Project Number PPM 1231

Bioretention Basin Removal Efficiencies

An Evaluation of Stormwater Best Management Practice Effectiveness and Implications for Design

A Major Qualifying Project Report

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Abstract

Stormwater best management practices (BMPs) remove contaminants that would otherwise enter a receiving water body, but the precise removal efficiency of different BMP designs is unknown. Two Massachusetts Department of Conservation and Recreation (DCR) BMPs were studied to determine their effectiveness in contaminant removal. A field sampling program was developed, laboratory analyses were performed on stormwater samples, and these results were utilized to create models of the basins. An ideal design approach was developed for a new DCR BMP.

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Capstone Design Requirement

This Major Qualifying Project satisfied the WPI Civil and Environmental Engineering Capstone design requirement. To meet this requirement, a design for a more effective stormwater management bioretention basin was developed for the Department of Conservation and Recreation on the Wachusett Reservoir Watershed. To develop this design approach, two other basins were assessed for their functionality through sampling efforts performed during multiple rainstorms and modeling of stormwater hydraulics of the basins. By comparing the two basin's designs and efficiencies, an ideal basin design was developed and recommendations were made for a new basin at a location adjacent to the Wachusett Reservoir. The project design took economic, environmental, sustainability, manufacturability, health and safety, social, and political constraints into consideration.

Environmental: Protection of a surface drinking water supply was the primary focus for this project, so environmental considerations were the major focus for the design criteria that were developed. The background on stormwater pollutants that are relevant to this project is located in Section 2, and the effects BMPs have on the discharged water is a common theme throughout the report.

Economic: A design for a bioretention basin needs to be economically feasible while still successfully protecting the water source, the Wachusett Reservoir. A detailed cost estimate was conducted for the new BMP design.

Sustainability: The BMP design should be sustainable and require minimal maintenance and yearly upkeep. Any recommendations for the basin should also be able to upgrade the existing basin without drastic modifications.

Manufacturability: The ease with which a design can be constructed is an important aspect of the design process. This also accounts for the reproducibility of the sampling plan developed in the Methodology.

Ethical: Neglecting to treat stormwater runoff contaminated by human development is unethical. This project aims to improve the treatment methods currently in place to mitigate the effects of these contaminants that would potentially harm humans and the ecosystem. In addition, the field work was conducted and the design was developed in an ethically appropriate manner.

Health and Safety: Since the primary focus of this project was water quality and the BMPs under study treat water entering the Wachusett Reservoir, the project had a direct impact on the health and safety of those drinking the water.

Social and Political: The DCR is required to protect public drinking water bodies, and this design followed that political mandate by ensuring that the water discharged from the basin is cleaner than the water entering. Since this design improves water quality, the society near the basin and those receiving the cleaner drinking water will benefit.

Executive Summary

Stormwater runoff from developed areas often requires controls to mitigate the effects of contaminants entering a water supply. These controls, or best management practices (BMPs), are designed to improve stormwater quality by removing contaminants and reducing stormwater runoff volumes. Cities and towns routinely require the use of BMPs to protect water quality and ecosystems in adjacent water bodies. Many large cities also strive to protect their water supplies by controlling contaminants at the source, rather than paying the costs of treating for those contaminants through extensive water treatment procedures.

The clean water needs of the Metropolitan Boston, an urban area with a population of 2.5 million, are supplied by a series of reservoirs in central and western Massachusetts, including the Wachusett Reservoir (Massachusetts Water Resource Authority, 2012). The Wachusett Reservoir is protected from polluted stormwater runoff by the Department of Conservation and Recreation (DCR). The DCR has focused on using stormwater treatment BMPs to intercept stormwater runoff from roadways in the area. Several treatment basins exist around the Wachusett Reservoir, but the effectiveness of the BMP designs for treating polluted runoff is not fully understood. The DCR has begun the development of new basins to decrease the volume of untreated stormwater that enters the reservoir using the most efficient design possible. However, there is a need to evaluate the effectiveness of current basins and estimate the potential impacts of proposed basins.

The goal of this project was to assist the DCR in this development process of new basins by analyzing current BMPs for stormwater quality and flow characteristics. The objectives were to analyze stormwater quality in existing treatment basins and to fully design a new stormwater BMP. To determine the best design for new BMPs, the existing basin designs were analyzed to determine which design aspects removed contaminants most efficiently. Two basins with different designs at the Wachusett Reservoir were chosen to be analyzed for stormwater quality, the Gate 27 and River Street basins. The analyses of the two basins were incorporated into an ideal design that will successfully remove contaminants from runoff before entering the Wachusett Reservoir.

Flow data and stormwater samples were collected from the inflows and outflows of both basins during multiple storm events from October through December, 2012. The samples were tested for a number of constituents, including nutrients, dissolved oxygen, TSS, pH and alkalinity, cations, and anions. The resulting data were analyzed using various laboratory techniques to find the loading of each constituent entering and leaving the basins. The laboratory procedures used include spectrophotometry, a dissolved oxygen probe, pH meter, turbidimeter, titration, graphite furnace atomic absorption, air/acetylene flame atomic absorption, and ion chromatography.

The hydraulics of the basins were analyzed using a modeling program (HydroCAD©) and the results were combined with the water quality data to determine pollutant removal efficiencies and contaminant loadings. The flow data for the two basins were also used to calculate how much of the runoff entering each basin infiltrates into the ground, as opposed to discharging into the reservoir. It is believed that expected that infiltration of stormwater through a BMP to the ground will remove the contaminants of concern in the runoff before reaching the reservoir. While the unlined Gate 27 basin allows most stormwater inflow to infiltrate freely to

the ground, River Street's lined basin bottom prevents infiltration to groundwater. The basin removal efficiencies proved that the Gate 27 design was more efficient than River Street due to infiltration to the ground.

The information gathered through sampling, modeling, and research on stormwater BMPs was used to design a new BMP located near the Wachusett Reservoir, at DCR Gate 25. The design process took into consideration the advantages and disadvantages of the River Street and Gate 27 basins. The basis of the new design was a bioretention basin that incorporated infiltration, specific filtration media, and vegetation. The size and capacity of the new basin was determined by the characteristics of its location in the watershed, such as the catchment area and soil type. The resulting basin design for Gate 25 was an effective treatment system for the Wachusett Reservoir.

This project provided empirical data of the typical stormwater quality and hydraulic performance of existing BMPs. The proposed design for the new basin also gave a design basis that can be utilized for later basins. By implementing the new design, the Wachusett Reservoir will be better protected from contamination, which will provide clean water for the Metropolitan Boston area.

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1 Introduction

Stormwater runoff from developed areas typically requires controls to mitigate the effects of contaminants entering a water supply. These controls are often stormwater best management practices, which manage the discharge of the runoff entering the water body and reduce the contaminant loads in the runoff. The Department of Conservation and Recreation manages many best management practices, and aims to maintain a high water quality in the Wachusett Reservoir.

1.1 Background

Maintaining a high quality of water in watersheds is important in keeping drinking water healthy and preserving surface water quality. Large municipalities often develop water bodies as reservoirs and build the reservoirs in areas that can be protected. If the reservoir ecosystem is not well maintained, there could be harmful effects to the population receiving the drinking water. The Metropolitan Boston area utilizes a system of watersheds across the state to supply its drinking water. The system originally consisted of the Chestnut Hill reservoir alone (Massachusetts Water Resources Authority, 2012). As the population of the city increased, the need for a larger water source increased as well. After maximizing the usage of local reservoirs, such as Chestnut Hill, water lines were added between Boston and the Wachusett Reservoir. When demand grew even greater, the Quabbin Reservoir was added to the series of drinking water supply for Boston. Chestnut Hill is no longer in use, and Wachusett Reservoir is currently the last water resource before Boston. The current drinking water distribution system for Boston and the MetroWest area is shown in Figure 1.

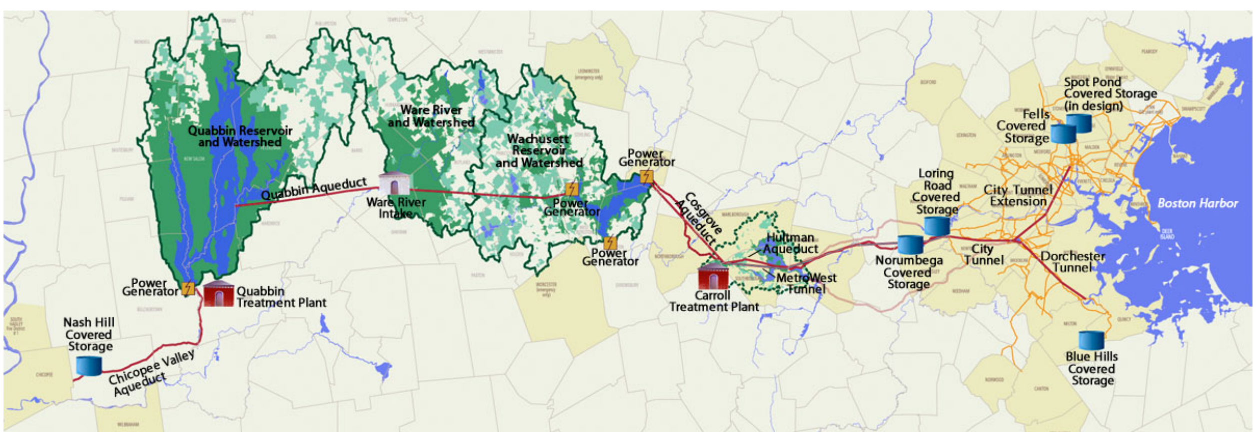


Figure 1: Distribution of Drinking Water for Boston, Massachusetts (Massachusetts Water Resources Authority, 2012)

The Massachusetts Water Resources Authority (MWRA) is not required to filter its drinking water according to the EPA’s Surface Water Treatment Rule due to a waiver obtained by the DCR and MWRA. The waiver allows the MWRA to distribute drinking water that has not been filtered as long as the watersheds used to provide the water have been aggressively managed and protected (Department of Conservation and Recreation, 2013).

It is more economical to protect the water supply from external contamination than to install extensive water filtration and other higher treatment processes. As such, the quality of water entering a reservoir largely depends on the land uses, populations, and impervious area surrounding it. The area around the Wachusett Reservoir is densely populated, which makes protecting the reservoir important. A map of the Wachusett Reservoir is shown in Figure 2. The possible contaminants that result from urbanized stormwater runoff present a problem for the reservoir, and must be controlled. Since the Wachusett Reservoir is the reservoir nearest to Boston, contaminants in that source have a direct impact on the Metropolitan Boston water supply. Therefore, stormwater that enters the reservoir is often controlled and treated through best management practices, or BMPs.

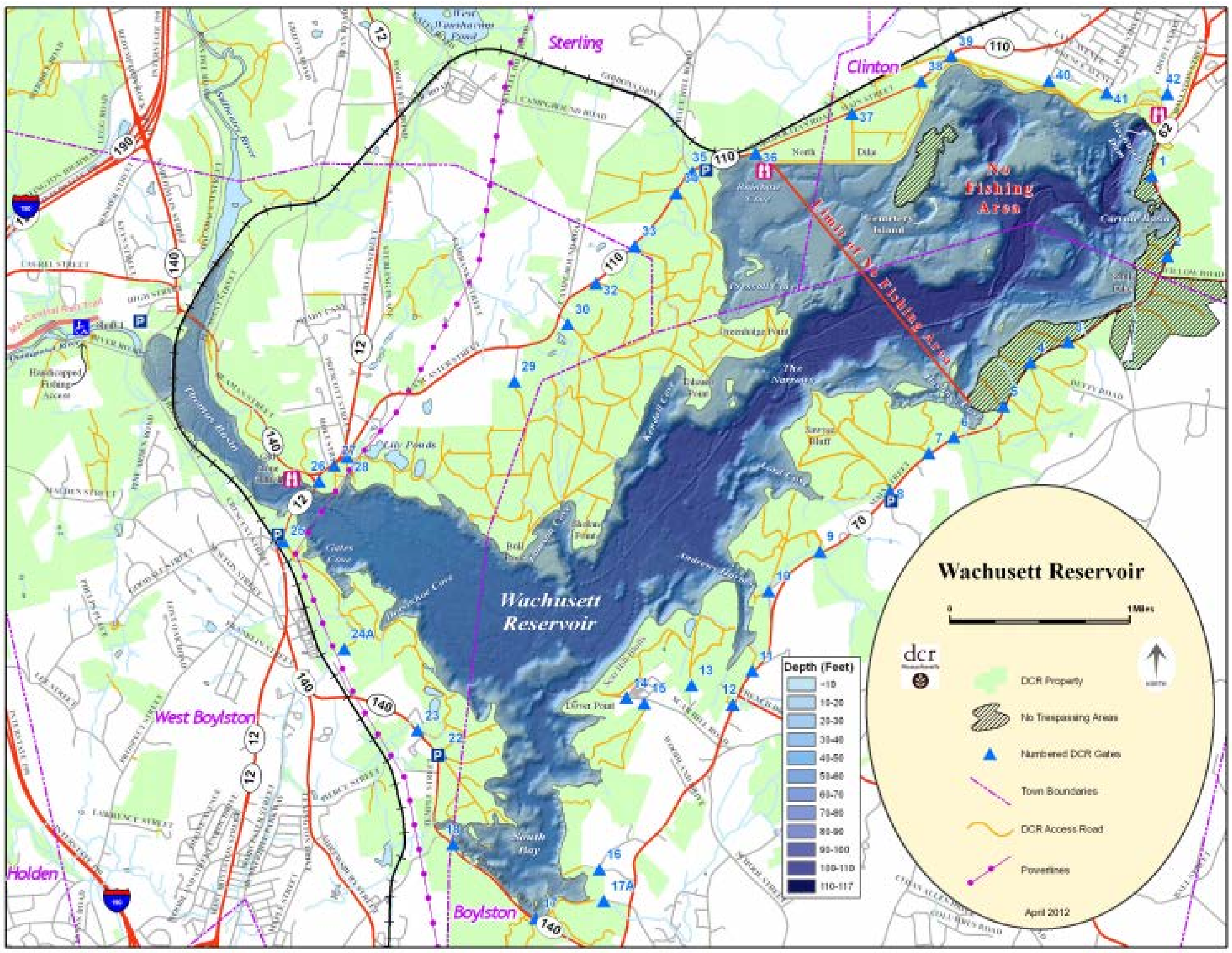


Figure 2: DCR BMP Gates Adjacent to the Wachusett Reservoir (Department of Conservation and Recreation)

There are many types of stormwater BMPs in use around the Wachusett Reservoir. The BMPs in place are all designed to control the discharge of runoff into the reservoir and reduce contaminant loads in the runoff. Bioretention basins hold water during stormwater events, with sediments settling out in a forebay and contaminants being removed through infiltration and biological treatment. This results in cleaner water being discharged to the reservoir.

One organization that helps treat the stormwater runoff to the Wachusett Reservoir is the Massachusetts Department of Conservation and Recreation (DCR). This organization maintains thousands of acres of natural environment, and is dedicated to preserving every part of it. The department has implemented many BMPs around the Wachusett Reservoir in an attempt to control and decontaminate stormwater runoff that enters the waters.

It is recognized that stormwater BMPs are effective in controlling the discharge rate of stormwater into the Wachusett Reservoir and have been shown to remove a large quantity of pollutants. As such, the BMPs around the Wachusett Reservoir must be carefully monitored because of the high level of pollutants entering the basins from the urbanized locations within their drainage area. However, the actual BMP efficiency in contaminant removal varies for each site and is unknown. It is important to be aware of the pollutants and the efficiencies of different types of BMPs to properly assess the contamination of stormwater entering the reservoir and develop BMP designs that effectively control this contamination.

1.2 Objectives and Scope

The goal of this project was to develop an improved stormwater BMP design to better remove various constituents. One objective was to conduct field sampling programs to characterize the pollutant removal efficiencies of two BMPs on the Wachusett Reservoir during wet-weather events. Another was to monitor and model flows and sample stormwater runoff entering and discharging from the basins of study, which would yield pollutant removal efficiencies of concern.

Once the pollutant removal efficiency of pollutants of concern for different types of bioretention basins was known, specific recommendations were made for an updated design approach, which was completed for another site in the Wachusett Watershed. The Gate 25 site was selected for context and this new basin is identified as an ideal basin throughout this report. The design of this ideal basin focused on incorporating the best attributes of the two initial bioretention basins of study to create a more efficient and effective stormwater bioretention basin.

1.3 General Approach

The overall approach included a combination of field monitoring and sampling, analysis and modeling, and design development for an idealized stormwater basin. Field monitoring was completed and samples were collected during wet weather events from October through December, 2012 and the monitoring results and samples were analyzed. A methodology was developed to ensure that the sampling was completed in the most efficient and comprehensive manner possible, and can be found in Section 3.5. Once the laboratory analyses were completed and the results were tabulated, the removal efficiencies of the bioretention basins under study were calculated.

This report includes the background information and methodology required to successfully complete a Major Qualifying Project on bioretention basin efficiencies. The field results and analysis of two bioretention basins are also included. The laboratory procedures are outlined in

Section 3.6, with detailed procedures in Appendix B. The efficiencies for both basins are located in Section 4.6. Comparisons between the basins were made and a design approach was developed to construct an ideal basin, taking into account the basin efficiencies determined during this project. A design for an ideal stormwater bioretention basin was also completed and is described in Section 5 of this report.

2 Background

This report examines two bioretention basins near the Wachusett Reservoir, which were analyzed to determine the ideal characteristics of a stormwater best management practice considering the land uses in the drainage area. The background section provides information on stormwater management and possible pollutants, the Massachusetts Department of Conservation and Recreation, the Wachusett Watershed, Massachusetts Department of Environmental Protection and US Environmental Protection Agency specifications, and stormwater modeling.

2.1 Stormwater Management

Non-point source pollution is the largest water quality problem in the United States (US Environmental Protection Agency, 2012). Also known as runoff, it occurs when rain or melted snow washes pollutants from ground surfaces into waterways. Polluted runoff can come from roads and highways, urban centers, agricultural areas, and any other area that contains contaminants that may be washed away. If stormwater infiltrates the soil and adds to the groundwater aquifers before reaching a water body, natural filtration occurs and the groundwater that seeps into streams or rivers is free of pollutants.

Runoff is important to control in areas with large areas of impervious surfaces, such as buildings, roads, and parking lots. In these areas, stormwater cannot seep into the ground and contaminants on these surfaces are carried with the runoff wherever it goes, often through storm drains into surface water. Runoff brings contaminants into surface waters and reservoirs, which can raise the pollutants levels above healthy concentrations.

Agricultural runoff can carry contaminants that are laid on the surface of fields. These contaminants include fertilizers, which are notable because they promote the growth of plants and can promote the growth of algae in surface waters. Many fertilizers include nitrogen, often in the form of nitrates (US Environmental Protection Agency, 2000). Controlling the spread of fertilizers is one method of controlling the growth of algae and plants in surface waters.

Stormwater runoff is an issue that requires mitigation due to its capacity to contain harmful byproducts, such as motor oil and suspended solids. To keep receiving water bodies from becoming polluted, best management practices (BMPs) are implemented and the contaminants are treated. This is discussed further in Section 2.1.2.

2.1.1 Constituents in Stormwater Runoff

There are many pollutants that can be carried into waterways by stormwater, including the constituents mentioned previously. The following constituents are those that were studied and tested for during this project.

2.1.1.1 Nutrient Pollution

The pollutants that are the most important to control are nutrients. Limiting growth factors of algae and plants in freshwater lakes, ponds, and reservoirs are especially important to regulate (US Environmental Protection Agency, 2000). Limiting nutrients are the nutrients that are in the lowest concentration compared with the other nutrients used in growth. Nitrogen and phosphorus are the limiting nutrients in growth in freshwater lakes and reservoirs, and the overabundance of either can lead to the rapid growth of certain types of algae and plants that have negative effects on the health of lakes and reservoirs (US Environmental Protection Agency, 2000). Algal blooms can produce toxins, which is an issue in drinking water systems.

2.1.1.2 Nitrogen

Nitrogen is essential for algal growth, making it useful in predicting algal blooms (US Environmental Protection Agency, 2000). It is not as much of a limiting nutrient in plant growth. The concentration of nitrogen is difficult to control because certain algae can absorb nitrogen directly from the air or from nearby plants. Nitrogen is generally measured in four forms, ammonia, nitrates, nitrites, and total Kjhedal nitrogen (also known as organic nitrogen), each of which defines nitrogen in different chemical structures (US Environmental Protection Agency, 2000).

The different forms of nitrogen are also important in understanding the processes happening in a treatment system. Ammonium (NH_4^+) that is present in the runoff is converted into nitrite (NO_2^-) by nitrifying bacteria. The nitrite is then converted to nitrate (NO_3^-) by similar bacteria. The overall reaction of these processes is shown in Reaction 1 (Davis & Masten, 2009).

$$NH_4^+ + 2O_2 = NO_3^- + 2H^+ + H_2O$$

Reaction 1: Nitrification

2.1.1.3 Total Phosphorus

Phosphorus is typically considered to be the most limiting factor in algal production in lakes and reservoirs (US Environmental Protection Agency, 2000). Controlling algal concentrations using phosphorus is easier than nitrogen because phosphorus cannot be absorbed from the atmosphere and is less abundant in nature. Phosphorus is also a limiting nutrient in plant growth, making it an important element to monitor and control.

Phosphorus passes through a series of processes. These processes convert the phosphorus between organic and inorganic forms. Pure phosphorus is typically not found naturally. Phosphorus is most commonly found as organic or inorganic phosphates in aquatic systems. The form of phosphorus changes as it travels through the environment due to a number of different natural processes, known as the phosphorus cycle (Davis & Masten, 2009). Inorganic phosphorus can be converted to organic phosphorus by aquatic plants. It is absorbed by the plants until they die, after which it is converted back to inorganic phosphorus by decomposition.

The term total phosphorus represents the total amount of phosphorous present in the sample, which can be either organic or inorganic. Inorganic phosphorus is more hazardous in freshwater systems than organic phosphorus because it can promote the growth of unhealthy bacteria or algae (US Environmental Protection Agency, 2012). These bacteria or algae can have negative impacts on the surface water quality. Plant life can promote the conversion of inorganic phosphorus into organic phosphorus in stormwater treatment basins.

2.1.1.4 Cations

Some of the most dangerous pollutants in freshwater systems are metals, such as mercury and lead. Many metals are toxic in high concentrations, and can cause health impairment in even the smallest quantities. Metals that are often monitored in freshwater drinking water sources include lead, mercury, and aluminum, which are all listed by the EPA as priority contaminants. Iron, which is listed as a non-priority contaminant by the EPA, is also often monitored in freshwater and drinking water bodies, though it does not have significant negative health effects.

Mercury is especially noteworthy for the Wachusett Reservoir because the reservoir has been listed as impaired due to mercury contamination in the fish population (US Environmental Protection Agency, 2010). The EPA lists the maximum acute concentration for mercury in freshwater bodies to be 1.4 µg/L (US Environmental Protection Agency, 1996). This concentration is low enough that even small flows of runoff carrying mercury can raise the concentration in the reservoir above the maximum allowed level.

Lead and aluminum can both have negative health impacts even at relatively low concentrations. The EPA mandated maximum acute concentration for lead is 65 µg/L. MassDEP requires action be taken for mercury concentrations of 0.015 mg/L (Massachusetts Department of Environmental Protection, 2012). The maximum concentration for aluminum is 750 µg/L. While mercury is currently at high enough levels in the Wachusett Reservoir to cause fish tissue impairment, these other metals should not be overlooked.

Iron is considered a non-priority contaminant as any negative health effects do not occur unless it is in very high concentrations. Iron is monitored to ensure that the reservoir is at healthy levels.

Calcium and magnesium, when present in water, create hard water and scale. Calcium does not have a maximum limit, but magnesium is to have a concentration of no more than 125 mg/L (Johnson & Scherer, 2012). Other cations, such as manganese and sodium, have low maximum concentrations; manganese has a limit of 0.05 mg/L and sodium has a limit of 100 mg/L. This is because these constituents can have an effect on human health and the aesthetics of the water in high quantities. Arsenic is another cation that can be extremely dangerous to human health. If a person is exposed to arsenic over a long period of time, they can become sick or develop cancer (Johnson & Scherer, 2012). The maximum level of arsenic allowed in drinking water is 10 parts per billion.

2.1.1.5 Anions

Anions do not have a large effect on human health or surface water impacts except in high concentrations. Measuring the concentrations of anions in a surface water body is useful to fully understand the complete range of constituents.

Sulfate is not a directly regulated constituent by the EPA. There is no maximum contaminant level specified for sulfate, although the EPA has set a recommended maximum load of 250 mg/L. The health impacts of high concentrations of sulfate have not been tested, but gastrointestinal discomfort has been reported (US Environmental Protection Agency, 2012).

Fluoride is often used as an additive for drinking water to aid dental health. However, in higher concentrations fluoride can cause negative health impacts such as degrading tooth enamel and weakening bone structures. The EPA has set two standards for fluoride concentrations, the maximum concentration and the recommended concentration. The maximum concentration of fluoride in drinking water is 4 mg/L (US Environmental Protection Agency, 2012). This concentration was determined based on the health impacts of fluoride done by the US Surgeon General. The Massachusetts Department of Environmental Protection has adapted the EPA standards based on the same study (Massachusetts Department of Environmental Protection, 1993). The EPA also developed a recommended maximum fluoride concentration for drinking water. The recommended concentration was developed to decrease the chance of negative health impacts by the fluoride concentration. The recommended maximum fluoride concentration is 2 mg/L (US Environmental Protection Agency, 2012).

Chloride concentrations are often linked to the concentration of sodium due to the use of sodium chloride, or salt, as a road deicer. The EPA has set a recommended drinking water standard for chloride, but has not set a maximum concentration level. The recommended maximum concentration is set at 250 mg/L (US Environmental Protection Agency, 2012).

2.1.1.6 Total Organic Carbon

Total Organic Carbon (TOC) is a measure of the amount of carbon contained in organic molecules in the water. While there are currently no EPA regulations on total organic carbon levels in surface water bodies, TOC is regulated during surface water treatment (US Environmental Protection Agency, 1999). The removal of TOC reduces the amount of water treatment disinfection byproducts that can be dangerous in drinking water. TOC concentrations of greater than 2.0 mg/L in the raw water of a water treatment system require treatment. Keeping TOC levels low is important in the Wachusett Reservoir as it is the raw water source for the MWRA water system (Massachusetts Water Resources Authority, 2012).

2.1.1.7 Dissolved Oxygen

Dissolved oxygen (DO) is a closely regulated criterion in surface waters. Dissolved oxygen is important to maintain the health of the reservoir, and also has major impacts on drinking water quality. The EPA requires dissolved oxygen concentrations of at least 5.0 mg/L in warm water and 8.0 mg/L in cold water (US Environmental Protection Agency, 1986). These values are determined by the oxygen requirements of fish and other wildlife. Modified requirements are determined based on wildlife in the surface water body.

2.1.1.8 Total Suspended Solids and Turbidity

Total suspended solids is the measure of particulate matter suspended in the water. Turbidity is a measure of the clarity of the water, the actual measurement being the absorption of light by material in the water (US Environmental Protection Agency, 2012). The two are closely related as the suspended solids absorb light and increase turbidity. High turbidity values increase temperatures during the day, which in turn decreases the dissolved oxygen content. Excessive turbidity measurements are caused by erosion, construction, and excessive algal amounts. The EPA regulations state that the turbidity levels should not reduce the depth of the compensation point for the photosynthetic activity more than 10 percent from the norm (US

Environmental Protection Agency, 1986). In effect, the turbidity cannot reduce the levels at which photosynthesis occurs normally by more than 10%.

The reduction of turbidity and total suspended solids is an important issue for drinking water sources as they can prevent the disinfection process from effectively treating the water. Pathogens can be shielded from disinfectant chemicals by suspended solids, which reduce the efficiency of disinfection (US Environmental Protection Agency, 1986). In the case of the Wachusett Reservoir, removing turbidity from stormwater runoff is critical due to the lack of advanced treatment in the MWRA drinking water system.

2.1.1.9 pH

The measured pH of surface water should be between 6.5 and 9 (US Environmental Protection Agency, 1986). pH is important in keeping the ecosystem healthy, and can have negative impacts on drinking water quality if the pH is not within EPA regulations.

2.1.1.10 Alkalinity

Alkalinity is a measurement of the buffering capacity of water in terms of pH (US Environmental Protection Agency, 1986). It neutralizes acids introduced to the water, such as acid rain, making it an important pH buffer for fish and aquatic life in the freshwater system. Alkalinity is important in drinking water systems because it determines the amount of chemicals needed to be added to the water to treat other properties, such as hardness. It is measured as mg/L as $CaCO_3$, which is a measurement of the concentration of a chemical, calcium carbonate, that produces the equivalent alkalinity. The minimum alkalinity according to the EPA is 20 mg/L as $CaCO_3$, except where the natural concentrations are less (US Environmental Protection Agency, 1986).

2.1.1.11 Microorganisms

The EPA regulates bacterial numbers for a number of specific bacteria types. The bacteria chosen are picked because they are particularly dangerous in drinking water applications or are indicators. Indicators are organisms that thrive in similar conditions to pathogenic organisms, are easier to identify, and are used to help identify when a harmful bacteria may be present. The pathogenic and indicator organism levels in drinking water must be zero because they can be incredibly harmful to human health (US Environmental Protection Agency, 2012).

Total coliforms and fecal coliforms are used as indicators for bacteria that may be found in drinking water. Fecal coliforms indicate that the source of the coliforms was the digestive tract of another organism, such as a human or animal. These coliforms are noteworthy because they indicate that bacteria that can cause enteric diseases may be present in the water sampled (US Environmental Protection Agency, 2012). Escherichia coli are often used as indicators for other pathogens.

Dangerous pathogens that the EPA has noted specifically include *Cryptosporidium*, *Giardia*, and *Legionella*. *Cryptosporisium* and *Giardia* both cause gastrointestinal illnesses, which can cause death in certain cases. *Legionella* is pathogen that causes Legionnaire's disease. The presence of these pathogens in drinking water is prohibited (US Environmental Protection Agency, 2012).

Another constituent that has an impact on bacterial treatment is turbidity. Turbidity can shelter pathogens from disinfection. Reducing turbidity increases disinfection efficiency.

2.1.2 Best Management Practices

A best management practice (BMP) is a mitigation technique that can encompass many aspects of protecting the environment. A BMP can range from cleaning trash at a work site to reducing the generation of a pollutant. There are BMPs for several environmental concerns, including agriculture, water quality, oil drilling, and stormwater treatment. This project utilizes the type of BMP that is a structural device that captures and treats stormwater runoff. Treating runoff has many benefits: bank erosion is controlled, downstream habitats are preserved, public health is protected, and flood control is utilized (US Environmental Protection Agency, 2007). The intent of implementing a BMP after construction at a site is to mitigate the impacts of development on the ecosystem. There are many types of stormwater BMPs; while all are used to control the aforementioned aspects of stormwater runoff, some are also used for an aesthetic or recreational purpose. The following sections describe a few common stormwater BMPs.

2.1.2.1 Green Roofs

Green roofs cover typical metal or shingled roofs with soil and vegetation, which stores rainfall and later dispels it through evapotranspiration. This reduces stormwater runoff caused by the impervious roof surfaces in industrial and commercial regions (US Environmental Protection Agency, 2008). If a community has combined sewer and stormwater drains, green roofs help reduce combined sewer overflows that discharge directly into a water body by retaining the initial precipitation. This precipitation then evaporates or is transpired into the atmosphere by the vegetation (Center for Neighborhood Technology, 2010). Vegetation on green roofs use nutrients from the precipitation that would otherwise become runoff and lower water quality in receiving water bodies. Green roofs help control building temperatures during summer months by decreasing the amount of direct sunlight hitting the roof (Massachusetts Department of Environmental Protection, 2008). The pleasing aesthetics of a rooftop garden are another positive attribute of green roofs.

2.1.2.2 Detention Basins

There are two types of detention pond BMPs: dry and wet. Both contain stormwater runoff for an extended period of time, which allows particles and pollutants in the water to settle (US Environmental Protection Agency, 2006). Wet detention ponds have a standing water level in the basin that does not dissipate, and dry detention ponds do not have any permanent water. Detention ponds typically have larger drainage areas, and function well with almost any soil type (US Environmental Protection Agency, 2006). Sediment forebays are often used to settle out particles before the stormwater reaches the main basin.

2.1.2.3 Infiltration Basins

Infiltration basins are shallow, man-made basins that collect stormwater and remove pollutants through groundwater infiltration (US Environmental Protection Agency, 2012). The basins can drain for up to a few days after a storm. These BMPs have specific soils requirements to increase infiltration and ensure there is no clogging. Permeable soils are ideal for quick infiltration and preventing clogging, but if it is too permeable, pollutant removal will not be as efficient. Pretreatment is often used to remove the larger suspended materials, which increases the overall efficiency of the system and provides more efficient maintenance. Infiltration basins are best utilized for small drainage areas, or there is a higher rate of failure (US Environmental Protection Agency, 2012).

Before stormwater runoff reaches the infiltration basin, large particles are often settled out in sediment forebays or vegetated filter strips. Infiltration basins are typically designed for smaller storms and focus mainly on water quality, rather than flow control (US Environmental Protection Agency, 2012). According to the EPA, a drawback of this BMP design could be its efficiency during different weather patterns. When the ground freezes during the winter, stormwater may not be able to infiltrate and the runoff would enter directly into the receiving water body. During the spring months, large amounts of snowmelt could overwhelm the basin and infiltration would not occur.

2.1.2.4 Bioretention Basins and Rain Gardens

Bioretention basins and rain gardens are shallow basins that mimic natural ecosystems and remove pollutants through soil filtration (US Environmental Protection Agency, 2012). This type of BMP has an underdrain that collects the filtered water and discharges to a receiving water body. They are typically used in smaller sites so the BMP does not clog. Rain gardens are located downhill from an impervious surface, which allows the runoff to be absorbed by the vegetation (Center for Neighborhood Technology, 2010).

Unlike infiltration basins, bioretention and rain gardens can contain any type of soil because it discharges to a drainage system (US Environmental Protection Agency, 2012). This BMP often utilizes particle settlers, such as a forebay, as a form of pretreatment. Bioretention basins and rain gardens are still effective during cold weather, when snow can be stored, and salt can be reduced before entering a water body. Bioretention basins alleviate flooding and pollution problems by retaining and infiltrating stormwater runoff (Center for Neighborhood Technology, 2010).

Bioretention areas have had minimal data collected concerning pollutant removal efficiencies. Section 2.1.3 covers some of the data that has been studied with respect to these BMPs.

2.1.3 Specifications and Guidelines for Bioretention Basins

The following sections describe the specifications for bioretention BMPs currently in use in Massachusetts.

2.1.3.1 MassDEP Specifications

The Massachusetts Department of Environmental Protection (MassDEP) is a state agency that protects the air, water and wetlands from toxic and hazardous waste. MassDEP implements regulations imposed at the state and national level. MassDEP gives local municipalities assistance to comply with the state regulations. They do this by making information available on BMPs and allocating monetary resources to vital projects.

The DCR has used information available from MassDEP on BMP in the construction of their bioretention basins surrounding the Wachusett Reservoir. MassDEP has provided a handbook on structural BMPs with specification that must be met and recommendations for stormwater treatment, along with data showing the efficiency of the various BMPs.

In the MassDEP handbook, bioretention areas are combined with rain gardens because they both use soils, plants, and microbes as a means of decentralized water treatment. The purpose of the bioretention areas installed by the DCR is to organically filter water before discharging it. An example of a bioretention basin design is shown in Figure 3.

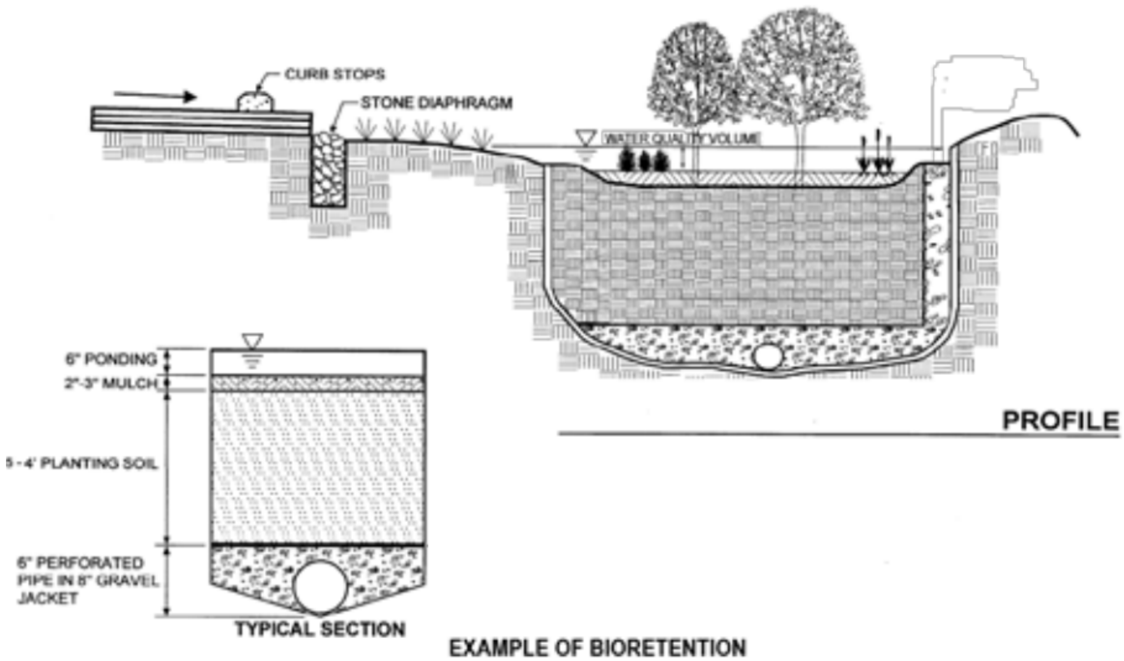


Figure 3: Bioretention Basin Design Example (Massachusetts Department of Environmental Protection, 2008)

Bioretention basins are used for TSS removal, high pollutant loads, discharge treatment in critical areas and are especially effective at treating the first flush of stormwater runoff. In order to effectively treat high pollutant loads in the stormwater runoff, there must be pretreatment that removes more than 40% of the TSS (some basins may require oil grid separators or sand filters as well). The bioretention cells that make up the basin are lined with gravel, sand and an underdrain, which discharges the water after treatment. Some older designs use fabric filters as a liner but have since been found to clog, making them less effective. The pollutant removal efficiencies for bioretention areas provided by MassDEP as follows:

Table 1: MassDEP Removal Efficiecies

Pollutant	Removal Efficiency
Total Suspended Solids (TSS)	90% with vegetated filter strip or equivalent
Total Nitrogen	30% to 50% if soil media at least 30 inches
Total Phosphorus	30% to 90%
Metals (copper, lead, zinc, cadmium)	40% to 90%
Pathogens (coliform, E. coli)	Insufficient data

In order to ensure TSS pretreatment, the DCR has installed sediment forebays on their bioretention basins. Sediment forebays are another BMP mainly used as pretreatment before bioretention, wet, or dry detention basins. The forebay is a large pool, which reduces the velocity of the inflow to allow suspended solids to settle and increases the effectiveness of future treatment, as seen in Figure 4.

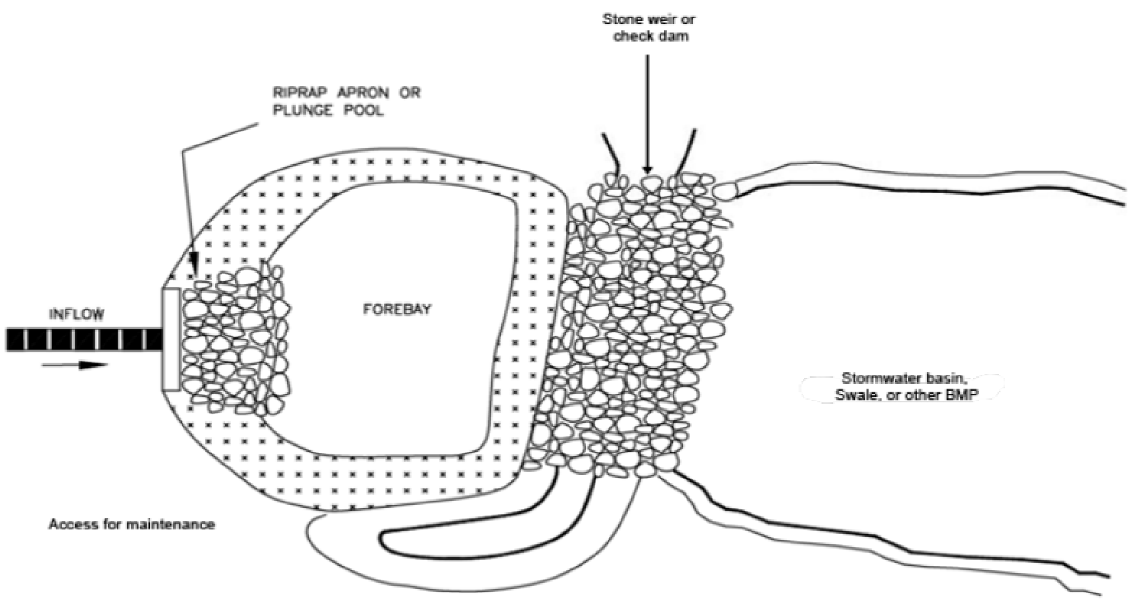


Figure 4: Bioretention Basin Forebay Design (Massachusetts Department of Environmental Protection, 2008)

MassDEP does not maintain data on removal efficiencies of a forebay nor a forebay used with a bioretention area. The MassDEP does require a sediment forebay along with a vegetated filter strip and grass-gravel combination so the BMP will have 90% TSS removal.

The soil used in the basins is required to be at least 2 feet thick. Most pollutant removal happens at depths of less than 2 feet. The soil is usually no thicker than 4 feet because of cost and diminishing returns in treatment. Nitrogen removal takes place below 2 feet. If the basin needs to reduce nitrogen loads, the soil should be at least 30 inches thick. Additionally, if the basin design includes trees or shrubs the soil must be at least 36 inches thick.

There are many benefits that bioretention basins offer beyond water treatment. These include the ease of installation for retrofitting, the low hazard to wildlife, and the ability to provide groundwater recharge if desired. While these benefits make bioretention basins worthwhile, they do have some drawbacks. Bioretention basins are unsuitable for treating large drainage areas and steeply sloped areas. According to MassDEP, a bioretention basin should be between 5-7% of the area draining to it. Inspection of the basin for standing water, sediment build up, and structural damage should be done regularly. The basins also require regular maintenance to ensure good removal of pollutants. Table 2 lists the required maintenance for a bioretention basin.

Table 2: Maintenance Required for Bioretention Basins

Activity	Frequency
Inspect and remove trash	Monthly
Mow	2 to 12 times per year
Mulch	Annually
Fertilize	Annually
Remove dead vegetation	Annually
Prune	Annually

During construction, the soil below the basin should be tested for permeability. Highly permeable soil is beneficial to treatment and compaction during construction can negatively impact the permeability. MassDEP recommends construction from the edge of the basin rather than directly on top of the basin. Water should also be diverted away from the basin until the bioretention basin is complete.

2.1.3.2 US EPA Illicit Discharge Detection and Elimination Program

The US EPA has developed many procedures for the reduction or eradication of stormwater runoff. One such program recommends that illicit discharges, or stormwater runoff, are reduced through the implementation of Illicit Discharge Detection and Elimination program (US Environmental Protection Agency, 2006). This program recommends that discharges are controlled through a series of audits identifying sources of contamination in urban stormwater systems. Examples of these sources include carwashes, or chemical spills in industrial areas. The information gathered about stormwater sources can then be used in an implementation procedure to eliminate the discharge.

