	8	15	15	0
	1	2008	3	8	15	30	0
	1	2008	3	8	15	45	0
	1	2008	3	8	16	0	0
	1	2008	3	8	16	15	0
	1	2008	3	8	16	30	0
	1	2008	3	8	16	45	0
	1	2008	3	8	17	0	0
	1	2008	3	8	17	15	0
	1	2008	3	8	17	30	0
	1	2008	3	8	17	45	0
	1	2008	3	8	18	0	0
	1	2008	3	8	18	15	0
	1	2008	3	8	18	30	0
	1	2008	3	8	18	45	0
	1	2008	3	8	19	0	0
	1	2008	3	8	19	15	0
	1	2008	3	8	19	30	0
	1	2008	3	8	19	45	0
	1	2008	3	8	20	0	0
	1	2008	3	8	20	15	0
	1	2008	3	8	20	30	0
	1	2008	3	8	20	45	0
	1	2008	3	8	21	0	0
	1	2008	3	8	21	15	0
	1	2008	3	8	21	30	0
	1	2008	3	8	21	45	0
	1	2008	3	8	22	0	0
	1	2008	3	8	22	15	0
	1	2008	3	8	22	30	0
	1	2008	3	8	22	45	0
	1	2008	3	8	23	0	0
	1	2008	3	8	23	15	0
	1	2008	3	8	23	30	0
	1	2008	3	8	23	45	0
	1	2008	3	8	24	0	0

100 Year – 24 Hour Storm

ID	Year	Month	Day	Hour	Minute	Rainfall (in)
1	2008	3	6	0	0	0
1	2008	3	6	0	15	0
1	2008	3	6	0	30	0
1	2008	3	6	0	45	0
1	2008	3	6	1	0	0
1	2008	3	6	1	15	0
1	2008	3	6	1	30	0
1	2008	3	6	1	45	0
1	2008	3	6	2	0	0
1	2008	3	6	2	15	0
1	2008	3	6	2	30	0
1	2008	3	6	2	45	0
1	2008	3	6	3	0	0
1	2008	3	6	3	15	0
1	2008	3	6	3	30	0
1	2008	3	6	3	45	0
1	2008	3	6	4	0	0
1	2008	3	6	4	15	0
1	2008	3	6	4	30	0
1	2008	3	6	4	45	0
1	2008	3	6	5	0	0
1	2008	3	6	5	15	0
1	2008	3	6	5	30	0
1	2008	3	6	5	45	0
1	2008	3	6	6	0	0
1	2008	3	6	6	15	0
1	2008	3	6	6	30	0
1	2008	3	6	6	45	0
1	2008	3	6	7	0	0
1	2008	3	6	7	15	0
1	2008	3	6	7	30	0
1	2008	3	6	7	45	0
1	2008	3	6	8	0	0
1	2008	3	6	8	15	0
1	2008	3	6	8	30	0

1	2008	3	6	8	45	0
1	2008	3	6	9	0	0
1	2008	3	6	9	15	0
1	2008	3	6	9	30	0
1	2008	3	6	9	45	0
1	2008	3	6	10	0	0
1	2008	3	6	10	15	0
1	2008	3	6	10	30	0
1	2008	3	6	10	45	0
1	2008	3	6	11	0	0
1	2008	3	6	11	15	0
1	2008	3	6	11	30	0
1	2008	3	6	11	45	0
1	2008	3	6	12	0	0
1	2008	3	6	12	15	0
1	2008	3	6	12	30	0
1	2008	3	6	12	45	0
1	2008	3	6	13	0	0
1	2008	3	6	13	15	0
1	2008	3	6	13	30	0
1	2008	3	6	13	45	0
1	2008	3	6	14	0	0
1	2008	3	6	14	15	0
1	2008	3	6	14	30	0
1	2008	3	6	14	45	0
1	2008	3	6	15	0	0
1	2008	3	6	15	15	0
1	2008	3	6	15	30	0
1	2008	3	6	15	45	0
1	2008	3	6	16	0	0
1	2008	3	6	16	15	0
1	2008	3	6	16	30	0
1	2008	3	6	16	45	0
1	2008	3	6	17	0	0
1	2008	3	6	17	15	0
1	2008	3	6	17	30	0
1	2008	3	6	17	45	0
1	2008	3	6	18	0	0
1	2008	3	6	18	15	0

1	2008	3	6	18	30	0
1	2008	3	6	18	45	0
1	2008	3	6	19	0	0
1	2008	3	6	19	15	0
1	2008	3	6	19	30	0
1	2008	3	6	19	45	0
1	2008	3	6	20	0	0
1	2008	3	6	20	15	0
1	2008	3	6	20	30	0
1	2008	3	6	20	45	0
1	2008	3	6	21	0	0
1	2008	3	6	21	15	0
1	2008	3	6	21	30	0
1	2008	3	6	21	45	0
1	2008	3	6	22	0	0
1	2008	3	6	22	15	0
1	2008	3	6	22	30	0
1	2008	3	6	22	45	0
1	2008	3	6	23	0	0
1	2008	3	6	23	15	0
1	2008	3	6	23	30	0
1	2008	3	6	23	45	0
1	2008	3	6	24	0	0
1	2008	3	7	0	15	0.0196
1	2008	3	7	0	30	0.0196
1	2008	3	7	0	45	0.0196
1	2008	3	7	1	0	0.0196
1	2008	3	7	1	15	0.0196
1	2008	3	7	1	30	0.0196
1	2008	3	7	1	45	0.0196
1	2008	3	7	2	0	0.0196
1	2008	3	7	2	15	0.02254
1	2008	3	7	2	30	0.02254
1	2008	3	7	2	45	0.02254
1	2008	3	7	3	0	0.02254
1	2008	3	7	3	15	0.02254
1	2008	3	7	3	30	0.02254
1	2008	3	7	3	45	0.02254
1	2008	3	7	4	0	0.02254

1	2008	3	7	4	15	0.02842
1	2008	3	7	4	30	0.02842
1	2008	3	7	4	45	0.02842
1	2008	3	7	5	0	0.02842
1	2008	3	7	5	15	0.02842
1	2008	3	7	5	30	0.02842
1	2008	3	7	5	45	0.02842
1	2008	3	7	6	0	0.02842
1	2008	3	7	6	15	0.03332
1	2008	3	7	6	30	0.03332
1	2008	3	7	6	45	0.03332
1	2008	3	7	7	0	0.03332
1	2008	3	7	7	15	0.05096
1	2008	3	7	7	30	0.05096
1	2008	3	7	7	45	0.05096
1	2008	3	7	8	0	0.05096
1	2008	3	7	8	15	0.0588
1	2008	3	7	8	30	0.0588
1	2008	3	7	8	45	0.07056
1	2008	3	7	9	0	0.07056
1	2008	3	7	9	15	0.07448
1	2008	3	7	9	30	0.07448
1	2008	3	7	9	45	0.08624
1	2008	3	7	10	0	0.08624
1	2008	3	7	10	15	0.10584
1	2008	3	7	10	30	0.10584
1	2008	3	7	10	45	0.13328
1	2008	3	7	11	0	0.13328
1	2008	3	7	11	15	0.18816
1	2008	3	7	11	30	0.18816
1	2008	3	7	11	45	0.32144
1	2008	3	7	12	0	1.26224
1	2008	3	7	12	15	0.79184
1	2008	3	7	12	30	0.79184
1	2008	3	7	12	45	0.19208
1	2008	3	7	13	0	0.19208
1	2008	3	7	13	15	0.13328
1	2008	3	7	13	30	0.13328
1	2008	3	7	13	45	0.10192

1	2008	3	7	14	0	0.10192
1	2008	3	7	14	15	0.0735
1	2008	3	7	14	30	0.0735
1	2008	3	7	14	45	0.0735
1	2008	3	7	15	0	0.0735
1	2008	3	7	15	15	0.0735
1	2008	3	7	15	30	0.0735
1	2008	3	7	15	45	0.0735
1	2008	3	7	16	0	0.0735
1	2008	3	7	16	15	0.03479
1	2008	3	7	16	30	0.03479
1	2008	3	7	16	45	0.03479
1	2008	3	7	17	0	0.03479
1	2008	3	7	17	15	0.03479
1	2008	3	7	17	30	0.03479
1	2008	3	7	17	45	0.03479
1	2008	3	7	18	0	0.03479
1	2008	3	7	18	15	0.03479
1	2008	3	7	18	30	0.03479
1	2008	3	7	18	45	0.03479
1	2008	3	7	19	0	0.03479
1	2008	3	7	19	15	0.03479
1	2008	3	7	19	30	0.03479
1	2008	3	7	19	45	0.03479
1	2008	3	7	20	0	0.03479
1	2008	3	7	20	15	0.02107
1	2008	3	7	20	30	0.02107
1	2008	3	7	20	45	0.02107
1	2008	3	7	21	0	0.02107
1	2008	3	7	21	15	0.02107
1	2008	3	7	21	30	0.02107
1	2008	3	7	21	45	0.02107
1	2008	3	7	22	0	0.02107
1	2008	3	7	22	15	0.02107
1	2008	3	7	22	30	0.02107
1	2008	3	7	22	45	0.02107
1	2008	3	7	23	0	0.02107
1	2008	3	7	23	15	0.02107
1	2008	3	7	23	30	0.02107

1	2008	3	7	23	45	0.02107
1	2008	3	7	24	0	0.02107
1	2008	3	8	0	15	0
1	2008	3	8	0	30	0
1	2008	3	8	0	45	0
1	2008	3	8	1	0	0
1	2008	3	8	1	15	0
1	2008	3	8	1	30	0
1	2008	3	8	1	45	0
1	2008	3	8	2	0	0
1	2008	3	8	2	15	0
1	2008	3	8	2	30	0
1	2008	3	8	2	45	0
1	2008	3	8	3	0	0
1	2008	3	8	3	15	0
1	2008	3	8	3	30	0
1	2008	3	8	3	45	0
1	2008	3	8	4	0	0
1	2008	3	8	4	15	0
1	2008	3	8	4	30	0
1	2008	3	8	4	45	0
1	2008	3	8	5	0	0
1	2008	3	8	5	15	0
1	2008	3	8	5	30	0
1	2008	3	8	5	45	0
1	2008	3	8	6	0	0
1	2008	3	8	6	15	0
1	2008	3	8	6	30	0
1	2008	3	8	6	45	0
1	2008	3	8	7	0	0
1	2008	3	8	7	15	0
1	2008	3	8	7	30	0
1	2008	3	8	7	45	0
1	2008	3	8	8	0	0
1	2008	3	8	8	15	0
1	2008	3	8	8	30	0
1	2008	3	8	8	45	0
1	2008	3	8	9	0	0
1	2008	3	8	9	15	0

1	2008	3	8	9	30	0
1	2008	3	8	9	45	0
1	2008	3	8	10	0	0
1	2008	3	8	10	15	0
1	2008	3	8	10	30	0
1	2008	3	8	10	45	0
1	2008	3	8	11	0	0
1	2008	3	8	11	15	0
1	2008	3	8	11	30	0
1	2008	3	8	11	45	0
1	2008	3	8	12	0	0
1	2008	3	8	12	15	0
1	2008	3	8	12	30	0
1	2008	3	8	12	45	0
1	2008	3	8	13	0	0
1	2008	3	8	13	15	0
1	2008	3	8	13	30	0
1	2008	3	8	13	45	0
1	2008	3	8	14	0	0
1	2008	3	8	14	15	0
1	2008	3	8	14	30	0
1	2008	3	8	14	45	0
1	2008	3	8	15	0	0
1	2008	3	8	15	15	0
1	2008	3	8	15	30	0
1	2008	3	8	15	45	0
1	2008	3	8	16	0	0
1	2008	3	8	16	15	0
1	2008	3	8	16	30	0
1	2008	3	8	16	45	0
1	2008	3	8	17	0	0
1	2008	3	8	17	15	0
1	2008	3	8	17	30	0
1	2008	3	8	17	45	0
1	2008	3	8	18	0	0
1	2008	3	8	18	15	0
1	2008	3	8	18	30	0
1	2008	3	8	18	45	0
1	2008	3	8	19	0	0

1	2008	3	8	19	15	0
1	2008	3	8	19	30	0
1	2008	3	8	19	45	0
1	2008	3	8	20	0	0
1	2008	3	8	20	15	0
1	2008	3	8	20	30	0
1	2008	3	8	20	45	0
1	2008	3	8	21	0	0
1	2008	3	8	21	15	0
1	2008	3	8	21	30	0
1	2008	3	8	21	45	0
1	2008	3	8	22	0	0
1	2008	3	8	22	15	0
1	2008	3	8	22	30	0
1	2008	3	8	22	45	0
1	2008	3	8	23	0	0
1	2008	3	8	23	15	0
1	2008	3	8	23	30	0
1	2008	3	8	23	45	0
1	2008	3	8	24	0	0

Appendix E

	crew	daily output	labor-hours	unit	2011 bare costs labor	equipment	total	total incl O&P
structural excavation for minor structures								
common earth, hydraulic backhoe								
1/2 CY bucket	B-12E	55	0.291	B.C.Y.	11.25	7.05	18.3	25
3/4 CY bucket	B-12F	90	0.178	B.C.Y.	6.9	7.55	14.45	18.75
1 CY bucket	B-12A	108	0.148	B.C.Y.	5.75	7.4	13.15	16.85
1 1/2 CY bucket	B-12B	144	0.111	B.C.Y.	4.31	7.05	11.36	14.3
2 CY bucket	B-12C	200	0.08	B.C.Y.	3.1	6.6	9.7	11.95
excavating, bulk, dozer: Open site (common earth)								
80 HP								
50' haul	B-10L	400	0.03	B.C.Y.	1.19	1.09	2.28	3
150'	B-10L	200	0.06	B.C.Y.	2.38	2.18	4.56	6
300'	B-10L	100	0.12	B.C.Y.	4.76	4.37	9.13	12
105 HP								
50'	B-10W	610	0.02	B.C.Y.	0.78	1.08	1.86	2.37
150'	B-10W	270	0.044	B.C.Y.	1.76	2.45	4.21	5.35
300'	B-10W	120	0.1	B.C.Y.	3.97	5.5	9.47	12.05
200 HP								
50'	B-10B	1230	0.01	B.C.Y.	0.39	0.97	1.36	1.65
150'	B-10B	516	0.023	B.C.Y.	0.92	2.31	3.23	3.93
300'	B-10B	270	0.044	B.C.Y.	1.76	4.41	6.17	7.5
Finish Grading: area to be paved with grader								
small	B-11L	400	0.04	S.Y.	1.52	1.56	3.08	4.02
large	B-11L	2000	0.008	S.Y.	0.3	0.31	0.61	0.8
hand grading	B-18	700	0.034	S.Y.	1.16	0.06	1.22	1.86