2.1.3.3 Other States' Use of BMPs

Other states have developed stormwater BMPs similar to Massachusetts. For example, Maine has developed BMPs to control stormwater and phosphorus through a number of methods (Maine Department of Environmental Protection, 2011). One of the stormwater control methods includes constructing basins similar to those around the Wachusett Reservoir. Other stormwater management practices include implementing low impact development (LID), pollution prevention, and designing treatment basins. Another state that has developed extensive BMPs is Minnesota. However, the BMPs utilized in that state typically focus on different land uses. While they do include methods of managing stormwater, the BMPs also list extensive methods of reducing erosion and controlling sediments (Minnesota Pollution Control

Agency, 2011). Minnesota also includes BMPs for groundwater management. The added BMPs are a result of differences in conditions between New England and Minnesota.

2.1.4 Design Parameters for Bioretention Basins

The following subsections describe many aspects of a stormwater BMP design. The design components were gathered from multiple sources of literature. This section focuses on other researchers' BMP evaluations and design approaches.

2.1.4.1 Stormwater Biofiltration Systems

"Water biofiltration is the process of improving water quality by filtering water through biologically influenced media" (Facility for Advancing Water Biofiltration, 2009). The water quality that is improved is typically stormwater or wastewater, and the biofiltration occurs when the water flows through vegetation and a "porous filter media," normally some form of soil, and exits through infiltration and/or a drainage pipe (Facility for Advancing Water Biofiltration, 2009). Figure 5 shows the design of a typical biofiltration system.

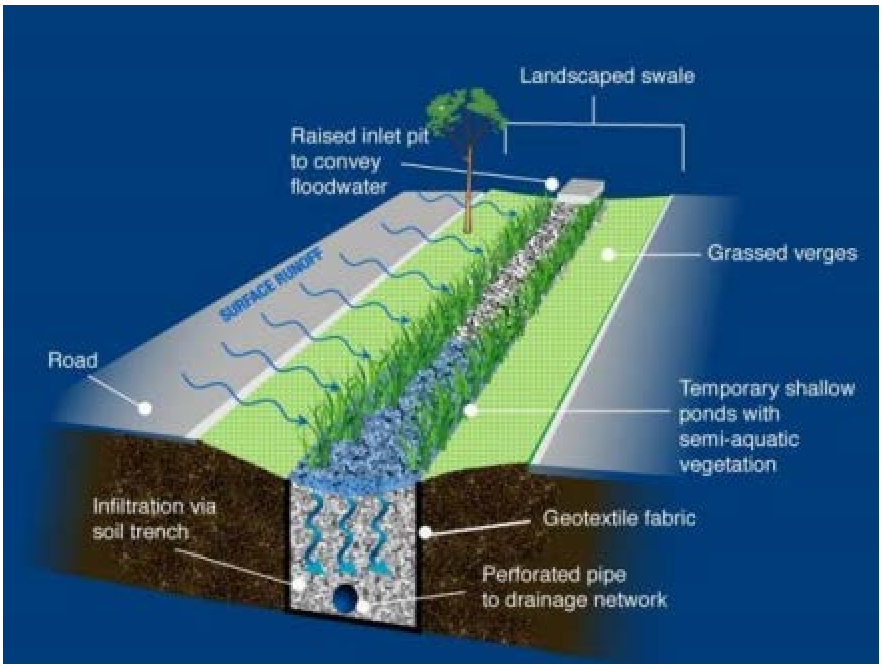


Figure 5: Example Biofiltration System Design

This design includes vegetation such as grass and taller plants, filter media, a soil trench that allows infiltration into the surrounding soil, and a drain for the outflow. There are many variations of design that can exist for biofiltration systems, and each variation has different consequences for the water treatment. If the outflow drain is removed from the design, the water will infiltrate into the surrounding soil. If the drain is included, but is placed above the bottom of the filtration system, more infiltration will occur during smaller wet-weather events and the design will still allow for water discharge to occur during larger storm events (Facility for Advancing Water Biofiltration, 2009). It is also possible to change the type of media and vegetation used for the design, which will be discussed further below.

In addition to water treatment, one of the primary goals of a biofiltration unit is to reduce the volume of stormwater runoff entering a water body from roads and the contributing watershed. Generally put, the purpose of a biofiltration system is to “maintain or restore runoff volumes and frequency to predevelopment levels” (Facility for Advancing Water Biofiltration, 2009). Since urban areas generate large volumes of stormwater runoff due to the amount of impervious area, biofiltration systems are an important method that helps to reduce the volume of runoff and improve the quality of the water. This goal is completed in three ways (Facility for Advancing Water Biofiltration, 2009):

1. Physical treatment occurs as water flows through the vegetation, which reduces the flow rate and helps with particle settling. Solids suspended in the water are also removed through filtration as the water infiltrates the soil.
2. Chemical treatment occurs when the particles in the water are attracted to the soil particles and are subsequently removed from the flow.
3. Biological treatment occurs when the vegetation utilizes the nutrients in the water for growth.

There are many aspects of the design that need to be considered before development of a biofiltration system. The individual elements of the design, such as the inflow pipe diameter, filter media, and vegetation type, are the most important aspects, but determining how the system will fit into the surrounding landscape and what impact it will have is also pertinent.

Each component of the overall biofiltration system design must meet certain standards or recommendations, often implemented on a state level. The design must be completed in a way that allows each element of the design to perform its duty in the most efficient manner. For example, the purpose of vegetation in a biofiltration system is to remove contaminants and promote evapotranspiration of the stormwater. Therefore, using vegetation types that are native to the area of the system is imperative, and it must also be able to withstand local weather conditions. Having a higher density of vegetation is also beneficial, as it will increase the nutrient uptake and evapotranspiration losses. An area at the inflow needs to be designed to slow down the flow entering the basin. This area can also be used as a small-scale settling device to remove suspended particles. An example of this a sediment forebay, where rocks slow down the flow rate and the small basin shape allows for settling to occur before the water travels into the main basin. Controls such as an outflow pipe and the amount of water allowed to infiltrate to groundwater are also important aspects to consider. The control method for infiltration is utilizing a liner and underdrain for the basin, which prevents the water from completely infiltrating. Not using a liner means all or most of the water that enters the basin will infiltrate to the ground.

The media contained within the basin itself is one of the most important aspects of a biofiltration system. The purpose of the media is to remove contaminants through filtration, support the vegetation, and retain the stormwater runoff to reduce flow rates (Facility for Advancing Water Biofiltration, 2009). The type of sand, silt, or clay that is used determines the infiltration rate of the overall basin. A soil type with particles packed closely together, like clay, will have a much slower infiltration rate than soil with loosely packed particles. This should be considered when determining what type of filter media will be used. The media must also be able to withstand nutrient leaching and compaction, so the infiltration rate does not change. According to the Facility for Advancing Water Biofiltration (FAWB) guidelines, the filter media should have these additional characteristics:

Table 3: FAWB Guidelines for Biofiltration System Filter Media

Parameter	
Hydraulic Conductivity	100 – 400 mm/hr
Soil Breakdown	< 3% silt and clay
Minimum depth for plant growth and heavy metal removal	300 mm
Minimum depth for tree growth	800 mm

Another aspect of the biofiltration system design is a submerged zone. This area in the filter is not required, but has multiple benefits. It is a layer under the filer media that maintains a constant volume of water, which helps the vegetation in the system grow, increases nitrogen removal, and can be used when the weather is in a dry period (Facility for Advancing Water Biofiltration, 2009). FAWB recommends that this zone, if utilized, be at least 300 mm deep, with an optimal depth of 450 mm.

The drainage ability of the biofiltration system is an important consideration for design. This includes the specifications for the underdrain, liner, and drainage layer. The drainage layer is the section of the system that contains the treated water and transports it to the outflow pipe (Facility for Advancing Water Biofiltration, 2009). Typically, the drainage layer is made up of gravel at least 50 mm deep, and should be designed to be at least as large as the detention volume for the system so the detention capacity remains unsaturated, even if many rainfall events occur (Facility for Advancing Water Biofiltration, 2009). The underdrain should have be a pipe that is slotted for water entry to outflow under the filter media, and a vertical section that extends to the surface. Figure 6 depicts the shape of the drainage layer and location of the underdrain to accommodate different purposes of the biofiltration system.

Figure 6: Variations on a Biofiltration System Drainage Layer Design

The design of furthest left image aims to collect as much water as possible. The middle and right images are designed to promote infiltration to groundwater. The raised location of the underdrain in the right image will have a greater infiltration success than the middle (Facility for Advancing Water Biofiltration, 2009). To determine the depth of the drainage layer for the furthest right design, the following equation can be used:

$$Drainage\ layer\ depth = 50\ mm + d_p + D$$

Equation 1: Drainage Layer Depth

Where:

50 mm = Pipe cover depth

d_p = Diameter of pipe

D = Depth from invert of pipe to bottom of drainage layer

If no infiltration to groundwater is desired, a liner is typically used to prevent it. Compacted clays or flexible membranes are two types of liners that can be utilized. The clay prevents infiltration because the water cannot easily flow through it, and the membrane provides complete infiltration prevention.

Once the biofiltration system is in place and begins treating the stormwater runoff, it requires maintenance to keep it running in its most efficient state. This includes removing trash, built up sediment, and weeds from the system, and mowing the vegetation. Another important task after the system is in place is monitoring to see if it is performing as designed. A note the FAWB includes in this biofiltration system review is that "biofilters require an establishment period of approximately two years to allow the filter media to settle and the vegetation to reach its design conditions," which means that the results of a monitoring plan may not be completely accurate if conducted before two years have passed (Facility for Advancing Water Biofiltration, 2009). The data that FAWB recommends gathering as part of the monitoring plan are as follows:

Table 4: FAWB Recommendations for Monitoring Plan Data

General	Specific
Catchment characteristics	Catchment area Slope Impervious area Geological characteristics Land use
Biofiltration system characteristics	Layout – size, slope, elevation Design capacity Material – filter media, vegetation, liner, submerged zone, underdrain Age Condition Maintenance practices
Climate	Rainfall Temperature Evapotranspiration
Constituents	Total suspended solids Total nitrogen Total phosphorus Heavy metals – copper, cadmium, lead, zinc
Physical parameters	pH, conductivity, temperature, dissolved oxygen
Flow	Can use weir, flumes, pipes and water levels, area/velocity meters
Water quality	Can use sensors for continuous collection, samples during rain events, base flow Ammonium Oxidized nitrogen Organic nitrogen Orthophosphate Metals – aluminum, chromium, iron, manganese, nickel

2.1.4.2 Sand and Other Media Filters

Filters remove floating particulates from stormwater by only allowing particles that have a smaller diameter to pass through the outlets. This removes an extent of the suspended solids in the water, which increases the overall quality of the effluent. The extent of removal depends on the type and size of media. For a sand filter, every diameter media has varied water “flow-through rates” and remove different sized suspended solids (Urbonas). If a media has smaller diameter particles, such as fine sand or clay, there is less room for water to travel between them, so it takes longer for it to flow through the media. In this same circumstance, more particulate matter is removed because there is more media obstructing the pathway. Conversely, when the media has particles of larger diameter, such as coarse sand or gravel, there is more space between them, so water flows quickly and more suspended matter passes through the media. Other types of media provide additional suspended solid removal, such as ion exchange that occurs in peat-sand media (Urbonas). The ideal media filter factors in the flow-through rate, diameter of particles, size, typical suspended solids loading, and cost of the filter. It must also be able to handle most storms.

Installing a detention area upstream from the filter increases the efficiency of the system (Urbonas). It allows the filter to receive a steady flow of stormwater, instead of all of the water at once, and provides pretreatment to remove suspended solids that could clog the filter. Detention storage also removes some suspended particles through settling. When the detention area is located completely or partially above the media filter, the TSS removal is completed entirely by the filter, and no suspended solids are removed by settling (Urbonas).

The basic form of Darcy's Law represents the characteristics of water flowing through a filter:

$$q = kI$$

Equation 2: Darcy's Law

Where:

q = Flow velocity (inches/hour)
k = Hydraulic conductivity (inches/hour)
I = Hydraulic gradient (feet/foot)

However, this equation is simple and is affected when the TSS builds up on the filter surface. When this occurs, the flow-through rate of the water decreases, and filtration takes longer to occur (Urbonas). When the filter clogs completely, the water will bypass the filter and become untreated effluent water. Therefore, the effluent water quality is a combination of the treated water leaving the filter and, if the filter malfunctions or a storm is larger than the filter is designed to handle, the quality of the water bypassing the filter (Urbonas).

2.2 Department of Conservation and Recreation

Massachusetts's Department of Conservation and Recreation (DCR) is one of the largest state park systems in the United States. It operates over 450,000 acres of forests, parks, greenways, historic sites, landscapes, seashores, lakes, ponds, reservoirs, and watersheds. The extensive park system the DCR manages not only helps to conserve natural resources, but it largely benefits the public by providing outdoor recreational opportunities.

The DCR's Division of Water Supply Protection deals with best management practices that have been placed on the Wachusett Reservoir, and is subdivided into two offices, the Office of Watershed Management and the Office of Water Resources. The Office of Watershed Management protects watersheds of more than two million residents in the Metropolitan Boston area.

One agency this division interacts with is the Massachusetts Water Resource Authority (MWRA). This public authority provides water and sewer services to 2.5 million people and 5,500 large industrial users in 61 metropolitan Boston communities (Massachusetts Water Resource Authority, 2012). While the MWRA and DCR do not perform the same operations, there are similarities in their capacities. The MWRA is charged with operating, regulating, financing, and improving the water distribution systems. The DCR is responsible for the construction, maintenance, and operation of the system of watersheds and reservoirs for the purpose of supplying sufficient pure water to the MWRA (Memorandum of Understanding, 2004).

The second subdivision in the Division of Water Supply Protection is the Office of Water Resources. This group provides technical support to the State's Water Resource Commission (WRC). The WRC is a state commission comprised of state officials and public members who are responsible for developing, coordinating, and overseeing Massachusetts's water policy planning. This commission also advises the Massachusetts Department of Environmental Protection (MassDEP) in the administration and enforcement of water pollution control and water management policies and regulations. The DCR's Office of Water Resources also monitors water quality, provides educational materials for the public, and manages floodplain technical information.

2.3 Wachusett Reservoir

In central Massachusetts, the DCR manages 21,028 acres of land within the 74,800 acre Wachusett Reservoir Watershed. When full, the reservoir capacity is 65 billion gallons, with a land area of 4,135 acres. This reservoir was built between 1897 and 1908 by damming the South Branch of the Nashua River (Department of Conservation and Recreation, 2012). It has been continuously supplying drinking water to the greater Boston area since 1907. The watershed that supplies this reservoir is almost 107 square miles in area. The watershed can be seen in the Geographic Information Systems (GIS) map in Figure 7.

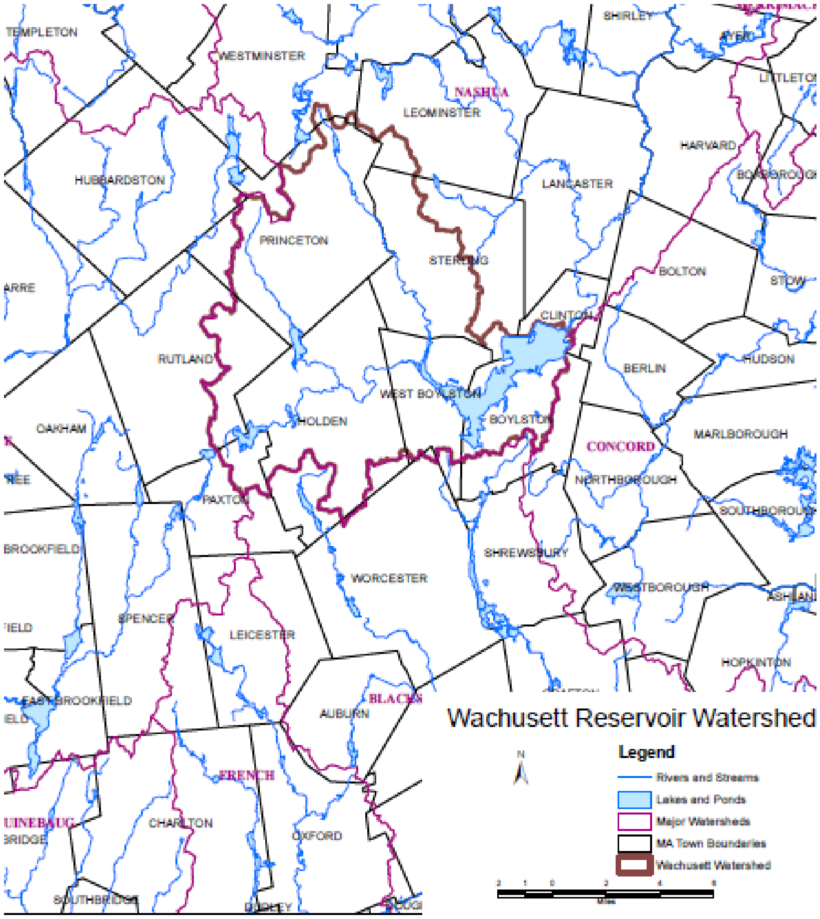


Figure 7: GIS Map of the Wachusett Reservoir

Since 1946 however, the Wachusett Reservoir has been supplemented by the much larger Quabbin Reservoir due to the increase of demand from the increasing population in the Metropolitan Boston area. Currently, there is a large network of reservoirs, aqueducts, and treatment plants that transport and deliver drinking water to homes throughout Massachusetts. This can be seen in Figure 8 from the MWRA's website (Massachusetts Water Resources Authority, 2012).

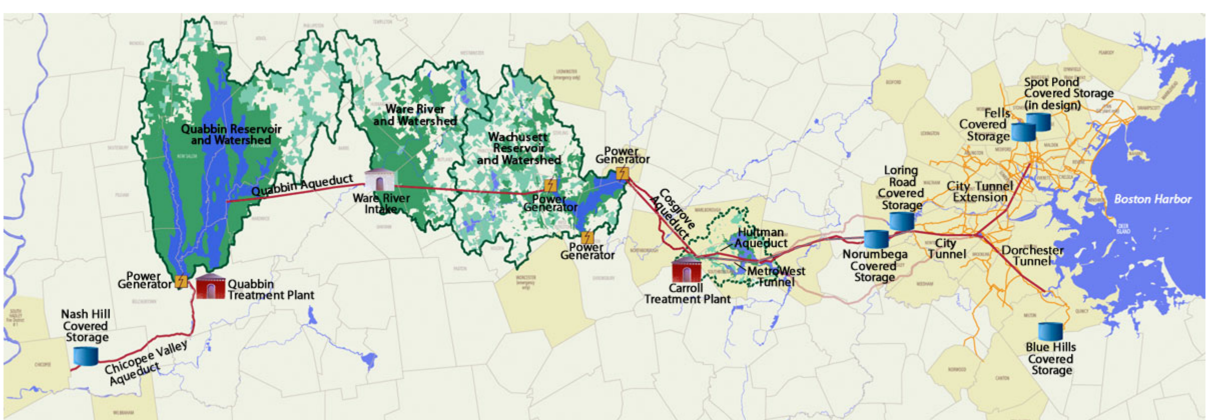


Figure 8: Massachusetts Drinking Water Distribution

The DCR and its Division of Water Supply Protection aim to protect the water quality of the water as it enters the reservoirs. This project was specifically concerned with the Wachusett Reservoir and the protective measures in place there. Protection of the reservoir is accomplished through a variety of BMPs, including bioretention areas and wet basins. The purpose of this project was to examine two bioretention basins that support the Wachusett Reservoir Watershed. They were located at the area known as Gate 27 in West Boylston, MA and on River Street in Clinton, MA. The two locations can be seen on the map in Figure 9.

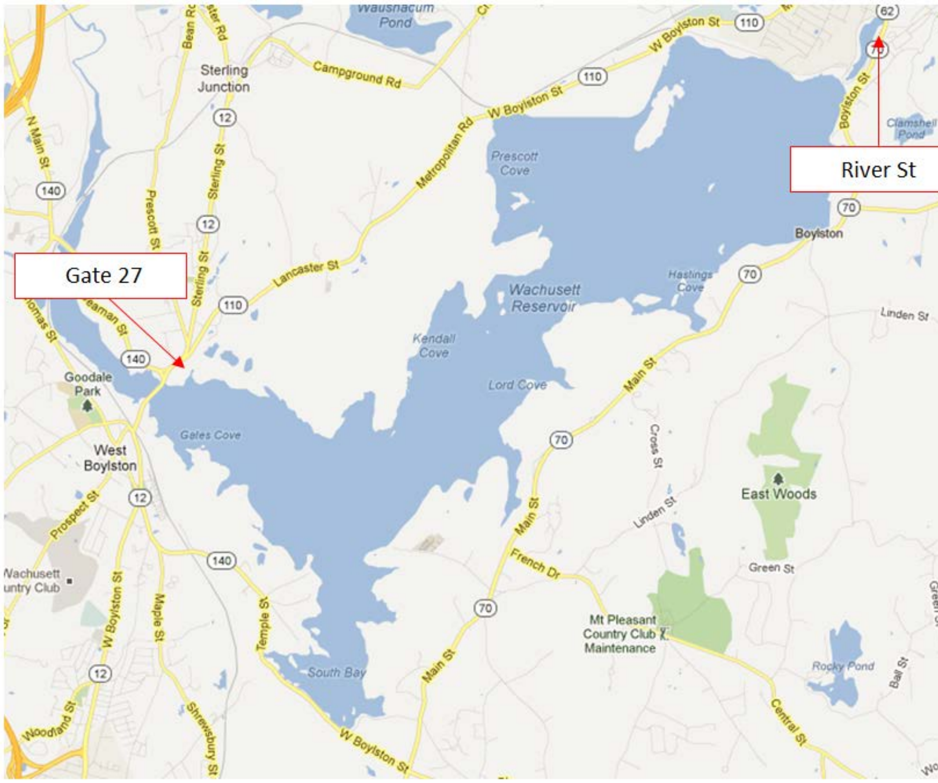


Figure 9: DCR Bioretention Basins Under Study

The two basins were chosen based on a number of factors. Both basins are fairly accessible and have easy access to their inflows and outflows. They also both have a single inflow and outflow. Finally, both have a similar design with underdrains and forebays. One difference is in their ages. Gate 27 is an older basin, in operation for more than five years, and River Street was completed in September of 2012. For a further description of each site, review Sections 3.5.1.1 and 3.5.1.2.

2.4 Modeling

Parameters for the Wachusett Watershed and bioretention basins were determined through different modeling programs.

2.4.1 Geographic Information System

Geographic Information Systems (GIS) “integrate hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information” (ESRI). GIS was utilized to determine basin and watershed characteristics, such as drainage area, soil type, and land use.

2.4.2 PHREEQC

PHREEQC is a computer program that is designed to “perform a wide variety of low-temperature aqueous geochemical calculations” that describe which type of reactions may occur within the basin to change the outflow constituent loading from the inflow loading (USGS, 2012). This program could be used to examine the biochemical processes that occur within each stormwater BMPs. Generally, PHREEQC is used to analyze the water quality of a specific area.

2.4.3 Stormwater Management Model

The Stormwater Management Model (SWMM) is a “dynamic rainfall-runoff simulation model used for single event or long-term … simulation of runoff quantity and quality” (US Environmental Protection Agency, 2013). It could be utilized to analyze the efficiencies and percent removal of stormwater BMPs. SWMM is used to analyze water quality of an area, but also looks at water volume control.

2.4.4 HydroCAD©

According to the HydroCAD© 10.00 Owner’s Manual, this computer aided design software is used for modeling the hydrology and hydraulics of stormwater runoff. It utilizes the procedures developed by the Natural Resources Conservation Service (NRCS) as well as various other hydrology calculations to create an interactive model. Through this process, runoff hydrographs for drainage basins and estimates for flows can be developed. This allowed for predictions to be made for differing storm intensities and different modeled designs. HydroCAD was used to accurately model the conveyance of the stormwater through the two bioretention basins under study.

In relation to this project, HydroCAD was used to model each bioretention basin. From this model, estimated peak flows and time of concentrations of the contributing drainage area can be determined, as well as the time it takes to reach the peak flow of the basin. HydroCAD also has the ability to provide related calculations for weighted curve numbers, detention pond volumes, and stage discharge curves. This information was useful in determining pollutant loadings and providing design recommendations for better efficiency.

To model the drainage system, the software is based around five watershed components, which are known as nodes in the program. These nodes are described in the following subsections.

2.4.4.1 Subcatchments

According to the HydroCAD Owner’s Manual, a subcatchment is a homogenous area of land that drains into a pond or a reach. It can also be used to illustrate the rainfall falling directly to a pond. This node is used to create a runoff hydrograph where discharge is shown varying with time (HydroCAD Software Solutions LLC, 2011). From this graph, the volume of runoff can be calculated by the area under the curve.

2.4.4.2 Ponds

The pond node can be used to model a variety of different features including a body that fills with water from one or more sources. The typical outlets for a pond node are over a weir, through a culvert, or another outlet device. Typical features include ponds, swamps, dams, catch basins, manholes, or drywells. The outflow of each pond is attenuated and the peak flow is delayed based on a hydrograph routing calculation. It may empty into a reach or another pond. A second outflow might be used to divert the discharge, or it might be discarded when there is no further routing, such as infiltration (HydroCAD Software Solutions LLC, 2011).

2.4.4.3 Catch Basins

A catch basin is a special type of pond that provides no storage, but has all the characteristics of a pond. It does not attenuate or detain its inflow because it has no storage. The hydrograph routing calculations performed can calculate the water surface level at each point in time (HydroCAD Software Solutions LLC, 2011).

2.4.4.4 Reaches

According to the HydroCAD Owner's Manual, a reach is a uniform stream, channel, or pipe that conveys transfers water from one point to another. This is accomplished by means of open channel flow. It can be used to route an upstream hydrograph through a subcatchment, and again, the outflow is determined by a hydrograph routing calculation. It typically delays and attenuates the peak flow and routes water to a pond or another reach (HydroCAD Software Solutions LLC, 2011).

2.4.4.5 Links

The final node available in HydroCAD is the link. This node is used to enter a hydrograph generated outside HydroCAD. It can also be used to interconnect several routing diagrams, scale a hydrograph, split a hydrograph into two components, or define a fixed or tidal tail water elevation (HydroCAD Software Solutions LLC, 2011).

3 Methodology

The goal of this project was to develop an improved design for a stormwater best management practice at the Wachusett Reservoir. This was completed by collecting data pertaining to stormwater runoff and bioretention basins on the Wachusett Reservoir.

3.1 Project Scope and Objectives

The Department of Conservation and Recreation (DCR) is concerned with the efficiency of bioretention basins in the removal of harmful constituents from stormwater runoff. Possible pollutants in the runoff can infiltrate the Wachusett Reservoir, causing negative effects on the environment and human health. This Major Qualifying Project completed the following objectives to determine an ideal best management practice:

1. Develop a sampling plan for various pollutants,
2. Conduct wet-weather sampling and laboratory tests on collected samples,
3. Model the inflow and outflow of each basin,
4. Analyze the efficiency of bioretention basins,
5. Develop an improved design for an ideal stormwater best management practice.

3.2 Overall Approach

This Major Qualifying Project focused on the quality and quantity of stormwater runoff to the Wachusett Reservoir. The data collection occurred at two bioretention basins located at Gate 27 and River Street, as seen in Figure 10. These basins were chosen based on their design, ease of access, and age. During rainfall events, the sampling procedure (Section 3.5.2) was implemented at the specified sites. Once completed, the samples were analyzed in a Worcester Polytechnic Institute or DCR laboratory, and the data were tabulated. A report was then composed and a design of an ideal bioretention basin to be located at a DCR gate was completed to fulfill the project requirements.

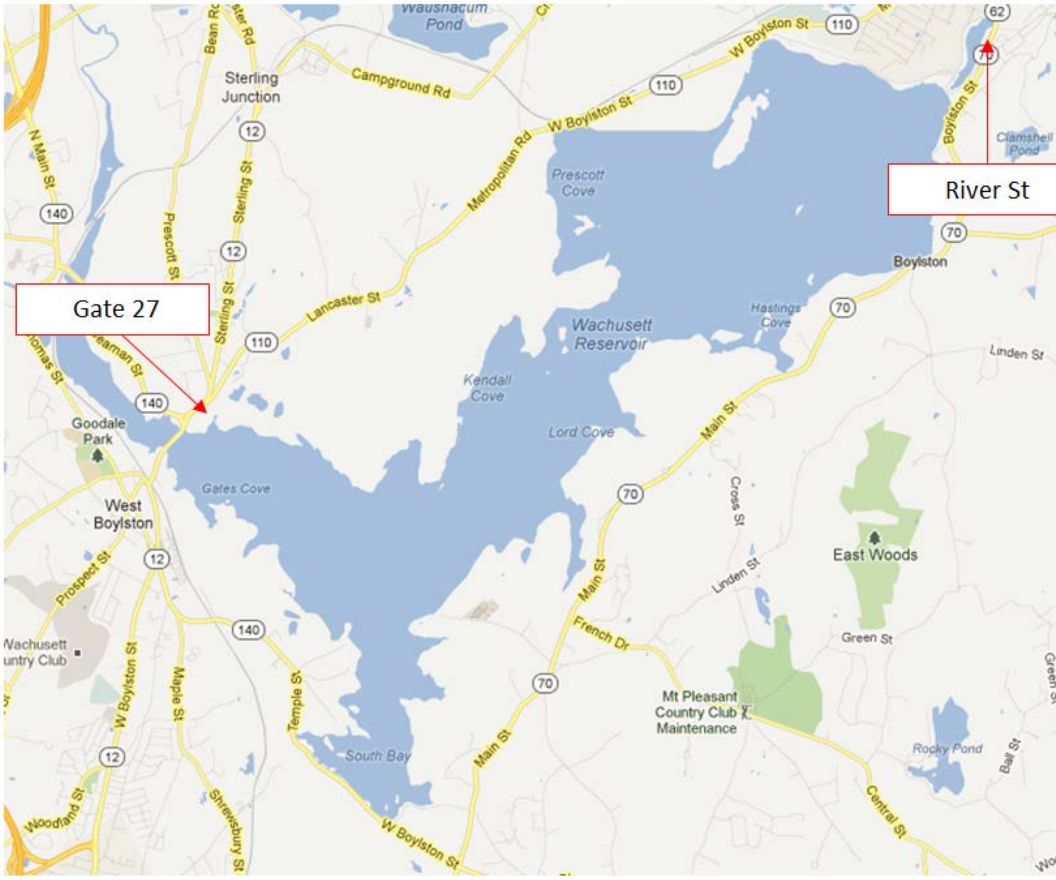


Figure 10: Target Bioretention Basins on the Wachusett Reservoir

3.3 Major Task List

The major tasks followed to successfully complete this project are listed below:

1. Review literature of best management practices, water quality, and other project-specific information,
2. Obtain information on the bioretention basins and reservoir under study and other project-specific information,
3. Complete field evaluations and sampling program,
4. Conduct sampling program on Gate 27 and River Street bioretention basins,
5. Perform laboratory analyses of samples,
6. Analyze results in context of the bioretention basins,
7. Describe the bioretention basins using models,
8. Evaluate current design methods,
9. Develop a new design approach for an ideal stormwater best management practice using the existing conditions at DCR Gate 25 as a basis,
10. Write and submit Major Qualifying Project report.

3.4 Review Literature and Obtain Information

There is a multitude of literature available on water quality requirements in stormwater, best management practices, and other subjects pertaining to this Major Qualifying Project. The Massachusetts Department of Environmental Protection is the leader in providing information on BMPs and the requirements for BMP design and pollutant removal in Massachusetts. Each state has its own specific criteria, and the Environmental Protection Agency provides extremely valuable information on the maximum constituent levels allowed in stormwater, and background on stormwater BMPs. There are many academic researchers that have completed evaluations on stormwater BMPs and types of biofiltration systems. Utilizing the research that others have done and the guidelines that MassDEP has required provided an excellent basis for the background research and finalized design of this project. The DCR also provided imperative data on the existing BMPs, including location maps, basin designs, and a multitude of other information.

3.5 Sampling Program

To accurately determine the effectiveness of these bioretention basins, water quality samples were taken at the inflows and outflows of the two basins in the study, Gate 27 and River Street. Multiple sets of samples at these two locations during different storms provided data to accurately determine the effectiveness of these basins. A sampling plan was developed to accomplish the following objectives:

- To determine constituent concentrations at the inflows and outflows of each bioretention basin,
- To measure flow rates at the inflows and outflows of each bioretention basin,
- To observe differences between various storm sizes.

Full sets of samples were taken for different storms to capture constituent data for various size storms and at different times throughout the storms. It was attempted to take the first set during the first flush of the storm and another set later in the storm.

3.5.1 Site Locations

For this analysis and set of design recommendations, the two basins chosen for examination were located at Gate 27 and River Street. Each basin was chosen because it had the characteristics that would provide the desired data, and the designs were easily compared between.

The specific target areas for sampling at each infiltration basin are shown in the following figures, namely the inflow and outflow locations for each basin. An aerial view of each basin is also provided, as well as the land use characteristics of each basin.

Figure 11: Gate 27 Inflow

Figure 12: Gate 27 Outflow

Figure 13: Google Earth Aerial View of Gate 27

The land surrounding the Gate 27 basin is mostly forest and low/medium residential. The commercial area near the basin is a strip mall with a parking lot that increases the runoff to the basin. A few major roads go through the contributing area. These are impervious and contribute to the stormwater runoff. The land use of the contributing area can be seen in Figure 14.

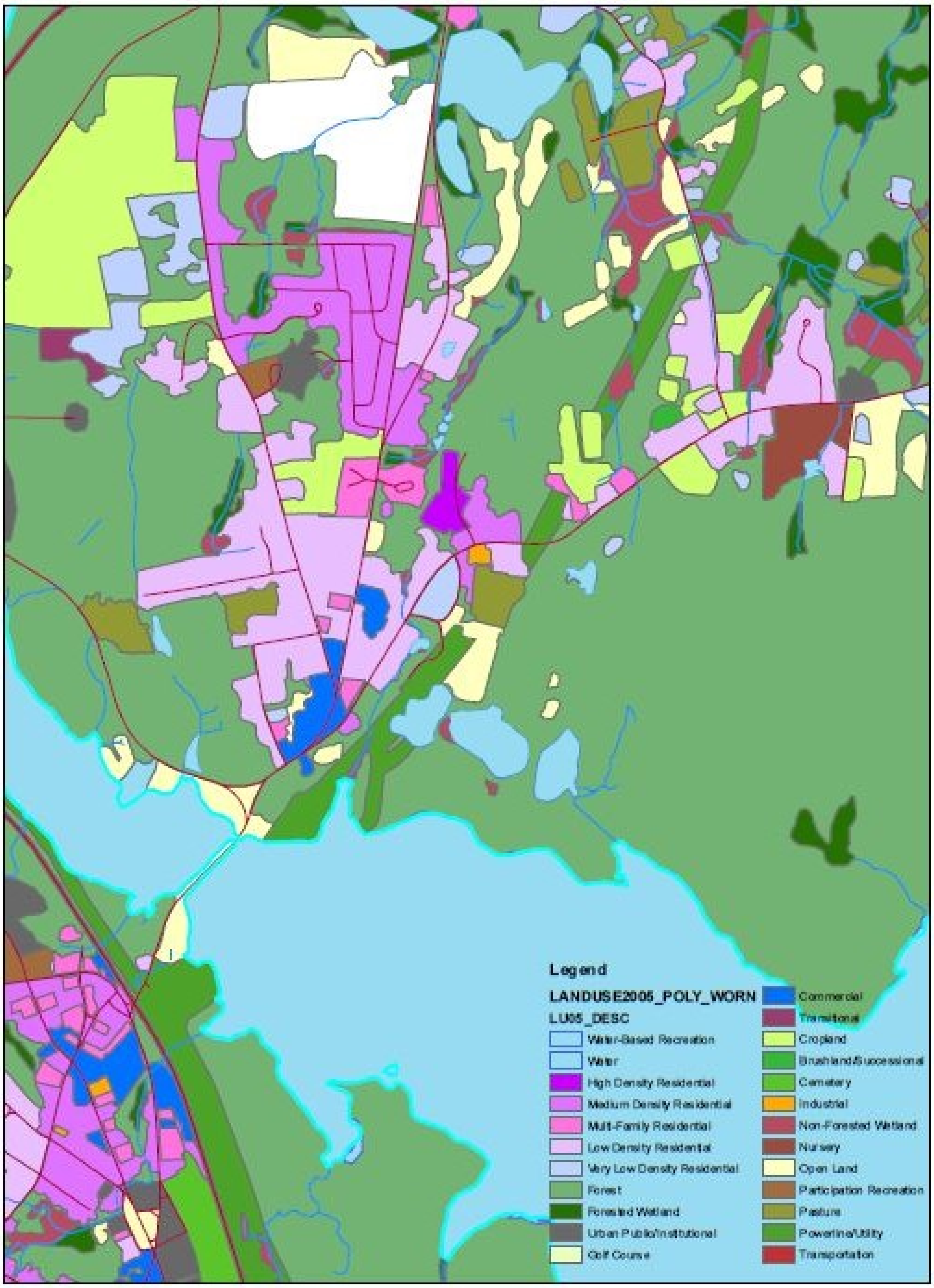


Figure 14: Land Use in the Gate 27 Basin Catchment Area

Figure 15: River Street Inflow

Figure 16: River Street Outflow

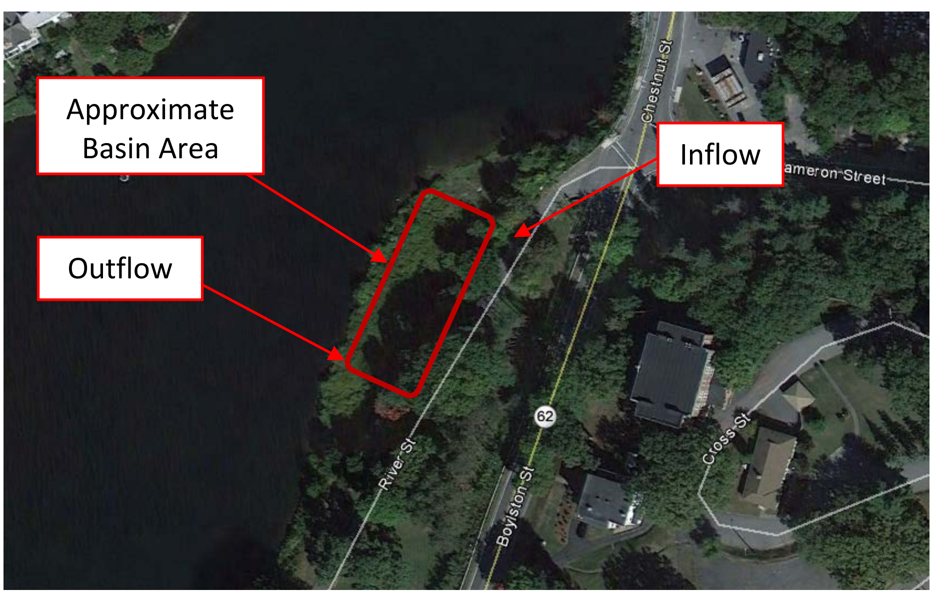


Figure 17: Google Earth Aerial View of River Street (Image Taken Prior to Development)

The land surrounding the River Street basin is mostly forest and medium residential. The developed residential areas increase the runoff to the basin. A major road going through the contributing area is impervious and contributes to the stormwater runoff. The land use of the contributing area can be seen in Figure 18.

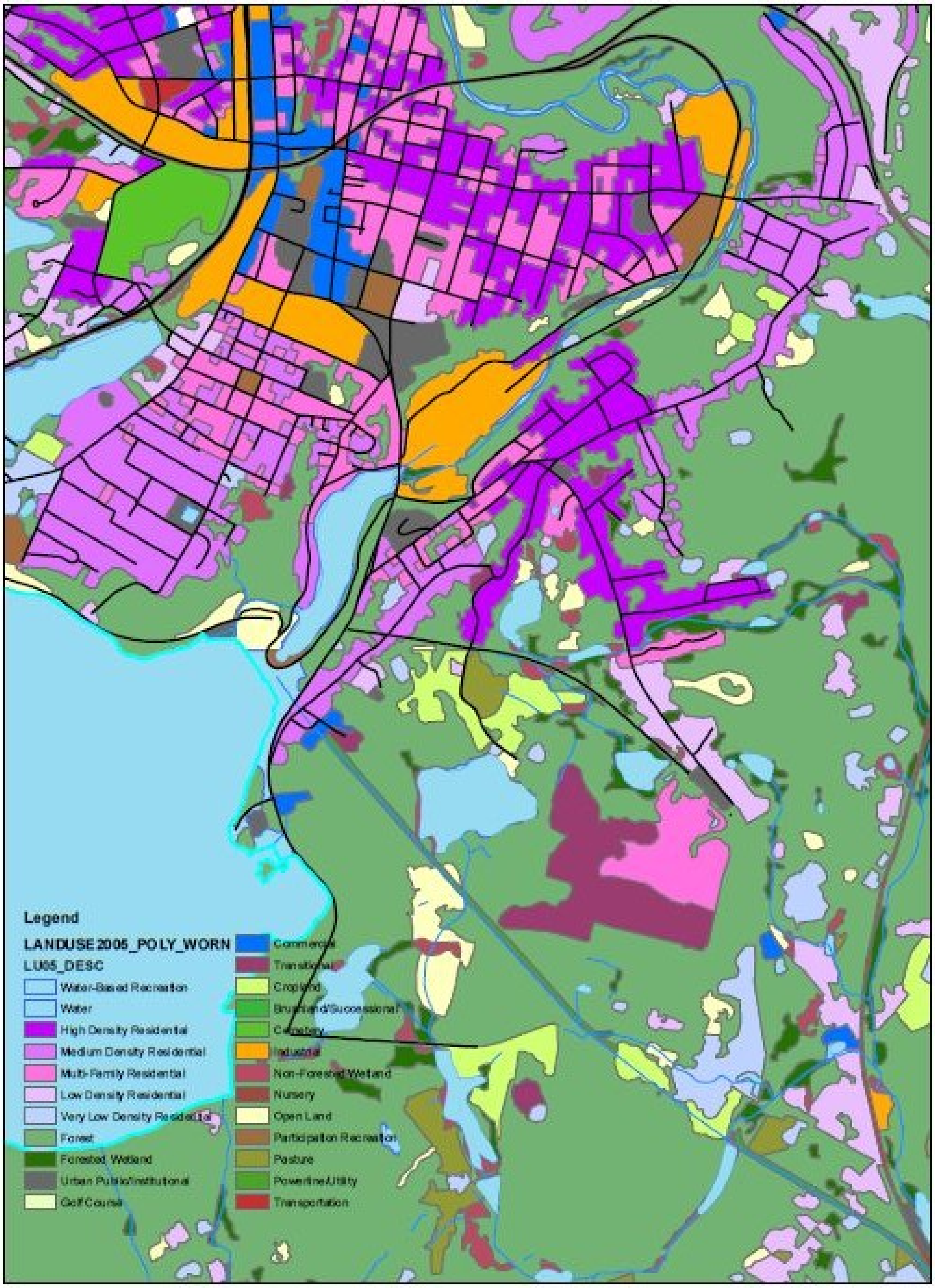


Figure 18: Land Use in the River Street Basin Catchment Area

3.5.1.1 Gate 27 Basin

The Gate 27 basin is a bioretention basin with a single trench drain. The basin only stores water for infiltration until the water has reached a certain depth, when it then is released through a single outlet. It is designed so that most storms do not reach the outlet depth, making the primary discharge for the basin infiltration.

This infiltration basin has three major sections: the forebay, the basin, and the trench drain. The forebay is constructed to provide some initial sediment and pollution removal before the water reaches the basin. The forebay also prevents the inflow from causing damage to the basin walls from scouring. The basin is essentially a small pond system that has two high flow safety features, such as a single discharge pipe when the basin levels reach a certain level. The basin is lined with vegetation to help remove contaminants during infiltration. When there is no water flowing into the basin the level of the water drops to a minimum level that always remains in the basin. The confining berm is a very slowly permeable barrier that holds the water in the basin after a storm to enable infiltration. The berm has an emergency spillway that only releases water during extremely high flow conditions. The trench drain has a discharge pipe that runs through the confining berm and discharges onto rocks that eventually lead to the reservoir. The trench drain allows the basin to drain within 72 hours after a storm event, since the soil infiltration was determined not to be capable of passing this volume. The DCR has been using this basin for over five years. It has required minimal maintenance by the DCR other than mowing, trash removal, and forebay sediment removal.

Figure 19 shows the basin cross section from the design plans for the Gate 27 basin.

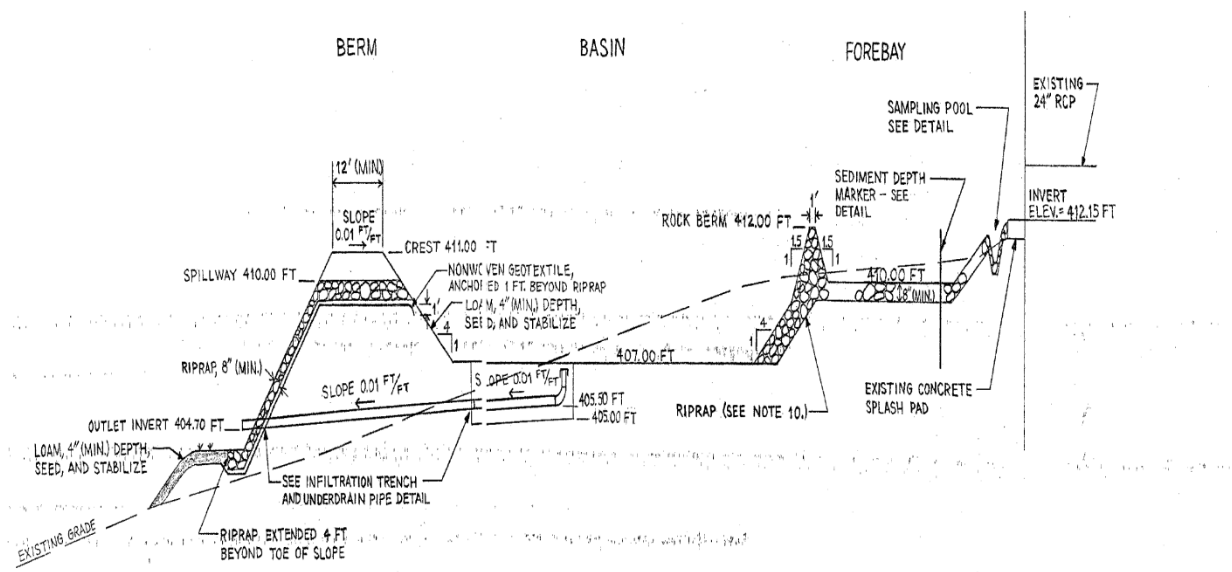


Figure 19: Gate 27 Basin Cross Section Plan

As long as the water level does not reach the outflow, the runoff will infiltrate through the ground to reach the reservoir. This means that the contaminants of concern typically associated with suspended solids will theoretically be removed through infiltration, as the runoff will join with the groundwater. It should be noted that infiltration to the ground may not completely remove all of the contaminants analyzed for this report. Contaminants that enter the ground travel through the soil over time. However, due to the extensive groundwater testing that would be required and the length of time that it takes for contaminants to travel through groundwater makes this infeasible with respect to the scope of this project. For the purposes of this project, infiltration to the ground effectively removes 100 percent of the contaminants considered in this project from runoff. This is discussed further in Section 4.7.3.

While infiltrating to groundwater is assumed to effectively remove 100 percent of contaminants, the water that enters the drainage trench percolates through the soil media filter. A smaller portion may enter the perforated outflow pipe, and will not receive additional treatment of complete infiltration. This makes the basin ideal for smaller storms, as the runoff will be treated completely. If the storm produces a large volume of water that fills the basin, then more water could reach the outflow pipe with less infiltration treatment. Since larger storms occur less frequently, sizing a basin to accommodate every storm instead of a typical, smaller design storm is expensive.

3.5.1.2 River Street Basin

The River Street basin is a bioretention basin with three connected underdrain pipes. The basin is designed to allow water to infiltrate through a small vegetated basin. The water then travels through the underdrain and is discharged from an outlet into Lancaster Mill Pond.

The River Street basin has three major sections: the forebay, the basin, and the underdrain. The forebay serves the same purpose as the forebay at the Gate 27 basin. It provides initial removal of sediment and prevents scouring of the basin. The basin is 18 inches deep with grasses in a soil mix 24 inches deep of engineered soil. The water spreads throughout the entire basin, infiltrates through the soil mixture, and enters one of the three underdrain pipes. The basin provides some flow regulation, more volume for sedimentation to remove particles and contaminants, and supports plant uptake of water and pollutants. The three underdrain pipes meet under the end of the basin farthest from the inflow and lead to an outflow into Lancaster Mill Pond. The outflow is protected against backflow from the river in the case of a high water level by a flapper valve. There is also an overflow weir at the far end of the basin to provide an outflow from the basin in case of high flow conditions. The weir sends water into a rock-lined channel that leads to Lancaster Mill Pond as well. The channel is designed to prevent erosion of the embankment. Construction of the basin was completed in September of 2012 and is one of three new basins constructed in the Wachusett Watershed. The vegetation is newly established and not fully developed, so some improvement may occur with time.

Figure 20 shows one of the design plans for the River Street Basin.

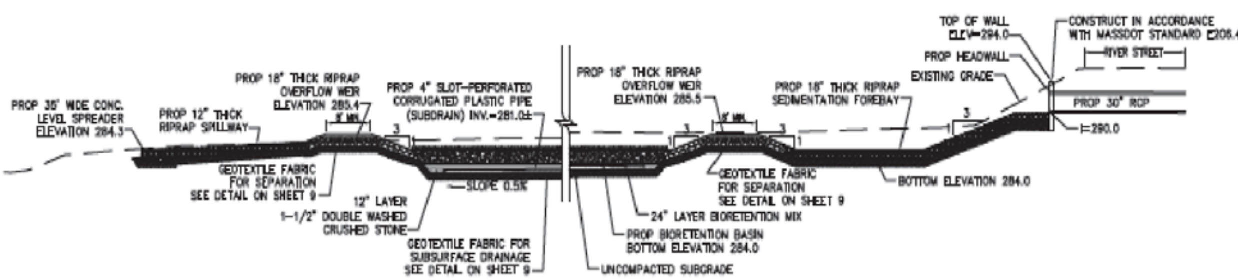


Figure 20: River Street Basin Cross Section Plan

The River Street basin treats water by using infiltration to remove suspended solids and using plant mass to help treat contaminants that are captured by the soil. The soil layer, a bioretention soil mix, is used to filter the inflow and is only 24 inches deep. This layer provides significant TSS removal. The soil is planted with vegetation that helps remove a number of the contaminants that pass through it. The vegetation is planted to consume nutrients such as phosphorus and nitrogen when growing. The vegetation also absorbs other contaminants such as heavy metals.

The underdrain allows River Street to drain while still maintaining treatment, which means that it can treat runoff more consistently and during high flow conditions. The discharge of the River Street basin enters downstream of the reservoir, and therefore discharges to the reservoir are completely removed. However, the basin's improved treatment would decrease the risk of contamination of the reservoir system even if it did discharge directly into the reservoir.

3.5.1.3 Gate 27 and River Street Comparison

The two basin designs treat stormwater runoff through infiltration and feature similar design characteristics. However, there are some differences between the two basin designs that have major impacts on the treatment process.

Both designs feature forebays, which are required for BMP designs by the MassDEP. This is beneficial for both locations as forebays reduce erosion and scouring of the basins, and also provide pre-treatment by removing sediments and detritus. Sediment forebays are also a major component in removing suspended solids from incoming stormwater and prevents TSS from interfering with infiltration in the basin itself.

The infiltration media used in the basins differed between Gate 27 and River Street. Gate 27 uses a mix of loam on top of the existing soil to provide infiltration. The existing soil was qualified as a Hinckley sandy loam. This soil was graded before a 4 inch loam layer was placed on top. The loam limits infiltration, but the shallow depth of the loam allows for infiltration to occur easily along vegetation stem and root systems in the basin. The exact composition of the infiltration media used at River Street was based on the bioretention soil mix from the Department of Transportation (DOT). This media is made up of 50% sand and 50% compost. The soil has a number of restrictions on particle sizes, including clay, silt, fine sands, very fine sands, and gravel. The compost is derived from organic wastes, including leaves and other yard wastes.

One major difference between the treatment processes of the two basin designs is whether the basin infiltrates into the ground or if the basin is lined and travels into the outflow piping. The Gate 27 basin does not have any lining underneath the infiltration media, which allows water passing through the basin to infiltrate into the ground. The River Street basin has a waterproof lining underneath the infiltration media, which prevents the water from infiltrating into the ground, but also prevents the groundwater from coming up through the bottom of the basin. Water that enters the River Street basin infiltrates through the filter media and enters an underdrain on the bottom of the basin, which leads to the outflow. The River Street design has an advantage in the fact that all water that enters the basin infiltrates through the infiltration media before reaching the outflow, whereas water in the Gate 27 basin may enter the outflow pipe instead of passing through the infiltration media to groundwater. However, the Gate 27 design has an advantage over the River Street design in that infiltrating to groundwater passes the water through significantly more infiltration media than in the River Street design, where depth of the basin is limited at only two feet of infiltration media.

Both basins were seeded with host vegetation to provide extra treatment, especially for nutrients. The DOT's bioretention soil mix specifies that a number of species of plants be prevented from growing in the basin in the River Street design. These plants include some types of grasses and noxious weeds. The bioretention seed mix for the River Street basin featured 14 different species of plants, which were mostly types of grasses. The vegetation in Gate 27 was listed as a Conservation mix, which is primarily made up of grasses as well. It should be noted that the vegetation in Gate 27 has probably changed over time, as the basin has been in operation for over five years. While the vegetation present in both basins was primarily made up of grass species that have similar nutrient removal efficiencies, the density of growth in the basin was quite different. The vegetation in the Gate 27 basin provided complete cover of the basin bed, while the vegetation in the River Street basin was much less densely populated, and only provided partial cover of the basin bed.

The outflow locations and methods were different for the two basin designs. The Gate 27 basin has a single trench drain located in one corner of the basin. This outflow only operates when the water level in the basin reaches the trench. The outflow pipe discharges onto the hill below the basin in an area bedded with rocks to prevent erosion. This discharge eventually reaches the Wachusett Reservoir. The River Street basin discharges directly into Lancaster Mill Pond, about a foot above the surface of the pond. The outflow at Gate 27 is better protected against scouring and erosion due to the fact that it discharges onto land. The outflow pipe at River Street discharges into a very shallow area of Lancaster Mill Pond, which showed evidence of scouring during site visits. The slope of the outflow pipe for Gate 27 was also much less steep than the outflow pipe at River Street, which reduces the risk of causing erosion or scouring.

Table 5: Design Comparisons Between Gate 27 and River Street

Design Characteristic	Basin	
	Gate 27	**River Street**
Sediment Forebay	Yes	Yes
Infiltration Media	Sand and loam	Bioretention mix
Lined	No	Yes
Underdrain	No	Yes
Vegetation	Yes	Yes
Outflow Type	Trench outflow	Direct discharge
Outflow Location	Hill below basin	Lancaster Mill Pond

3.5.2 Sampling Procedure

Prior to a storm, materials such as bottles, labels, a cooler, and rain gear were prepared. Bottles were prepared in the manner listed in Table 6. Uniform labels printed on waterproof labels were prepared beforehand as well. The convention for these labels included: constituent measured for, basin location, date, time, group ID, and number in set, as seen in Table 8.

Table 6: Constituent Breakdown

Constituent	Constituent Code	Bottle Size	Frequency of Samples	Bottles per storm per basin
Dissolved Phosphorus Nitrite Nitrate	DP-N	60 mL	Two inflow/two outflow + hourly	4 - 10
Total Phosphorus	TP	60 mL	Two inflow/two outflow + hourly	4
Ammonia	NH3	60 mL	Two inflow/two outflow	4
Total Suspended Solids Turbidity	TSS-Turb	1000 mL	Two inflow/two outflow	4
Dissolved Oxygen	DO	300 mL (glass)	Two inflow/two outflow	4
Total Organic Carbon	TOC	50 mL (glass)	Two inflow/two outflow	4
pH Alkalinity	pH-Alk	250 mL	Two inflow/two outflow	4
Cations	Metals	30 mL	Two inflow/two outflow	4

The quantity of bottles required for each storm at each basin is listed in Table 7:

Table 7: Sampling Bottle Quantities

Bottle Size (mL)	Bottle Type	Quantity
30	Plastic	4
50	Glass	4
60	Plastic	12 – 18
250	Plastic	4
300	Glass BOD	4
1,000	Plastic	4

Any abbreviations used on labels are listed in Table 8.

Table 8: Labeling Key

Item	Item Code
Gate 27, West Boylston	G27
River Street, Clinton	RSC
Major Qualifying Project Group	PPM 1231
Inflow	Inflow
Outflow	Outflow
Multiple Samples Required	#1, #2, #3, etc.

Upon arrival at the site prior to the start of the storm, testing proceeded in this manner:

1. Prepare rain gear and sampling equipment,
2. Set up flow control device (See Section 3.5.3),
3. Set up flow monitoring device in inflow and/or outflow, upstream from flow control device if applicable. Leave in place for the duration of sampling,
4. Measure inflow and outflow flow rate (See Section 3.5.3),
5. Sample inflow and outflow per Table 6,
6. Repeat steps 4 and 5 at regular intervals throughout the storm, per Table 6 or at discretion of project team,
7. Pack samples in cooler and bring to laboratory.

3.5.3 Measuring Flow

A major aspect in this analysis was measuring the flow rate of the inflows and outflows to the bioretention basin. This was necessary to determine the contaminant loadings and allowed for comparisons of the amount of pollutants at different flows. Multiple methods of measuring flow were utilized, as described in the following subsections. Section 4.1 describes the effectiveness of each method.

3.5.3.1 Bucket Method

One method is to time the filling of a bucket of a known volume. This will give an accurate measurement of the volume per unit time, as seen in Equation 3.

$$Q = \frac{Volume\ of\ bucket}{Time\ to\ fill\ completely} = \frac{gallon}{seconds} * \frac{0.13368\ ft^3}{gallon} = cfs$$

Equation 3: Bucket Method Flow Rate Calculation

One challenge in pursuing this method is fitting a bucket under the inflow and outflow pipes. The inflow of Gate 27 basin has a wide apron sitting immediately under the 24” inlet pipe. This apron spreads the water out and after about 3 feet drops it into a small pooling area in the forebay. The discharge from the Gate 27 basin has many rocks which needed to be moved to place a bucket under the 4” pipe. At the River Street basin, the 36” inflow pipe has many rocks that needed to be moved as well. The 6” outlet pipe of this basin only has one rock that caused an issue in catching the water. In both basins' inflows, a sheet of plastic and/or aluminum assisted in funneling the water into the collection bucket.

3.5.3.2 Weir

Another method which can fairly accurately describe the volumetric flow is with the use of a weir. The main function of a weir is to increase the water level, or the water head. This obstruction is well documented in open channel hydraulics and equations have been derived to calculate volumetric flow based on the height or head of the upstream water (Engineering ToolBox). Flow can be described by this equation for v-notch weirs:

$$Q = \frac{8}{15} C_d (2g)^{\frac{1}{2}} \tan\frac{\theta}{2} h^{\frac{5}{2}}$$

Equation 4: Flow Over a V-Notch Weir

Where:

- C_d = Empirically derived discharge constant
- g = Acceleration due to gravity
- θ = V-notch angle
- h = Water head above the v-notch

A weir can be purchased or fabricated. A commercial one, though expensive, would prove to be the easiest, though a variety of sufficient ones could be made. One potential design was to create a box with a notched out weir on one side. The water would flow into the box and exit through the weir. This would create a controlled weir that could be placed below the inflow or outflow pipe. This method was utilized for the outflow at the Gate 27 basin. The height of the water immediately upstream of the weir would need to be measured to appropriately calculate the flow rate. This measurement was accomplished by hand with a tape measure when a spot measurement of the flow was required. The fabricated weir that was placed on the outflow of Gate 27 had a 47.56° angle and 8.75 cm height to the notch from the bottom. Details of the Gate 27 weir are located in Appendix F: Weir.

3.5.3.3 Manning's Equation

A rough approximation of flow rate can also be made through the use of Manning's equation. Manning's equation is used to find the velocity of a stream, and that coupled with the rough cross sectional area of the channel that the water flows through allows for the calculation of volumetric flow (Bedient, Huber, & Vieux, 2013).

$$v = \frac{k}{n} R^{2/3} S^{\frac{1}{2}}$$

Equation 5: Manning's Equation

Where:

v = Cross sectional average velocity
k = Conversion factor
n = Manning coefficient
R = Hydraulic radius
S = Slope of the water surface

By using this method, a number of educated assumptions were made, which largely affected the hydraulic radius. With such large-diameter inflow pipes and relatively small flow of water, it was difficult to calculate the cross sectional area and wetted perimeter necessary for Manning's equation. Multiple iterations were required following a rough approximation and along with measuring the slope, a velocity of the water was calculated. To find flow (Q), the velocity is multiplied by the cross sectional area as in this equation:

$$Q = A\,v$$

Equation 6: Flow Through a Channel

This is a good approximation for calculating the volumetric flow in a pipe, and served as a comparative value for other methods of measurement.

3.5.3.4 Depth Probe

A depth probe was used at both inflows and outflows for different storms. The probe that was used was the In-Situ Level TROLL 500 Instrument. It is a vented, or gauged, unit. These have a "vent tube in the cable [that] applies atmospheric pressure to the back of the strain gauge. The basic unit for vented measurements is PSIG (pounds per square inch 'gauge'), measured with respect to atmospheric pressure. Vented sensors thus exclude the atmospheric or barometric pressure component" (In-Situ Inc., 2010). The following tables list the effective ranges and efficiencies of the probe.

Table 9 : Level TROLL® 500 Depth Probe Efficiencies (In-Situ Inc., 2010)

Depth Probe Component	
Temperature Range	-20-80^{o}C
Pressure/Level Sensor at: 15^{o}C 0-50^{o}C -20-0, 50-80^{o}C	Full scale ± 0.05% ± 0.1% ± 0.25%

Table 10: Range and Usable Depth (In-Situ Inc., 2010)

Range		Usable Depth	
PSIG	*kPa*	*Meters*	*Feet*
5	34.5	0-3.5	0-11.5
15	103.4	0-11	0-35
30	206.8	0-21	0-69
100	689.5	0-70	0-231
300	2068	0-210	0-692
500	3447	0-351	0-1153

Once these data were tabulated, Manning's equation was used to calculate the flow in the pipe. The variables in the equation were modified to apply to flow through a pipe; the wetted perimeter is the arc length of the water, etc.

3.5.3.5 ISCO Meter

ISCO meters are area velocity meters that were provided by the DCR. The meters accurately display the flow in cubic feet per second for the individual pipe programmed into the unit. As stated in the ISCO manual, the area velocity meter requires three measurements: water level, water velocity, and channel dimensions. The internal sensor records the level and velocity by a differential pressure transducer that measures pressures transferred by a stainless steel diaphragm exposed to the streams flow. The recorded velocity is multiplied by the area, which is calculated from a combination of the water level and the pipe's characteristics. The water level is determined from the pressure on the sensor and the pipe's characteristics are programmed into the unit beforehand.

3.6 Laboratory Analyses of Samples

The following subsections contain a basic overview of the laboratory analyses performed during this Major Qualifying Project. The full analysis procedures are located in Appendix B.

3.6.1 Total Phosphorus

The analysis for total phosphorus is conducted by digesting the samples under a fume hood, adding phenolphthalein indicator, NaOH, and Molybdovanadate to the solution, and recording the reading from the DR/3000 Spectrometer. The full procedure is listed in Appendix B, Section 9.2.1.

3.6.2 Dissolved Oxygen

The dissolved oxygen concentration is determined by quickly inserting a calibrated DO probe into a 300 mL glass DO bottle and recording the reading. The full procedure is listed in Appendix B , Section 9.2.2.

3.6.3 Alkalinity and pH

The procedure to measure alkalinity and pH is closely related. Once the pH probe is calibrated, it is inserted into a beaker of the sample. The pH is then recorded at specific intervals throughout the procedure. Small increments of acid are added to the beaker and the resulting pH is recorded in a specific spreadsheet. This spreadsheet calculates the overall alkalinity of the sample. The detailed procedure for measuring pH and alkalinity, as well as an example of the alkalinity spreadsheet, are located in Appendix B, Section 9.2.3.

3.6.4 Ammonia

Ammonia is determined by adding Mineral Stabilizer, Polyvinyl Alcohol Dispersing Agent, and Nessler Reagent to a filtered (if necessary) sample in a sample cell. This solution is then placed in the DR/3000 Spectrometer and the reading is calculated using the calibration number and dilution factor (if applicable). The full procedure is located in Appendix B, Section 9.2.4.

3.6.5 Total Suspended Solids

The amount of total suspended solids in a sample is determined by weighing a filter, filtering a known amount of sample through a pump, and weighing the filter again. The TSS is then calculated using the following equation:

$$TSS = m_{filter\ with\ sample} - m_{initial\ filter}$$

Equation 7: TSS Calculation

The detailed procedure is listed in Appendix B, Section 9.2.5.

3.6.6 Turbidity

Turbidity is measured by shaking a sample very well, pouring a small amount into a spectrometer cell, and reading the value from the HACH 2100N Turbidimeter. The complete procedure is located in Appendix B, Section 9.2.6.

3.6.7 Cations

The laboratory analyses for Arsenic and Lead were completed using Graphite Furnace Atomic Absorption. All other cations were analyzed using Air/Acetylene Flame Atomic Absorption.

3.6.8 Anions

The analysis for anions is completed using Ion Chromatography. A new anion program is created, as well as a shutdown program. A sequence is run using samples and record results. The full procedure is listed in Appendix B, Section 9.2.8.

3.7 Analyzing Flow Monitoring and Laboratory Results

The results that were determined from measuring flow rates and conducting laboratory procedures were analyzed in the context of the BMPs under study. This entailed comparing the effectiveness of the basins in removing certain constituents and determining which aspects of each design contributed to that effectiveness. This information was then used to design an ideal BMP, as discussed in Section 5.

3.8 HydroCAD Modeling

In order to compare the pollutant removal efficiencies of each basin, a pollutant loading needed to be calculated. This loading is based off of the amount of volumetric flow that passes through the basin from which the samples were taken. This requires continuous flow data for the inflows and outflows of the basin throughout each storm. While the field monitoring that took place captured flow data for small periods throughout the sampled storm, modeling software such as HydroCAD can help fill the gaps in data.

3.8.1 Parameters

Various site specifications had to be determined to effectively create the HydroCAD model for each basin. This was accomplished largely through mapping GIS data layers and examining site drawings provided by the DCR, which can be seen in

Appendix G: Gate 27 Designs and Appendix H: River Street Designs. The basis of the model is described in Section 2.4.4 with different nodes associated with the various aspects of a water system (subcatchments, reaches, ponds, and links). A separate model for each basin was created by defining a series of nodes.

To model the existing conditions for the two basins, an estimate for the drainage from the subcatchments that contribute to the basins' inflow was determined. These estimates are based on the municipal stormwater system's catch basins, as seen in Appendix I: West Boylston Stormwater System. HydroCAD uses the size of the contributing area, the curve number, the hydraulic length, and the slope to calculate a time of concentration for the subcatchment.

The final models for both basins can be seen in Figure 21 and Figure 22. In the model for both basins, the catchment node is directed to a reach. This reach represents the inflow pipe and includes the slope and Manning's roughness coefficient that pertain to each reinforced concrete pipe (RCP). This pipe's flow is then channeled to a series of pond nodes. The first pond represents the forebay and the second represents the larger detention pond. Both pond nodes have inputs for the size of the basin and the resulting outlets. The forebay outlet is a broad crested overflow weir, which spills into the detention pond. The larger pond node for the River Street basin has an impermeable lining, so there are no losses to infiltration. There are also a series of under drain pipes leading to the 6 inch outfall. Gate 27 does not have a lining but rather has an infiltration trench with a perforated pipe. This basin does have losses to groundwater. In both basins, an emergency spillway has been designed for high flow storms. This is represented as a secondary routing.

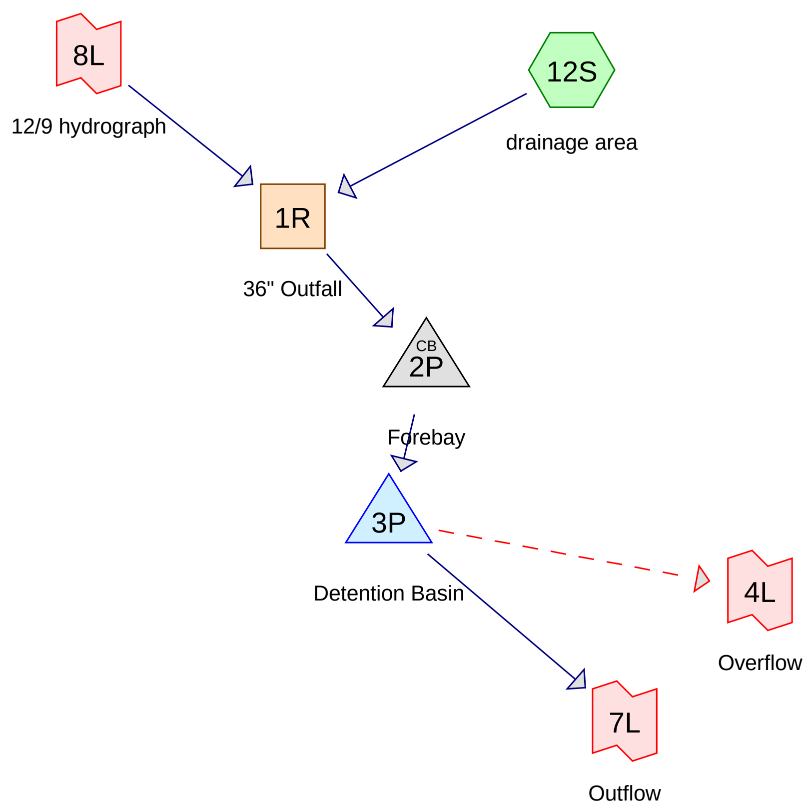


Figure 21: River Street Basin Final HydroCAD Model

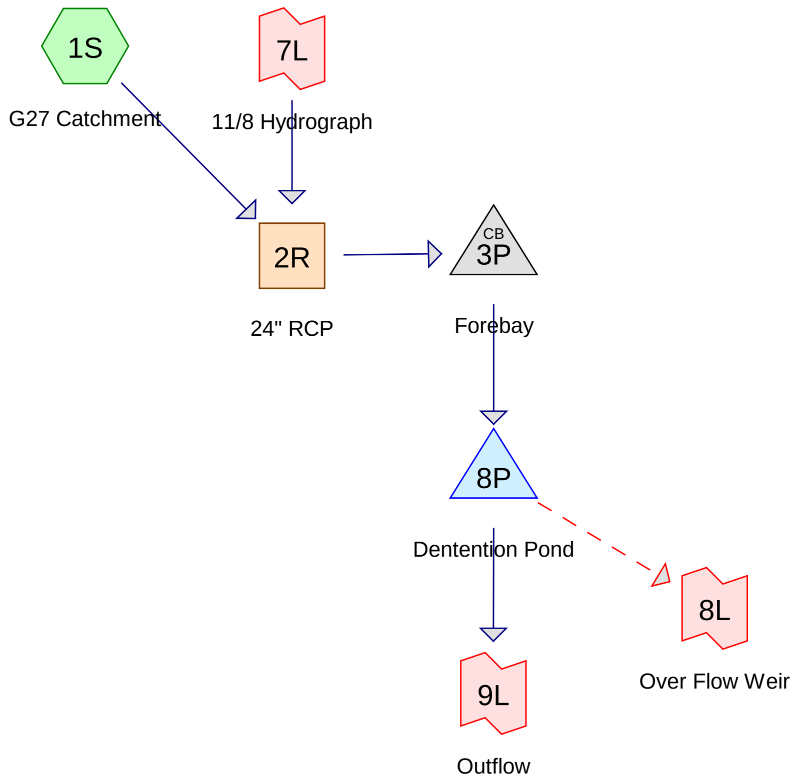


Figure 22: Gate 27 Basin Final HydroCAD Model

A table of key parameters derived from GIS, site drawings, and observations is included in Table 11.

Table 11: HydroCAD Parameters

Parameter	**Gate 27 Basin**	**River Street Basin**
Catchment Area	12.850 acres	35.750 acres
Curve number	70	65
Time of Concentration	15.9 mins	44.3 mins
Inflow Pipe Diameter	24”	36”
Inflow Pipe Invert	412.15’	290.3’
Forebay – overflow invert	412’	285.5’
Pond bottom elevation	407’	284’
Pond Overflow weir	411’	285.4’
Perforated Pipe invert	405.5’	282’
Outlet Pipe Diameter	4”	6”
Outlet Pipe elevation	404.7’	281’
Pipe Slope	0.1081 ft/ft	0.0053 ft/ft
Forebay volume	2,821 ft^3	2,582 ft^3
Pond volume	29,920 ft^3	16,463 ft^3

Further information on the Gate 27 and River Street HydroCAD models can be found in Appendix D: Final Gate 27 HydroCAD Model Report and Appendix C: Final River Street HydroCAD Model Report, respectively.

3.8.2 Validating and Tuning the Model

To validate the model, rainfall data from the storms that were monitored was input into HydroCAD. Observed flow rates were compared to the model's predicted flow rates. From this comparison, adjustments were made to the HydroCAD model to further fine tune it.

During storm monitoring, a Level TROLL 500 depth probe was placed in the inflow pipes. This measured the change in water depth over the course of the storm. With this information and through the use of Manning's Equation, Equation 5, flow rates were determined over the course of the storm.

To calculate the area of the water in a partial filled round pipe the following equation was used (Raymond, 2012):

$$A = \frac{r^2(\theta - \sin\theta)}{2}$$

Equation 8: Area of Water in a Pipe

Where:

r = Radius of pipe

θ = Central angle of water height

Where:

$$\theta = 2\arccos\left(\frac{r-h}{r}\right)$$

Equation 9: Central Angle of Water Height in a Pipe

Where:

r = Radius of pipe

h = Water height

These data were tabulated in Excel, and hydrographs over the course of the storm were created. To import this data into HydroCAD, the Excel spreadsheet was converted to a text file and then imported through a link node. When directing this node and its subsequent hydrograph to the inflow pipe, an exact representation of the monitored storm could be put through the system. This allowed for further adjustments. The resulting hydrographs, from both the HydroCAD model and depth probe, can be found in the Results chapter.

3.8.3 Final Models

The final models, seen previously in Figure 21 and Figure 22, represent the existing conditions for the site and have allowed for a fairly accurate representation of the flow data for the rainfall events that were sampled. Further information on these models can be found in the model report file included in Appendix C: Final River Street HydroCAD Model Report and Appendix D: Final Gate 27 HydroCAD Model Report.

3.9 Evaluate Current Design Approaches

There are many literary resources available that discuss stormwater BMPs being used around the world for different purposes. The analyses contained in these resources contributed to knowledge on the subject of bioretention basins and an ideal design. Most BMPs focus on reducing stormwater runoff volumes and improving the water quality of the runoff. Many also included designs of specific BMPs or variations on a design for a single BMP.

For example, the MassDEP stormwater handbook contains a section on BMP design. There, it lists every type of BMP, a basic design, advantages and disadvantages, possible removal efficiencies, and a myriad of other information. This was a good source to analyze different types of stormwater BMPs and determine which would be most ideal for the new design. The EPA also has a great deal of information on stormwater BMPs, and was a helpful source for the new design.

Once it was determined that a biofiltration basin was going to be the type of BMP designed, one resource that was especially helpful was a report by the Australian Facility for Advancing Water Biofiltration, which describes how to design a biofiltration system. This report delves into every step necessary for determining the best components of the design, including filter media, planning required before installation, and technical considerations of the design.

3.10 Develop New Design Approach

It was decided that the design of the new basin would be primarily based off of the basin designs of both River Street and Gate 27. The basin design followed the regulations required by the Massachusetts Department of Environmental Protection. Finally, the size of the basin and the materials used in the construction of the basin were developed based on the land characteristics of the surrounding area, and on previous basin designs.

The new design took into account the advantages and disadvantages of both existing designs, weighing them based on the location of the new basin. This included analyzing the proximity of the basin location to the reservoir itself, as well as the elevation of the basin compared to the reservoir. The data that was gathered and analyzed for both of the basins was used to find which design treated the runoff more efficiently.

The basin regulations were taken from the MassDEP Stormwater Management Standards, from the Massachusetts Stormwater Handbook. The standards include regulations on treatment efficiencies of the basin, such as the removal of total suspended solids, and on the discharge of contaminants to protected water bodies.

The dimensions and materials used in the new design were developed based on the land characteristics of the surrounding area. The dimensions were dependent on the volume of flow entering the basin. The flow volume was determined by the size of the contributing area. The materials used in the basin construction were determined by finding the required infiltration rate of the basin.

4 Results

The goal of this project was to analyze the different designs of two stormwater BMPs on the Wachusett Reservoir and design an ideal BMP. This was completed by conducting a sampling program and collecting stormwater samples and flow data. This chapter summarizes the results of this field sampling program. The data collected show differences in the flow characteristics and water quality between the River Street and Gate 27 basins. The flow results are summarized in Sections 4.1 and 4.2. Water quality results are discussed in Section 4.4 and tabulated in Appendix A: Laboratory Analyses Results. The different flow characteristics are due to the specific designs of the basin and the characteristics of the contributing area. This section also details the pollutant removal efficiencies of each basin.

4.1 Flow Monitoring

As described in Section 3.5.3, flow was monitored by four different methods: bucket method, weir method, an area velocity meter (ISCO unit), and a depth probe. Each method was used at different times and at different locations. A summary of the flow rates is displayed in Table 12.

Table 12: Flow Monitoring Data for River Street

Date	Rainfall (in)	Time	Location	Flow (cfs)	Method
11/8/2012	0.45	10:00	Inflow	0.38	ISCO
			Outflow	0	ISCO
		10:40	Inflow	0.23	ISCO
			Outflow	0	ISCO
		11:10	Inflow	0.18	ISCO
			Outflow	0	ISCO
		11:40	Inflow	0.199	ISCO
			Outflow	0.071	ISCO
		12:10	Inflow	0	ISCO
			Outflow	0.088	ISCO
		12:40	Inflow	0	ISCO
			Outflow	0.109	ISCO
		17:30	Outflow	0.0353	Bucket
		17:40	Inflow	0.0283	Bucket
11/28/2012	Snowmelt	12:00	Inflow	0.0044	Bucket
			Outflow	0	Visual
12/9 - 12/10/2012	0.57	22:45	Outflow	0	Visual
		23:45	Outflow	0	Visual
		9:30	Inflow	0.0059	Bucket
		9:45	Outflow	0.043	Bucket
		10:00	Inflow	0.0049	Bucket
		10:15	Outflow	0.042	Bucket

Table 13: Flow Monitoring Data for Gate 27

Date	Rainfall (in)	Time	Location	Flow (cfs)	Method
11/8/2012	0.45	10:00	Outflow	0	Visual
		10:15	Outflow	0	Visual
		10:30	Outflow	0	Visual
		11:00	Outflow	0	Visual
		11:30	Outflow	0	Visual
		12:00	Outflow	0	Visual
		17:00	Outflow	0.00447	Bucket
11/28/2012	Snowmelt	11:30	Inflow	0	Visual
			Outflow	0	Visual
12/9 - 12/10/2012	0.57	23:15	Outflow	0	Visual
			Inflow	0.0671	Bucket
			Inflow	0.067	Bucket
		8:20	Outflow	0.0157	Weir
		9:10	Outflow	0.012	Bucket
			Outflow	0.00603	Weir
		10:35	Outflow	0.0071	Bucket
			Outflow	0.00485	Weir

The flow measurements that were taken during field sampling are effective in providing a general look at the flow tendencies, but they are subject to sampling error. It is more efficient to use a continuous method of flow monitoring, such as a depth probe. The following methods were utilized for flow monitoring as listed in the tables above.

- The bucket method was used during the rainfall events of 11/8/2012, 11/28/2012, 12/9/2012, and 12/10/2012. A few different bucket and bottles of known volumes were used to collect water at a timed interval.
- The three measurements that were obtained by the weir method were reasonably close to what was captured via the bucket method. Calculations for determining flow based on the weir method are located in Appendix F: Weir.
- ISCO readings were taken at the times stormwater samples were collected. This method is a very accurate way of measuring the flow and was used exclusively at the River Street basin. It was used during the 11/8/2012 storm, but during subsequent storms, other methods were utilized because of their ease of set up and use, comparatively.

4.1.1 Depth Probe

Using a depth probe was the only method that provided a full hydrograph for the storm. Flow data resulting from the other methods were spot measurements and did not provide continuous information. This method captured the water height in the pipe and was used to calculate the flow rate based on Manning's Equation for the pipe. A depth probe was used in the inflow of Gate 27 during the 11/8/2012 storm and in the inflow of River Street during the 12/9/2012 to 12/10/2012 storm. The two inflow hydrographs are displayed in Figure 23 and Figure 24, and the raw data can be found in Appendix J: Depth Probe Data. The hydrographs shown represent the continuous flow data provided by the depth probe.

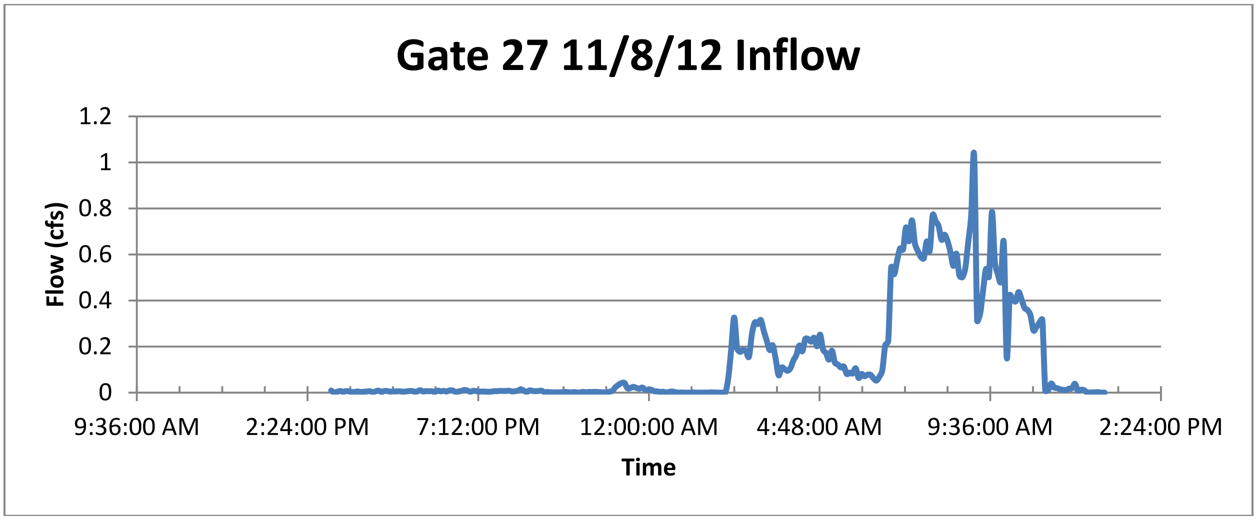


Figure 23: Gate 27 Inflow Hydrograph from the Depth Probe (11/8/2012)

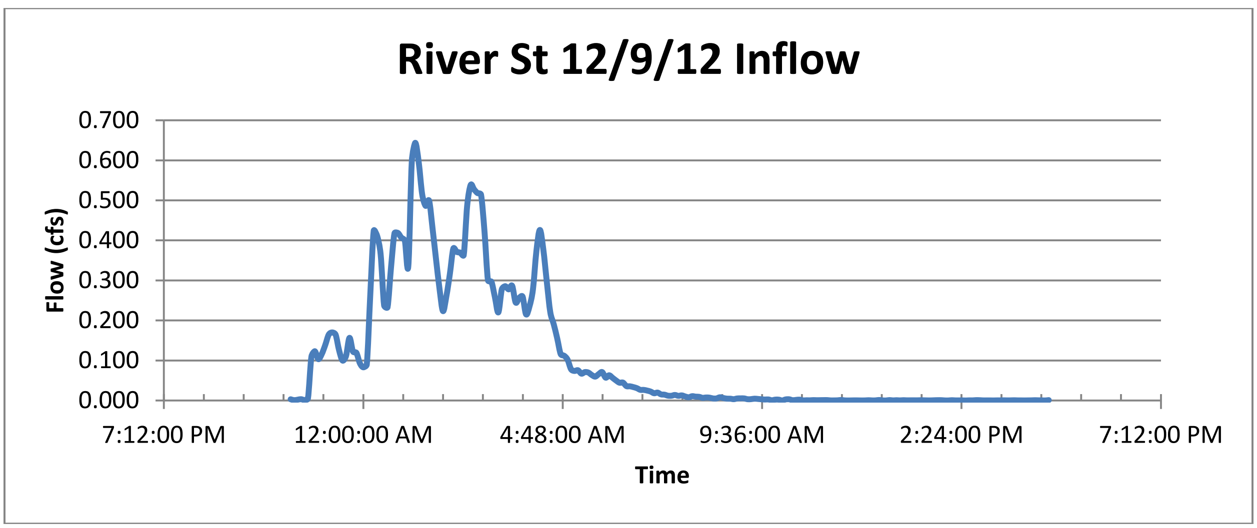


Figure 24: River Street Inflow Hydrograph from the Depth Probe (12/9/2012)

4.2 Flow Characteristics

Flow measurements taken on site using methods detailed in Section 3.5.3 were used in combination with HydroCAD to estimate the flow rates of each basin during the course of a stormwater event. The flow rates in Figure 25 and Figure 26 are modeled flows from HydroCAD based on observed data. These estimated flow rates revealed useful information about each basin. The inflow for the River Street basin was found to be significantly greater than the inflow to the Gate 27 basin. During the stormwater event on 12/10/2012, River Street basin received just over 13,000 cubic-feet of runoff, more than twice the runoff as the Gate 27 basin (just over

5,000 cubic-feet). This agrees with data in Table 11 that indicates River Street has a larger contributing impervious area than Gate 27.

The River Street basin is lined with an impermeable membrane. This forces all of the inflow to be discharged through the outflow pipe with infiltration only occurring within the filter media. As seen in Figure 25, the outflow was fairly consistent throughout the entire storm. This contrasts with the Gate 27 design, which only has impermeable walls but allows infiltration into the ground. The majority of the runoff flowing into Gate 27 infiltrates into the ground and only a fraction was discharged. During the 12/10/2012 stormwater event, only 8.5% of the inflow was ever discharged. As seen in Figure 26, the infiltration and discharge rates are consistent throughout the storm. The inflow to Gate 27 has a much sharper peak in the inflow than the River Street basin, but a smaller volume of flow overall due to the smaller impervious area in the catchment area.