Backfill: structural, dozer or F.E. loader, from exisiting stockpile, no compaction, common earth

80 HP

50' haul	B-10L	975	0.012	L.C.Y.	0.51	0.42	0.93	1.24
300' haul	B-10L	330	0.036	L.C.Y.	1.52	1.25	2.77	3.66

105 HP

50' haul	B-10W	1225	0.01	L.C.Y.	0.41	0.41	0.82	1.06
300' haul	B-10W	415	0.029	L.C.Y.	1.21	1.22	2.43	3.15

200 HP

50' haul	B-10B	2200	0.005	L.C.Y.	0.23	0.48	0.71	0.87
300' haul	B-10B	735	0.016	L.C.Y.	0.68	1.43	2.11	2.59

CREW TABLES

CREW	BARE COSTS		INCL. SUBS O&P		COST PER LABOR-HR	
B-12A	HR	DAILY	HR	DAILY	BARE COSTS	INCL. O&P
1 Equip. Ope	44.40	355.20	66.45	531.60	38.75	58.75
1 Laborer	33.10	264.80	51.05	408.40		
1 Hyd. Excavator, 1 CY		801.60		881.76	50.10	55.11
16 L.H., Daily Totals		1421.60		1821.76	88.85	113.86
B-12B						
1 Equip. Ope	44.40	355.20	66.45	531.60	38.75	58.75
1 Laborer	33.10	264.80	51.05	408.40		
1 Hyd. Excavator, 1.5 CY		1017.00		1118.70	63.56	69.92
16 L.H., Daily Totals		1637.00		2058.70	102.31	128.67
B-12C						
1 Equip. Ope	44.40	355.20	66.45	531.60	38.75	58.75
1 Laborer	33.10	264.80	51.05	408.40		
1 Hyd. Excavator, 2 CY		1321.00		1435.10	82.56	90.82
16 L.H., Daily Totals		1941.00		2375.10	121.31	149.57
B-12E						
1 Equip. Ope	44.40	355.20	66.45	531.60	38.75	58.75
1 Laborer	33.10	264.80	51.05	408.40		
1 Hyd. Excavator, 0.5 CY		386.60		425.26	24.16	26.58
16 L.H., Daily Totals		1006.60		1365.26	62.91	85.33
B-12F						
1 Equip. Ope	44.40	355.20	66.45	531.60	38.75	58.75
1 Laborer	33.10	264.80	51.05	408.40		
1 Hyd. Excavator, 0.75 CY		677.80		745.58	42.36	46.60
16 L.H., Daily Totals		1297.80		1685.58	81.11	105.35
B-10B						
1 Equip. Ope	42.95	343.60	64.30	514.40	39.67	59.88
0.5 Laborer	33.10	132.40	51.05	204.20		
1 Dozer, 200 H.P.		1192.00		1311.20	99.33	109.27
12 L.H., Daily Totals		1668.00		2029.80	139.00	169.15
B-10L						
1 Equip. Ope	42.95	343.60	64.30	514.40	39.67	59.88
0.5 Laborer	33.10	132.40	51.05	204.20		
1 Dozer, 80 H.P.		436.60		480.26	36.38	40.02
12 L.H., Daily Totals		912.60		1198.86	76.05	99.90
B-10W						
1 Equip. Ope	42.95	343.60	64.30	514.40	39.67	59.88
0.5 Laborer	33.10	132.40	51.05	204.20		
1 Dozer, 105 H.P.		660.40		726.44	55.03	60.54
12 L.H., Daily Totals		1136.40		1445.04	94.70	120.42
B-34B						

1 Truck Drive	33.15	265.20	50.55	404.40	33.15	50.55
1 Dump Truck, 12 C.Y., 40(		667.80		734.58	83.47	91.82
8 L.H., Daily Totals		933.00		1138.98	116.62	142.37
B-11L						
1 Equip. Ope	42.95	343.6	64.3	514.4	38.02	57.67
1 Laborer	33.1	264.80	51.05	408.40		
1 Grader, 30,000 Lbs.		622.20		684.42	38.89	42.78
16 L.H., Daily Totals		1230.60		1607.22	76.91	100.45
B-18						
1 Labor Fore	35.1	280.80	54.1	432.80	33.77	52.07
2 Laborers	33.1	529.60	51.05	816.80		
1 Vibratory Plate, gas, 21"		43.60		47.96	1.82	2.00
24 L.H., Daily Totals		854.00		1297.56	35.59	54.07

Appendix F: Project Proposal

Quinsigamond Avenue Stormwater Management MQP Proposal

A Major Qualifying Project

Submitted to Faculty of

Worcester Polytechnic Institute

In Partial Fulfillment of the Requirements for the

Degree of Bachelor of Science

Submitted by

____

Joseph Allen

____

Katy Mattern

____

Matt McCarthy

March, 2013

____

Professor Paul P. Mathisen, Co-Advisor

____

Professor Suzanne LePage, Co-Advisor

Abstract

The Quinsigamond Avenue area in Worcester Massachusetts is a highly commercial area with a historically bad flooding problem. This project involves the development of a set of recommendations aimed at improving the area's CSO system, which is believed to be the cause of these flooding problems. Based upon previous reports, this project expands on prior research and experiments with different improvements scenarios for the area. Recommendations for improvements include flap valve installation, as well as subsurface detention tanks.

Acknowledgements

Green Island MQP

Capstone Requirements

Worcester Polytechnic Institute's Civil and Environmental Engineering program requires students working on their major qualifying project (MQP) to undergo a capstone design experience for its Accreditation Board for Engineering and Technology (ABET)-accredited Bachelor of Science program. The capstone design experience requires students to fulfill Criterion 4 of the ABET. Criterion 4 encourages students to prepare for engineering practice through a major design experience that incorporates engineering standards and constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social and political (WPI, 2002-03).

In order for this MQP to meet capstone design requirements, flood mitigation techniques will be applied to reduce flooding in the Quinsigamond Avenue area. This project will provide practical solutions to flooding on Quinsigamond Avenue by considering realistic constraints. Economic, environmental, constructability, ethical, health and safety, social and political constraints will all be considered. The following list describes how this project is for the purpose of helping and selecting a preferred design option:

Economic:

This project will estimate the costs associated with installing a flap valve into a storm drain on Quinsigamond Avenue. In addition to estimating the costs directly associated with installing the flap valve, the project will also estimate the costs associated with adding subsurface detention in Crompton Park. These costs will be determined by working with the Worcester Department of Public Works for estimates.

Environment:

This project will examine the positive and negative environmental impacts of flooding associated with the Quinsigamond Avenue area. The environmental impacts that will be considered include constraints affecting flows in Quinsigamond Avenue storm drain and the reduction of stormwater runoff due to subsurface detention at Crompton Park.

Constructability:

This project will investigate the constructability associated with installing a flap valve at the furthest downstream manhole along the Quinsigamond Avenue storm drain and subsurface detention methods at Crompton Park. This will include determining what needs to be done in order to install a flap valve and a subsurface storage unit. Considerations for this will include earthwork, location and time period.

Ethical:

Ethics are an important consideration with most flooding issues. In some cases, flooding is unavoidable. This project will recommend methods to reduce flooding on Quinsigamond Avenue while considering the American Society of Civil Engineer's code of ethics which include the following (ASCE):

1. Using knowledge and skill for the enhancement of human welfare and environment
2. Being honest and impartial and serving with fidelity the public, their employers and clients
3. Striving to increase the competence and prestige of the engineering profession
4. Supporting the professional and technical societies of their disciplines

Health and Safety:

Flooding problems lead to several health and safety concerns. One of the main goals of this project is to protect the health and safety of Quinsigamond Avenue residents. This will include researching what types of health and safety concerns relate to flooding in urban areas such as Worcester, Massachusetts. Waterborne diseases and damage to infrastructure are two examples of the kind of concerns that will be considered in this project.