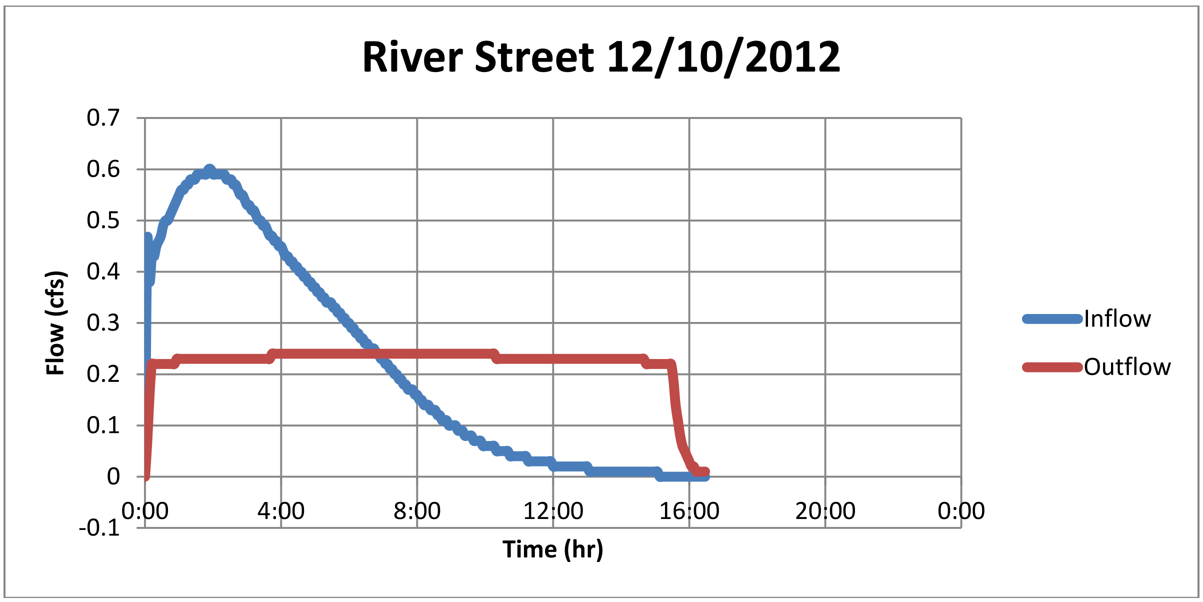


Figure 25: Modeled Flow Characteristics of River Street Basin

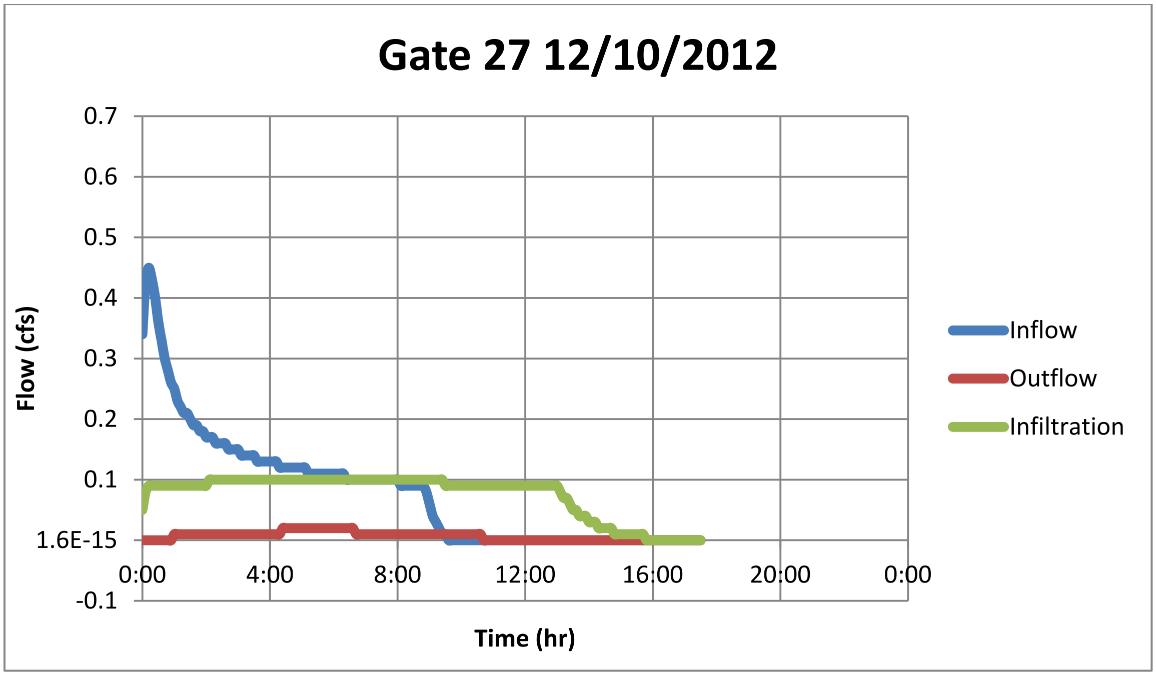


Figure 26: Modeled Flow Characteristics of Gate 27 Basin

4.3 Modeling

Hydrographs were developed from the HydroCAD models of the two basins to describe the flows for the inflows and outflows of each basin. The final models can be seen in Figure 21 and Figure 22. The flow rates resulting from the depth probes were imported into HydroCAD and directed to the inflow pipes via a link node. This allowed for a representative model of what occurred during two sampled storms. The precipitation data for the storms is located in Table 12 and Table 13. While taking into consideration the contributing areas' catchment characteristics, a model was developed that could describe rainfall events with different magnitudes. The final model for Gate 27 is found in Section 3.8.3, Figure 22. The final model for River Street is found in the same Section, Figure 21. The following sections describe the resulting models developed in HydroCAD.

4.3.1 River Street 12/9/2012 HydroCAD Model

The model hydrographs that illustrate the flows into and from the River Street basin during the 12/9/2012 storm are shown in Figure 27. Each line for all River Street HydroCAD hydrographs represents a specific parameter in the physical basin.

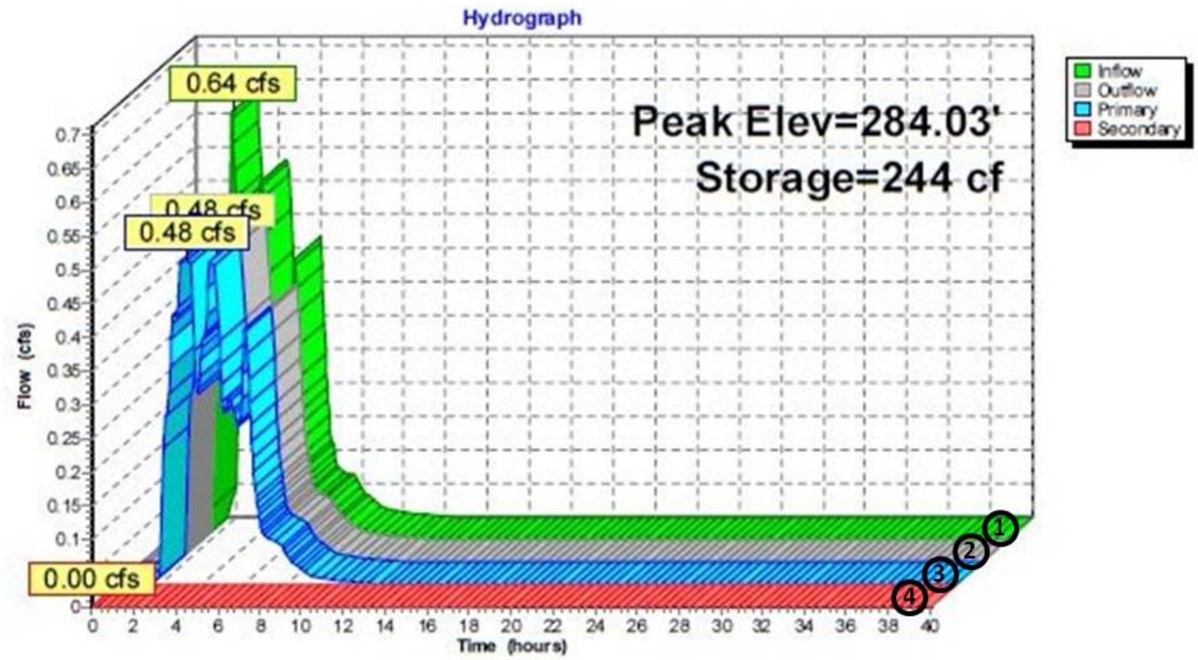


Figure 27: HydroCAD River Street Hydrograph (12/9/2012), where Line 1 is the 36" RCP inflow, Line 2 is the total outflow, Line 3 is the 6" PVC primary outflow, and Line 4 is the emergency spillway

The total outflow from the basin (Line 2) is the sum of the flows from the primary outflow (Line 3) and the emergency spillway (Line 4). The flow over the emergency spillway is 0 cfs during this storm, which means there was no water traveling over the spillway. The peak inflow is 0.64 cfs at hour 3. The peak outflow is 0.48 cfs at hour 3.35. This means that there is a lag time of 21 minutes from the peak flow to reach the outlet. These values align with the flow measurements gathered through other means, such as the bucket or weir methods.

4.3.2 General River Street HydroCAD Model

A model based off the characteristics of the River Street subcatchment for the 12/9/2012 storm was created and the hydrograph output is modeled in Figure 28. The software model created is capable of representing the typical behavior of the basin and stormwater flowing through it for any storm.

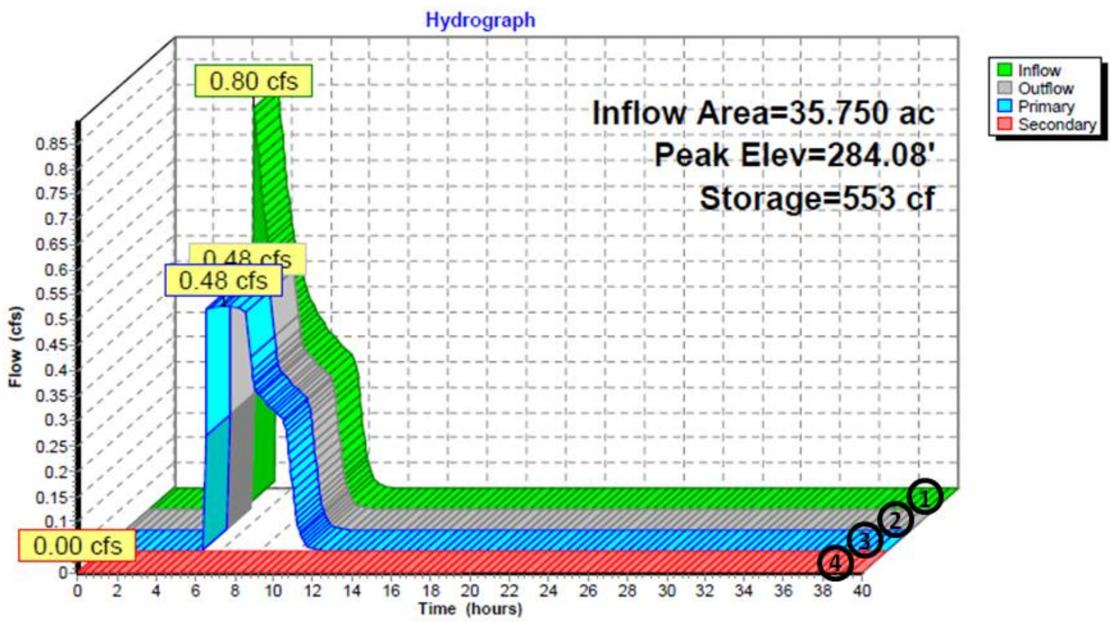


Figure 28: Generic River Street HydroCAD Hydrograph

Figure 26 shows a hydrograph for a storm with similar flow characteristics as the storm observed on 12/9/2012. Line 1 represents the basin inflow, Line 2 represents the total outflow, which is the sum of Lines 3 and 4 (primary outlet pipe and overflow weir, respectively). The model created to represent this storm is completely independent of any observed data. Different storm sizes and precipitation amounts can be input to show flow patterns within the basin under varying conditions.

4.3.3 Gate 27 11/8/2012 HydroCAD Model

The model hydrograph that illustrates the flows into and from the Gate 27 detention basin during the 11/8/2012 storm is shown in Figure 29. Each line for all Gate 27 HydroCAD hydrographs represents a specific parameter in the physical basin.

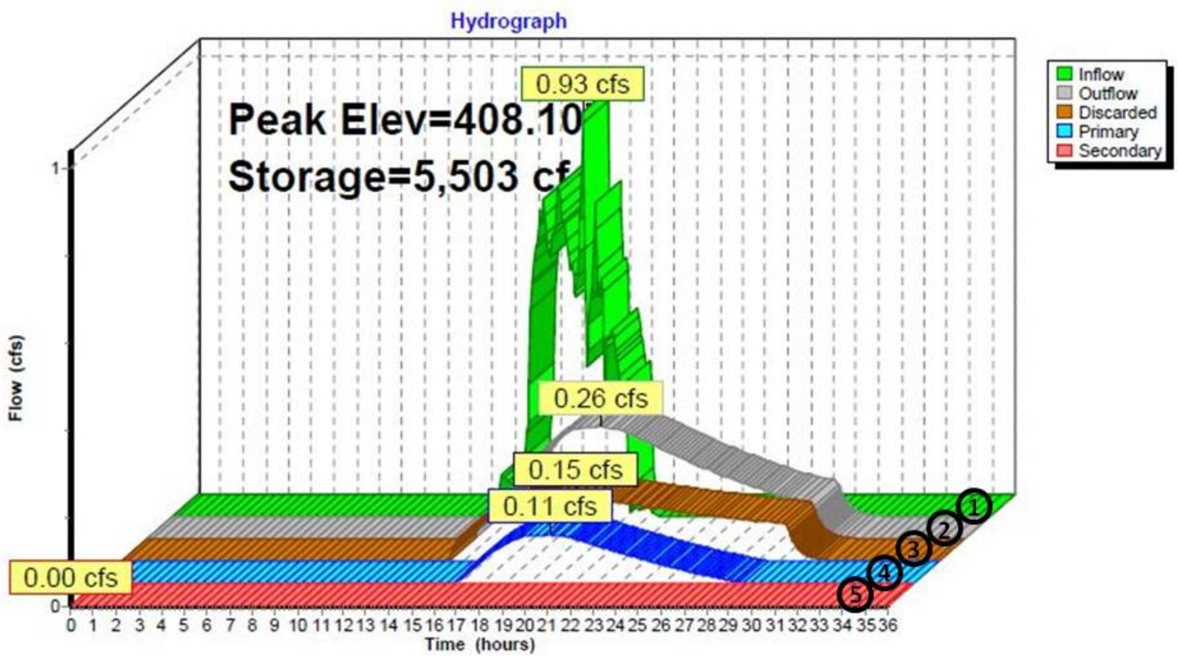


Figure 29: HydroCAD Gate 27 Hydrograph (11/8/2012), where Line 1 is the 24" RCP inflow, Line 2 is the total outflow, Line 3 is the infiltration/losses to groundwater, Line 4 is the 4" PVC primary outflow, and Line 5 is the emergency spillway

The total outflow from the basin (Line 2) is the sum of the flows from the primary outflow (Line 4) and flow over the emergency spillway (Line 5). The flow over the spillway is 0 cfs during this storm, which means there was no flow. The peak inflow is 0.93 cfs at hour 18.08. The peak outflow is 0.26 cfs at hour 20.03. This means that there is a lag time of 116.8 minutes from the peak flow to reach the outlet. These values align with the flow measurements gathered through other means, such as the bucket or weir methods.

4.3.4 General Gate 27 HydroCAD Model

A model based on the Gate 27 subcatchment characteristics for the 11/8/2012 storm was created and the hydrograph output is shown in Figure 30. The software model created is capable of representing the typical behavior of the basin and stormwater flowing through it for any storm.

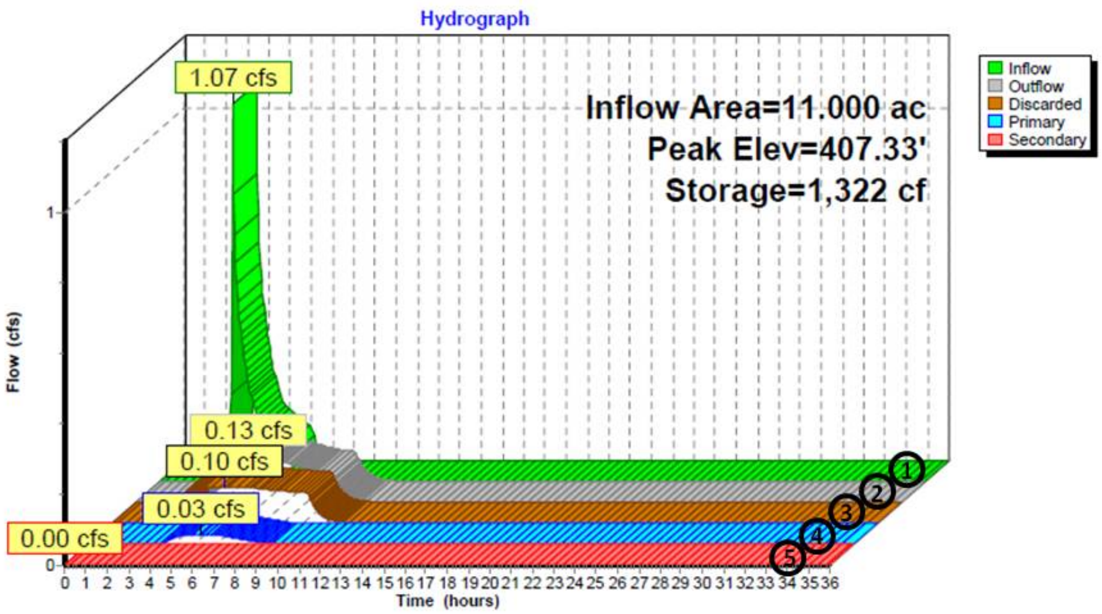


Figure 30: Generic Gate 27 HydroCAD Hydrograph

Figure 28 shows a hydrograph for a storm with similar flow characteristics as the storm observed on 11/8/2012. Line 1 represents the basin inflow, Line 2 represents the total outflow, which is the sum of Lines 4 and 5 (primary outlet pipe and overflow weir, respectively). Line 3 represents the infiltration to the ground. The model created to represent this storm is completely independent of any observed data. Different storm sizes and precipitation amounts can be inputted to show flow patterns within the basin under varying conditions.

4.4 Laboratory Results

This section discusses the data gathered from the laboratory procedures conducted on stormwater samples from the 9/18/2012, 9/28/2012, 11/8/2012, 11/28/2012, and 12/10/2012 storms. For full laboratory procedures, see Appendix B. The results presented in Figure 31, Figure 32, and Figure 33 represent snapshots of constituent concentrations averaged over each storm that was sampled. The full set of data is located in Appendix A: Laboratory Analyses Results.

There are many common trends that are apparent after analyzing the data. The River Street basin has higher concentrations of constituents on average than Gate 27, which is likely caused by the land use characteristics of the contributing area. When comparing the concentrations of constituents entering the basins in the inflow and leaving the basins in the outflow, it is apparent that the River Street basin serves as a source of constituents during the sampled storms, while the Gate 27 basin removes some and serves as a source for others. The generation of constituents could be associated with the nutrient-rich materials in the basins, including the filtration soils. The concentrations of many dangerous pollutants, such as arsenic, lead, and iron, are extremely low for both the inflow and outflow, which are well below the maximum limit provided by the EPA.

A summary table detailing which constituents increased or decreased from the inflow to the outflow for the sampled storms is in Table 14. In this table, if the constituent concentration is greater in the outflow than the inflow, it is marked as increasing (+). If the concentration is less in the outflow than the inflow, it is marked as decreasing (-).

Table 14: Constituent Trend for Each Basin from Inflow to Outflow

Constituent	River Street Basin	Gate 27 Basin
NO_3	+	-
NH_3	+	-
Total Phos	-	-
F	+	-
Cl	+	+
SO_4^{-2}	+	-
PO_4^{-3}	+	+
NO_2	-	-
Br	+	-
K	+	+
As	-	-
Mg	+	+
Fe	+	-
Mn	+	-
Pb	-	-
Ca	+	+
Na	+	-
DO	-	+
TSS	-	-
Turbidity	-	-
pH	-	+
Alkalinity	+	+

The concentrations for total phosphorus, nitrite, arsenic, lead, total suspended solids, and turbidity were lower in the outflow than inflow for each basin. This means that they were both effective at removing those constituents. The Gate 27 basin was more effective overall at removing constituents than the River Street basin. Reasons for this are discussed further in Section 4.7.2.

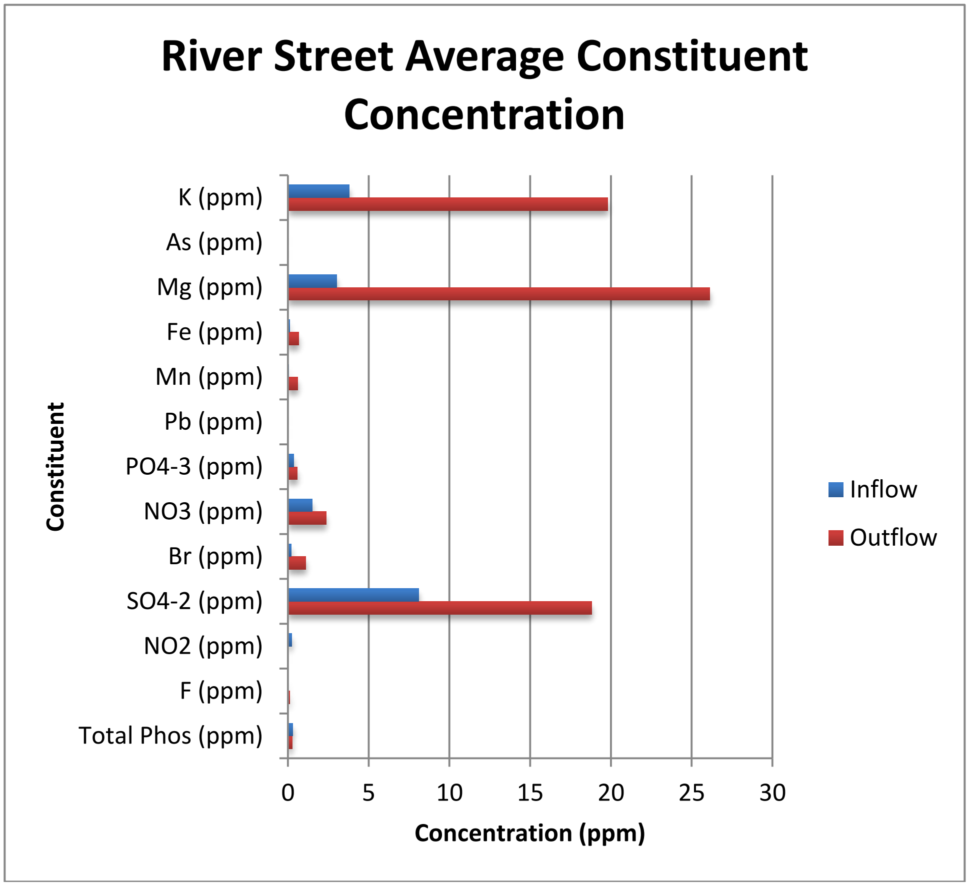


Figure 31: Average Constituent Consentration for River Street

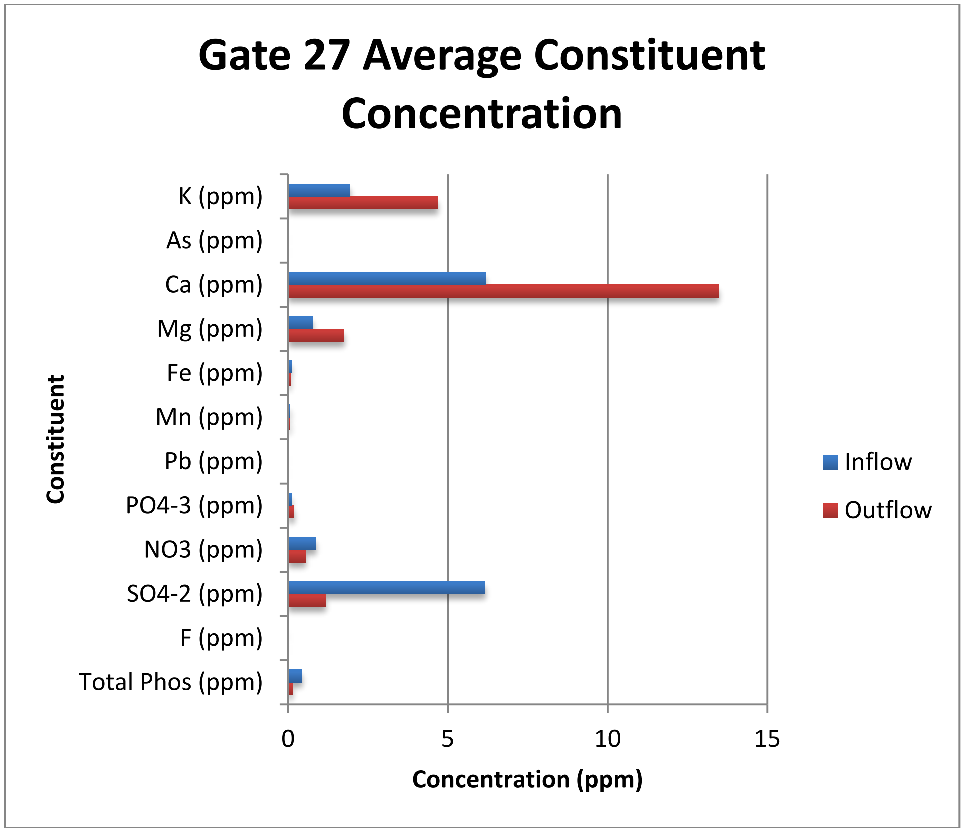


Figure 32: Average Constituent Concentration for Gate 27

The concentrations of a few constituents were so large for both basins that they skewed the scale of the results. Therefore, they were placed on a separate chart to better depict their tendencies. Figure 33 shows the average concentrations of sodium and chlorine ions for the inflows and outflows of both basins during sampling. Chlorine has the highest concentration of any constituent tested, at almost 3000 parts per million in some cases. One cause of the high chlorine and sodium concentrations was the road salting that occurred just prior to one of the storms. The salt that was placed on the roads nearby in preparation of snow was promptly washed into the BMP when rain started falling. It is apparent from the figure that both the sodium and chlorine concentrations are higher exiting the basins than entering. This means that the basins were inefficient at treating for chlorine and sodium during the storms that were sampled.

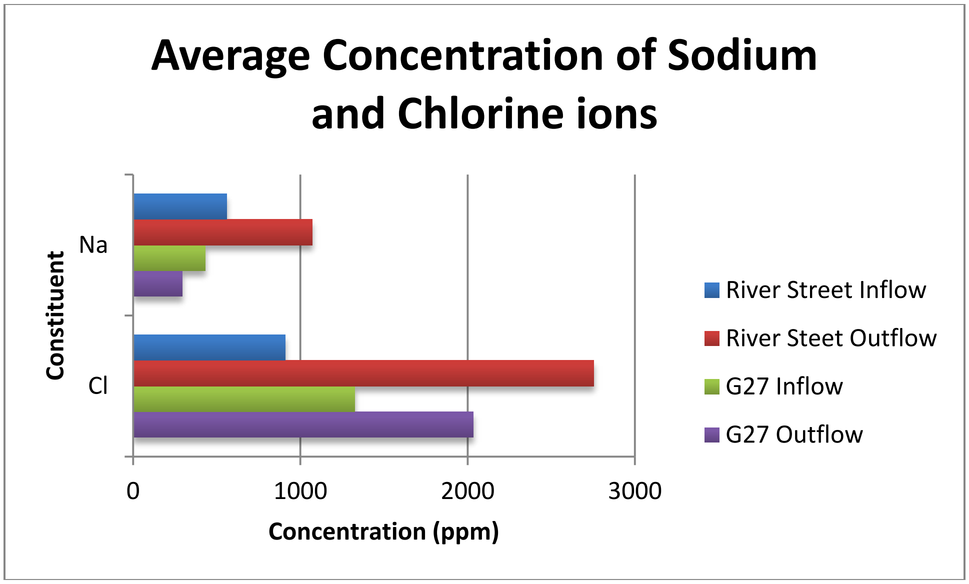


Figure 33: Average Na and Cl Concentrations for Gate 27 and River Street

4.5 Contaminant Loadings

This section describes the loading of pollutants, or total mass of each constituent in a volume of water, that was present for both Gate 27 and River Street during the 12/9 – 12/10/2012 storm. It is presented by major constituents, including TSS, Total Phosphorus, Nitrogen, and Sulfate. The charts in each section depict the differences in constituent loadings between the inflow and outflow of the basin. The figures showing the contaminant loadings were created by combining the modeled flow data and interpolating between the concentrations during samples taken. This gave the continuous mass flow data seen in the loading graphs and was used to calculate the percent removal of the selected pollutants. The low outflow and high infiltration in Gate 27 contributed to the high percentage of removal found through the basin, as seen in many of the figures in this chapter.

4.5.1 Total Suspended Solids

Both basins are primarily designed to remove suspended solids from the influent by utilizing a sediment forebay. The inflow of TSS was much higher at the very beginning of the storm, during the first flush. Overall, both basins remove over 90% of the suspended solids in solution. The collected data show that these basins meet the standards for TSS removal expected for detention basins.

Despite receiving more than twice the flow, the River Street basin received a smaller load of TSS than the Gate 27 basin received. Seven kilograms of TSS were discharged into the Gate 27 basin and only 6 kilograms were discharged to the River Street basin. This difference was reflected as a much higher concentration of TSS in the influent to the Gate 27 basin.

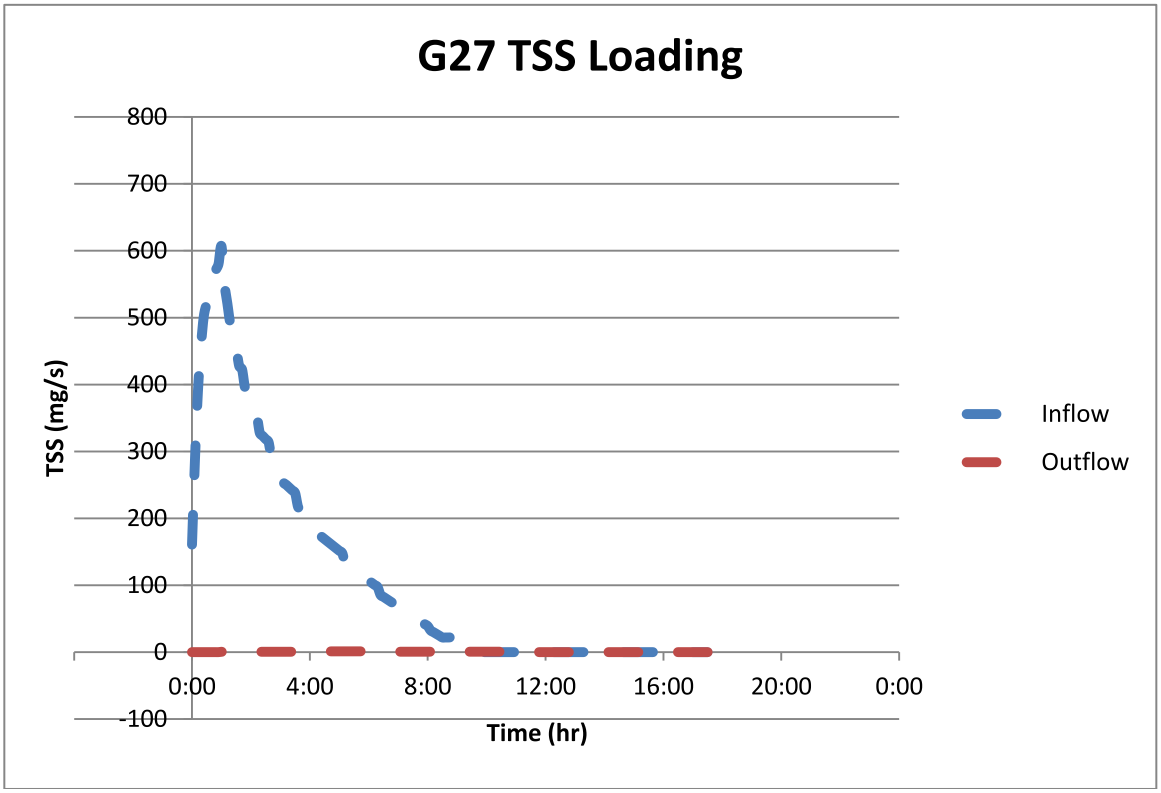


Figure 34: TSS Loading at Gate 27 (12/9 – 12/10/2012)

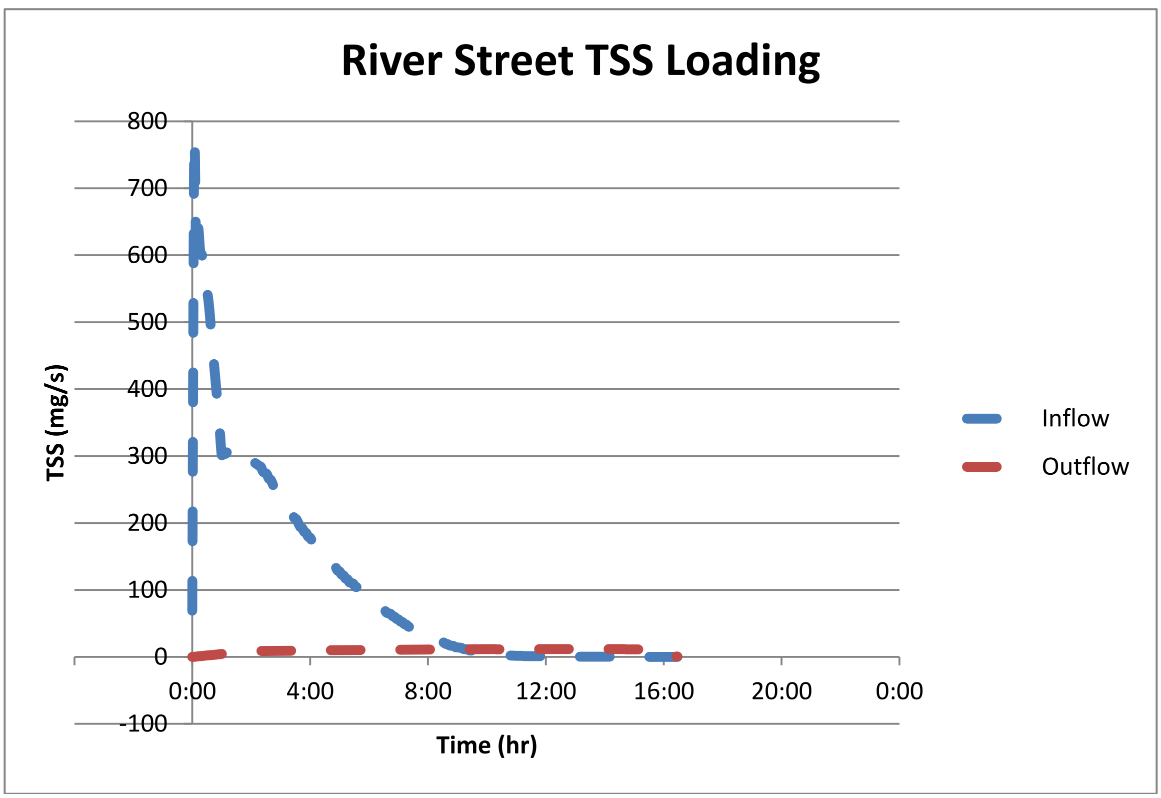


Figure 35: TSS Loading at River Street (12/9 – 12/10/2012)

4.5.2 Total Phosphorus

The mean concentration of phosphorus entering River Street basin was 0.49 mg/L while the concentration entering Gate 27 basin was 0.31 mg/L. Over the course of the storm 127 grams of phosphorus entered River street basin, nearly four times more than the 36 grams that entered the Gate 27 basin. One potential reason for this disparity is the nature of the two drainage areas. River Street is surrounded by high traffic density roads and most of the runoff from this area comes from these roads. This could result in more phosphorus from vehicle emissions.

Gate 27 removed the majority of the phosphorus that entered the basin. The concentration of the phosphorus was also decreased through the basin. The River Street basin was not effective at treating the runoff for phosphorus. The effluent from River Street contains more phosphorus than the runoff entering the basin. This could be because of the recent completion of construction of the basin, where the soil mix may be leaching phosphorus and other nutrients.

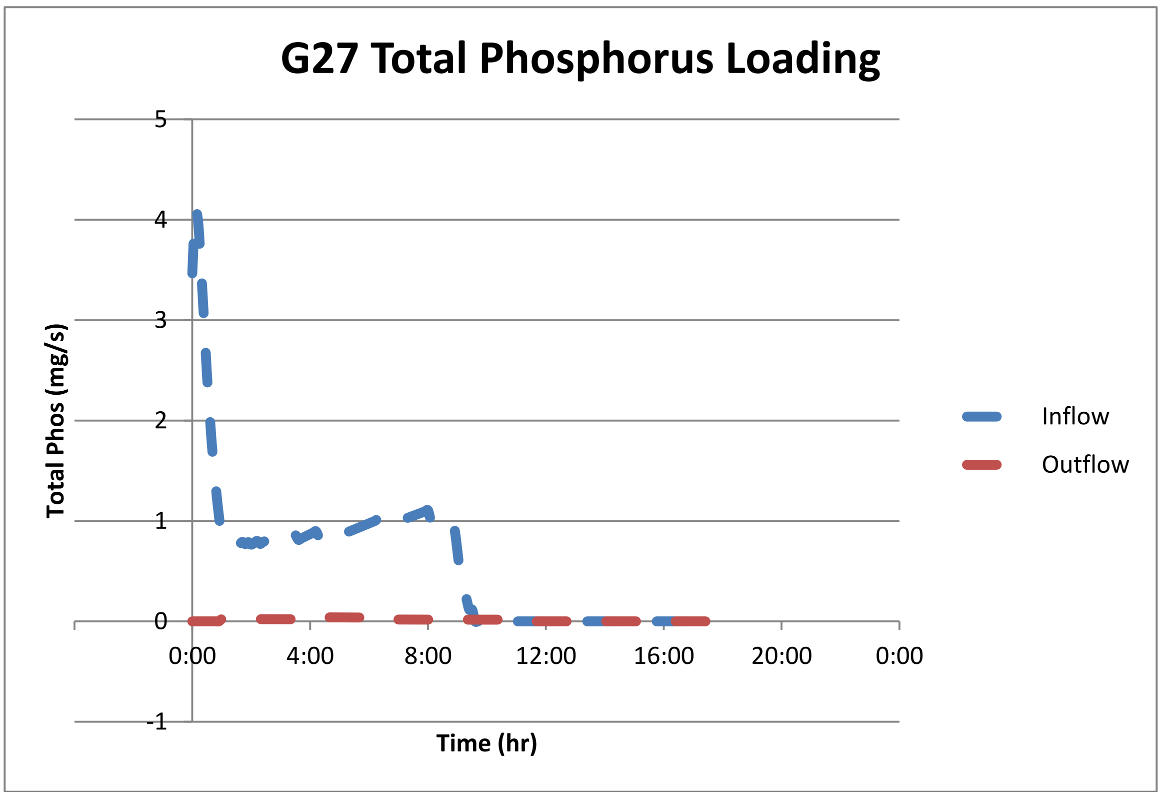


Figure 36: Total Phosphorus Loading at Gate 27 (12/9 – 12/10/2012)

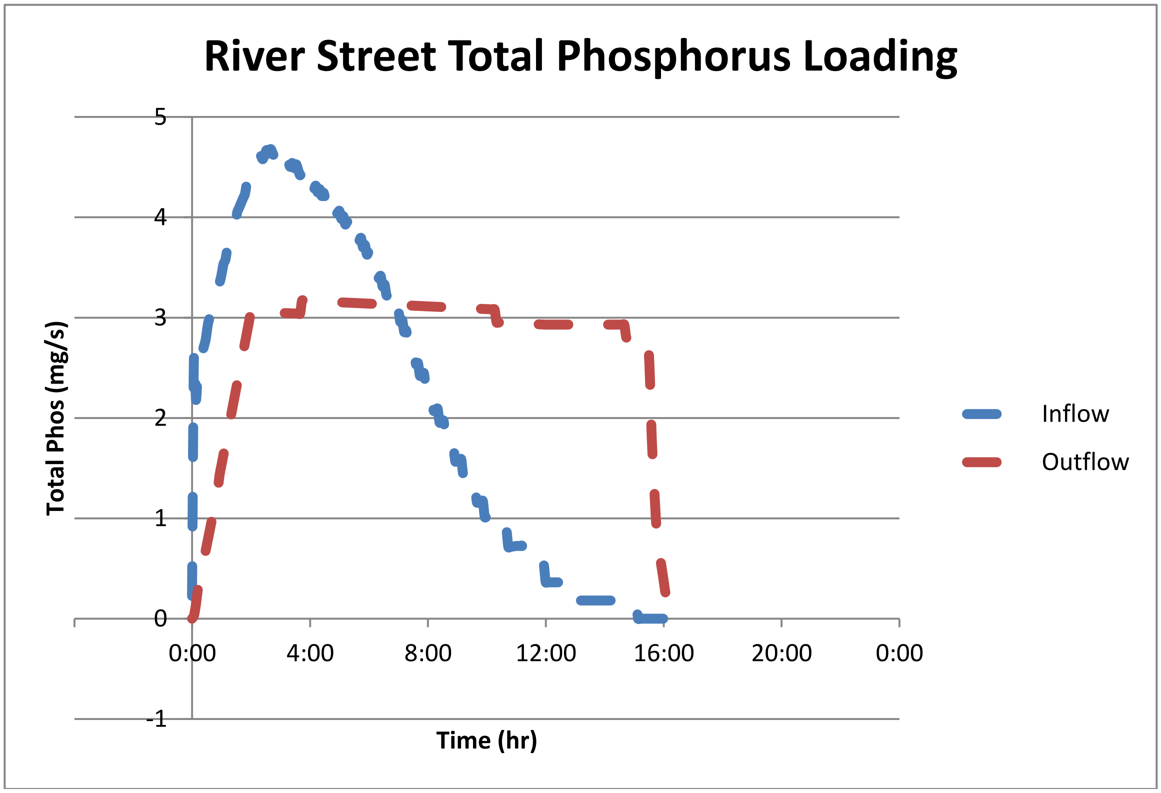


Figure 37: Total Phosphorus Loading at River Street (12/9 – 12/10/2012)

4.5.3 Nitrogen (NO_3 and NH_3)

The mean concentration of nitrogen entering each basin was similar. The influent concentration of NO_3 was close to 1 mg/L for both basins. The concentration of NH_3 entering the Gate 27 basin (1mg/L) was slightly higher than the concentration entering the River Street basin (0.6mg/L). Over the duration of the storm, more nitrogen entered the River Street basin because it received more flow.

If it is assumed that there is no nitrate transported through the groundwater, the Gate 27 basin would remove a majority of the nitrogen that entered. The data indicated that nitrogen was not removed effectively by the River Street basin.