Social:

The social impacts of flooding are an important consideration. This project will include how residents of Quinsigamond Avenue are personally affected by flooding in the area. The quality of living for Quinsigamond Avenue residents will be a major consideration throughout this project. Displacement of residents and damage to property are two examples of the social impacts that will be considered during this project.

Political:

All recommendations will consider regulations set by the Environmental Protection Agency (EPA), The Massachusetts Department of Environmental Protection (MDEP), the City of Worcester's DPW, Worcester's city council and any other organizations having a legal influence in the area. The project will also include recommendations to existing stormwater permits and any other permits directly involved with flooding in the city of Worcester.

Table of Contents

TABLE OF FIGURES

TABLE OF TABLES

1.0 Introduction

Neighborhood flooding has been an increasingly severe problem in the United States. Floods are the nation's most frequent and dangerous natural hazard, with damages ranging from mold and mildew, to even loss of life (Mileti, 1999). With a significant portion of the United States' flood damage happening to uninsured owners, the prevention of these events is as important as ever (Browne & Hoyt, 2000).

In the city of Worcester Massachusetts, flooding is often caused by backwater effects from the overflow of rivers or conduits, which results in excess water making its way into low lying areas. Older cities such as Worcester often operate a combined sewer overflow (CSO) system, which will combine the city's wastewater and stormwater for treatment during high rainfall events. Due to the inability of Worcester's combined sewer systems to handle such high amounts of water in a short period of time, flooding can occur throughout the system. This can lead to the flood waters containing trace amounts of waste making its way into streets and basements throughout the city.

Quinsigamond Avenue in the Green Island area of Worcester is a low lying, flat neighborhood which makes it a natural location for floods. Figure 1 displays Quinsigamond Avenue on September 8th, 2011, when one of the worst floods in recent memory hit the area. This storm resulted in massive floods throughout the neighborhood resulting in some residents to refer to the area as "not safe" (Wright, 2012).

Figure 1:Quinsigamond Avenue Flood (Corpuz, 2011)

There could be many factors that led to the influx of excess water into this location, including heavy rain falls, flood diversion programs, and a high amount of impervious surfaces in the area. With a population of 1,720 living in an area of only 0.408 square miles, a flooding incident affects all of the area's residents (City Data, 2011). During major storm events, the city of Worcester is forced to use a flood diversion plan due to the rapid increase in flows and limited storage at the Quinsigamond CSO Storage and Treatment Facility. This diversion plan works to reduce the usual treatment the Quinsigamond CSO Storage and Treatment Facility provides to a flash treatment, and release flows directly to the Millbrook Conduit. This reduces the flow rate to the Upper Blackstone Regional Wastewater Treatment Facility, which receives flows from treatment facilities throughout the area. But the increase in flows to the Millbrook Conduit may be leading to the flooding of Quinsigamond Ave, as well as other areas throughout the city.

Flooding is a major concern in the Quinsigamond Ave. area of the Green Island neighborhood. There are several different factors that contribute to flooding in the area. One of the biggest problems is the complicated combined sewer system that is located throughout the Quinsigamond Avenue area. The system is not able to handle the large amounts of flow that occur during wet weather occurrences. Based on the "Southbridge Street and Quinsigamond Avenue Area Flood Study" completed by Kleinfelder/S E A Consultants Inc. in 2010, this project will focus on SEA's recommendation of adding a flap valve in a drain manhole on Quinsigamond Avenue. It mentions that this valve, in conjunction with subsurface detention in Crompton Park, may decrease flooding on Quinsigamond Avenue. However, further analysis of feasibility, level of benefit, and cost still needs to be completed. This project will analyze this idea and determine if this is a practical solution to reduce flooding in the area. The project will also investigate and determine other possible best management practices to mitigate surface flooding on Quinsigamond Avenue in Green Island.

2.0 Background

2.1 Site description

The Quinsigamond Avenue area is located south of Union Station and extends from Southbridge Street to Crompton Park in Worcester, Massachusetts. Figure 2 outlines the street in relation to the green island neighborhood's boundaries. It is an area that has a great variety of industry, business, and homes. The street is between hills and has some of the lowest lying areas

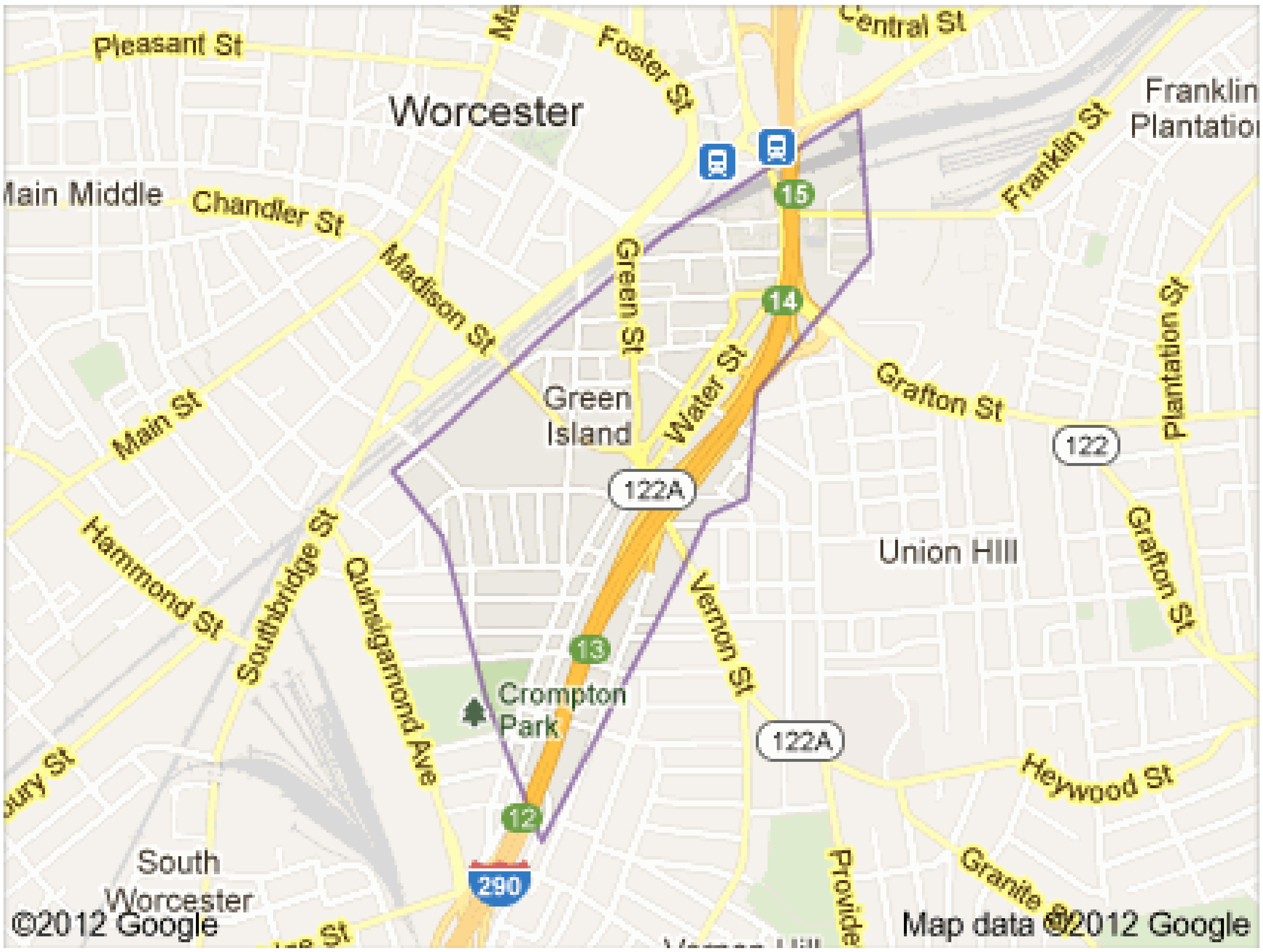


Figure 2: Outline of Quinsigamond Avenue (Green Island, 2012)