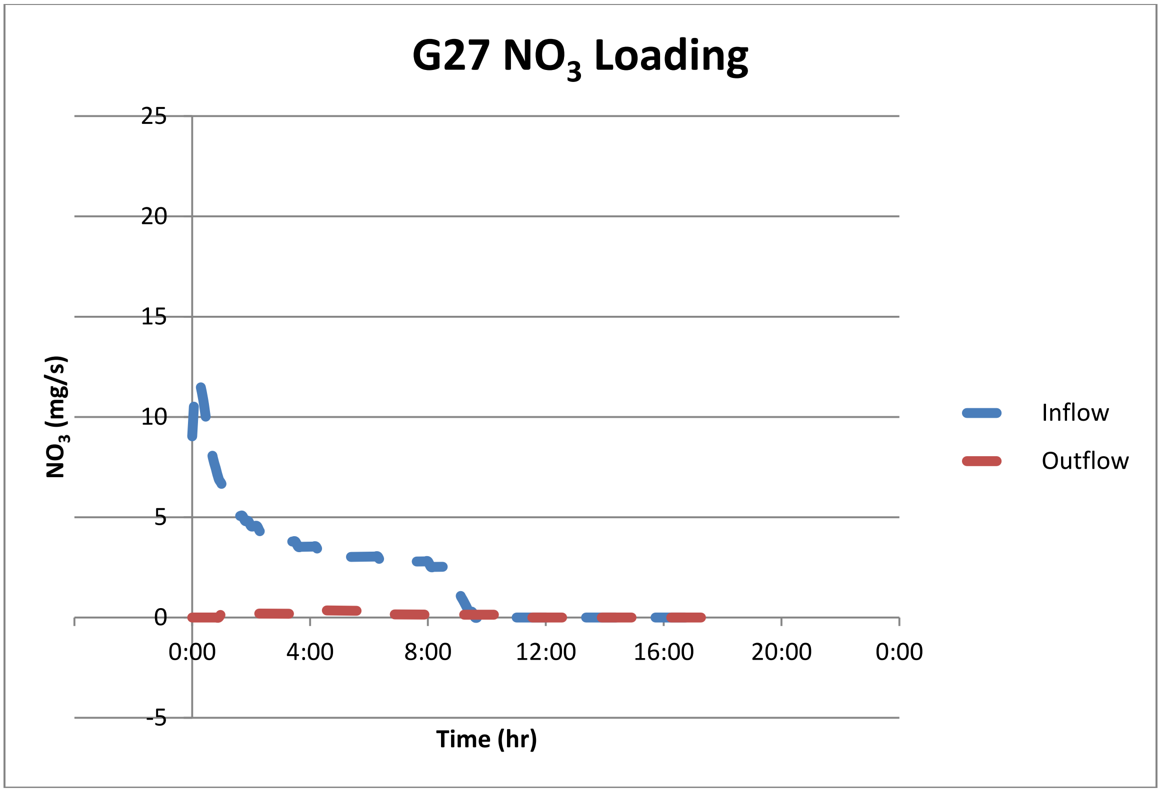


Figure 38: NO_3 Loading at Gate 27 (12/9 – 12/10/2012)

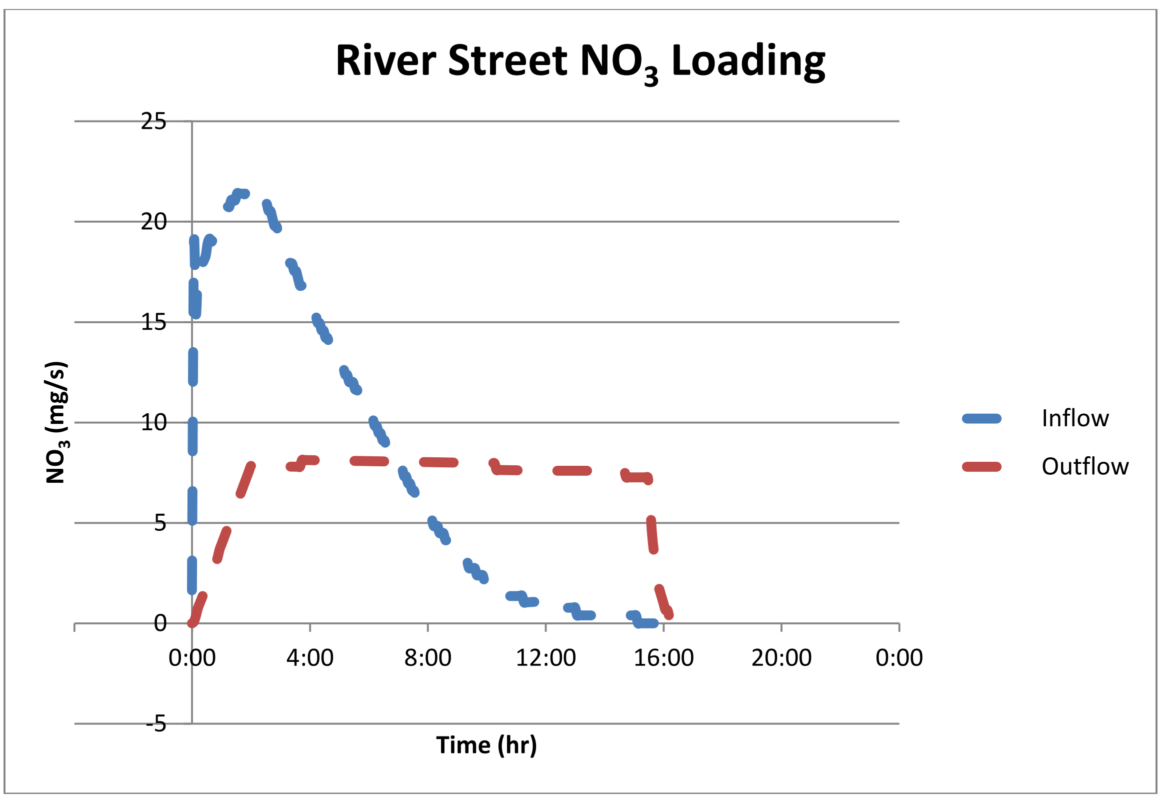


Figure 39: NO_3 Loading at River Street (12/9 – 12/10/2012)

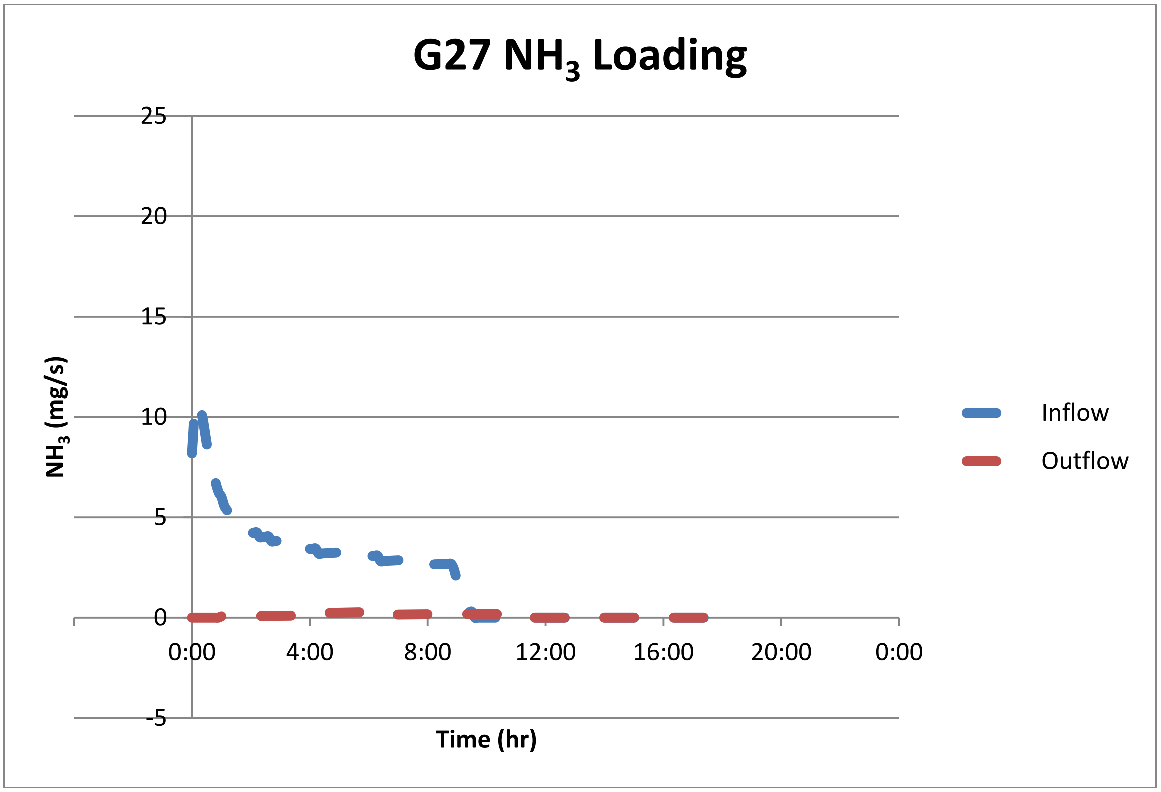


Figure 40: NH_3 Loading at Gate 27 (12/9 – 12/10/2012)

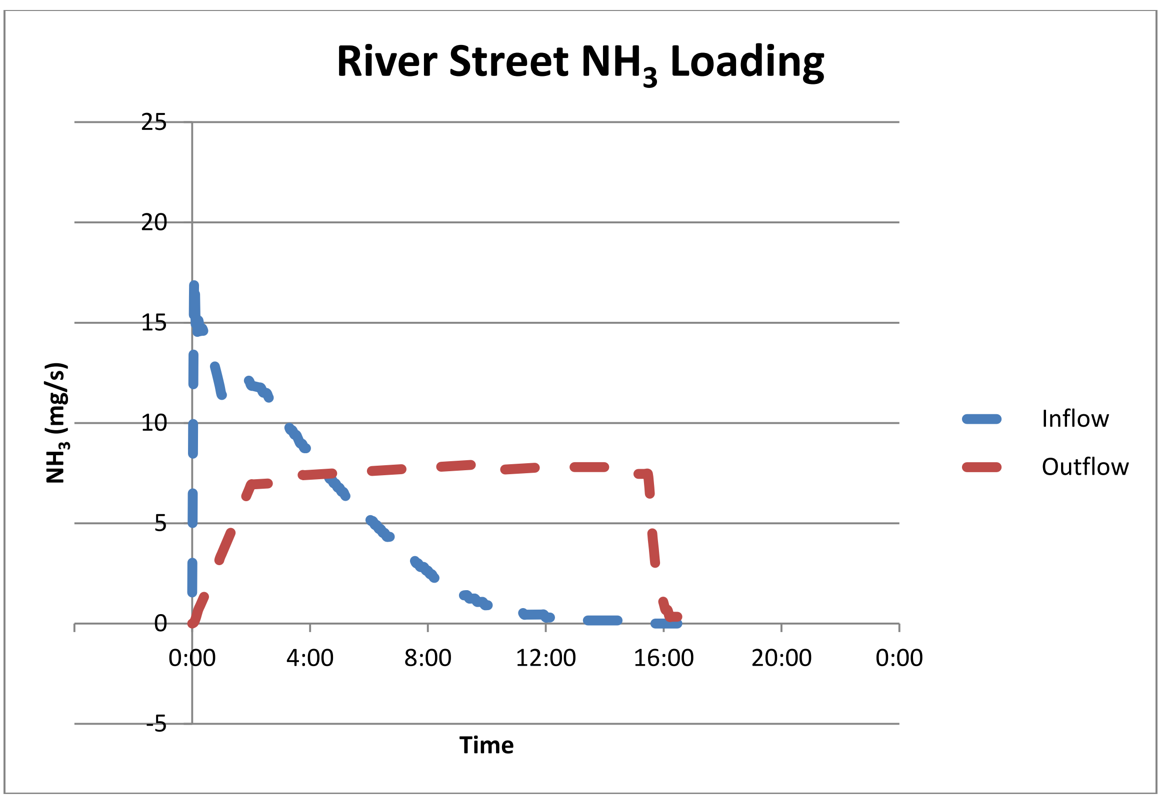


Figure 41: NH_3 Loading at River Street (12/9 – 12/10/2012)

4.5.4 Sulfate (SO_4)

The River Street basin received significantly more SO_4 than the Gate 27 basin. The influent concentration to the River Street basin was around 6.5mg/L while the Gate 27 basins influent only had a SO_4 concentration of 2.2mg/L. One potential reason for the higher observed levels of sulfate at the River Street basin is the nature of the two drainage areas. River Street is surrounded by high traffic density roads and most of the runoff from this area comes from these roads. This could result in more sulfates from vehicle emissions.

Gate 27 removed the majority of the SO_4 that entered the basin. The concentration of the SO_4 was also decreased through the basin. The River Street basin treated the runoff for SO_4 but less effectively than Gate 27.

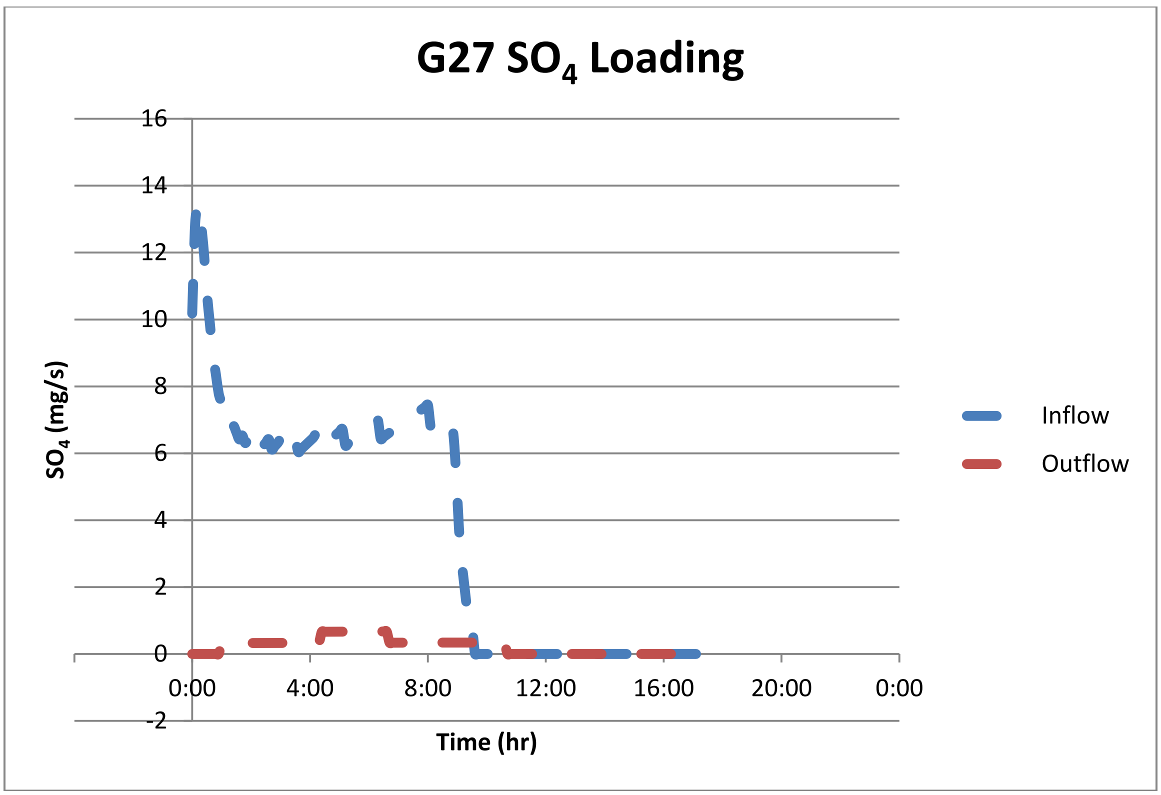


Figure 42: SO_4 Loading at Gate 27 (12/9 – 12/10/2012)

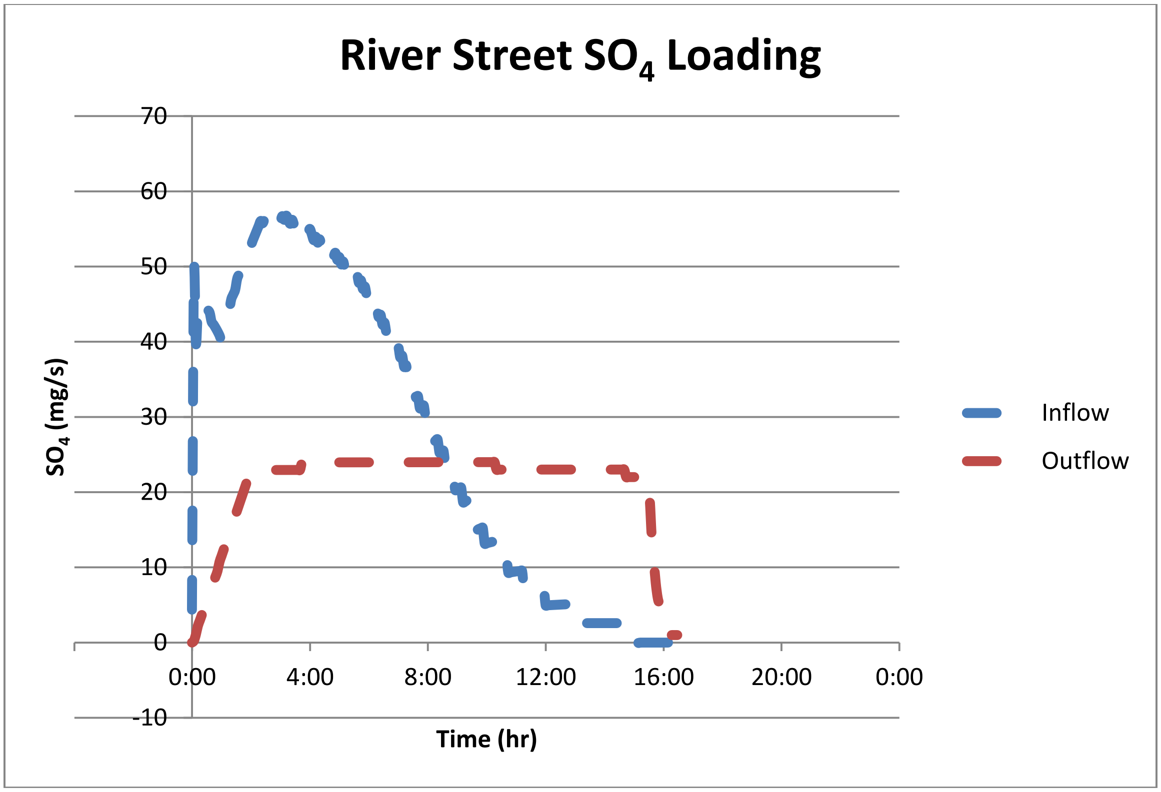


Figure 43: SO_4 Loading at River Street (12/9 – 12/10/2012)

4.6 Basin Efficiencies

This section discusses the effectiveness of each basin in the removal of certain constituents. Both basins were effective at removing TSS. The average removal efficiencies for the events monitored were above 90%. River Street was less effective at removing nitrogen, phosphorus and sulfur. During the stormwater event on 12/10/2012, the data from River Street basin showed generation of phosphorus and ammonia through the basin.

Gate 27 removed over 94% of every pollutant of concern. The extremely high efficiency was due to the large amount of infiltration associated with these events. However, it is anticipated that a larger storm would pass more flow through the trench drain and ultimately affect efficiency. Although most of the removal comes from infiltration, other factors such as vegetation uptake also have some contribution to removal. The effluent concentrations were also lower than the influent concentrations, despite the difference in flow volume. River Street was less effective in its treatment of pollutants; in some cases more constituents were released through the outflow than came in through the inflow (e.g. for total phosphorus and NH_3). The removal data are summarized in Table 15:

Table 15: Average Percent Removal of Selected Pollutants

Constituent	River Street Basin	Gate 27 Basin
TSS	90%	99%
Total Phosphorus	-26%	98%
NO_3	12%	95%
NH_3	-53%	96%
SO_4	24%	94%

The major differences between the basins included flow volume, detention time, treatment area to impervious area ratio, and the presence of a basin liner. The Gate 27 basin had lower flow volumes, a longer detention time, and the bottom of the basin was unlined, which allowed for infiltration. The River Street basin had a higher flow volume, shorter detention time, and a lined bottom that prevented infiltration.

The lining of the basins had the largest impact on the basin efficiencies. The Gate 27 basin maintained a smaller amount of effluent flow, which is assumed to be due to the infiltration capacity of the basin and the smaller contributing area.

4.7 Discussion of Results

This section discusses the advantages and disadvantages associated with the various methods used to monitor flow, as well as the water quality results gained through analyses of the River Street and Gate 27 basins.

4.7.1 Flow Monitoring

The bucket method provided a reliable and fairly accurate means of measuring flow at a quick snapshot. During larger flow conditions this method could prove to be more challenging and as a result not as precise. For relatively smaller flows, especially on the outflows, this was an efficient means to capture the flow. This method was subject to error because the total flow needed to be captured. This can be difficult depending on the site conditions and the bucket used. For example, the apron at the inflow of Gate 27 spreads out the flow, which can make it difficult to capture in its entirety.

The weir method is typically a standard method of calculating flow, but it was not as useful and accurate for this project. The weir set up on the outflow of Gate 27 saw flow only on a couple of occasions and when it did, the flow was so minimal that the water traveling over the weir was subject to error. It was often difficult to measure the water level as it travels over the v-notch because it was very close to the notch itself.

The ISCO unit is another very accurate way to get spot readings of flow. It was only used for one storm, however, because other flow monitoring methods proved to be easier and simpler to use.

This method was the preferred method because it was very accurate in showing a full display of the storm's precipitation distribution. It easily allowed a model to be developed of what came through the inflow and outflow.

4.7.2 Water Quality

This section discusses the water quality of stormwater near the River Street and Gate 27 basins that was determined by laboratory analyses.

4.7.2.1 Total Suspended Solids

The Gate 27 basin performed well when considering removal of the constituents analyzed. The basin removed 99% percent of the total suspended solids present in the inflow. This number was extremely high, likely due to the amount of infiltration to the ground as well as the presence of a sediment forebay.

The River Street basin removed 90% of the total suspended solids present in the inflow. This number was likely due to the presence of a sediment forebay. This efficiency was not quite as high as the removal efficiency of Gate 27 because the volume of water that exits through the outflow of the basin during a storm was normally equal to the volume that enters through the inflow, or there is minimal infiltration. The volume of water that exits through the outflow of River Street was significantly more than that of Gate 27, which allows for more particles to pass through the basin to the outflow.

The relatively high TSS removal rates of both basins implied that any amount of infiltration has a huge impact on the total suspended solids present in stormwater runoff. This also made the presence of a sediment forebay in any new designs important.

4.7.2.2 Nutrients

One of the more noticeable differences in the removal efficiencies found for the two basins was in the removal of nutrients.

The Gate 27 basin removed over 94% of all of the nutrients analyzed. This number was likely due to the volume of water that infiltrated to ground and the relatively small volume of water that entered the outflow pipe.

The River Street basin had greater mass loads of nutrients in the outflow than in the inflow in some cases. There were a number of causes that could explain this. The soil mixture used in the River Street basin was approximately half compost, which is primarily made up of organic materials. The basin was completed less than two years ago, so the compost in the soil of the basin could be leaching nutrients into the outflow. The lack of dense vegetation in the basin also may have impacted the removal of nutrients from the stormwater because there are less vegetation to uptake the constituents. The basin could see an improvement in the removal of nutrients as the vegetation in the basin expands. Another explanation for the additional nutrients present in the outflow could be that nutrients deposited in the infiltration media from previous storms was being flushed into the outflow. The relatively high mass loads of sodium and chloride entering the basin could have impacted the ability of the infiltration media to retain the nutrients trapped in the soil particles.

Comparing the nutrient removal efficiencies of the two basins showed that using infiltration to the ground is significantly better for removing nutrients than restricting infiltration as long as infiltrating to the ground is feasible.

4.7.3 Infiltration to the Ground

It has been assumed that pollutants carried with stormwater to the ground through infiltration achieve a 100 percent removal. This is based on the assumption that the stormwater has zero contaminants in it once it travels the distance to the reservoir through the groundwater table. However, this assumption is only appropriate for the scope of this project. Some constituents may travel through all filter media, soil, and groundwater to reach the reservoir. This could have a negative impact on the water quality. For example, phosphorus is typically completely removed from stormwater due to adsorption to soil minerals (Pitt, 2003). This means that the reservoir would receive a zero concentration of phosphorus. However, nitrogen is able to travel through groundwater and is not adsorbed as readily by soil media (Pitt, 2003). Therefore, the reservoir could receive some nitrogen from a treatment basin such as Gate 27.

The exact removal efficiency of soil is dependent upon the specific characteristics of the soil. To determine this efficiency, extensive groundwater sampling and soil testing would need to occur.

Another consideration for groundwater infiltration is the chance of saturation after a long period of time. If the ground becomes saturated, infiltration will not occur and the pollutants could cause contamination in the groundwater. Pollutants that are initially removed could reach the reservoir if saturation occurs.

The Gate 27 basin is likely not as effective as stated in this report because the infiltration to the ground does not capture all pollutants. For example, if infiltration only removes 50 percent of pollutants, instead of the assumed 100 percent, the basin will achieve only 40 to 50 percent removal efficiency. This is because the 50 percent of pollutants not removed will travel through the ground to the water supply.

5 Stormwater Best Management Practice Design

According to the stormwater discharge permit for the DCR, public drinking water sources should be protected from untreated stormwater discharges (Department of Conservation and Recreation, 2007). The DCR has been using bioretention basins to intercept stormwater before it reaches the Wachusett Reservoir and provide basic treatment to remove contaminants.

The DCR has recently begun an effort to increase the amount of stormwater that receives treatment during each storm. Part of the DCR's stormwater management program includes retrofitting and reactivating an older retention basin at DCR Gate 25. The design of the new basin for Gate 25 has not been chosen, so the site was considered to be an appropriate context for developing a design that would reflect the results of the River Street and Gate 27 basin analyses completed as part of this project. While certain existing conditions from Gate 25 were used as a platform for design, the major intent of this project was to design an ideal basin and illustrate the major considerations involved in such a process. This chapter begins with an analysis of the Gate 27 and River Street basins, along with a review of the existing conditions at Gate 25. After reviewing the MassDEP standards for design of a bioretention basin, the chapter includes a detailed design for an ideal basin at the Gate 25 location. Each aspect of design is included, such as basin sizing, the filter media and sand makeup, and outflow controls.

5.1 Analysis of Gate 27 and River Street Basins

This section describes the treatment basins at the River Street and Gate 27 locations. The design of the River Street basin is beneficial in that it provides treatment without using a great deal of space.

The design of the Gate 27 basin is beneficial because it theoretically removes 100 percent of the contaminants of concern in the stormwater runoff that infiltrate to the ground. Runoff that enters the basin is infiltrated into groundwater, removing all suspended solids and allowing for other contaminants like metals and nutrients to be absorbed by vegetation. However, during high flow situations the Gate 27 basin tends to discharge runoff that is treated less than the water that completely infiltrates.

The River Street basin has lower removal efficiencies than the Gate 27 basin during infiltration due to the limited depth of the soil layer. The River Street basin infiltrates stormwater through a soil layer two feet deep before discharging. This gives the vegetation planted in the basin less time to remove nutrients and other contaminants before they are washed into the underdrain system. The vegetation is not fully established at River Street, so performance may improve with time. The underdrain system does allow for the basin to discharge relatively quickly. This reduces the chance that the basin directly discharges untreated runoff.

The elevation above the reservoir is a factor in determining the appropriate design for a location. The Gate 27 basin had to be high enough above the surface of the reservoir to keep the groundwater table from rising into the basin or interfering with infiltration. The location of the River Street Basin would not allow for a basin of the same design as Gate 27 because the elevation of the basin is only a few feet above the water level of the nearby Lancaster Mill Pond. The River Street basin has impervious material underneath, so the elevation of the basin above the surface water does not affect the efficiency of the basin. The exceptions to this are when the water level of the Lancaster Mill Pond rises and interferes with flow through the forebay or when the water level rises and spills over the berm and into the basin.

5.2 MassDEP Standards

Designs for best management practices in Massachusetts are based on the regulations put forth by the organization responsible for BMP designs in Massachusetts, the Massachusetts Department of Environmental Protection (MassDEP). The design for the new basin followed the same approach.

MassDEP created a series of regulations on stormwater management in 2008 called the Stormwater Management Handbook. The handbook has a number of regulations on the design specifications for stormwater BMPs.

The Stormwater Management Standards for BMPs are made up of ten basic regulations covering the design of all BMPs in Massachusetts. These regulations are specifically geared towards controlling the contents of discharges into wetland resources. The MassDEP regulations are performance standards and do not extensively specify what the dimensions or materials of the BMP should be. This allows the design of BMPs to be variable, as long as the outflow meets the MassDEP standards (Massachusetts Department of Environmental Protection, 2008). The following subsections summarize the standards presented in this source.

5.2.1 Standard 1

Standard 1 from the MassDEP Stormwater Management Standards requires that the outflow of any BMP be designed to prevent scouring or erosion of the surface it is discharging to. River Street dealt with this issue by layering rocks in the water where the outflow pipe discharged into the pond. During sampling visits, the pond bed near the outflow pipe did show signs of scouring. Gate 27 had a small trench lined with rocks at the discharge of the outflow pipe, which appeared to successfully prevent erosion of the area at the discharge point. New designs should take this into account and use more gravel and stones to avoid the scouring.

5.2.2 Standard 2

The second standard from the MassDEP Management Standards states that post-development peak discharge rates do not exceed pre-development peak discharge rates. In effect, this standard merely requires that the construction of a BMP should not create more stormwater runoff. This would occur if the BMP was constructed using impermeable materials, or if the material used in the basin had lower infiltration rates than the soil material originally present.

5.2.3 Standard 3

Standard 3 pertains to the recharge rate of groundwater in the area. The standard states that the groundwater recharge rate should, at a minimum, be approximately the same as the groundwater recharge rate of the site before the construction of the BMP. The recharge rate of the BMP is determined by the infiltration rate of the BMP, which is dependent on the soil type used for the basin. Standard 3 and Standard 4 were both used to calculate the required volume that the basin needs to hold. For this standard, the volume was calculated using MassDEP procedures to find the recharge volume.

5.2.4 Standard 4

Standard 4 concerns the removal of total suspended solids. The standard requires that the BMP removes 80% of the average annual TSS load from the inflow. The standard lists a number of conditions that will help fulfill the requirement when met. These conditions include sizing the BMP to capture the required amount of runoff, using correct pretreatment for the flow in accordance with the Massachusetts Stormwater Handbook, and creating a plan to deal with pollution and to control the inflow.

To meet Standard 4, the new basin design had to achieve an 80% TSS removal. Achieving 80% removal can be accomplished by designing the basin to handle a specific volume of water. The MassDEP provided an equation that solves for the basin volume required to reach the 80% TSS removal, which is shown Equation 10 (Massachusetts Department of Environmental Protection, 2008).

$$V_{WQ} = \frac{D_{WQ}}{12\frac{in}{ft}} * A_{IMP} * \frac{43{,}560\ sq\ ft}{acre}$$

Equation 10: Required Water Quality Volume for BMP Sizing

Where:

V_{WQ} = Required water quality volume (ft^3)
D_{WQ} = Water quality depth
A_{IMP} = Impervious area (acres)

The site-specific calculation assumes either 0.5 inches of runoff or 1 inch of runoff if the discharge is near a critical resource, such as the Wachusett Reservoir. A 1 inch volume is used for this case. This amount is multiplied by the impervious area of the catchment area.

5.2.5 Standard 5

The fifth standard applies to areas that contain land uses with higher potential pollutant loads. For these areas, pollutant prevention and source control are to be practiced to reduce the amount of stormwater runoff from those particular sites. The proposed BMP is not covered by this standard, as the drainage area does not have land uses with higher potential pollutant loads. This standard applies to areas that handle large quantities of substances that produce contaminants, such as fertilizer manufactures.

5.2.6 Standard 6

Standard 6 pertains to stormwater discharges that occur in public water supply areas, which applies to the Wachusett watershed. Stormwater BMPs discharging into or near public water supplies have to meet a number of conditions specified by the MassDEP. These conditions are specified in 314 CMR 3.00 and 314 CMR 4.00. These two regulations are listed under the water and sewers chapter of the MassDEP regulations and standards. The first, 314 CMR 3.00, is a permitting process for surface water discharges. The other regulation, 314 CMR 4.00 is the list of Surface Water Quality Standards. The new basin design will likely pass the permitting process and follow the Surface Water Quality Standards as long as the design process follows the MassDEP design procedure.

5.2.7 Standard 7

Standard 7 applies to redevelopment of old BMPs, modifying the requirements of earlier standards. This standard does not apply to the basins that the DCR is constructing. While there is already a basin at the Gate 25 location, the DCR is completely redesigning the basin and constructing a new one.

5.2.8 Standard 8

Standard 8 requires that a plan to control construction-related impacts be developed and implemented during the construction of the new basin. This plan must control the release of contaminants from erosion, sedimentation, land disturbance activities, and other sources of pollutants. The DCR has overseen the construction of a number of BMPs in the past, and already has experience in planning for construction related impacts.

5.2.9 Standards 9 and 10

Standard 9 requires that the new BMP has a long-term operation and maintenance plan. This plan should ensure that the basin performs according to standards for the full design life of the basin. Standard 10, the final standard, requires that all illicit discharges to the BMP be prohibited. This entails monitoring the basin over time to check for extra discharges or signs of dumping into the reservoir. Due to the DCR’s previous experience with developing BMPs, plans for maintaining, operating, and protecting basins have already been developed.

5.3 Gate 25 Existing Conditions

The area being considered for a new stormwater BMP is known as Gate 25, which is in reference to the gate nearby at the entrance to the DCR’s land. The area was already developed by the DCR in 2004, including a forebay and retention basin. The area itself is located about a mile south of Gate 27 on the same road, as seen in Figure 44. The contributing area that feeds both of the retention basins comes from catch basins on nearby streets.

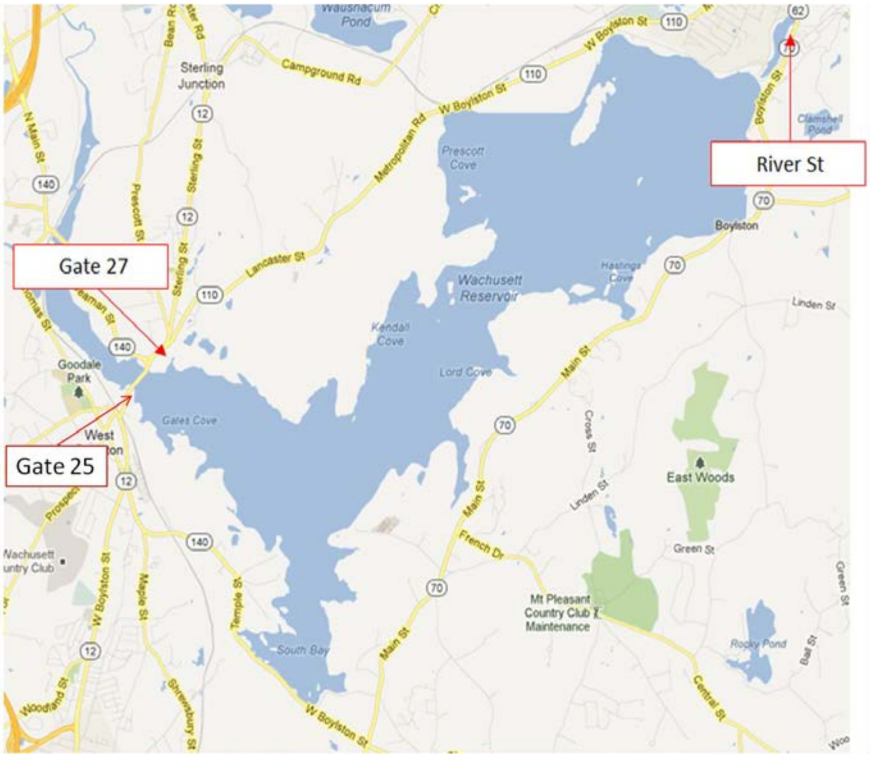


Figure 44: Locations of River Street, Gate 27, and Gate 25

Figure 45 shows the sediment forebay. The formation of rocks at the far side of the basin marks the inflow of the basin. The original design of this basin appears to be similar to the design of the Gate 27 basin, infiltrating the inflow into the ground.


Figure 45: Gate 25 Basin Forebay

There is an overflow channel that leads to the retention basin. The retention basin also has an inflow, and appears to function by infiltrating to the ground similar to Gate 27. There is an overflow weir in the basin that leads to the reservoir itself.

The overall area is large enough to fit a basin of a similar design to Gate 27 or River Street. Even if the volume of runoff is significantly more at this site than at the other two sites, the site would still be able to maintain a basin much larger than either Gate 27 or River Street.

The DCR's plan for developing the site includes hiring a consultant to recommend a design for the location. The most applicable basin design depends on a number of factors including the removal efficiencies for different contaminants, the cost effectiveness of the different designs, and the required area needed to treat the inflow runoff. This report outlines these major considerations and develops an ideal basin using pertinent existing conditions of the Gate 25 site.

5.3.1 Soil Type

Although no soil survey or laboratory procedures were completed to identify the properties of the soil surrounding Gate 25, other data were used to estimate likely soil conditions. MassGIS has created GIS layers with data collected by the United States Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS) (MassGIS, 2012). These layers include information on the soil types throughout Massachusetts. From this information an estimate of what type of soil to expect could be made.

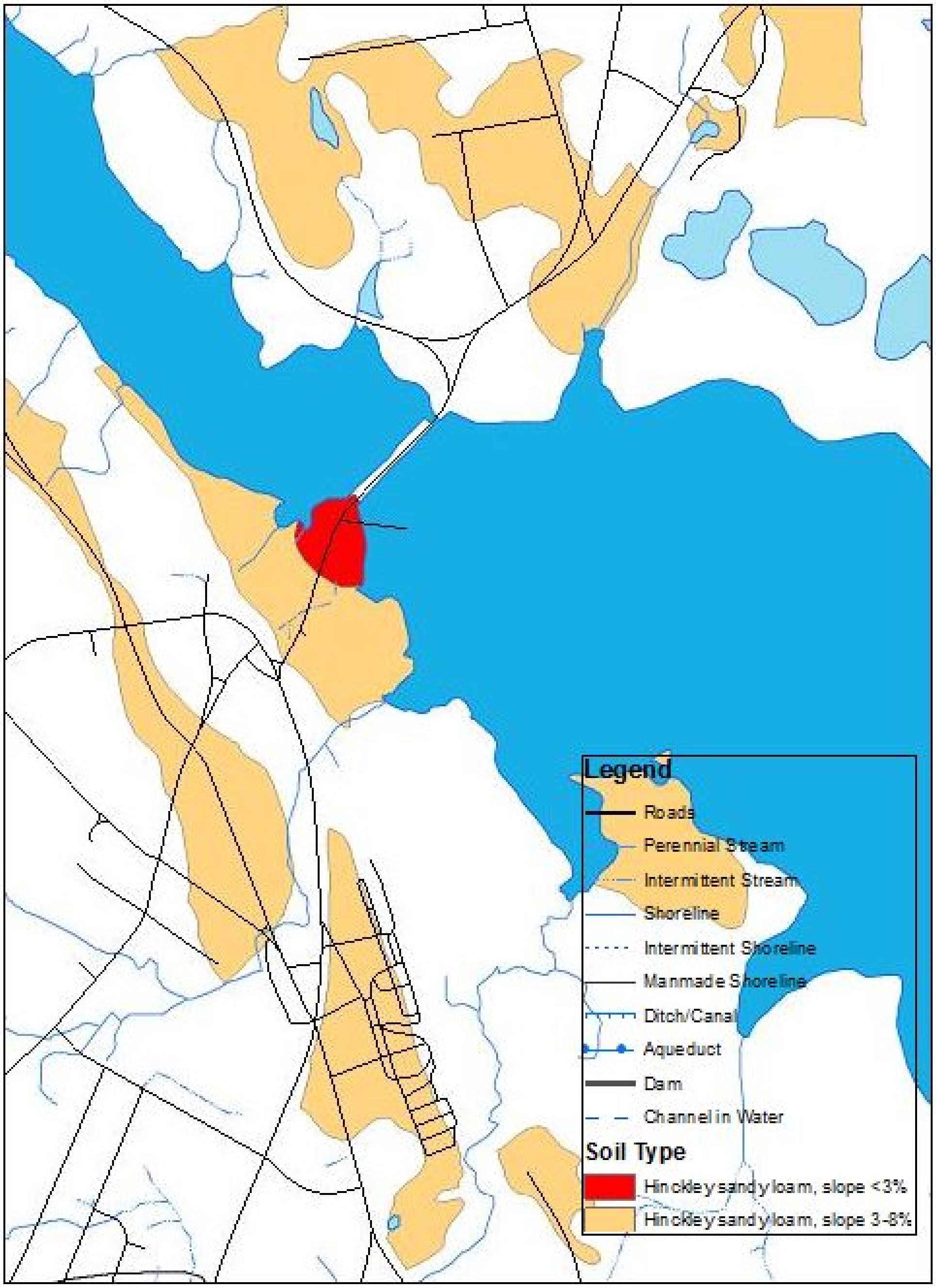


Figure 46: Gate 25 Existing Soil Conditions

Gate 25 is located on top of Type A Hinckley sandy loam with slopes ranging from 0 to 3%. Similar soil is located throughout Massachusetts. The USDA has additional information about these soils, stating that the soil is "very deep, gently sloping, and excessively drained" (US Department of Agriculture, 1985). The USDA also indicates that the substratum has very rapid permeability. Good permeability allows for water to infiltrate rapidly and reduces the probability of large storms overwhelming the treatment basin and water flowing past the overflow weir. The depth to high water table is also generally more than 6 feet. However, the water table depth as this site may be less than 6 feet due to its close proximity to the Wachusett Reservoir. The proposed space for the Gate 25 basin would be ideal for a basin with infiltration.

5.3.2 Land Use

The contributing area to the current Gate 25 basin is surrounded by forest, medium density residential, and commercial areas. The residential and commercial areas increase stromwater runoff. The current basin is on open land and is right next to a powerline. The powerline has minimal effect on runoff going to the basin.

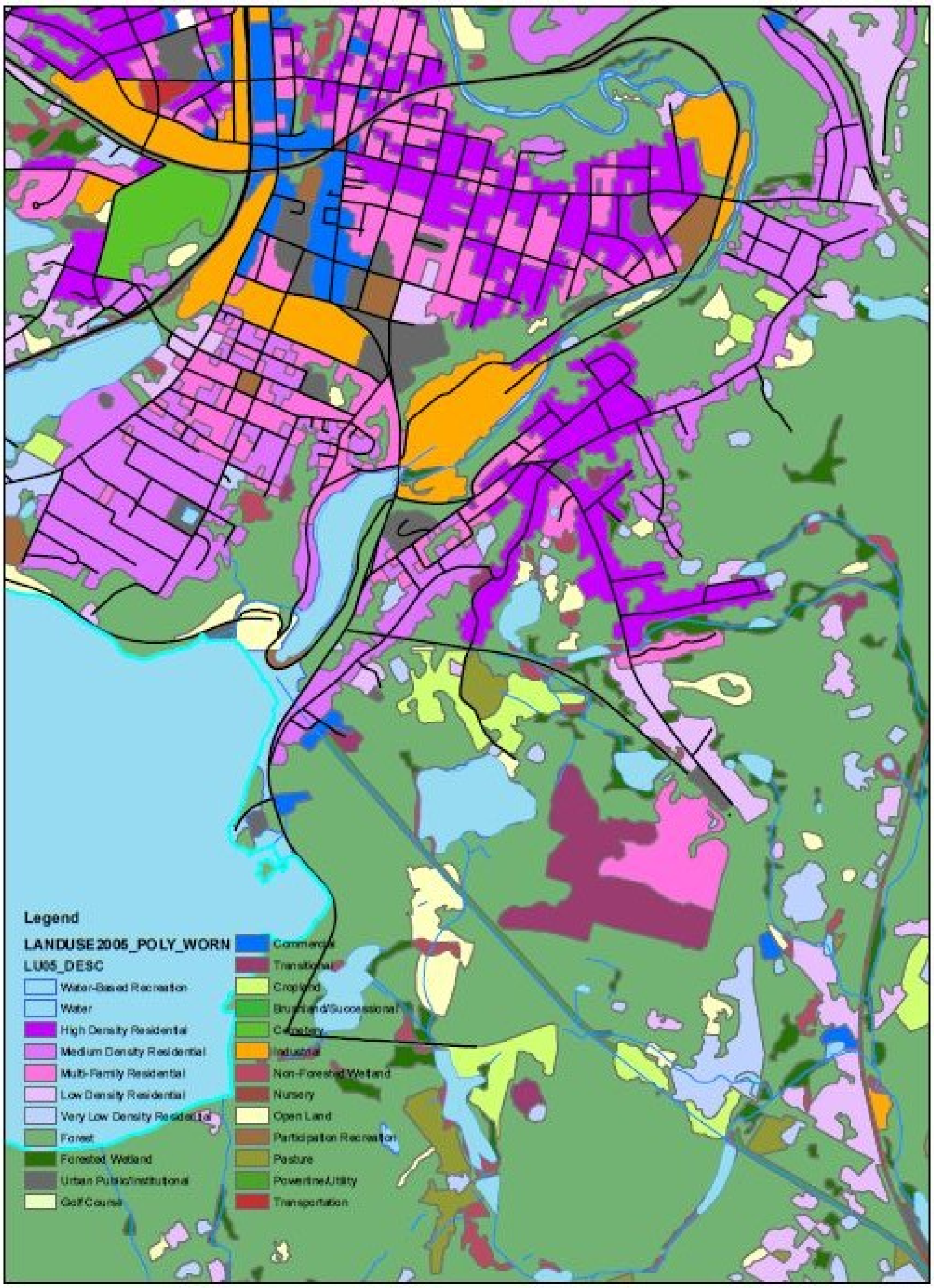


Figure 47: Land Use in the New Basin Contributing Area

5.4 New Ideal Design

This chapter lists each step taken to determine the final basin design for the new stormwater best management practice.

5.4.1 Filter Media Design

The major component and ultimate design consideration for an infiltration basin is the filter media. This soil layer is what removes particulates and contaminants before discharging.

5.4.1.1 Hydraulic Conductivity of Soil

According to the DEP standard on recharge volume, the design hydraulic conductivity should be equal to the Rawls Rate. This rate is based on research completed by W. J. Rawls in estimating soil water properties in 1982. It has been adopted by the MassDEP as a standard for hydraulic conductivity based on the texture and soil type. These as defined by the MassDEP are listed in Table 18.

Table 16: 1982 Rawls Rates from DEP Stormwater Manual

Texture Class	NRCS Hydrologic Soil Group (HSG)	Infiltration Rate (Inches/Hour)
Sand	A	8.27
Loamy Sand	A	2.41
Sandy Loam	B	1.02
Loam	B	0.52
Silt Loam	C	0.27
Sandy Clay Loam	C	0.17
Clay Loam	D	0.09
Silty Clay Loam	D	0.06
Sandy Clay	D	0.05
Silty Clay	D	0.04
Clay	D	0.02

For the purposes of this project, these rates were used as reference. From further research and observation, a new hydraulic conductivity was developed as explained in the following sections.

5.4.1.2 Filter Media

The filter media is to have a thickness of 20 inches and to be comprised of a well-graded soil that meets the following grading specifications is recommended for the basin fill (Facility for Advancing Water Biofiltration, 2009):

Table 17: Filter Media Soil Type Specifications

Sand Type	Percent Fill (%)	Particle Size (mm)
Clay and silt	< 3	< 0.05
Very fine sand	5-30	0.05-0.15
Fine sand	10-30	0.15-0.25
Medium to coarse sand	40-60	0.25-1.0
Coarse sand	7-10	1.0-2.0
Fine gravel	< 3	2.0-3.4

A well-graded soil will ensure that the properties of the soil (hydraulic conductivity, etc.) will not change drastically as the basin ages. The soil should not be well sorted. Soil that includes too many fine soil particles will increase the chance of a structural failure due to particle movement over time. The soil media should also have the following properties:

Table 18: Soil Media Properties

Property	
pH	5.5-7.0
Total nitrogen (TN) content	< 1000 mg/kg
Organic matter content	> 3%
Foreign matter	< 1%

The desired hydraulic conductivity for the basin is 8 in/hr (200 mm/hr). This is equivalent to the infiltration rate. It would need to be tested before implementation of the new BMP. Filter media with a hydraulic conductivity that is too high will not support plant growth which is critical for effective bioretention treatment.

The basin is comprised of 3 layers. The top layer is the filter media. Below the filter media lays a transitional layer and the drainage layer. This can be seen in Figure 48.

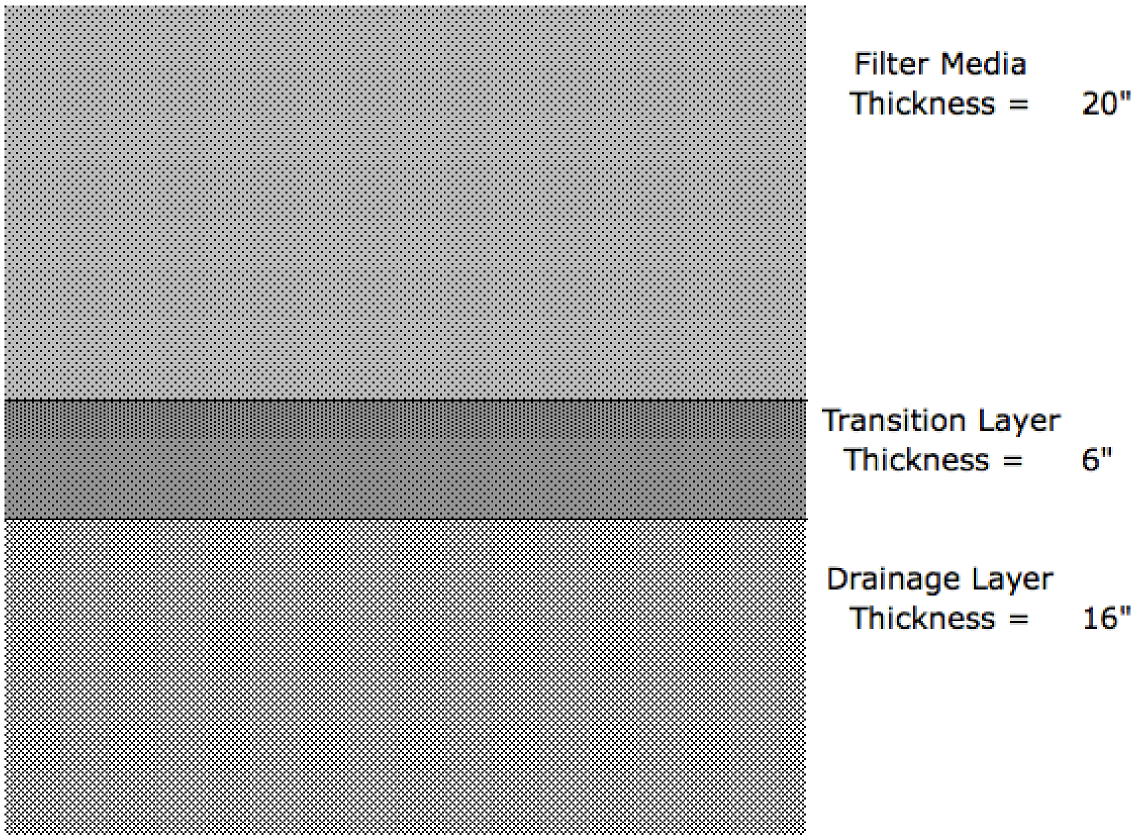


Figure 48: Soil Media Profile

The transition layer is a dual layer. In order to prevent the filter media from washing out, the top layer of the transition layer will be a fine sand layer. This layer should be 2 inches thick. The bottom layer will be 4 inches thick and comprised of a more coarse and well-graded sand with no more than 2% fines. This dual layer design increases the effectiveness of the basin in removing turbidity and TSS (Facility for Advancing Water Biofiltration, 2009).

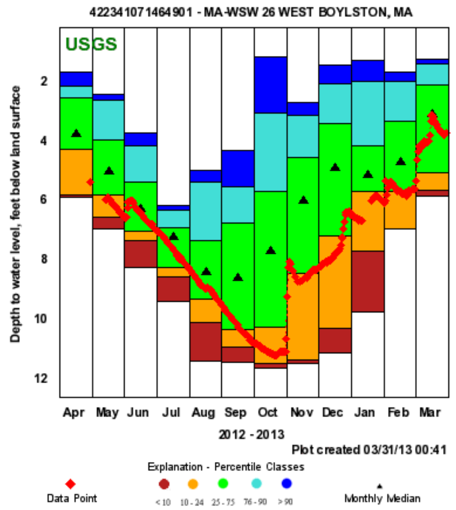
The drainage layer is a coarse layer that is comprised of fine gravel (diameter of 2-5 mm). This layer is 16 inches thick.

In order to ensure proper infiltration and treatment, the new basin should use a soil mixture brought from off-site for the filter media instead of relying on the soil in the current location.

5.4.2 Seasonal High Groundwater

The groundwater table is a critical factor that plays into how to design an infiltration or bioretention basin. For example, if the groundwater table is close to the ground surface, infiltrating to the ground would not be feasible. Since groundwater elevation is often difficult to predict, both an analysis of the site via installed observation wells and seasonal records need to be examined. Groundwater elevation is dependent on the seasons and can vary from year to year. The USGS operates a number of monitoring wells throughout the country that record daily high groundwater elevations. At a USGS monitoring station roughly 2 miles from the Gate 25 location, statistical analyses have been recorded since 1995. Figure 49 shows the groundwater table variation near Gate 25.

Site Statistics



Most recent data value: 3.24 on 3/31/2013
Period of Record Monthly Statistics for 422341071464901
Depth to water level, feet below land surface
All Approved Continuous & Periodic Data Used In Analysis
Note: Bold values in the table indicate closest statistic to the most recent data value.

Month	Lowest Median	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	Highest Median	Number of Years
Jan	9.78	7.72	5.71	5.14	4.16	1.99	1.30	16
Feb	6.95	6.95	5.69	4.74	3.35	1.99	1.69	17
Mar	5.85	5.66	5.08	3.10	2.13	1.41	1.27	17
Apr	5.92	5.81	4.28	3.76	2.57	2.16	1.67	17
May	6.95	6.59	5.84	5.03	3.97	2.65	2.45	17
Jun	8.25	7.37	7.05	6.31	5.39	4.17	3.75	17
Jul	9.41	8.59	8.25	7.24	6.92	6.32	6.19	17
Aug	11.40	10.10	9.34	8.44	7.35	5.40	5.01	17
Sep	11.45	10.95	10.37	8.63	6.75	5.53	4.32	17
Oct	11.64	11.51	10.27	7.73	5.71	3.06	1.19	17
Nov	11.50	11.39	8.46	6.03	4.58	3.16	2.70	18
Dec	11.13	10.33	7.22	4.92	3.44	2.10	1.45	18

As of 3/30/2013 02:30-2

Statistics Options

View month/year statistics

Figure 49: USGS Groundwater Watch for Gate 25 (USGS, 2013)

The station shows that the 50th percentile groundwater depth is 3.10 to 8.63 feet below the surface over the course of the year. A more conservative estimate is the 75th percentile, which shows a depth between 2.13 and 7.35 feet. This would severely limit the depth of any basin to be installed. Seasonal high groundwater tables are a major consideration when implementing a BMP, and must be verified with field testing before receiving permits. It was not considered for the scope of this project.

5.4.3 Drainage Area

The drainage area is often defined using maps of the contours and elevations of the surrounding area along with the stormwater infrastructure present. For the Gate 25 basin, this area was provided by the DCR and can be seen in Figure 50.

Figure 50: Drainage Area for Gate 25

The drainage area is 19.90 acres, and it is comprised of high density ¼-acre residential lots with some smaller commercial and retail land use. A map of the contours is shown in Figure 51, and the current stormwater system is shown in Appendix I: West Boylston Stormwater System.

Figure 51: Gate 25 Contours and Slopes

Another important aspect of the contributing drainage area is the amount of impervious surface throughout it. This includes roads, rooftops, parking lots, and sidewalks. This quantity was later used to calculate the recharge volume and water quality volume. In the Gate 25 drainage area, 12% of the area is impervious. This means that out of the 19.90 acres, 2.39 acres are impervious surface.

5.4.4 Recharge Volume

By altering the pervious nature of the environment and adding impenetrable surfaces, less water is being allowed to infiltrate to groundwater. These changes harm the habitats of aquatic organisms by altering the natural hydrology of streams and wetlands and reduce dry weather flows of stream systems. Massachusetts is one of the only states that requires stormwater recharge to groundwater. This regulation is an attempt to reverse the impact of urban development on the environment by requiring a specific volume of runoff to be recharged to groundwater (Stormwater Manager's Research Center).

MassDEP defines the recharge volume as the target depth factor associated with a hydrologic soil group multiplied by the impervious area as shown in Equation 11.

$$R_v = F * A_{imp}$$

Equation 11: Recharge Volume

Where:

R_v = Recharge volume

F = Target depth factor

A_{imp} = Impervious area

The MassDEP set depth factors are included in Table 19.

Table 19: Depth Factors for Recharge Volume

NRCS Hydrologic Soil Type	Approximate Soil Texture	Target Depth Factor (F)
A	Sand	0.6-inch
B	Loam	0.35-inch
C	Silty loam	0.25-inch
D	Clay	0.1-inch

The drainage area leading to the Gate 25 basin is composed of hydrologic type A soil, but a conservative value between type A and type B was used to calculate the recharge volume. The impervious cover, as stated previously, was 12% of the total drainage area. The calculations below show the required recharge volume.

$$R_v = F * A_{imp} = 0.48in\left(\frac{1\,ft}{12\,in}\right) * 2.39\,acres\left(\frac{43560\,ft^2}{1\,acre}\right) = 4164\,ft^3$$

5.4.5 Basin Sizing

The storage volume can be determined by a number of different approaches. As mentioned, according to MassDEP regulations, the size of the basin needs to be able to contain the required recharge volume. For the new basin at Gate 25 the catchment area was 12% impervious out of the total 19.9 acres, or 2.388 acres. The required water quality volume was calculated and came out to 8,668 ft^3. However, the design volume calculated from the Simple Dynamic Method was 20,967 ft^3. The volume of the basin was kept at 20,967 ft^3 to fulfill all standards. The process for this sizing is seen below.

The method that was used to determine the size of the Gate 25 basin was the Simple Dynamic Method. It is dynamic in the sense that the stormwater infiltrates into the groundwater as the basin is filling. It is simplified because it assumes the recharge volume is discharged to the infiltration basin at a rate of 8.0 in/hr.

In addition to the required recharge volume, there are other equations that the Simple Dynamic Method uses in the process of sizing the basin. These equations are listed below.

$$A = \frac{R_v}{(D + KT)}$$

Equation 12: Minimum Surface Area of Basin Required for Infiltrating Recharge Volume

Where:

A = Minimum required surface area of the basin that allows for the necessary infiltration of the required recharge volume

R_v = Recharge volume

D = Depth of the basin

K = Hydraulic conductivity rate

T = Allowable drawdown time during the peak of the storm

$$V = A * D$$

Equation 13: Volume of Basin

Where:

A = Calculated minimum area

D = Depth of the basin

V = Volume of the basin

The Gate 25 basin has a required recharge volume of 4,164 ft^3, which can be used to calculate a minimum basin size. With a depth of 3 feet, hydraulic conductivity rate of 8.0 in/hr, and allowable drawdown time during peak of storm, the minimum surface area can be determined.

$$A = \frac{R_v}{(D + KT)} = \frac{4164 ft^3}{3ft + 8.0\frac{in}{hr} * 2hr} = 961\ ft^2$$

From this, the minimum required volume of the basin can be determined by multiplying the surface area by the depth of the basin. This is equal to 2,883 ft^3. This computation method accurately provides a way of calculating, based on groundwater recharge, a minimum volume size for the basin. The basin is approximately sized at 70 ft x 100 ft x 3 ft.

5.4.6 Sediment Forebay

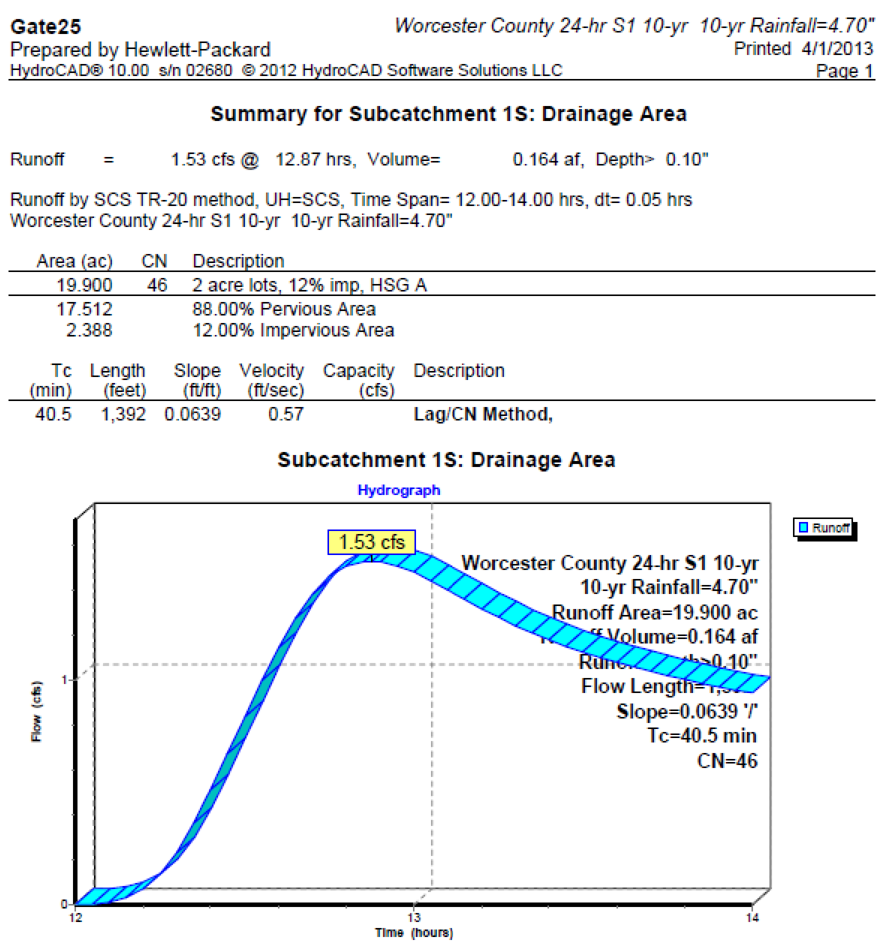
To aid in complying with Standard 4, as seen in Section 5.2.4, a sedimentation forebay was added to the design as a pretreatment method for suspended solids. While this does not provide peak flow attenuation or groundwater recharge, it does effectively remove TSS from stormwater runoff before discharging to the bioretention basin. It also slows velocities of incoming stormwater and provides longevity to the receiving infiltration basin (Massachusetts Department of Environmental Protection, 2008).

According to the Massachusetts Stormwater Handbook, forebays are designed to hold at a minimum 0.1 inch/impervious acre of its contributing water. It must also be able to withstand the higher design storm's velocities. To meet both these requirements and to provide maximum protection for the bioretention basin, a volume of 10% of the designed infiltration basin was used. In the case of Gate 25, the total basin volume was 20,967 ft^3 (as seen in Section 5.4.5). A sedimentation forebay of 2,097 ft^3 has been designed to meet this standard and provide extra protection to the basin. If this size volume has a depth of 1.5 feet, an area of 1,398 ft^2 is required. This will provide a higher removal efficiency of TSS for the designed BMP.

The outflow from the forebay is a broad crested weir. It has been designed in HydroCAD in the same manner as the emergency spillway from the bioretention basin. It was designed to handle the flow from the forebay.

5.4.7 Modeling the Recharge Volume and Emergency Spillway

Computer software can further be utilized to determine the ability for the basin to handle various flow sizes. HydroCAD was used to examine 24-hour Type III storms for the Worcester, MA area. Then the hydrograph report window was set to the peak two hours. Various size storms were examined, and it was iteratively determined that a 10-year storm would produce roughly the equivalent of the required recharge volume, as seen in Figure 52.


Gate25 *Worcester County 24-hr S1 10-yr 10-yr Rainfall=4.70"*
Prepared by Hewlett-Packard Printed 4/1/2013
HydroCAD® 10.00 s/n 02680 © 2012 HydroCAD Software Solutions LLC Page 1

Summary for Subcatchment 1S: Drainage Area

Runoff = 1.53 cfs @ 12.87 hrs, Volume= 0.164 af, Depth> 0.10"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 12.00-14.00 hrs, dt= 0.05 hrs
Worcester County 24-hr S1 10-yr 10-yr Rainfall=4.70"

Area (ac)	CN	Description
19.900	46	2 acre lots, 12% imp, HSG A
17.512		88.00% Pervious Area
2.388		12.00% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
40.5	1,392	0.0639	0.57		**Lag/CN Method,**

Subcatchment 1S: Drainage Area

Figure 52: Gate 25 10-Year Recharge Volume from HydroCAD

To make the basin more robust, a larger design storm was used. A 25-year storm would produce roughly 0.481 acre-feet (20,952 ft^3) of runoff volume during the peak two hours of the storm. This volume, with a depth of 3 feet, would require 6,984 ft^2 of surface area. A hydrograph of the resulting basin with these specifications and a hydraulic conductivity of 8.0 in/hr is shown in Figure 53.

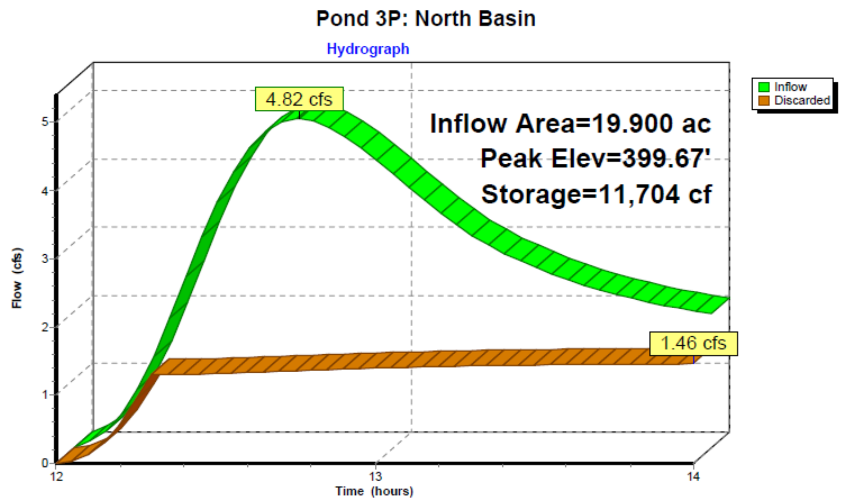


Figure 53: Gate 25 25-Year Recharge Volume from HydroCAD

The 25-year storm would produce a peak flow of 4.82 cfs into the basin and with the 8.0 in/hr hydraulic conductivity, the flow would infiltrate at a constant rate of 1.46 cfs.

To incorporate an emergency spillway into the design, a design storm of 50 years was used. To obtain this volume, an additional 1 foot embankment will be added around the perimeter of the basin. Figure 54 shows the hydrograph for a 50-year storm.

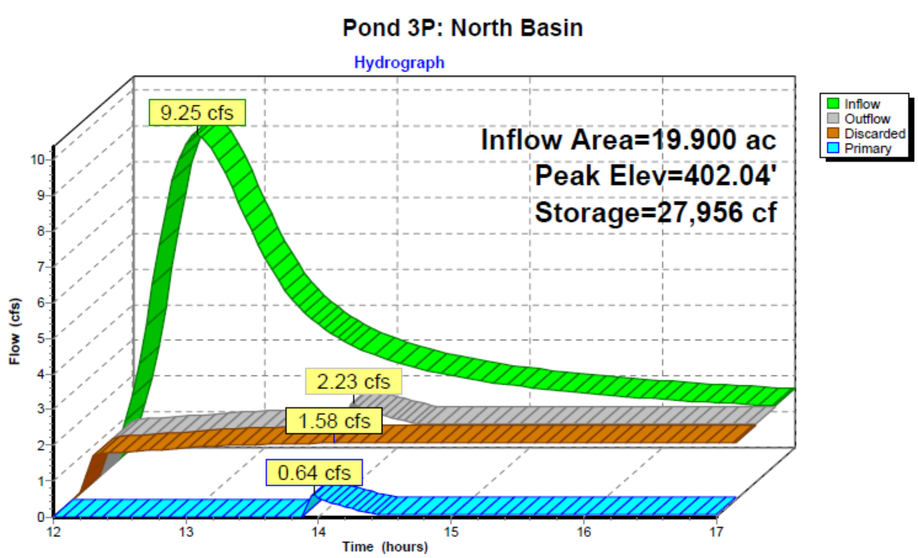


Figure 54: Gate 25 Hydrograph for a 50-Year storm

The added embankment will conform to regulatory guidelines put forth by the Office of Dam Safety (302 CMR 10.00). This additional storage will allow for a 20 feet long by 1 foot wide broad crested spillway to be constructed at one side of the basin. This spillway will be designed to convey water to an area that will not damage wetlands or buildings. Also along this spillway will be large rocks and vegetation to provide some degree of sediment and nutrient removal for the overflow water. The full HydroCAD report for the Gate 25 basin is located in Appendix E: Final Gate 25 HydroCAD Model Report.

5.4.8 Drawdown Time

Another requirement of Mass DEP is that the drawdown time, or the time it takes for water to completely drain out of the basin, must be less than 72 hours. This calculation is based off the design hydraulic conductivity rate and is calculated by Equation 14.

$$T_{draw} = \frac{R_v}{K * A_{bottom}}$$

Equation 14: Drawdown Time

Where:

R_v = Recharge volume

K = Design hydraulic conductivity

A_{bottom} = Surface area of the bottom of the basin

In the case of the Gate 25 basin, the basin volume is 20,967 ft^3, the hydraulic conductivity is 8.0 in/hr, and the bottom area is 6,989 ft^2 (with the increased, more robust size). These specifications yield a drawdown time of less than 5 hours, as follows:

$$T_{draw} = \frac{R_v}{K * A_{bottom}} = \frac{20967\ ft^3}{8.0in\left(\frac{1ft}{12in}\right) * 6989ft^2} = 4.5\ hr$$

Clearly, with the increased basin size the design parameters would allow the basin to drain well under the 72 hour requirement. If the basin's hydraulic conductivity is much lower than anticipated, a 1 in/hr rate has been calculated below.

$$T_{draw} = \frac{R_v}{K * A_{bottom}} = \frac{4164ft^3}{1.0in\left(\frac{1ft}{12in}\right) * 6989ft^2} = 7.15\ hr$$

Even under these conditions, the basin will be completely drained in well under 72 hours.

5.4.9 Vegetation

Vegetation is an important part of a bioretention basin. In addition to helping treat the influent, vegetation also adds stability to the basin. The root systems create a stronger top layer that is more resistant to being washed out. Vegetation increases the hydraulic conductivity of the basin by allowing water to infiltrate along the roots. Plants, such as trees or bushes, with large root systems can increase infiltration but should not be grown in the basin. The large root systems can damage the basin. During high flow, with saturated soils, trees may uproot and damage the filter media. Invasive and noxious weeds will also be removed from the basin.

The vegetation for the ideal basin should include multiple types of grasses. Grasses has small root systems that will not endanger the structural integrity of the basin. The grasses help keep the top soils in place during high flow and absorb nutrients in the basin. A detailed analysis of different grass strains was not conducted. The ideal basin therefore uses the MassDEP recommendation of planting grasses from the festuca genus. These grasses are able to withstand dry and wet conditions and germinate quickly. The grass will be installed using seeds. Although the seeds require more maintenance during installation and the first 2 months, using seeds instead of sod is important. Sod prevents the roots from taking hold into basin and will not help improve hydraulic conductivity.

After the prior installation of the grass seeds, the basin should be inspected to ensure proper growth. If insufficient growth is present, more grass seed should be added.

5.4.10 Outflow Controls

For the purposes of this project, outflow controls such as an underdrain or perforated pipe are not recommended for the proposed Gate 25 basin. As such, all water entering the basin infiltrates to the ground. This approach is appropriate at this location because the soil selected for the basin has a high hydraulic conductivity rate (8 in/hr) and the soil surrounding the basin is also permeable. According to data compiled by the USDA, Hinckley sandy loam, which is the current soil around the basin location, will allow for water to infiltrate rapidly (although the exact hydraulic conductivity for the location is unknown). The ability to rapidly infiltrate reduces the need for an outflow pipe to handle high flows from large storm events. In the event that the basin capacity is too small, the overflow weir will prevent failure of the basin. If an underdrain system is included, it will allow for more control of the flow paths and transport of contaminants, but will likely require maintenance since the capacity of the media will be limited.

The sediment forebay will be lined with a semi-permeable membrane to avoid infiltration before treatment. The liner ensures that the stormwater inflow travels completely through the sediment forebay, and therefore suspended solids are removed.

5.4.11 New Basin Design Summary

Table 20 lists all of the design parameters and respective values of the new basin.

Table 20: Gate 25 Design Parameter Summary

Parameter	
Contributing Impervious Area (acres)	2.39
Recharge Volume (ft^3)	4164
Basin Design Volume (ft^3)	20967
A_{bottom} (ft^2)	6989
Depth (ft)	3
Overflow Embankment (ft)	1
Additional Embankment Volume (ft^3)	27956
Hydraulic Conductivity (in/hr)	8.0
$T_{drawdown}$ (hr)	0.89
Forebay Area (ft^2)	1398
Forebay Volume (ft^3)	2097
Forebay Depth (ft)	1.5
Invert Elevation (ft)	402.5
Forebay Bottom Elevation (ft)	400.5
Basin Bottom Elevation (ft)	395
Weir Elevation (ft)	402
Emergency Spillway (ft)	399
Media Depth (ft)	3.5

The basin will be located in the Gate 25 area per the following site plan, and a profile of the basin design is also provided.

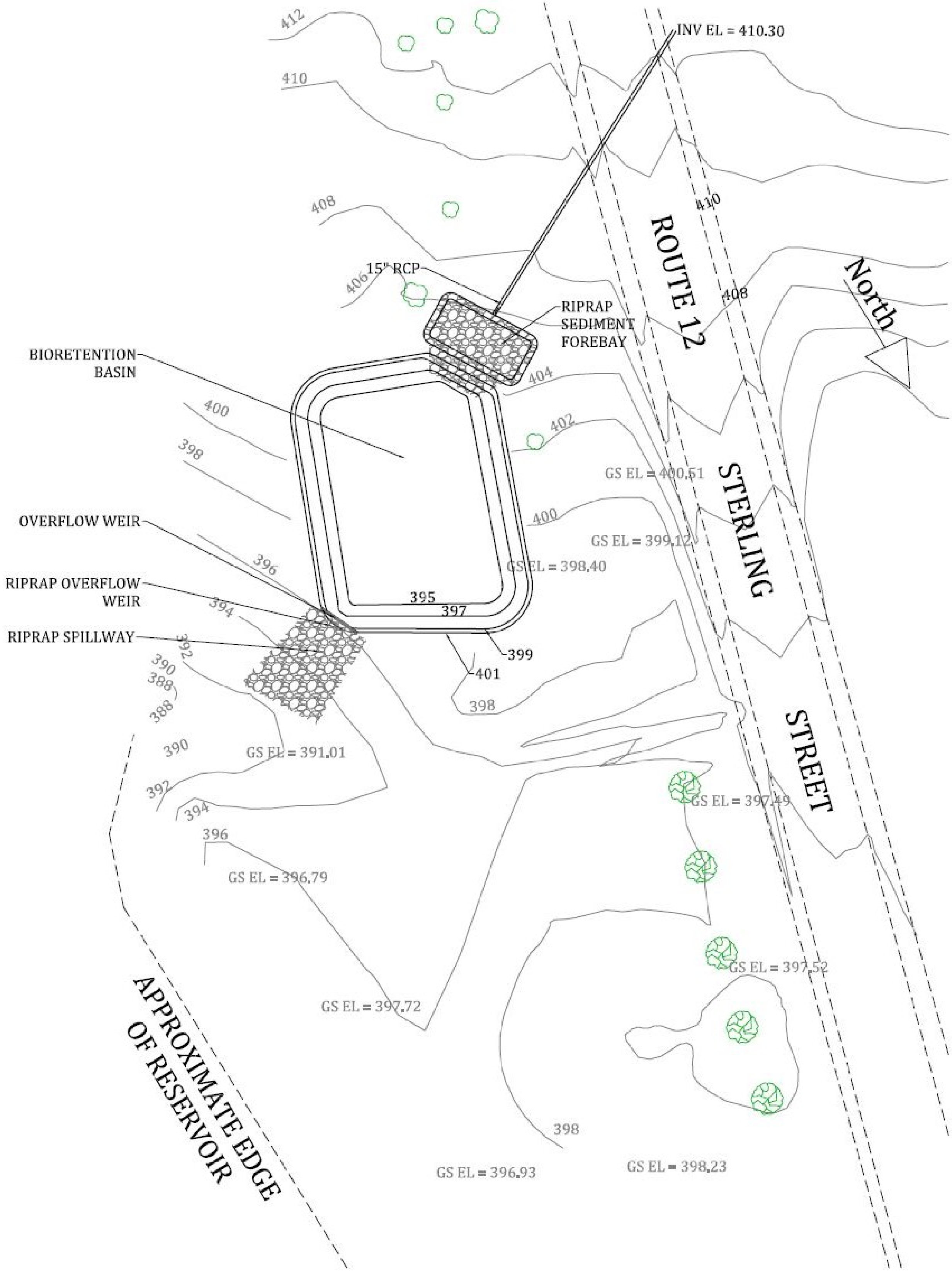


Figure 55: New Basin Site Plan

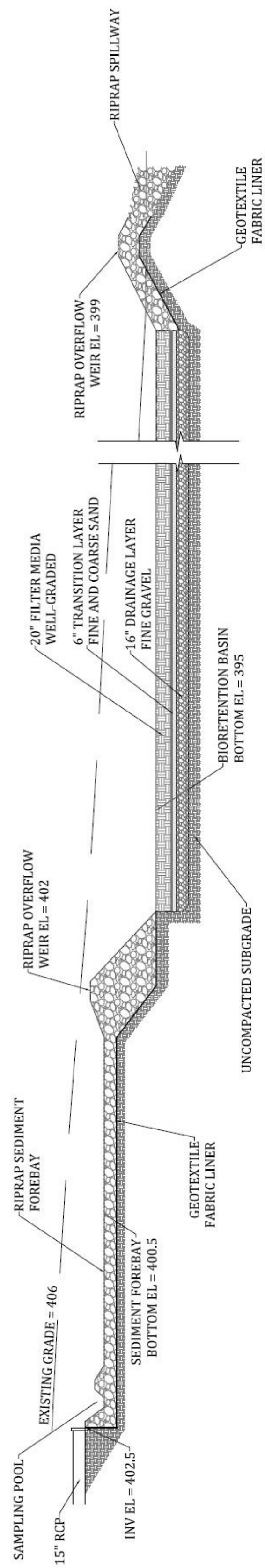


Figure 56: New Basin Elevation Plan

5.5 Expected Performance

The efficiency of the newly designed basin is expected to be similar to the efficiency of the Gate 27 basin. This is because of the similar contaminant removal method that both basin designs share. This means that the expected removal efficiency for total suspended solids is at least 90% and likely close to the 99% TSS removal efficiency that was calculated for the Gate 27 basin. The expected removal efficiency of the basin is expected to be well over the 80% removal required by the MassDEP standards.

The unlined basin means that the nutrient removal efficiency is likely going to be greater than the efficiencies observed at the River Street basin. When the vegetation of the basin is fully grown, the nutrient removal efficiencies will likely be similar to the Gate 27 basin.

It should also be noted that the new design does not include an outflow drain, which means that all of the runoff entering the basin will infiltrate to the ground unless the runoff volume reaches the overflow weir. The removal efficiency for this case will likely be better than if a limited infiltration layer and underdrain is used since all outflow will infiltrate to the ground before subsequent discharge to surface water.

5.6 Cost Estimate

The EPA provides estimates for the designing, permitting, and construction costs of both bioretention and infiltration basins. Equation 15 shows the costs associated with a bioretention basin (US Environmental Protection Agency, 2012).

$$C = 7.3\, V^{0.99}$$

Equation 15: Cost Estimate

Where:

C = Cost ($)

V = Volume of water (ft^3) treated by the basin

With a volume of roughly 21,000 ft^3, the cost would be roughly $139,000. The EPA estimates infiltration basins at about $2 per cubic foot of storage (US Environmental Protection Agency, 2012). With this in mind, the cost for an infiltration basin of 21,000 ft^3 would be $42,000. The design of the basin from this report, is more closely related to that of a bioretention basin, so that rough cost estimate would be more representative.

Due to the nature of this project, the majority of costs will be associated with earth removal and the addition of the chosen filter media. An analysis of current construction cost data and combined with an estimate on the amount of earthwork required can help to determine a more accurate estimate on the cost of constructing this basin.

RSMeans Construction Cost Data (2011) supplies unit costs associated with the different aspects of construction. The following table displays what is required to construct a basin, keeping in mind the amount of new earth required, seeding and plants post construction, and construction erosion control. These unit costs are multiplied by conservative estimates for quantities associated with the construction of a basin.

Table 21: Cost Estimate Summary (RSMeans, 2011)

Description	Units	Quantity	Estimate ($)	Budget Cost ($)
Brush clearing	Acre	1	$213.00	$213.00
Excavation Cut	CY	2500	$6.75	$16,875.00
Excavation Fill	CY	35	$3.70	$129.50
Borrow - loam	CY	450	$43.00	$19,350.00
Borrow - sand	CY	100	$51.50	$5,150.00
Borrow - fine sand	CY	55	$55.00	$3,025.00
Borrow gravel	CY	325	$42.00	$13,650.00
Berm Mix	Ton	400	$71.50	$28,600.00
Fine Grading	SY	2000	$3.90	$7,800.00
Compacting	CY	750	$2.11	$1,582.50
Hydro Seed - Grass	SY	2300	$0.45	$1,035.00
Riprap - Forebay and Overflow	CY	300	$36.50	$10,950.00
Geotexile Membrane	SY	500	$10.00	$5,000.00
Silt Fence for Erosion Control	LF	400	$1.34	$536.00
Hay Bales for Erosion Control	LF	400	$7.80	$3,120.00
15" Inflow Pipe Flared End	EA	1	$195.00	$195.00
			TOTAL =	**$117,211.00**

The detailed cost estimate for constructing a bioretention basin, as it relates to the Gate 25 site, is roughly $120,000. This estimate closely aligns with the rough estimate proposed by the EPA ($140,000). The cost also aligns with the DCR estimates for treatment basins of similar size and characteristics. Differences in cost may be the lack of an outflow device and different materials used. Overall, this cost is subject to change in material and labor costs and unexpected problems with the site.

6 Conclusions

Two DCR stormwater BMPs were evaluated for effectiveness of pollutant removal efficiencies and design. After comparison, specific design parameters were determined to be ideal for a new BMP development and a design approach was created. This project provided the DCR with empirical data of the typical stormwater quality and hydraulic performance of existing BMPs. The proposed design for the new basin also provided a design basis that could be utilized for development of other basins. By implementing the new design, the Wachusett Reservoir will be better protected from contamination, which will provide clean water for the Metropolitan Boston area.

6.1 Results

The data gathered from the analysis of Gate 27 and River Street for water quality constituents and flow rates were used to find the effectiveness of the basins for the removal of runoff contaminants. The effectiveness was calculated as the removal efficiency of each basin using contaminant loading rates for the inflow and outflow over time.

MassDEP standards specifically target the Total Suspended Solids removal of the basins as a major aspect of the design. The removal efficiencies of the two basins were both over 90%. This value is well over the 80% TSS removal required by the MassDEP.

In terms of removing water quality contaminants, the River Street basin was less effective than the Gate 27 basin at removing nitrogen, phosphorus and sulfur. Gate 27 removed over 94% of every pollutant tested, which was significantly better than River Street in some cases. However, this result is based on analyses that assume full removal of constituents during infiltration to the ground. During the stormwater event on 12/10/2012, the data from the River Street basin showed that it actually served as a source of phosphorus and ammonia within the basin, when those constituents should be removed before the basin discharges into the reservoir.

The major differences between the basins included flow volume, detention time, and basin liner. The Gate 27 basin had lower flow volumes, a longer detention time, and the bottom of the basin was unlined, which allowed for infiltration. The River Street basin had a higher flow volume, shorter detention time, and a lined bottom that prevented infiltration. The lining of the basins had the largest impact on the basin efficiencies, as infiltration to groundwater effectively removes contaminants.

6.2 New Design Approach

The removal efficiencies of the two basins were compared and the results were considered when designing a new basin at another location adjacent to the Wachusett Reservoir. Due to the higher removal efficiencies of the Gate 27 basin (as seen in Table 14 and Section 4.5), the new basin was designed as an infiltration basin that includes vegetation and other biofiltration devices. The feasibility of groundwater infiltration was confirmed by estimating the groundwater table at the location of the new basin.

Sizing the basin conformed to MassDEP standards, which rely on the volume of water that flows into the basin during a storm. This volume was calculated using the impervious area that contributes to stormwater runoff and a sample storm of a specific size.

The materials used to line the basin were designed to provide a specific infiltration rate to groundwater. The basin material was designed as three separate layers of filtering media to provide structural stability and effective infiltration. The surface layer was fine sand, which prevents contaminants from washing out of the filter media and back into the basin. The deepest layer was comprised of gravel to increase the infiltration rate. The middle layer is a mixture of the two. The full summary of the new basin characteristics is located in Table 20.

7 Recommendations

A number of recommendations were developed over the course of the project. These recommendations were generated to give future researchers an understanding of what attributes of the project could be expounded upon or other areas to research that would expand the analyses of stormwater best management practices.

In order to create fully accurate models of the stormwater basins around the reservoir, the sampling of the basins should be continued in the future. A big factor in this recommendation is that the River Street basin has been in operation for less than two years. The recommended amount of time to allow a basin to become fully operational, according to the Facility for Advancing Water Biofiltration, is two years. The sampling completed as a part of this project may not reflect the final contaminant removal efficiencies of the basin design. Sampling the basins periodically would provide an idea of how the basin performs over time.

As a part of future testing at the basins, testing the groundwater for water quality around the basin would provide information on the efficiency of the infiltration. The DCR has created models for the basin with the assumption that infiltration to the ground effectively removes all contaminants. By testing the groundwater at a number of distances from the basin, it would be determined how contaminant levels change as the distance to the basin increases. It should be noted that groundwater testing would be less reliable than testing inflows and outflows, as the source of the groundwater samples could vary.

In addition to groundwater testing, measuring the water level within the basins over the course of the sampling period would give insight into what is happening in the basin. This would be especially useful during the modeling process for basins that infiltrate to groundwater, as the volume of water in the inflow and outflow can be calculated but the volume of water that infiltrates to groundwater cannot be directly measured. Measuring the water level in the basin over the course of a storm and using measured flow values would allow for the flow rate of water in the basin to be calculated. Combining the flow values for infiltration into the groundwater with the water quality results from groundwater testing would provide a full picture on the effectiveness of infiltrating to groundwater. This would allow assumptions about groundwater infiltration to be adjusted, as the current assumption is that infiltration effectively removes all contaminants.

Continuing sampling and analysis of the Gate 27 and River Street basins would provide a more detailed picture of how the basin designs perform, but only for those two designs. Starting a sampling program for other basins around the reservoir would allow analyses of other basin designs in use around the reservoir. Comparing all of the basin designs in use around the reservoir would help determine the most effective basin design, which could then be implemented for future basins. Sampling other basins around the reservoir would show whether contaminant levels in runoff are similar around the basin, or if certain areas experience higher contaminant loads the others.

As part of future sampling and analysis, researchers may want to monitor the effects of seasonal weather on the basin efficiency. By sampling basins in the summer and winter, the effectiveness of the basin in different temperatures can be compared. Basins that infiltrate to may not work as effectively in fall or winter if the ground freezes and reduces the groundwater infiltration rate. This may make different basin designs more favorable for lower temperatures.

If projects with similar objectives to this one are organized in the future, the methods of this project can be modified to provide more detailed data.

Future groups should try to set up depth probes or similar devices in the inflows and outflows at all of the basins being tested. These devices provide continuous output on the flow rate entering or exiting the basin. The bucket and weir methods of measuring flow rates only provide flow data at specific times when the basins are sampled, which makes modeling and analyzing the effectiveness of the basin more difficult.