in Worcester. Quinsigamond Avenue has many impervious surfaces surrounding it, such as pavement and buildings. This prevents rainwater from naturally soaking into ground, which is a process that is also impeded by the area's naturally high water table. These features make Quinsigamond Avenue an area especially prone to flooding. The surrounding neighborhoods are very densely populated area and many people travel throughout the area on a daily basis.

2.2 Combined Sewer Overflow System

Worcester, Massachusetts has had two facility plans prepared for the city's combined sewer system over the past 23 years. The first plan began in 1975 and implemented in 1989. The plan successfully reduced the combined sewer system area by 0.5 square miles and led to the implementation of four large overflow collections. The plan also included a conduit to carry upstream stormwater through the combined sewer system, and the construction of the Quinsigamond Avenue Combined Sewer Overflow Treatment Facility (QACSOTF).

(Insert figure from CDM)

The facilities have mitigated the impact of combined sewer overflows (CSO) throughout the city of Worcester. According to CDM's 2002 Long Term Control Plan Report, during a typical five-year period there are no dry weather overflows or untreated bypasses. In addition to this, 100 percent of the flow from the combined sewer system is treated and 94 percent of the flow undergoes secondary treatment at the Upper Blackstone Wastewater Treatment Facility. The remaining 6 percent is treated only at the QACSOTF. Treatment at the QACSOTF includes screening, storage, disinfection, and dechlorination. However, the system is not as efficient during wet weather events. During wet weather, CDM's 2002 report states that slightly over 75 percent of rainfall events are completely treated at the Upper Blackstone Wastewater Treatment

Facility and the QACSOTF rarely discharges treated effluent into the Blackstone River without additional treatment.

2.3 Worcester Stormwater Management History

Throughout the past 55 years, the city has completed a multitude of projects that alleviate flooding in the area. In 1957, a diversion dam project known as the Worcester Local Protection Program, started in 1957 and was finished in 1960. There were many dams built on major rivers around the south, east, and west of Worcester. A couple of man-made lakes were also built to divert water from overflowing into Webster Square. The entire project allows water that would overflow from the Leesville Pond area to bypass Worcester by directing water into a diversion tunnel that leads to the Blackstone River. This project has been very successful in preventing flooding in Worcester, especially to the Webster Square Area.

In 1985, the city started a Flood Control Project, which had a goal of increasing the system capacity. In 2003, a Southbridge Street Sewer Separation project was started. It aimed to reduce the frequency and extent of flooding in the Green Island area. It separated storm water drainage from the combined sewer system and re-directed the storm water to a drain on Cambridge Street. This removed some influence of drainage entering the CSO Facility, which reduced flooding. Recent observations have shown that this reduced levels in storm drain surcharging by approximately five feet. However, this project has only impacted flooding on Southbridge Street. In 2007, the Millbrook Conduit was extended to drain downstream to a lower elevation on the Blackstone River. This extension decreased the river flood stage impact on drain outfall. The new outfall location has a lower tailwater impact that has been decreased by ten feet.

Recently, there have been many more high intensity storms over short periods of time, which contribute greatly to flooding. Rainfall trend data has been updated since the 1960s and there were changes from previous rainfall trends. Since the 1960s, there has been an increase in the frequency of two-inch rainfall events and storms that were once 1- in- 100 year storm events have become more frequent and likely to occur almost twice as often. Because of these changes in rainfall, measures that were taken before and were successful in reducing flooding may not be as effective anymore due to high volumes of water entering the system more and more often. (Flooding Presentation, 2011)

2.4 Subsurface Detention

Storing excess water in subsurface detention chambers is a practice used by many designers when stormwater overflow is deemed to be an issue. Underground stormwater detention systems are efficient methods of collecting and storing stormwater runoff from surrounding impervious surfaces. Since the systems are below grade they increase the amount of usable land in the area. It is common for parking lots and recreational green areas to be built on top of these types of systems (Underground Storage). Subsurface stormwater detention systems usually involve systems of large diameter interconnected storage pipes or chambers. The systems work by storing stormwater in these pipes and later releasing the water through an outlet pipe at rates to reduce peak flow conditions. The stormwater is either released back into the stormwater system or infiltrates to recharge groundwater. (Subsurface Detention)

Figure 1: Subsurface Detention System (Underground Storage)

2.5 Check Valves

Check valves are often used by designers to help prevent the backflow of fluids within storm drain pipes. A valve that allows flow in only one direction, and closes when the flow tries to reverse accomplishes this. This prevention of backflow reduces the amount of water that needs to be treated by CSO treatment facilities, while also reducing the possibility of overflow and flooding. When a combined sewer flow passes through a check valve, it cannot reverse its path back through the pipe. The valves are designed this way be having pressure sensors or manual controls that will open the valve in only one direction, and prevent water from returning from where it came. The water that would reverse through the pipe and often lead to overflow floods could be stored in subsurface detention tanks, where it can be released into the system during low flow times. There are several varieties of check valves, with different material make-up, shape, and sensitivity, all which are useful in the correct scenario. Hinge flap gates are common models that are usually made from stainless steel. Flap valves are another popular model, which are usually made of rubber (Tideflex Technologies, 2012)**.**

Figure 4: T-1 Flap Valve (Tideflex Technologies, 2012)

2.6 Previous Studies

2.6.1 Kleinfelder/S E A Report

In 2010, a "Southbridge Street and Quinsigamond Avenue Area Flood Study" was completed by Kleinfelder/S EA consultants Inc. They investigated the Southbridge Street area in order to determine why the area floods so much. "...field investigations during wet and dry weather conditions, and performing evaluations of the City storm drain and sewer systems including analysis using a hydrologic/hydraulic model of those systems," was completed. Southbridge Street, Southgate Street, Cambridge Street, Quinsigamond Avenue, and the Providence & Worcester Facility were the main areas of focus for this study. Sediment accumulation, drain slopes, low elevation of the area, lack of adequate draining, weak pumps, and damage to drains and manholes all contribute to flooding in the Quinsigamond Avenue area. There was a multitude of recommendations given, including:

- Cleaning sediment from storm drains
- A new catch basin should be installed at a low point on Southbridge Street
- Redirecting catch basins from Southgate St. from the CSO to the storm drain and manholes secured to prevent overflows
- Upgrading pumps in the Cambridge St. drainage pump station to a higher capacity
- Adding a flap valve to a drain manhole on Quinsigamond Avenue in conjunction with adding subsurface detention
- Upgrading the Quinsigamond Avenue Combined Sewer Overflow Treatment Facility

2.6.2 Phase 1 CSO Long-term Control Plan Report

In 2000, the EPA and the city of Worcester signed a consent order that required the city to develop a two-phase Long-term Control Plan (LTCP). In March of 2002, CDM completed a "Phase 1 CSO Long-term Control Plan Report". This particular report presents Phase I finding of the LTCP "for mitigating the water-quality impacts of its combined sewer system's combined sewer overflows (CSOs)." The report provides information that includes the following: "Worcester's combined sewer system (CSS), effectiveness of existing facilities, and the CSS's relative impact on the Blackstone River; future planned improvements at the Upper Blackstone Wastewater Treatment Facility (UBWWTF), and how they will further mitigate CSS impacts on the Blackstone River; Evaluation of additional alternatives, beyond UBWWTF improvements, to further minimize CSS impacts; Financial impacts of potential CSS improvements; Regulations affecting the CSS; and Phase II of the LTCP."

CDM researched and developed ways to improve the CSS and found quite a few possible ways. These improvements include diversion of two ponds out of the CSS; increasing storage in Kelly Square, the Harding Street Overflow Collector; increasing pump capacity at the QACSOTF. Ongoing projects that were already in the process of completion that would improve the CSS were also considered and included in the study. These projects included building a dechlorination facility in order to improve water quality, meet fecal coliform and total residual chlorine permit limits, and upgrades to the UBWWTF. A particularly helpful improvement made to the UBWWTF was that the QACSOTF was able to pump 70 mgd more to the UBWWTF, which allowed the QACSOTF to discharge about once every two months, as opposed to the previous discharge of more than once per month. (Phase I CSO Long-term Control Plan Report, 2002)

2.7 Permits

A major consideration when analyzing solutions to reduce flooding is the issue of permits issued by the Environmental Protection Agency (EPA). The EPA writes and regulates different permits relating to water. There are two treatment plants in the area, the Upper Blackstone Wastewater Treatment Facility (UBWWTF) and the Quinsigamond Avenue Combined Sewer Overflow Treatment Facility (QACSOTF) and Treatment Facility, which each require a permit. There is another city-wide permit that aims to regulate stormwater. These permits must be taken into consideration when making any adjustments to the system. Any changes made to the systems must be in compliance with these permits.

However, having to take into account three different permits can cause conflicts. Because the systems are all interconnected, changes or requirements in one permit can have a direct effect on another permit. For example, if a new permit for the QACSOTF increases the amount of flow they are allowed to discharge, and UBWWTF can only accept a certain amount of flow from all the various plants and drains that feed into this plant, the new QACSOTF flow might cause the UBWWTF inlet flow to be exceeded. Not only do any changes made in the system be in compliance with the permits, but changes must also be examined to ensure it will not indirectly violate another permit.

3.0 Methodology

The goal of this project is to develop an efficient, feasible alternative design plan to reduce the flooding problems that currently plague the Quinsigamond Avenue area in Worcester, Massachusetts. This plan will include a set of preliminary designs for any structural components associated with the stormwater management plan, as well as recommendations for best management practices. To accomplish this, our project team will complete a list of tasks that will ultimately lead to all of the necessary information for the completion of this project. These tasks will include:

1. Research flooding issues associated with the Quinsigamond Avenue area
2. Identify a specific area of focus and a recommendation for flood mitigation
3. Gather all available data relating to flooding issues in the Quinsigamond Avenue area
4. Evaluate current conditions in the Quinisigamond Avenue area in relation to flooding
5. Generate and evaluate preliminary design options
6. Evaluate the feasibility of preliminary design options
7. Provide a recommendation to the City of Worcester

3.1 Research flooding issues associated with the Quinsigamond Avenue area

To further research flooding issues in the Quinsigamond Avenue area, the various factors that contribute to the flooding were discussed with Joe Buckley and Philip Guerin of the Worcester Department of Public Works & Parks. The "Southbridge Street and Quinsigamond Avenue Area Flood Study" completed by Kleinfelder/SEA in 2010 was also analyzed. The study focused on five areas in the Southbridge Street area of the Green Island in order to obtain a better understanding as to why flooding is such a severe problem in the neighborhood. After presenting the various factors associated with flooding in the area, SEA's report listed conclusions and also provided recommendations for possible solutions that could alleviate some of the flooding.

These recommendations were reviewed in order to determine which recommendation would best provide a desired major qualifying project experience.

3.2 Identify specific area of focus and recommendation for flood mitigation

An effective method to solving flooding issues in large areas is to focus in on smaller sections of the area that are contributing to the problem. When smaller sections are focused on, solving a major problem may become easier because a clear step by step approach is being used. After reviewing various recommendations made in the Kleinfelder/SEA report, a specific recommendation was chosen for further analysis. This project will focus on a recommendation that includes adding a flap valve to the Quinsigamond Avenue storm drain in conjunction with subsurface detention. The goal of this recommendation is to reduce surface flooding associated with the Quinsigamond Avenue area. This recommendation was chosen based on several factors. A major reason was because the Kleinfelder/SEA report stated that it "required further analysis to determine feasibility, level of benefit, and cost." This is an important consideration because one of the goals of this task was to find a project that needed more analysis. The topic was also chosen because it challenges the project team to use course related knowledge to solve a problem which was an additional consideration for the completion of this task.

3.3 Gather all available data relating to flooding in the Quinsigamond Avenue area

A general outline of the flooding issues in the Quinsigamond Avenue area was presented by employees in the Worcester Department of Public Works & Parks. These employees have agreed to provide useful information needed to complete the project. The Worcester DPW has past studies, technical data, general knowledge about Quinsigamond Avenue and the flooding that occurs in the area, as well as information regarding the combined sewer overflow system. Online research and data gathering from newspaper articles, studies and reports associated with flooding in the area was conducted.

Other factors the project considers include the health and safety concerns flooding may have on the area. Some examples of health and safety concerns that relate to flooding include waterborne illness, damage to infrastructure, property damage, and water quality. Health and safety concerns in the Quinsigamond Avenue area due to flooding will be identified. When a final recommendation is generated, these concerns will be considered and addressed.

3.4 Identify flows in the Quinisigamond Avenue Area under existing conditions

Existing conditions associated with the Quinsigamond Avenue storm drain lead to surface flooding in the area during large rain events. Flooding occurs as a result of capacity issues in the Quinsigamond Avenue storm drain. Capacity issues in the 74” by 72” are mainly caused by backflow conditions in the Mill Brook conduit. During dry flow the storm drain line drains into the Mill Brook conduit from an elevation that is above the water level in the conduit. When the storm drain is able to drain into the conduit, flooding is not an issue because backflow will not be present in the drain. During wet weather events, backflow conditions exist when the grade line in the conduit is raised to a point that prevents flow from exiting the storm drain. This is because the backflow conditions block stormwater from exiting the drain. Backflow in the Quinsigamond Avenue storm is usually a result of the operation conditions in the Quinsgiamond Avenue Combined Sewer Overflow Treatment Facility. When stormwater is unable to exit the storm drain during a rain event, capacity issues in the drain can arise which lead to surface flooding throughout the Quinsigamond Avenue area. Figure-5 below illustrates circumstances when backflow conditions are and are not an issue.