One aspect of water quality that this project did not extensively explore was bacteria. Bacterial samples were taken for one storm, but do not provide detailed information on bacterial numbers entering the basin. Bacterial sampling should be done for future basin sampling to find the removal efficiencies of the basins for bacteria, and also to give the DCR information on the quantity of bacteria entering the reservoir through basin outflows.

It would be beneficial for the understanding of stormwater management to continue researching existing treatment basin performance abilities. It is important to characterize the basins to determine the most efficient means of treating stormwater runoff and improving water quality in the Wachusett Reservoir.

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9 Appendices

9.1 Appendix A: Laboratory Analyses Results

The following tables list the results for multiple constituents in stormwater runoff determined by the laboratory procedures. For the full laboratory procedures, see Appendix B.

Table 22: DO, pH, Alkalinity, Ammonia, TSS, Turbidity Laboratory Results - River Street 11/8/2012 Storm

Location	Time	DO (mg/L)	pH	Alk (mmol/L)	Alk (mg/L as CaCO3)	NH3 (mg/L)	TSS (mg/L)	Turbidity (NTU)
Inflow	10:00		6.56	0.3123	16	1.4121996	143.3	212
	12:10	8.86	6.51	0.2573	13	1.168207	20.4	20.2
	17:45		6.83	0.8129	41		11.6	
Outflow	10:00		6.84	1.4920	75	2.8133087	0.5	1.4
	12:10		6.69	0.8223	41.1524	0.8539741	7.7	8.29
	17:30	8.6	6.37	0.4004	20	2.2476895	7.1	9.53
	8:00 (11/9/12)	9.05					1.5	

Table 23: Bacteria, Total Phosphorus, Anions Laboratory Results - River Street 11/8/2012 Storm

Location	Time	E. coli (MPN/100mL)	Total Phos (ppm)	Cl (ppb)	SO4-2 (ppb)	Br (ppb)	NO3 (ppb)	PO4-3 (ppb)	Pb (ppb)
Inflow	10:00	12033	0.73	4131860	21917.83	657.879	1161.97		4.262
	10:40	2143		1840111	11260.01	281.518	1114.333	589.8105	
	11:10	24196		1576255	9662.991	130.3709	1247.371	256.7131	
	11:40	> 24196		1334293	8513.533	174.3612	1531	637.0205	
	12:10	24196	0.17	1035931	7050.415	90.0347	1457.182	718.7295	2.777
Outflow	10:00		0.04	5578286	32134.31	986.5445	4319.465		3.549
	10:40	14136		6266345	35401.62	2139.251	4336.129		
	11:10	15531		6022645	34154.05	2036.583	3859.1		
	11:40	6897		3999280	22948.07	901.3525	2551.135		
	12:10	4611	0.05	2852932	14777.25	481.0875	1630.234		1.890
	17:30		0.162						1.847
Forebay	17:40								3.361

Table 24: Cations Laboratory Results - River Street 11/8/2012 Storm

Location	Time	Mn (ppm)	Fe (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)	As (ppb)	K (ppm)
Inflow	10:00	0.164	0.275	13.640	26.500	2716.000	1.916	8.862
	12:10	0.096	0.123	2.795	17.000	672.000	1.145	5.920
Outflow	10:00	0.437	0.072	37.290	241.000	3024.000	1.832	33.390
	12:10	0.738	0.094	53.900	317.000	1515.000	-0.356	31.180
	17:30	2.367	1.128	57.110	325.000	1381.000	-1.538	33.850
Forebay	17:40	0.140	0.210	3.156	16.900	592.600	4.488	6.258

Table 25: DO, pH, Alkalinity, Ammonia, TSS, Turbidity Laboratory Results - River Street 12/9 - 12/10/2012 Storm

Location	Time	DO (mg/L)	pH	Alk (mmol/L)	Alk (mg/L as CaCO3)	NH3 (mg/L)	TSS (mg/L)	Turbidity (NTU)
Inflow	8:45	8.89	6.89	0.30547	15	1.116451	7.05	18.9
	9:30	12.07	7.38	0.48648	24	0.5175601	1.4	3.5
	10:00	11.33	7.43	0.49641	25	0.5471349	0.95	3.5
	22:45	11.28	6.81	0.26313	13	1.3678373	60.91	26.9
	23:45	11.96	7.06	0.21964	11	0.7319778	19.37	21.5
Outflow	8:45	10.51	6.97	1.79244	90	4.0147874	9.8	24.1
	9:45	11.54	6.95	0.58182	29	1.064695	-0.45	10.9
	10:15	11.28	6.96	0.57151	29	1.1977819	1.79	9.97

Table 26: Total Phosphorus, Anions Laboratory Results - River Street 12/9 - 12/10/2012 Storm

Location	Time	Total Phos (ppm)	F (ppb)	Cl (ppb)	NO2 (ppb)	SO4-2 (ppb)	Br (ppb)	NO3 (ppb)	PO4-3 (ppb)
Inflow	8:45	0.08	29.2145	20122.28		3795.009	57.4811	2480.728	236.0331
	9:30	0.07	43.9643	9830.758	327.0112	8353.809		1198.423	397.5679
	10:00	0.64	45.2025	9134.124	298.0452	9132.718		1398.156	195.3982
	22:45	0.2	28.2936	23763.53		3866.521	64.371	1453.186	224.6551
	23:45	0.22	21.8933	14714.94		2586.977		1286.733	218.2916
Outflow	8:45	0.4	84.4694	41164.17		18655.36	74.5913	746.1986	531.7956
	9:45	0.47	156.797	17343.69		3523.04		1203.172	820.5787
	10:15	0.45	134.0774	17042.42		3532.382		1166.753	821.1722

Table 27: Cations Laboratory Results - River Street 12/9 - 12/10/2012 Storm

Location	Time	Mn (ppm)	Fe (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)	K (ppm)
Inflow	8:45	0.034	0.085	0.644	3.67	130.1	2.008
	9:30	0.031	0.046	1.403	12.5	70.77	3.021
	10:00	0.026	0.043	1.414	12.6	62.95	3.007
	22:45	0.029	0.085	0.693	3.25	153.4	2.261
	23:45	0.031	0.074	0.503	2.59	105.9	1.544
Outflow	8:45	0.098	1.8	5.613	35.9	274.9	11.39
	9:45	0.031	0.478	1.394	8.56	116.6	4.517
	10:15	0.024	0.49	1.362	8.35	112.6	4.515

Table 28: Additional Laboratory Results - River Street

Location	Date	Time	F (ppb)	Cl (ppb)	NO2 (ppb)	SO4-2 (ppb)
Forebay	9/28/2012	23:30	15.7832	2125.1288	90.5981	2968.0114
Inflow	9/28/2012	23:30	15.4924	2329.3424	99.8298	2968.1292
Outflow	9/28/2012	23:30	91.7592	2132.1862	5.0458	4222.4945

Table 29: Additional Laboratory Results - River Street

Location	Date	Time	NO3 (ppb)	PO4-3 (ppb)	Pb (ppb)	Mn (ppm)	Fe (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)
Forebay	11/28/2012	12:00			1.044	0.041	0.015	1.108	12.300	113.500
	9/28/2012	23:30	2369.69	115.7032						
Inflow	9/28/2012	23:30	2251.423	114.3966						
Outflow	9/28/2012	23:30	1369.617	118.3194						

Table 30: Additional Laboratory Results - River Street

Location	Date	Time	DO (mg/L)	NH3	TSS (mg/L)	As (ppb)	K (ppm)
Forebay	11/28/2012	12:00				1.364	3.948
Inflow	11/28/2012	12:00	9.1	2.25	1.2		

Table 31: DO, pH, Alkalinity, Ammonia, TSS, Turbidity Laboratory Results - Gate 27 11/8/2012 Storm

Location	Time	DO (mg/L)	pH	Alk (mmol/L)	Alk (mg/L as CaCO3)	NH3 (mg/L)	TSS (mg/L)	Turbidity (NTU)
Inflow	10:00	8.89	6.75	0.3677	18	1.146025878	130	195
	12:00		6.15	0.0845	4	0.561922366	12.4	61.7
Outflow	17:00	9.1	8.93	0.4429	22	0.399260628	1.5	2.08

Table 32: Bacteria, Total Phosphorus, Anions Laboratory Results - Gate 27 11/8/2012 Storm

Location	Time	E.coli (MPN/100mL)	Total Phos (ppm)	Cl (ppb)	SO4-2 (ppb)	Br (ppb)	NO3 (ppb)
Inflow	10:00		0.9	2206474.046	9994.6705	252.768	775.461
	10:15			2571792.353	11380.5825	351.529	807.1215
	10:30	20		3156320.839	12717.925	187.9545	895.02
	11:00	63		1667696.508	6796.5575	191.6337	731.223
	11:30	86		1247750.781	5448.8325	70.4838	1138.9615
	12:00	74	0.37	1055174.13	4345.6405	109.8892	725.666
Outflow	17:00		0.081				

Table 33: Cations Laboratory Results - Gate 27 11/8/2012 Storm

Location	Time	Pb (ppb)	Mn (ppm)	Fe (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)	As (ppb)	K (ppm)
Inflow	10:00	2.909	0.120	0.138	2.012	18.000	1419.000	-0.043	4.688
	12:00	2.360	0.091	0.128	1.439	9.660	657.300	0.556	4.023
Outflow	17:00	3.129	0.065	0.371	1.002	8.190	410.300	1.456	2.852
	17:00	1.702	0.107	-0.002	4.729	37.300	667.100	-2.607	7.362
	17:00	1.962	0.118	-0.005	4.620	34.800	645.300	-1.232	16.370
Pond	17:10	1.231	0.061	-0.009	1.116	6.660	162.300	-1.129	4.121

Table 34: DO, pH, Alkalinity, Ammonia, TSS, Turbidity Laboratory Results - Gate 27 12/9 - 12/10/2012 Storm

Location	Time	DO (mg/L)	pH	Alk (mmol/L)	Alk (mg/L as CaCO3)	NH3 (mg/L)	TSS (mg/L)	Turbidity (NTU)
Inflow	23:15	11.42	6.47	0.08736518	4	1.293900185	16.7	26.4
	0:10	11.79	6.4	0.06904375	3	0.850277264	85.72	57
	8:25	11.81	6.8	0.17416398	9	1.049907579	8.59	27.9
Inflow forebay	10:35	11.72					8.4	21.7
Forebay	8:30					0.687615527		
Outflow	8:20	11.86	6.61	0.10558991	5	0.22181146	1.8	7.42
	9:15	11.86	6.48	0.09664653	5	0.628465804	2.3	6.02
	10:35	11.21	6.55	0.09847966	5	1.744916821	-42.98	4.34
Outflow discharge	8:30					0.739371534		

Table 35: Total Phosphorus, Anions Laboratory Results - Gate 27 12/9 – 12/10/2012 Storm

Location	Time	Total Phos (ppm)	F (ppb)	Cl (ppb)	NO2 (ppb)	Fe (ppm)	Mg (ppm)
Inflow	23:15	0.36	13.4417	6760.2543	203.106	0.063	0.072
	0:10	0.12	10.0852	2474.9355		0.08	0.065
	8:25	0.41	14.4845	2514.8402	118.6015	0.128	0.202
Inflow forebay	10:35	0.06					
Forebay	8:30		17.9456	6900.8785			
Outflow	8:20	0.08	-2.489	1907.299		0.05	0.047
	9:15	0.06	-1.9434	1992.5453		0.042	0.044
	10:35	0.31	-1.1819	2055.6412		0.044	0.042
Outflow discharge	8:30		19.0944	2184.0698			

Table 36: Cations Laboratory Results - Gate 27 12/9 - 12/10/2012 Storm

Location	Time	Ca (ppm)	Na (ppm)	K (ppm)
Inflow	23:15	0.636	51.02	0.263
	0:10	0.432	15.31	0.251
	8:25	2.16	20.33	0.476
Outflow	8:20	0.214	15.29	0.487
	9:15	0.196	16.77	0.497
	10:35	0.175	16.05	0.487

Table 37: Additional Laboratory Results - Gate 27

Location	Date	Time	NH3	TSS (mg/L)	F (ppb)	Cl (ppb)	SO4-2 (ppb)	NO3 (ppb)	PO4-3 (ppb)
Forebay	9/18/2012	23:00			9.0811	3737.1502	1436.3282	983.9443	214.8658
Inflow	9/18/2012	23:00				3005.3641	877.4893	406.3133	149.1773
Pond	9/18/2012	23:00			11.8964	8613.869	2582.3992	2447.1891	375.167
Forebay	11/28/2012	11:30		24.2					
Pond	11/28/2012	11:30		19.2					
Forebay	12/10/2012	8:30	0.687616		17.9456	6900.8785	3226.458	1445.8842	167.3472

Table 38: TOC Results*

Basin	Location	Time	Date	TOC (mg/L)
Gate 27	Inflow	12:10 AM	12/10/2012	4.084
Gate 27	Inflow	8:25 AM	12/10/2012	2.541
River Street	Inflow	10:45 PM	12/9/2012	7.044
River Street	Outflow	10:15 AM	12/10/2012	11.29
River Street	Inflow	10:00 AM	12/10/2012	2.273
River Street	Inflow	9:30 AM	12/10/2012	2.332
Gate 27	Inflow	11:15 PM	12/9/2012	2.836
10 mg/L Standard				10.31
River Street	Outflow	9:45 AM	12/10/2012	12.19
Gate 27	Outflow	10:35 AM	12/10/2012	2.834
Gate 27	Outflow	9:15 AM	12/10/2012	2.569
River Street	Inflow	11:45 PM	12/9/2012	4.277
River Street	Inflow	8:45 AM	12/8/2012	4.454
River Street	Outflow	8:45 AM	12/8/2012	51.57
Gate 27	Outflow	8:20 AM	12/10/2012	2.706
0 mg/L Standard				0.089

* The TOC results may not be accurate due to machine malfunctioning and delayed analysis.

9.2 Appendix B: Laboratory Procedures

The following subsections outline the general procedures for the laboratory analyses conducted for this Major Qualifying Project.

9.2.1 Total Phosphorus

The analysis for total phosphorous can be completed at any time after the sample is taken. The procedure follows the steps below.

1. Digest 25 mL from the 60 mL sample bottle and a blank under the fume hood
    a. Add 5 mL of nitric acid
    b. Add 1 mL sulfuric acid
    c. Bring sample down to fumes of sulfuric acid
2. Turn on HACH DR/3000 Spectrophotometer and let run for several hours to warm up
3. Prepare blank Spectrometer sample
    a. Add one drop of phenolphthalein to a square Spectrophotometer vial
    b. Titrate with 5 N NaOH to phenolphthalein red
    c. Fill to 25 mL mark with DI water
    d. Add 1 mL of Molybdovanadate to solution and swirl
    e. Fill to line with DI water
4. Transfer digested sample to a Spectrophotometer vial
    a. Add one drop of phenolphthalein to sample
    b. Titrate with 5 N NaOH to phenolphthalein red
    c. Add 1 mL of Molybdovanadate to sample and swirl
    d. Fill to line with DI water
5. Prepare Spectrometer
    a. Press On
    b. Press Timer
    c. Input 3 minutes
    d. Press Timer to begin
6. Once the Spectrometer is ready, insert the blank vial with the line facing outwards and read the result
    a. Press Abs
    b. Zero
7. Insert prepared samples and read the result

9.2.2 Dissolved Oxygen

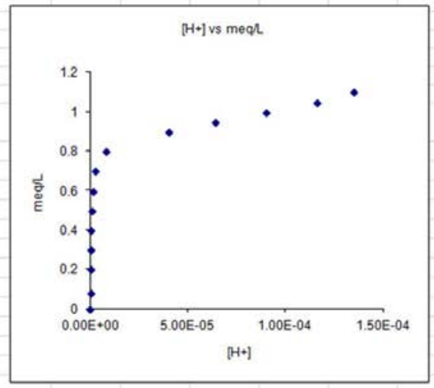
1. Clean the DO probe with brown circular material; empty cover and refill with Electrolyte solution
2. Calibrate DO probe (Orian 3star Thermo) in water saturated air:

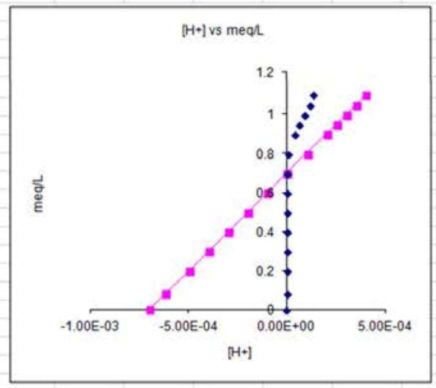
   a. Fill beaker with partway with water and insert probe (it should not be fully submerged)
   b. Place on stir plate
   c. Turn on spec and press calibrate
   d. Let sit for several hours to properly saturate the air with water
3. Remove DO probe from calibration solution and insert into 300 mL glass DO bottle, exposing the probe to the least amount of air possible
4. Quickly record reading
5. Rinse DO probe with DI water
6. Repeat steps 3 to 5 for each sample

9.2.3 Alkalinity and pH

1. Calibrate the Accumet Basic AB15 pH meter (Calibration procedure provided by the Accumet Basic AB15/15+ User Manual)
   a. Press and release the mode key until your digital display indicates pH mode. This key toggles between the pH, mV and Rel mV modes.
   b. Press the setup key twice and then press the enter key to clear an existing standardization.
   c. Rinse the electrode with distilled water using a squeeze bottle and immerse the rinsed electrode into pH 4 (pink) buffer solution.
   d. Press std again to access the Standardization mode. The selected buffer group is displayed briefly.
   e. Wait for the reading to stabilize.
   f. Press std again to initiate standardization. The meter will automatically recognize the buffer (4.00 not 7.00) and then return to the Measure screen.
   g. Repeat steps 3-6 with the pH 10 (blue) buffer solution.
   h. NOTE: When the meter accepts the second , pH 10, buffer solution, it will briefly display the percent slope associated with the electrode's performance prior to returning to the Measure mode. If the electrode is within the range of 90 – 102%, the GOOD ELECTRODE message will appear. If the electrode is outside this range, the meter will display the ELECTRODE ERROR message.
2. Set up digital titrator
3. Use a volumetric flask to measure 100 mL of sample and empty into a beaker
4. Put stir bar in beaker, and place on stir plate
5. Measure pH of sample and record in spreadsheet (see below)
6. Add acid to sample in increments and record volume added in spreadsheet and pH
7. Repeat step 6 until the alkalinity measurements until the slope is approximately 1
8. Clean the beaker in between samples

Basin:	River Street	Outflow	*12:10PM*						
Sampled:	8-Nov-12								
Analyzed	20-Nov-12				*Alkalinity=*	0.8223			
Volume(L):	0.100			Alk (mg/L CaCO3)=		41.1524			
volume added	pH	Volume, uL	meq/L	[H+]	R^2	*Alkalinity (meq/L)*			
0	6.69	0	0	2.12E-07	#DIV/0!		#DIV/0!	-0.00021	-6.97E-04
40	6.58	50	0.08	2.73E-07	1.0000	-0.2775	1.31E+03	0.079727	-6.17E-04
100	6.45	125	0.2	3.68E-07	0.9999	-0.2700	1.28E+03	0.199632	-4.97E-04
150	6.31	188	0.3	5.08E-07	0.9775	-0.1991	1.01E+03	0.299492	-3.97E-04
200	6.18	250	0.4	6.85E-07	0.9692	-0.0997	7.52E+02	0.399315	-2.97E-04
250	6.02	313	0.5	9.90E-07	0.9665	0.0485	4.73E+02	0.49901	-1.97E-04
300	5.84	375	0.6	1.50E-06	0.9509	0.1830	2.90E+02	0.598502	-9.71E-05
350	5.56	438	0.7	2.85E-06	0.8923	0.3584	1.27E+02	0.697146	2.85E-06
400	5.09	500	0.8	8.42E-06	0.8006	0.5335	3.38E+01	0.791577	1.03E-04
450	4.41	563	0.9	4.03E-05	0.7430	0.6692	6.09E+00	0.859684	2.03E-04
475	4.21	594	0.95	6.39E-05	0.8955	0.7316	3.67E+00	0.886104	2.53E-04
500	4.06	625	1	9.03E-05	0.9835	0.7891	2.43E+00	0.909745	3.03E-04
525	3.95	656	1.05	1.16E-04	0.9994	0.8223	1.97E+00	0.933729	3.53E-04
550	3.886	688	1.1	1.35E-04	0.9936	0.8140	2.08E+00	0.965267	4.03E-04





9.2.4 Ammonia

Store the samples up to 28 days by adding conc. sulfuric acid (H_2SO_4) at least 20µl per 10ml (reducing the pH to 2 or less). Store at 4°C or less.

Procedure using the DR/3000 (Refer to DR/3000 Procedure Code N.3 – 34 STORED PROGRAM)

1. Shake sample
2. Filter sample if necessary
    a. Fold #4 filter twice and insert into funnel
    b. Filter sample into beaker or graduated cylinder
3. Dilute sample if necessary
    a. Fill a 25 mL volumetric flask with sample
    b. Transfer to appropriately sized volumetric flask to achieve the correct dilution (ex. 50 mL for 2x dilution, 100 mL for 4x dilution)
    c. Fill to line with DI water
4. Fill a clean sample cell to the 25ml mark with sample.
5. Fill a second cell with 25ml of E-pure water as blank.
6. Add 3 drops of Mineral Stabilizer to each cell. Stopper. Invert several times to mix.

7. Add 3 drops of Polyvinyl Alcohol Dispersing Agent to each cell — hold the dropping bottle straight vertically. Stopper. Invert several times to mix.
8. Pipette 1ml of Nessler Reagent into each cell. Stopper. Invert several times to mix.
    a. Note: Nessler reagent is toxic and corrosive. Use a pipet filler when pipetting and pipette carefully.
    b. Note: A yellow color will develop if ammonia is present. The blank will be a faint yellow color.
    c. Note: Complete Steps 6-10 within 5 minutes after adding Nessler's Reagent.
9. Press: TIMER – 1 – TIMER
    a. Note: A one-minute reaction period will begin. The display will indicate 1 min and then decrease in increments of tenths until 0 is reached.
10. To calibrate Spec:
    a. Press: Manual Program, then rotate the wavelength selector dial to a setting of 425 nm.
    b. After the timer beeps, place the blank into the cell holder. The 25ml mark on the cell should face the front of the instrument for proper orientation. Close the compartment door.
    c. Zero the instrument by pressing Zero Abs. or Zero %T, then the display should read 0.000 Abs or 100% T, respectively. If not, press the ZREO key again.
11. Place the prepared sample in the cell holder. Close the sample compartment door. Press Abs. Read the absorbance or %T from the display.
12. Calculate result
    a. Divide absorbance value by calibration number
    b. Multiply by dilution factor if applicable
13. Rinse vial and stopper several times before next sample
14. Pour any waste with the Nessler reagent into the appropriate toxic waste bottle

9.2.5 Total Suspended Solids

1. To prepare filters:
    a. Set up pump
    b. Label aluminum pans
    c. Use tweezers to place 1.5 µm in pump
    d. Filter with DI water
    e. Place filters and aluminum pans in oven to dry for a few hours
2. Weigh filter and record result (make sure to record the entire number)
3. Place filter in pump and pump sample through
    a. If there is a lot of TSS, can use 500 mL or 250 mL instead of 1000 mL and multiply the result by the correct factor

4. Dry filters with sample in oven for a few hours
5. Zero aluminum pan
6. Add filter with sample and record entire result
7. Calculate the amount of suspended solids
    a. $TSS = m_{filter\ with\ sample} - m_{initial\ filter}$

9.2.6 Turbidity

1. Shake sample well
2. Pour sample into spec cell and clean cell
3. Insert cell into the HACH 2100N Turbidimeter (arrow out) and record the result
4. Can use the same vial for each sample if cleaned in between

9.2.7 Cations

The laboratory analyses for Arsenic and Lead were completed using Graphite Furnace Atomic Absorption. All other cations were analyzed using Air/Acetylene Flame Atomic Absorption.

9.2.8 Anions

<u>Creating a Program</u>

1. Under "File," select "New…"
2. When dialog box appears, select "Program File"
3. Timebase: Select "CEE11_1" under "my computer"
4. Pump_ECD Options:
    - Gradient Type — Isocratic
    - Pressure Limits — 200-3000
    - Flow rate — 1.2 μl/min

    (these are settings unique to the particular column (anions, in this case)
5. Eluent generator Options:
    - Mode — Isocratic
    - Start — 38.00
    - CR-TC — On
6. Sample Preparation Options:
    - Loop Mode
    - Delivery Speed — 4 ml/min
    - Flush Factor — 2
    - Edit Mode — Basic
    - Volume — From Sequence
    - Bleed — None
7. Acquisition Options:

- Acquisition Time   0 to 23 minutes
- Only need to check ECD_1.Acq since we will use the autozero function

8. Options:
   - "yes" on autozero
   - cell temperature = 35°C
   - column temperature (depends on column) = 30°C for the anion column
9. Accept next 3 screens
10. "Title" and review
11. Save to folder CEE11_1\Programs\

<u>Creating a Shutdown Program</u>

1. Use the Autosampler Program as a base
2. Open in Command View
3. Delete "Acqoff" command at end
4. "Semicolon out" (entering a semicolon before a command line tells the program to ignore that command) the following commands that the shutdown program will not be using
   - Deliver Speed
   - Delay Volume
   - Flush factor
   - Sampler Load Position
   - Deliver Sample
   - End Sample Prep
   - Wait
   - Inject
   - ECD_Acqon
5. Delete "Begin Overlap" at 0.5
6. At 0.5 minute, press F8 (or control-command) to get a list of program commands
7. In the Pump_ECD folder, select the following 3 commands:
   - Suppressor_Mode >>> off >>> select "ok"
   - CR_TC >>> off >>> select "ok"
   - Eluent Generator\Mode >>> off >>> select "ok"
8. At 1.6 minutes, press F8 (or control-command) to get a list of program commands
   - Pump_ECD >>> off (in menu)
9. Save to folder CEE11_1\Programs\

<u>Starting Up the IC</u>

1. Start the Hardware first
2. Next, start the computer
3. Then, start the panels

- Check connected
- Pump – start with half flow rate (0.6 ml/min) >> once the PSI has reached a value higher than 1000, increase the pump rate to 1.2 ml/min
- *If PSI levels are bouncing, there is probably an air bubble in the system. This can be resolved by turning the valve and selecting "prime"*

4. Next, turn on the suppressor (mode = on) after checking that the current is appropriate for the column installed (113 for the anion column)
5. Turn on EG and CR-TC
6. Blue Dot >> Acquire all *(optional)*
7. Let sit for about 30 minutes to establish a baseline

<u>Creating a Sequence</u>

1. Under "File," select "New…Sequence"
2. When dialog box appears, select "create sequence using wizard"
3. Timebase: Select "CEE11_1" under "my computer"
4. Unknowns >> this screen is where you set up for each sample
   - number of vials = number of samples
   - start position >> make sure you account for appropriate number of standards/blanks that will precede the samples
   - volume of sample = volume of loop being used
5. Standards >> same inputs as unknowns
6. CEE Laboratory Manager typically includes one blank at beginning of sequence – it should be entered as an "unknown" with a start position of 1.
7. Two blanks should be included at the end of each sequence as well. The first should be entered as "unknown," similar to the first blank. The last sample should be entered as a "blank." ***After the sequence is created, the program for the last sample should be changed to the Shutdown program. This sample will not actually be injected, it is merely a placeholder to allow for the activation of the shutdown program.***
8. Methods and Reporting >> using the "browse" function, select the appropriate program, method, and report files (use default and modify later if unknown)
9. Preferred Channel = CEE11_1
10. Sequence Name >> use date that sequence is run in the file name and store in Directory CEE11_1\Sequences

<u>Loading the Auto Sampler</u>

1. Open the Auto sampler lid
2. Press the "Carousel Release" button – this will allow free rotation of the carousel
3. Remove any vials from previous runs

4. Use the vial stand to fill vials with blanks, standards, and samples using the position number identified in the sequence.
5. Vials should be filled to the upper level of the vial stand.
6. Place black cap with pointy end up in vial.
7. Use tool (black rod) to press vial caps down: center on one side; then push down with flat side until vial cap is flush with top of vial.
8. Place vials in appropriate tray locations.
9. Press “Carousel Release” button to lock carousel. Watch to ensure that loading arm is positioned over vial #1.

Running a Sequence

1. Under “New,” select “Batch”
2. Select “Start” (perform a “ready check first”)
3. Watch to ensure that first position vial is delivered and injected properly.

Viewing Results

- Double-clicking on a sample from the sequence pane will display the results for that sample
- “Peak Calipers” shows the window of expected retention time. When viewing results, right-click on the graph window and select “decoration.” The peak caliber tab can be used to select “show peak calipers” and “show all caliper drop lines”

Creating a Method

1. From within a sequence, double-click on any sample to open the method window (Details regarding that sample will appear)
2. On the menu bar, select QNT Editor to manipulate the method
3. Within the QNT Editor, follow the bottom tabs across as indicated below.

“General”

- How are results interpreted? – Enter dimension amount (usually PPB)
- Mode of Calibration
  - Total – all samples in sequenced that are labeled as “standards” will be used to calibrate
  - Fixed – standards from previous sequences can be utilized
- Blank run and matrix subtraction is available on this tab if needed

“Detection”

1. Minimum area – arbitrary amount (typically has been set to .005)
2. This is the tab where “inhibit integration” can be turned on or off at specified times – which will eliminate the detection of negative peaks or others that the User would like to not include in the reported results, because they are not accurately reflecting constituents or amounts.

“Peak Table”

Autogenerate peak table

- Right-click on line 1
- select “autogenerate peak table”
- pop-up window – click “ok”
- Name peaks by clicking on “default - #” cell
- right-click and select “edit field”
- rename appropriately
- Save before closing window
- Double-click on a standard
- Click “QNT Editor” button
- “Assign Standards on Basis of…” select >Name<
- Select all standards
- Auto generate
- Apply
- ok
- In table, manually type in standard concentrations
- Calibration Type – set to “linear” – the program will automatically force the calibration curve through zero. This can be changed by double-clicking “calibration type” and unchecking “force through zero” in the pop-up window

“Amount Table” & “Peak Tracking”

- no changes

“Calibration”

- If “ok” appears, then all the peaks were found in the specified time intervals
- If using standards from a previous sequence for calibration
    - Mode in “general tab” should be set to “fixed”
    - Right-click on line and select “append standard”
    - Using “browse” function, select standards of choice

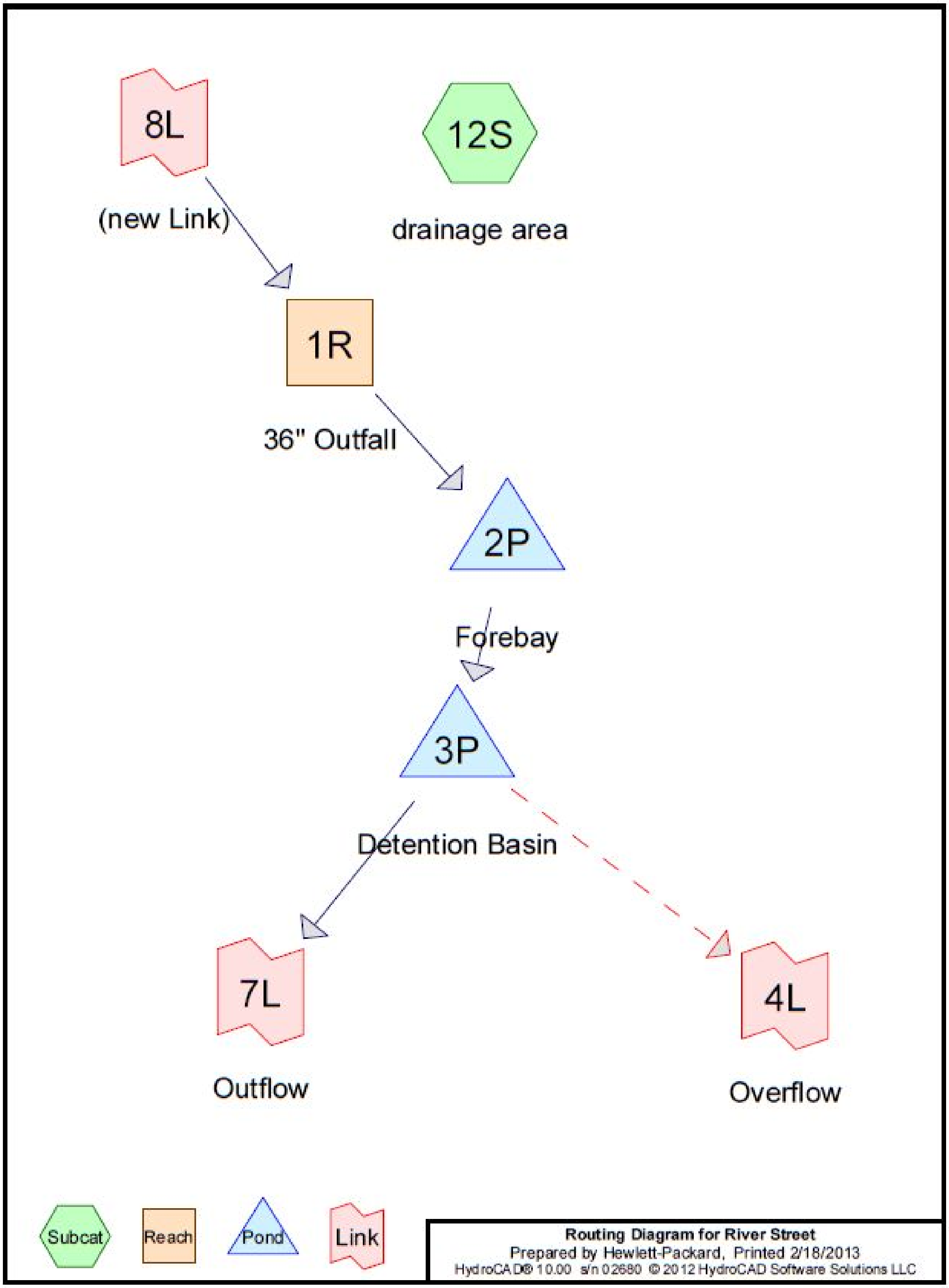
The last two tabs in QNT editor are not likely to be used

The calibration curve values for anions, as provided by the WPI Laboratory Manager, are listed in Table 39:

Table 39: Calibration Curve Values

Constituent	**Curve Calculations (ppb)**
Fluoride	40-80-120-300-500
Phosphate	400-800-1200-3000-5000
Chloride, Sulfate, Bromide, Nitrate, Nitrite	200-400-600-1500-2500

9.3 Appendix C: Final River Street HydroCAD Model Report



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Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
35.750	65	2 acre lots, 12% imp, HSG B (12S)
35.750	**65**	**TOTAL AREA**

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Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Diam/Width (inches)	Height (inches)	Inside-Fill (inches)
1	1R	290.30	290.00	57.0	0.0053	0.013	36.0	0.0	0.0
2	3P	281.00	280.00	70.0	0.0143	0.020	6.0	0.0	0.0
3	3P	282.00	281.00	180.0	0.0056	0.025	4.0	0.0	0.0
4	3P	282.00	281.00	180.0	0.0056	0.025	4.0	0.0	0.0
5	3P	282.00	281.00	180.0	0.0056	0.025	4.0	0.0	0.0
6	3P	282.00	281.00	180.0	0.0056	0.025	4.0	0.0	0.0

Time span=0.00-40.00 hrs, dt=0.05 hrs, 801 points
Runoff by SCS TR-20 method, UH=SCS
Reach routing by Stor-Ind method - Pond routing by Stor-Ind method

Subcatchment 12S: drainage area Runoff Area=35.750 ac 12.00% Impervious Runoff Depth=1.03"
Flow Length=4,700' Slope=0.0310 '/' Tc=94.8 min CN=65 Runoff=11.11 cfs 3.064 af

Reach 1R: 36" Outfall Avg. Flow Depth=0.24' Max Vel=2.39 fps Inflow=0.64 cfs 0.163 af
36.0" Round Pipe n=0.013 L=57.0' S=0.0053 '/' Capacity=48.39 cfs Outflow=0.64 cfs 0.163 af

Pond 2P: Forebay Peak Elev=285.54' Storage=969 cf Inflow=0.64 cfs 0.163 af
Outflow=0.64 cfs 0.142 af

Pond 3P: Detention Basin Peak Elev=284.03' Storage=244 cf Inflow=0.64 cfs 0.142 af
Primary=0.48 cfs 0.142 af Secondary=0.00 cfs 0.000 af Outflow=0.48 cfs 0.142 af

Link 4L: Overflow Inflow=0.00 cfs 0.000 af
Primary=0.00 cfs 0.000 af

Link 7L: Outflow Inflow=0.48 cfs 0.142 af
Primary=0.48 cfs 0.142 af

Inflow=0.64 cfs 0.163 af
Primary=0.64 cfs 0.163 af

Total Runoff Area = 35.750 ac Runoff Volume = 3.064 af Average Runoff Depth = 1.03"
88.00% Pervious = 31.460 ac 12.00% Impervious = 4.290 ac

Summary for Subcatchment 12S: drainage area

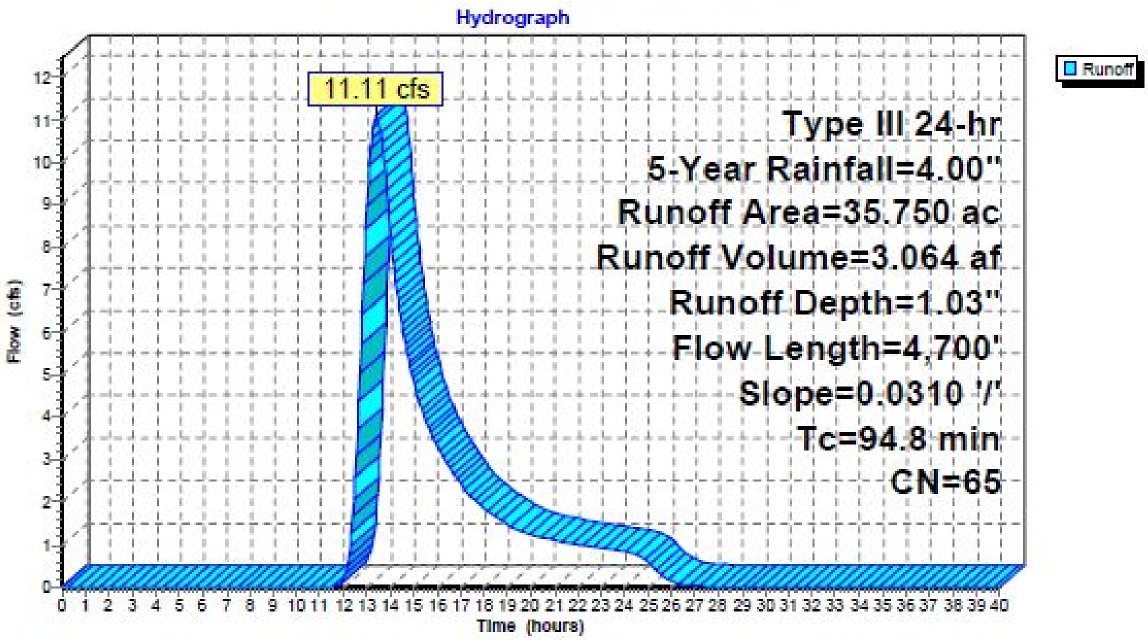
Runoff = 11.11 cfs @ 13.40 hrs, Volume= 3.064 af, Depth= 1.03"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 0.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 5-Year Rainfall=4.00"

Area (ac)	CN	Description
35.750	65	2 acre lots, 12% imp, HSG B
31.460		88.00% Pervious Area
4.290		12.00% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
94.8	4,700	0.0310	0.83		**Lag/CN Method,**

Subcatchment 12S: drainage area



Summary for Reach 1R: 36" Outfall

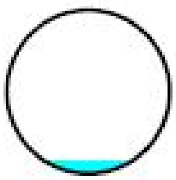
[52] Hint: Inlet/Outlet conditions not evaluated

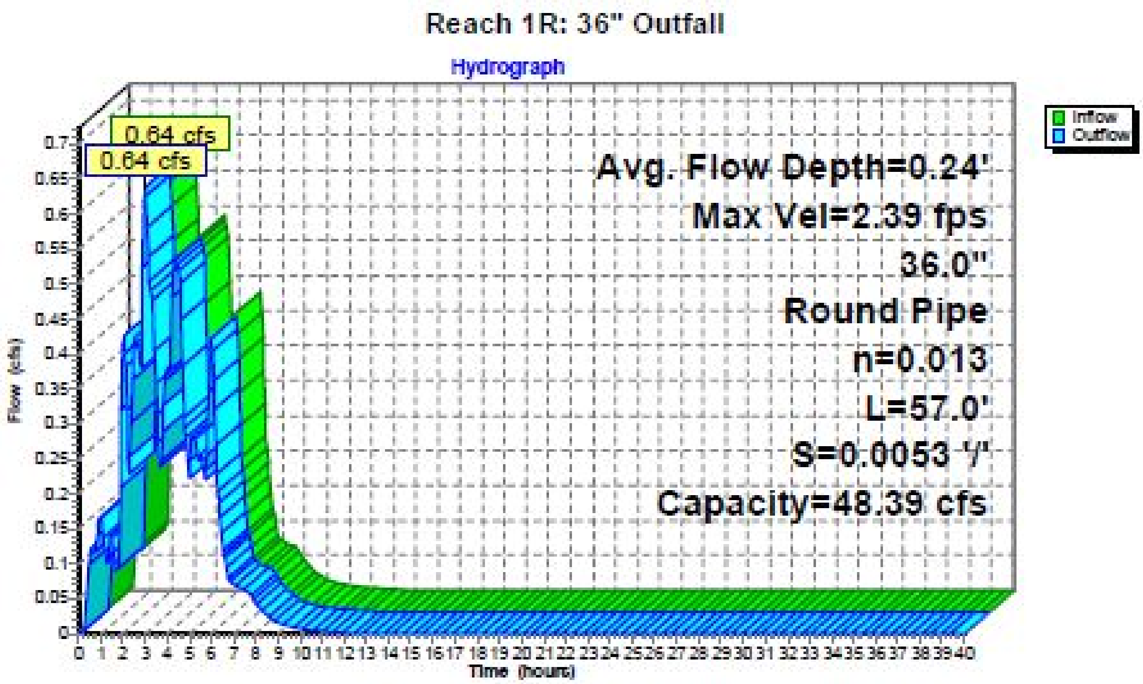
Inflow	=	0.64 cfs @	3.00 hrs,	Volume=	0.163 af
Outflow	=	0.64 cfs @	3.00 hrs,	Volume=	0.163 af, Atten= 1%, Lag= 0.3 min

Routing by Stor-Ind method, Time Span= 0.00-40.00 hrs, dt= 0.05 hrs
Max. Velocity= 2.39 fps, Min. Travel Time= 0.4 min
Avg. Velocity = 1.10 fps, Avg. Travel Time= 0.9 min

Peak Storage= 15 cf @ 3.00 hrs
Average Depth at Peak Storage= 0.24'
Bank-Full Depth= 3.00' Flow Area= 7.1 sf, Capacity= 48.39 cfs

36.0" Round Pipe
n= 0.013
Length= 57.0' Slope= 0.0053 '/'
Inlet Invert= 290.30', Outlet Invert= 290.00'





Summary for Pond 2P: Forebay

Inflow	=	0.64 cfs @	3.00 hrs, Volume=	0.163 af
Outflow	=	0.64 cfs @	3.02 hrs, Volume=	0.142 af, Atten= 0%, Lag= 0.8 min
Primary	=	0.64 cfs @	3.02 hrs, Volume=	0.142 af

Routing by Stor-Ind method, Time Span= 0.00-40.00 hrs, dt= 0.05 hrs / 2
Peak Elev= 285.54' @ 3.02 hrs Surf.Area= 851 sf Storage= 969 cf

Plug-Flow detention time= 53.0 min calculated for 0.141 af (87% of inflow)
Center-of-Mass det. time= 25.0 min (268.4 - 243.4)