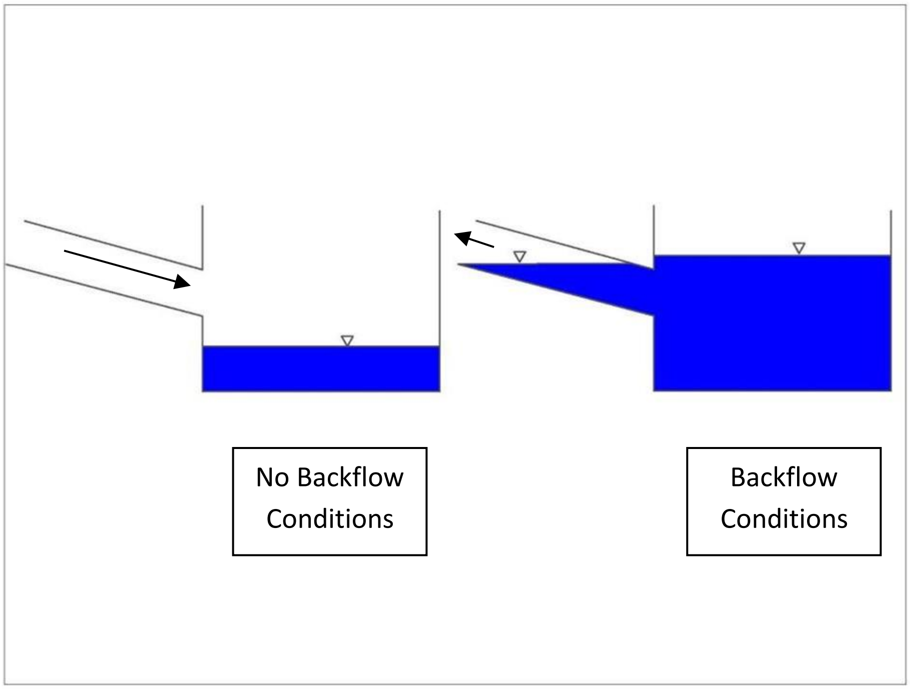


Figure 2: Backflow Conditions

This task will include analyzing surface flooding associated with the Quinsigamond Avenue area without taking any action. In order to complete this task, the flow levels in the Quinsigamond Avenue storm drain during dry and wet weather will be determined. There are 3 metering locations in the Quinsigamond Avenue storm drain. The locations of the meters are at the beginning, middle and close to the end of the storm drain. (Insert Schematic) Using information from the meters in combination with rainfall intensity information for the area, the flows throughout the storm drain will be determined for specific storm events. These calculations will also consider the backflow conditions form the Mill Brook Conduit influencing the Quinsigamond Avenue storm drain.

3.5 Generate and Evaluate Preliminary Design Options

In order to prepare an efficient, feasible design plan to reduce flooding associated with Quinsigamond Avenue, different scenarios will be analyzed. It is important to consider different alternatives to a flood mitigation design in order to obtain a better understanding of what is a feasible and effective solution. After evaluating various alternatives for flood mitigation in the area, SEA's recommendation for the Quinsigamond Avenue area was to install a flap valve in the Quinsigamond Avenue storm drain and to use the valve in combination with subsurface detention to reduce surface flooding. All design plans will include at least one part of this recommendation. The scenarios will differ based on whether or not subsurface storage is included in the design. If storage is involved, determining how much storage is necessary and whether or not other methods of flood mitigation are being considered are other factors that will be analyzed. All scenarios will include the same model of flap valve, which was decided upon by comparing several different kinds.

3.5.1 Selection of Flap Valve Model

In the selection of the proper flap valve to be used to mitigate flooding of the Quinsigamond Avenue area, several different features were considered. Table 1 displays the different models that were investigated, as well as the features and benefits that were taken into consideration. All of these models are made with a lightweight, all-elastomer design that will not warp or freeze open or shut. All models will not rust or corrode, and are great replacements for flanged flap gates. The hinge pins in flanged flap gates often deteriorate if they are not properly maintained, which allows for unwanted backflow.

Table 1: Comparison between Different Check Valve Designs				
	Tideflex Check Valve Model			
Features and Benefits	Series TF-1	Series 35-1	Series TF-2	Series 37
Eccentric, flat bottom design	✓	✓		
Flanged		✓		✓
Slip-on	✓		✓	
Cost effective, maintenance free design	✓		✓	✓
Ideal for manhole installations	✓			

Table 1 illustrates the four different Tideflex models that were investigated for the selection of the proper flap valve. Features such as design, maintenance, flanged, and slip on were considered as well as the cost of installation. These benefits and features were used to select the best possible model of flap valve to be used in all of the design scenarios.

Series 37

The Series 37 flap valve is made with an extremely simple design, with the maintenance-free rubber check sleeve as the only moving part. Also, the Series 37 requires no outside source of air or electricity, so the operating costs are minimal. This model is designed to be installed between two mating flanges in a connected pipe, which eliminates the need for a valve body.

Figure 6: Series 37 Flap Valve (Tideflex Technologies, 2012)

Series 35-1

The Series 35-1 flap valve is constructed with a flat bottom design, and has an all rubber flange. This design comes with galvanized or stainless steel back up rings when installed, and has a lightweight, all-elastomer design. The flange design allows the Series 35-1 to be mounted directly to flanged outfall pipes, or to headwalls where the pipe is flush.

Figure 7: Series 35-1 Flap Valve (Tideflex Technologies, 2012)

Series TF-2

The Series TF-2 is Tideflex's revolutionary design in backflow prevention. This design has a very long operational lifespan and requires no maintenance or repairs, resulting in a very cost-effective solution. No outside air or electricity is required for this model, so operating costs are also extremely low. The clearance space needed for the bottom of the Series TF-2 is relatively high, because this model does not feature a flat bottom design. This makes the Series TF-2 more suitable for open ended pipes.

Figure 8: Series TF-2 Flap Valve (Tideflex Technologies, 2012)

Series TF-1

The Series TF-1 is the ideal Tideflex model for use inside of a manhole vault. The flat bottom design allows for a very small clearance between the bottom floor of the vault and the bottom of the pipe. As seen if Figure XXXXXXX, the bottom of the flap valve is very close to the floor, so a flap valve without the Series TF-1's flat bottom design would not be able to fit. The slip-on, all-elastomer rubber design is constructed in one piece, so this model is easily installed and requires virtually no maintenance. The configuration of the Series TF-1 also allows for installation without manhole configuration, which further reduces the initial installation costs.

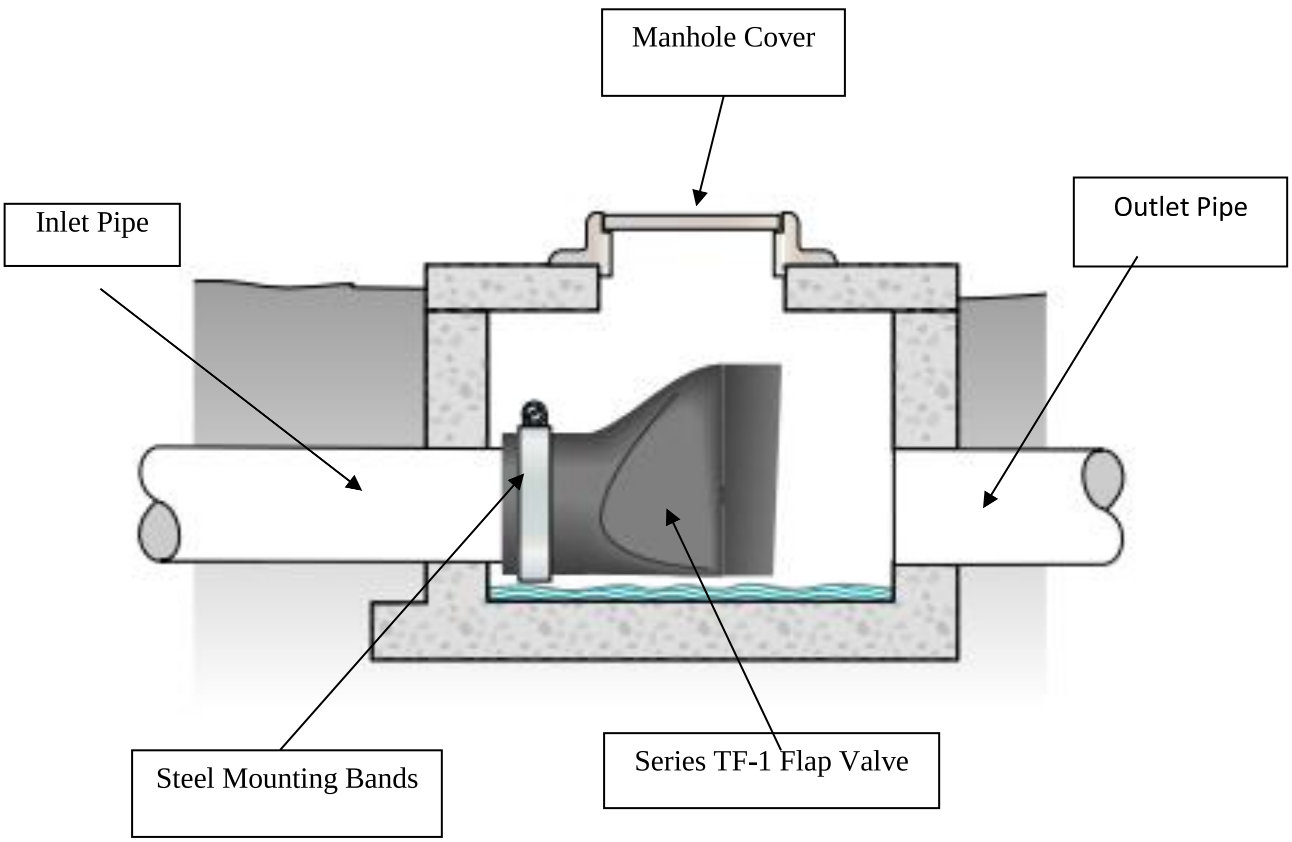


Figure 9: Series TF-1 Flap Valve (Tideflex Technologies, 2012)

3.5.2 Scenario 1 – Flap Valve

This scenario will include analyzing the levels of flooding associated with the Quinsigamond Avenue area after the implementation of a flap valve at the furthest downstream manhole location of the Quinisgamond Avenue storm drain. It will be assumed that the backflow conditions in the Quinsigamond Avenue storm drain from the Mill Brook conduit are no longer impacting the drain beyond the manhole where the flap valve is installed. The significance of this scenario is to determine the maximum amount of capacity the 72 by 74 inch storm drain can provide under various conditions. This scenario will include evaluating what storm events will result in surface flooding with the presence of a flap valve in the storm drain.

3.5.3 Scenario 2 - Flap Valve Plus Storage

This scenario will include analyzing the levels of flooding associated with the Quinsigamond Avenue area after the implementation of a flap valve at the furthest downstream manhole location of the Quinisgamond Avenue storm drain in combination with subsurface detention in Crompton Park. This task will consider the results from Scenario 1 and add additional subsurface storage to dramatically decrease surface flooding in the area. Major considerations for this task is determining how much storage will be needed for various storm events and the installation of subsurface detention basins while considering groundwater levels and other constraints.

3.5.4 Scenario 3 - Flap Valve, Storage, and More

This scenario will include major improvements to flood mitigation to the Quinsigamond Avenue area. The scenario will include implementing a flap valve to the Quinsigamond Avenue storm drain and providing some type of subsurface detention under Crompton Park. Scenario 3 will be evaluated only if Scenario 2 is impractical due to subsurface storage constraints in Crompton Park.

3.6 Analyze design to evaluate the feasibility of recommendations

To analyze the design in order to evaluate the feasibility of the recommendations, the project team will look at the different design options and their financial requirements. These different levels of improvement will require varying levels of financial backing, depending on how intricate the design is. The project team will evaluate what the financial requirements will be for improvement Scenarios 1, 2, and 3. Financial data gathered from online research, the City of Worcester, local contractors and similar projects and studies will be used to evaluate the costs associated with the different scenarios. This task will also include analyzing the installation process for flap valves and subsurface detention. The cost of installation and maintenance of flap valves and subsurface detention will be determined and included in all cost estimations for specific scenarios.

3.7 Provide a Recommendation to the City of Worcester

Based on the effectiveness and the feasibility of the flood mitigation improvement scenarios, a final design recommendation will be presented to the city of Worcester. This recommendation will include a cost effective and efficient flood mitigation design for the Quinsigamond Avenue area that will not have major impacts on the rest of Worcester's CSO system. Considering the economic situation alongside the effectiveness of each design scenario will be how the feasibility and overall quality of each recommendation is determined.

Works Cited

Browne, M. J., & Hoyt, R. E. (2000). The Demand for Flood Insurance: Emperical Evidence. *Journal of Risk and Uncertainty* , 291-306.

City Data. (2011). *Green Island Neighborhood City Data*. Retrieved October 9, 2012, from City Data Web Site: http://www.city-data.com/neighborhood/Green-Island-Worcester-MA.html

Corpuz, B. (2011, September 8). *CBS Boston*. Retrieved November 1, 2012, from CBS Boston Website: http://boston.cbslocal.com/2011/09/08/heavy-rains-cause-significant-flooding-in0-worcester/

Green Island. (2012). Retrieved September 2012, from Google: http://maps.google.com/maps?hl=en&bav=on.2,or.r_gc.r_pw.r_qf.&biw=1231&bih=612&q=green+island,+worcester&um=1&ie=UTF-8&hq=&hnear=0x89e4067a80fb3ea9:0xe3802d5b104104ee,Green+Island,+Worcester,+MA&gl=us&sa=X&ei=yrtsUOKCAq6p0AHvjYGIDw&ved=0CFoQtgM

Green Island Area Flooding Presentation. (2011, October 19). 29. Worcester, MA: City of Worcester.

Lerner, K. L., & Lerner, B. W. (2008). *Flooding* (Vol. 3). Detroit: The Gale Group, Inc.

Mileti, D. (1999). *Disasters by Design: A Reassessment of Natural Hazards in the United States.* Washington D.C.: John Henry Press.

(2002). *Phase I CSO Long-term Control Plan Report.* CDM.

Struzziery, J. J. *Southbridge Street and Quinsignamond Avenue Area Flood Study Draft Technical Memorandum.* Kleinfelder/S E A Consultants Inc.

Subsurface Detention. (n.d.). Retrieved October 2012, from A & M Contractors: http://www.am-contractors.com/index.php?option=com_content&view=article&id=60&Itemid=68

Tideflex Technologies. (2012). *Tideflex Technologies*. Retrieved October 3, 2012, from Tideflex Technologies Web Site: http://www.tideflex.com/tf/index.php/content/view/228/368/

Underground Storage. (n.d.). Retrieved 10 2012, from Lake Superior Streams: http://www.lakesuperiorstreams.org/stormwater/toolkit/underground.html

WPI. (2002-03). WPI CEE DEPARTMENT 30-DAY REPORT. *CAPSTONE DESIGN* .

Wright, M. (2012, 9 27). Flooding Makes Green Island Earn Its Name, Property Owners Say. *Worcester Telegram & Gazette* .