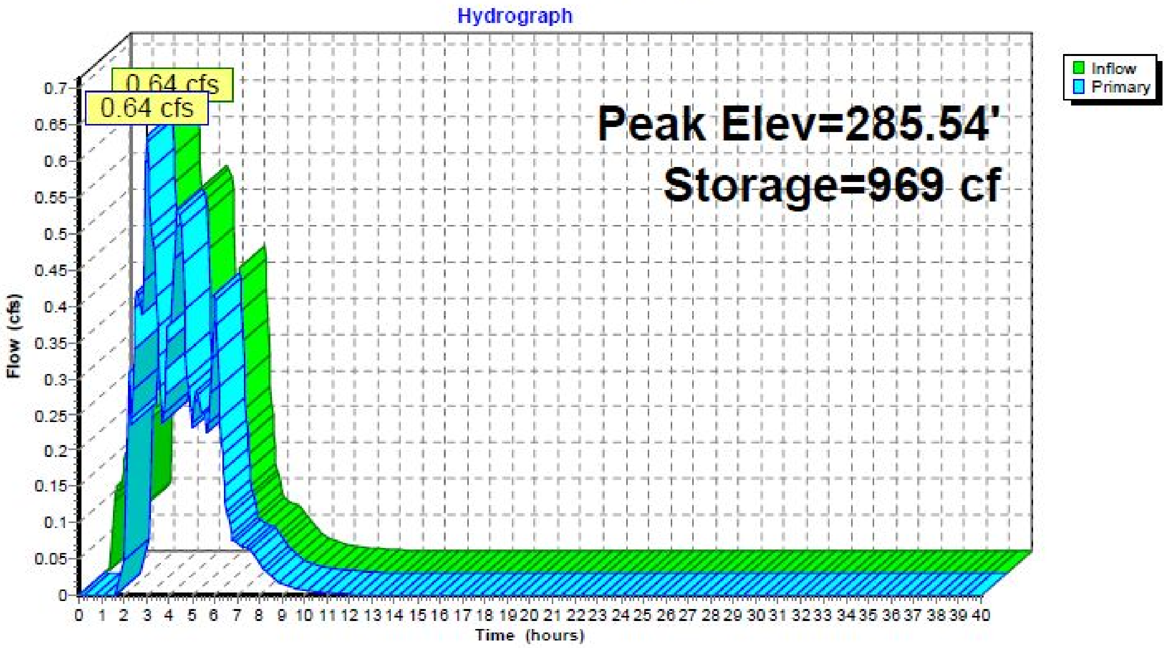
Volume	Invert	Avail.Storage	Storage Description
#1	284.00'	2,582 cf	**Custom Stage Data (Prismatic)**Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
284.00	406	0	0
286.00	984	1,390	1,390
287.00	1,400	1,192	2,582

Device	Routing	Invert	Outlet Devices
#1	Primary	285.50'	**30.0' long x 8.0' breadth Broad-Crested Rectangular Weir** Head (feet) 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 Coef. (English) 2.43 2.54 2.70 2.69 2.68 2.68 2.66 2.64 2.64 2.64 2.65 2.65 2.66 2.66 2.68 2.70 2.74

Primary OutFlow Max=0.60 cfs @ 3.02 hrs HW=285.54' (Free Discharge)
└─**1=Broad-Crested Rectangular Weir** (Weir Controls 0.60 cfs @ 0.49 fps)

Pond 2P: Forebay



Summary for Pond 3P: Detention Basin

Inflow =	0.64 cfs @	3.02 hrs,	Volume=	0.142 af
Outflow =	0.48 cfs @	3.35 hrs,	Volume=	0.142 af, Atten= 24%, Lag= 20.1 min
Primary =	0.48 cfs @	3.35 hrs,	Volume=	0.142 af
Secondary =	0.00 cfs @	0.00 hrs,	Volume=	0.000 af

Routing by Stor-Ind method, Time Span= 0.00-40.00 hrs, dt= 0.05 hrs / 3
Peak Elev= 284.03' @ 3.35 hrs Surf.Area= 7,007 sf Storage= 244 cf

Plug-Flow detention time= 5.4 min calculated for 0.141 af (100% of inflow)
Center-of-Mass det. time= 5.4 min (273.8 - 268.4)

Volume	Invert	Avail.Storage	Storage Description
#1	284.00'	16,463 cf	**Custom Stage Data (Prismatic)**Listed below (Recalc)

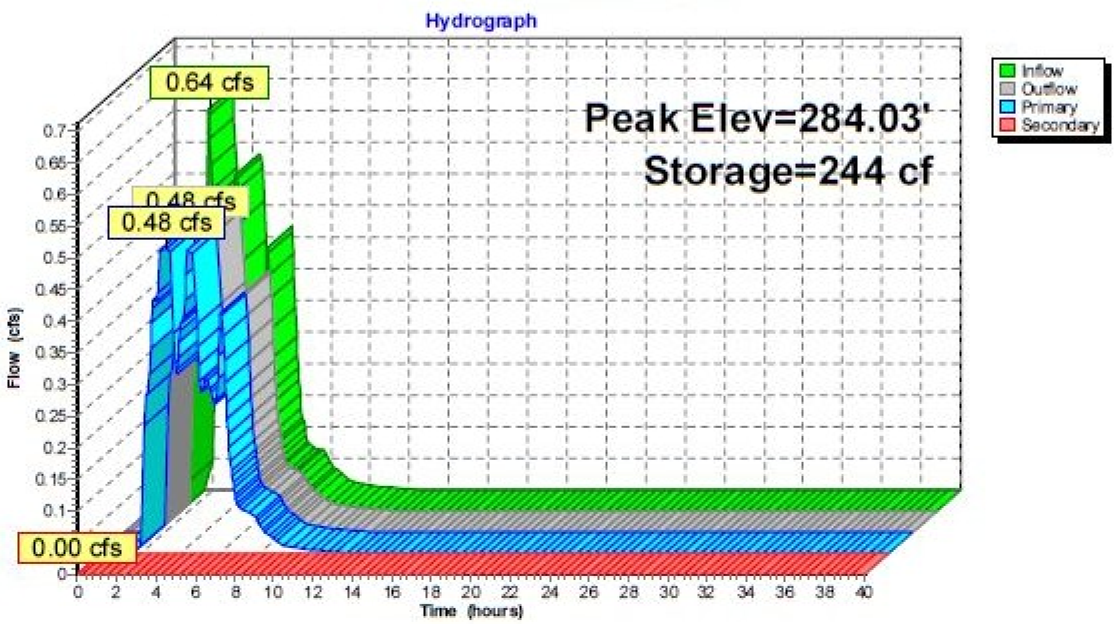
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
284.00	6,963	0	0
286.00	9,500	16,463	16,463

Device	Routing	Invert	Outlet Devices
#1	Secondary	285.40'	**28.0' long x 10.0' breadth Broad-Crested Rectangular Weir** Head (feet) 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 Coef. (English) 2.49 2.56 2.70 2.69 2.68 2.69 2.67 2.64
#2	Primary	281.00'	**6.0" Round Culvert** L= 70.0' Ke= 0.200 Inlet / Outlet Invert= 281.00' / 280.00' S= 0.0143 '/' Cc= 0.900 n= 0.020, Flow Area= 0.20 sf
#3	Device 2	282.00'	**4.0" Round Culvert** L= 180.0' Ke= 0.200 Inlet / Outlet Invert= 282.00' / 281.00' S= 0.0056 '/' Cc= 0.900 n= 0.025, Flow Area= 0.09 sf
#4	Device 2	282.00'	**4.0" Round Culvert** L= 180.0' Ke= 0.200 Inlet / Outlet Invert= 282.00' / 281.00' S= 0.0056 '/' Cc= 0.900 n= 0.025, Flow Area= 0.09 sf
#5	Device 2	282.00'	**4.0" Round Culvert** L= 180.0' Ke= 0.200 Inlet / Outlet Invert= 282.00' / 281.00' S= 0.0056 '/' Cc= 0.900 n= 0.025, Flow Area= 0.09 sf
#6	Device 2	282.00'	**4.0" Round Culvert** L= 180.0' Ke= 0.200 Inlet / Outlet Invert= 282.00' / 281.00' S= 0.0056 '/' Cc= 0.900 n= 0.025, Flow Area= 0.09 sf
#7	Device 3	284.00'	**10.000 in/hr Exfiltration over Surface area above 281.00'** Conductivity to Groundwater Elevation = 0.00' Excluded Surface area = 0 sf
#8	Device 4	284.00'	**10.000 in/hr Exfiltration over Surface area above 281.00'** Conductivity to Groundwater Elevation = 0.00' Excluded Surface area = 0 sf
#9	Device 5	284.00'	**10.000 in/hr Exfiltration over Surface area above 281.00'** Conductivity to Groundwater Elevation = 0.00' Excluded Surface area = 0 sf
#10	Device 6	284.00'	**10.000 in/hr Exfiltration over Surface area above 281.00'** Conductivity to Groundwater Elevation = 0.00' Excluded Surface area = 0 sf

Primary OutFlow Max=0.48 cfs @ 3.35 hrs HW=284.03' (Free Discharge)
└─**2=Culvert** (Passes 0.48 cfs of 0.78 cfs potential flow)
  ├─**3=Culvert** (Barrel Controls 0.12 cfs @ 1.38 fps)
  │ └─**7=Exfiltration** (Passes 0.12 cfs of 1.62 cfs potential flow)
  ├─**4=Culvert** (Barrel Controls 0.12 cfs @ 1.38 fps)
  │ └─**8=Exfiltration** (Passes 0.12 cfs of 1.62 cfs potential flow)
  ├─**5=Culvert** (Barrel Controls 0.12 cfs @ 1.38 fps)
  │ └─**9=Exfiltration** (Passes 0.12 cfs of 1.62 cfs potential flow)
  └─**6=Culvert** (Barrel Controls 0.12 cfs @ 1.38 fps)
    └─**10=Exfiltration** (Passes 0.12 cfs of 1.62 cfs potential flow)

Secondary OutFlow Max=0.00 cfs @ 0.00 hrs HW=284.00' (Free Discharge)
└─**1=Broad-Crested Rectangular Weir**(Controls 0.00 cfs)

Pond 3P: Detention Basin

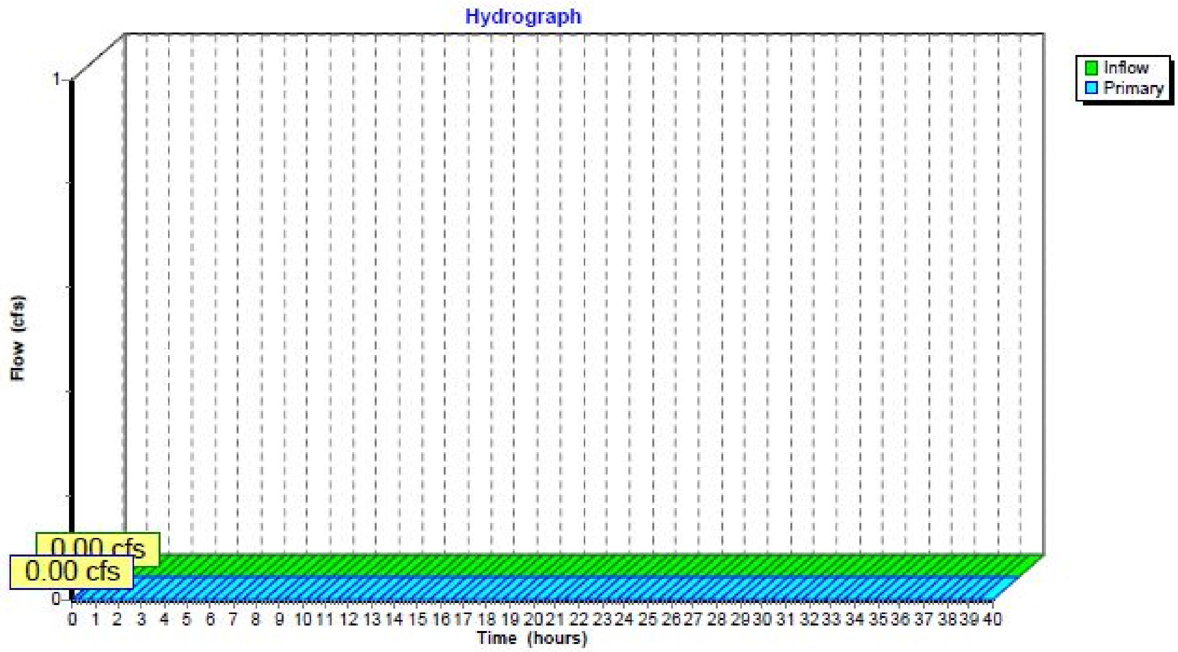


Summary for Link 4L: Overflow

Inflow	=	0.00 cfs @	0.00 hrs, Volume=	0.000 af	
Primary	=	0.00 cfs @	0.00 hrs, Volume=	0.000 af,	Atten= 0%, Lag= 0.0 min

Primary outflow = Inflow, Time Span= 0.00-40.00 hrs, dt= 0.05 hrs

Link 4L: Overflow

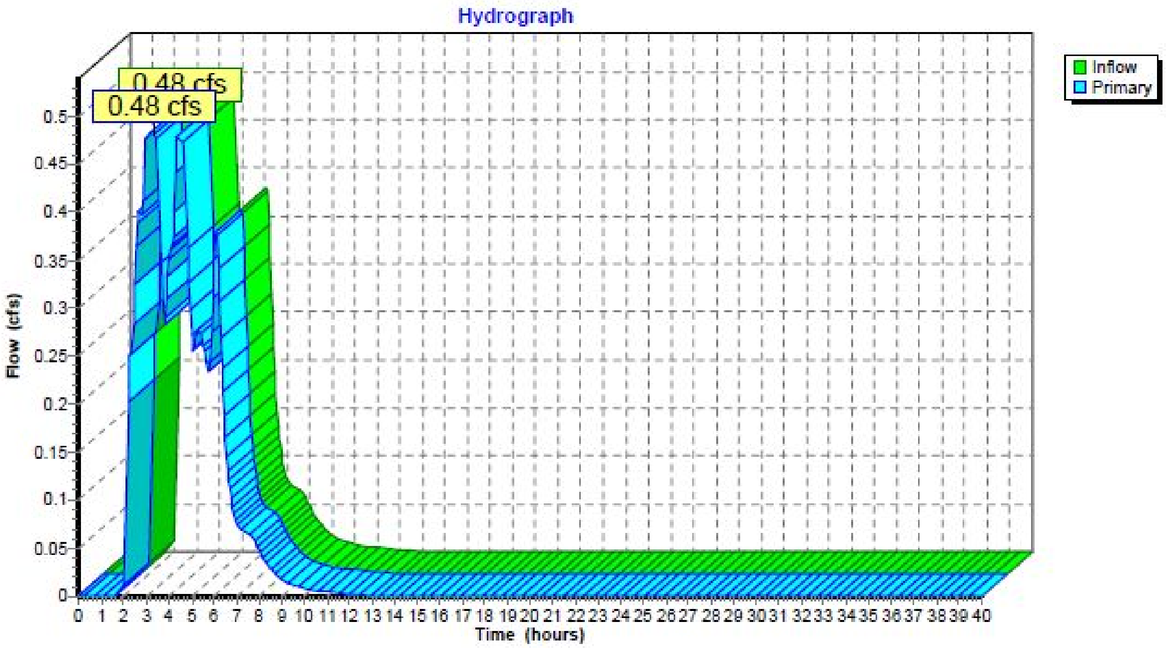


Summary for Link 7L: Outflow

Inflow	=	0.48 cfs @	3.35 hrs, Volume=	0.142 af
Primary	=	0.48 cfs @	3.35 hrs, Volume=	0.142 af, Atten= 0%, Lag= 0.0 min

Primary outflow = Inflow, Time Span= 0.00-40.00 hrs, dt= 0.05 hrs

Link 7L: Outflow

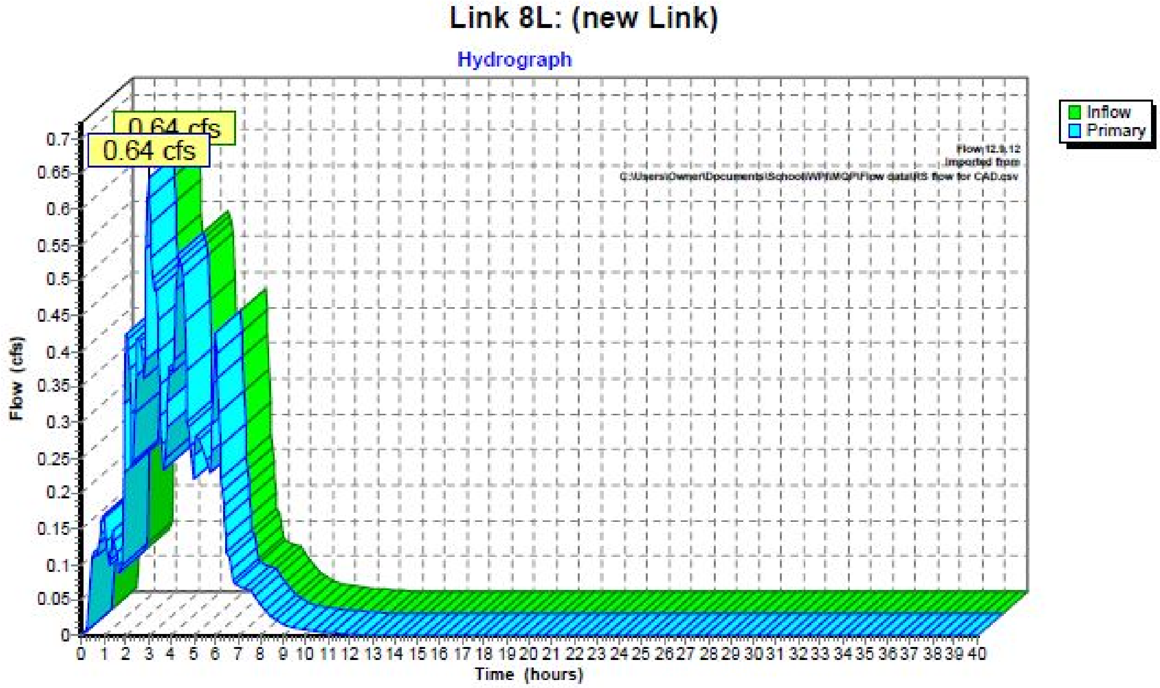


Summary for Link 8L: (new Link)

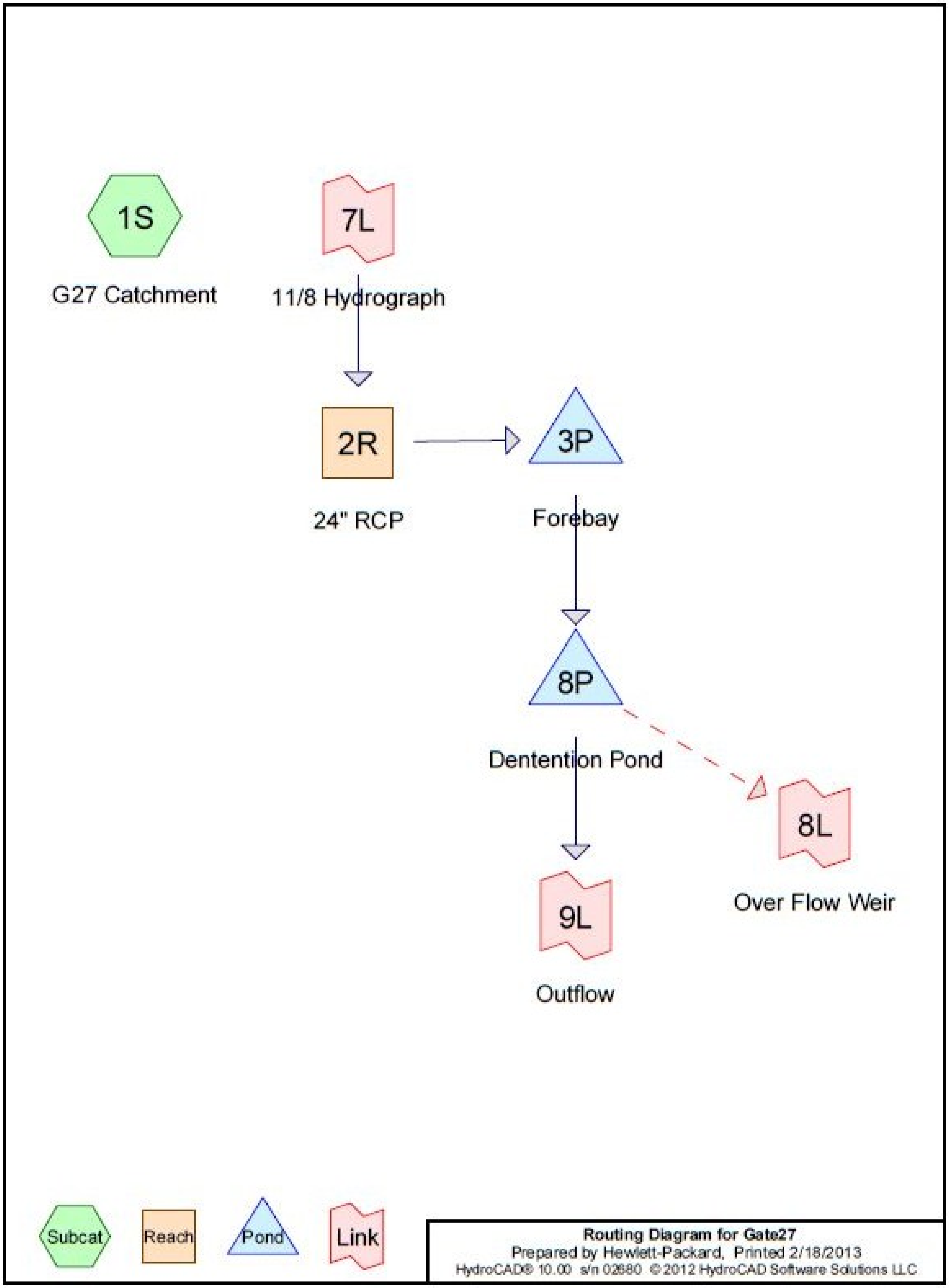
Inflow	=	0.64 cfs @	3.00 hrs, Volume=	0.163 af
Primary	=	0.64 cfs @	3.00 hrs, Volume=	0.163 af, Atten= 0%, Lag= 0.0 min

Primary outflow = Inflow, Time Span= 0.00-40.00 hrs, dt= 0.05 hrs

Flow 12.9.12 Imported from C:\Users\Owner\Documents\School\WPI\MQP\Flow data\RS flow for CAD.csv



9.4 Appendix D: Final Gate 27 HydroCAD Model Report



Gate27
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Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
12.850	90	1/2 acre lots, 25% imp, HSG B (1S)
12.850	**90**	**TOTAL AREA**

Gate27
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Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Diam/Width (inches)	Height (inches)	Inside-Fill (inches)
1	2R	421.50	412.15	86.5	0.1081	0.015	24.0	0.0	0.0
2	8P	405.28	404.70	58.0	0.0100	0.010	4.0	0.0	0.0
3	8P	405.50	405.28	22.0	0.0100	0.013	4.0	0.0	0.0

Gate27 — *Worcester County 24-hr S1 1-yr 9.00 hrs 12/9-10 Rainfall=0.50"*
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Time span=0.00-36.00 hrs, dt=0.05 hrs, 721 points
Runoff by SCS TR-20 method, UH=SCS
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment 1S: G27 Catchment — Runoff Area=12.850 ac 25.00% Impervious Runoff Depth=0.06"
Flow Length=1,042' Slope=0.0211 '/' Tc=15.9 min CN=90 Runoff=0.45 cfs 0.059 af

Reach 2R: 24" RCP — Avg. Flow Depth=0.17' Max Vel=7.34 fps Inflow=0.94 cfs 0.263 af
24.0" Round Pipe n=0.015 L=86.5' S=0.1081 '/' Capacity=64.46 cfs Outflow=0.92 cfs 0.263 af

Pond 3P: Forebay — Peak Elev=412.02' Storage=2,489 cf Inflow=0.92 cfs 0.263 af
Outflow=0.93 cfs 0.207 af

Pond 8P: Dentention Pond — Peak Elev=408.10' Storage=5,503 cf Inflow=0.93 cfs 0.207 af
Discarded=0.15 cfs 0.142 af Primary=0.11 cfs 0.065 af Secondary=0.00 cfs 0.000 af Outflow=0.26 cfs 0.207 af

Inflow=0.94 cfs 0.263 af
Primary=0.94 cfs 0.263 af

Link 8L: Over Flow Weir — Inflow=0.00 cfs 0.000 af
Primary=0.00 cfs 0.000 af

Link 9L: Outflow — Inflow=0.11 cfs 0.065 af
Primary=0.11 cfs 0.065 af

Total Runoff Area = 12.850 ac Runoff Volume = 0.059 af Average Runoff Depth = 0.06"
75.00% Pervious = 9.637 ac 25.00% Impervious = 3.212 ac

Summary for Subcatchment 1S: G27 Catchment

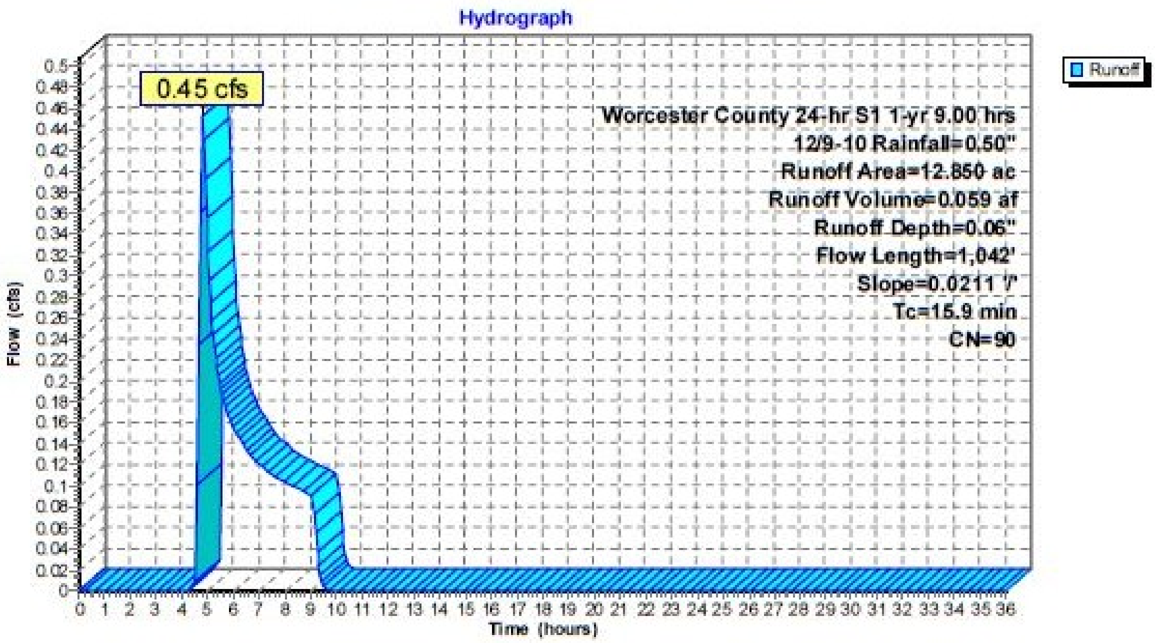
Runoff = 0.45 cfs @ 4.80 hrs, Volume= 0.059 af, Depth= 0.06"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 0.00-36.00 hrs, dt= 0.05 hrs
Worcester County 24-hr S1 1-yr 9.00 hrs 12/9-10 Rainfall=0.50"

	Area (ac)	CN	Description
*	12.850	90	1/2 acre lots, 25% imp, HSG B
	9.637		75.00% Pervious Area
	3.212		25.00% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
15.9	1,042	0.0211	1.09		**Lag/CN Method,**

Subcatchment 1S: G27 Catchment



Summary for Reach 2R: 24" RCP

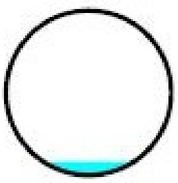
[52] Hint: Inlet/Outlet conditions not evaluated

Inflow	=	0.94 cfs @ 18.06 hrs, Volume=	0.263 af
Outflow	=	0.92 cfs @ 18.07 hrs, Volume=	0.263 af, Atten= 1%, Lag= 0.5 min

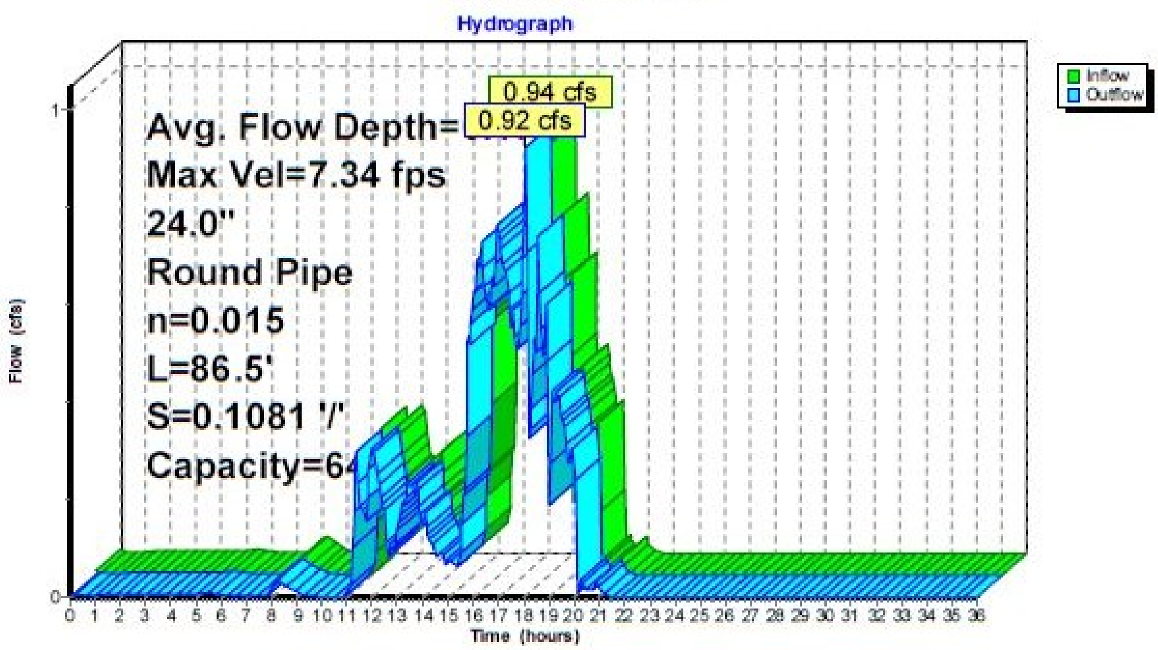
Routing by Stor-Ind+Trans method, Time Span= 0.00-36.00 hrs, dt= 0.05 hrs
Max. Velocity= 7.34 fps, Min. Travel Time= 0.2 min
Avg. Velocity = 3.31 fps, Avg. Travel Time= 0.4 min

Peak Storage= 11 cf @ 18.07 hrs
Average Depth at Peak Storage= 0.17'
Bank-Full Depth= 2.00' Flow Area= 3.1 sf, Capacity= 64.46 cfs

24.0" Round Pipe
n= 0.015 Concrete sewer w/manholes & inlets
Length= 86.5' Slope= 0.1081 '/'
Inlet Invert= 421.50', Outlet Invert= 412.15'



Reach 2R: 24" RCP



Summary for Pond 3P: Forebay

[88] Warning: Qout>Qin may require Finer Routing>1

Inflow	=	0.92 cfs @	18.07 hrs, Volume=	0.263 af
Outflow	=	0.93 cfs @	18.08 hrs, Volume=	0.207 af, Atten= 0%, Lag= 0.4 min
Primary	=	0.93 cfs @	18.08 hrs, Volume=	0.207 af

Routing by Stor-Ind method, Time Span= 0.00-36.00 hrs, dt= 0.05 hrs / 3
Peak Elev= 412.02' @ 18.08 hrs Surf.Area= 2,083 sf Storage= 2,489 cf

Plug-Flow detention time= 117.6 min calculated for 0.207 af (79% of inflow)
Center-of-Mass det. time= 72.0 min (1,053.5 - 981.5)

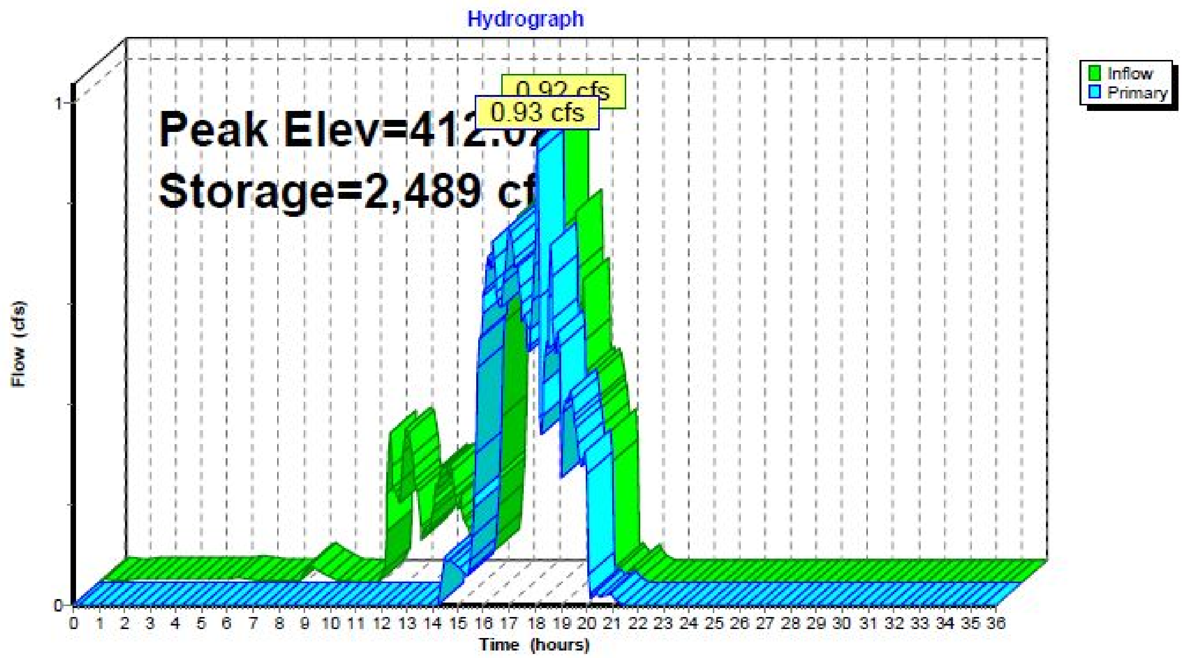
Volume	Invert	Avail.Storage	Storage Description
#1	410.00'	2,821 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
410.00	727	0	0
411.00	1,125	926	926
412.00	1,914	1,520	2,446
412.15	3,088	375	2,821

Device	Routing	Invert	Outlet Devices
#1	Primary	412.00'	**99.0' long (Profile 33) Broad-Crested Rectangular Weir** Head (feet) 0.49 0.98 1.48 Coef. (English) 2.99 3.51 3.80

Primary OutFlow Max=0.88 cfs @ 18.08 hrs HW=412.02' (Free Discharge)
↑—**1=Broad-Crested Rectangular Weir** (Weir Controls 0.88 cfs @ 0.43 fps)

Pond 3P: Forebay



Summary for Pond 8P: Dentention Pond

Inflow =	0.93 cfs @ 18.08 hrs,	Volume=	0.207 af
Outflow =	0.26 cfs @ 20.03 hrs,	Volume=	0.207 af, Atten= 72%, Lag= 116.8 min
Discarded =	0.15 cfs @ 20.03 hrs,	Volume=	0.142 af
Primary =	0.11 cfs @ 20.03 hrs,	Volume=	0.065 af
Secondary =	0.00 cfs @ 0.00 hrs,	Volume=	0.000 af

Routing by Stor-Ind method, Time Span= 0.00-36.00 hrs, dt= 0.05 hrs / 2
Peak Elev= 408.10' @ 20.03 hrs Surf.Area= 6,268 sf Storage= 5,503 cf

Plug-Flow detention time= 247.1 min calculated for 0.207 af (100% of inflow)
Center-of-Mass det. time= 247.6 min (1,301.1 - 1,053.5)

Volume	Invert	Avail.Storage	Storage Description
#1	407.00'	29,920 cf	**Custom Stage Data (Prismatic)**Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
407.00	3,609	0	0
408.00	6,169	4,889	4,889
410.00	8,167	14,336	19,225
411.00	13,222	10,695	29,920

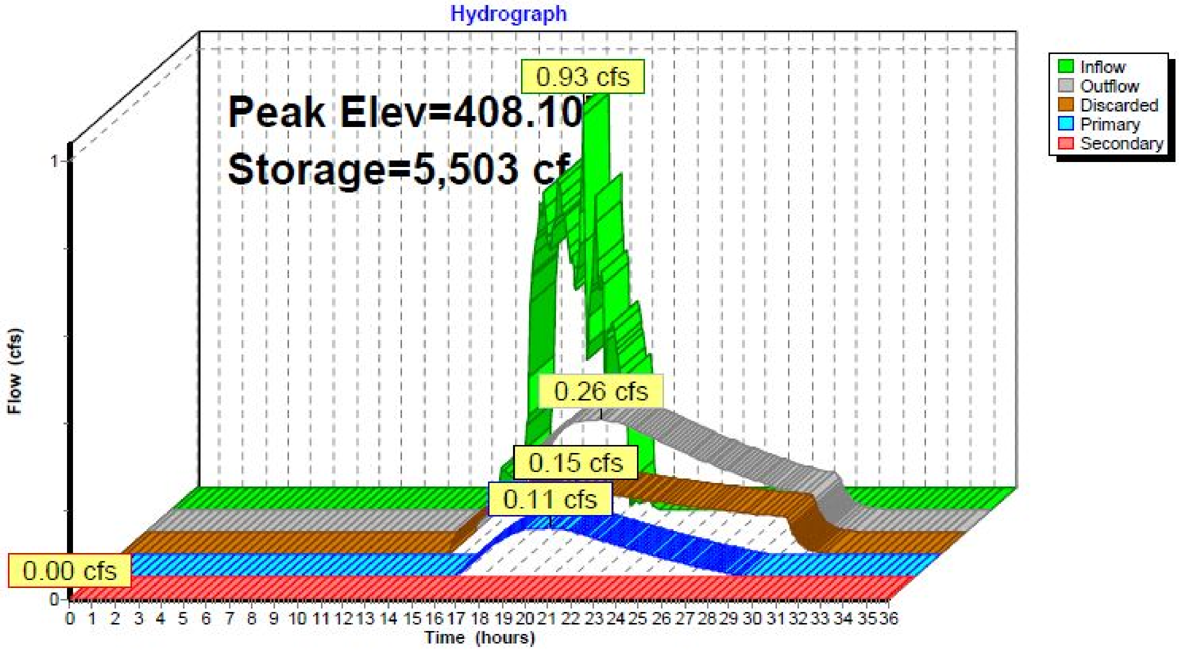
Device	Routing	Invert	Outlet Devices
#1	Primary	405.28'	**4.0" Round Culvert** L= 58.0' Ke= 0.100 Inlet / Outlet Invert= 405.28' / 404.70' S= 0.0100 '/' Cc= 0.900 n= 0.010 PVC, smooth interior, Flow Area= 0.09 sf
#2	Device 1	405.50'	**4.0" Round Culvert** L= 22.0' Ke= 0.100 Inlet / Outlet Invert= 405.50' / 405.28' S= 0.0100 '/' Cc= 0.900 n= 0.013 Corrugated PE, smooth interior, Flow Area= 0.09 sf
#3	Device 2	407.10'	**2.000 in/hr Exfiltration over Surface area above 407.10'** Conductivity to Groundwater Elevation = 0.00' Excluded Surface area = 3,865 sf
#4	Secondary	410.00'	**20.0' long x 12.0' breadth Broad-Crested Rectangular Weir** Head (feet) 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 Coef. (English) 2.57 2.62 2.70 2.67 2.66 2.67 2.66 2.64
#5	Discarded	407.00'	**1.000 in/hr Exfiltration over Surface area** Conductivity to Groundwater Elevation = 0.00'

Discarded OutFlow Max=0.15 cfs @ 20.03 hrs HW=408.10' (Free Discharge)
└5=**Exfiltration** (Controls 0.15 cfs)

Primary OutFlow Max=0.11 cfs @ 20.03 hrs HW=408.10' (Free Discharge)
└1=**Culvert** (Passes 0.11 cfs of 0.51 cfs potential flow)
  └2=**Culvert** (Passes 0.11 cfs of 0.55 cfs potential flow)
    └3=**Exfiltration** (Controls 0.11 cfs)

Secondary OutFlow Max=0.00 cfs @ 0.00 hrs HW=407.00' (Free Discharge)
└4=**Broad-Crested Rectangular Weir**(Controls 0.00 cfs)

Pond 8P: Dentention Pond



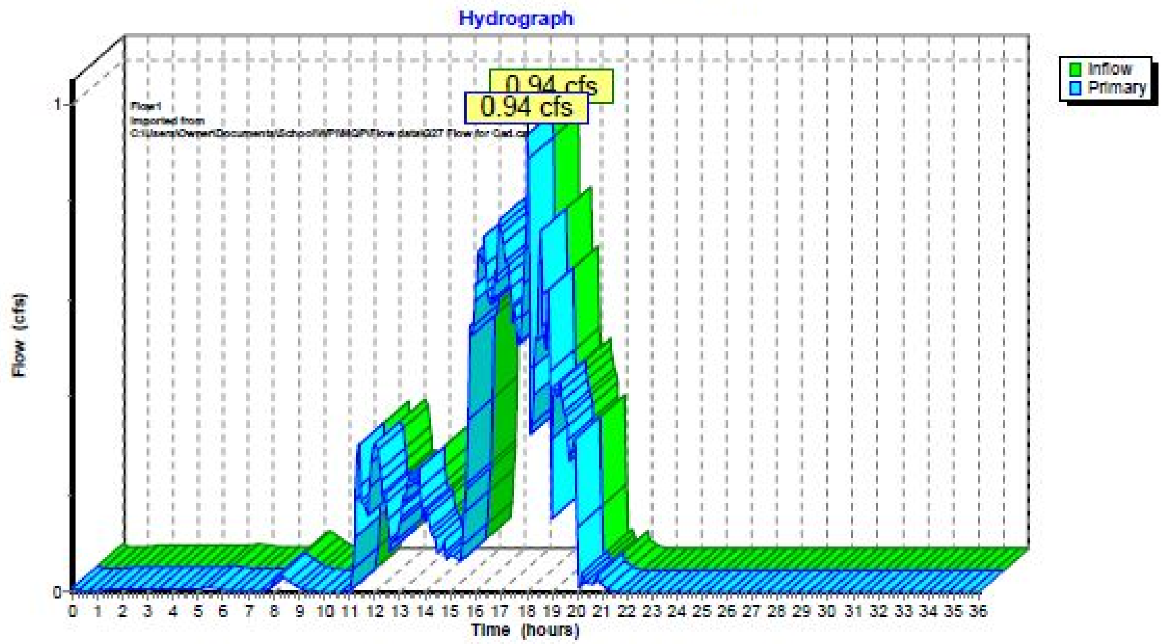
Summary for Link 7L: 11/8 Hydrograph

Inflow	=	0.94 cfs @	18.06 hrs, Volume=	0.263 af
Primary	=	0.94 cfs @	18.06 hrs, Volume=	0.263 af, Atten= 0%, Lag= 0.0 min

Primary outflow = Inflow, Time Span= 0.00-36.00 hrs, dt= 0.05 hrs

Flow1 Imported from C:\Users\Owner\Documents\School\WPI\MQP\Flow data\G27 Flow for Cad.csv

Link 7L: 11/8 Hydrograph

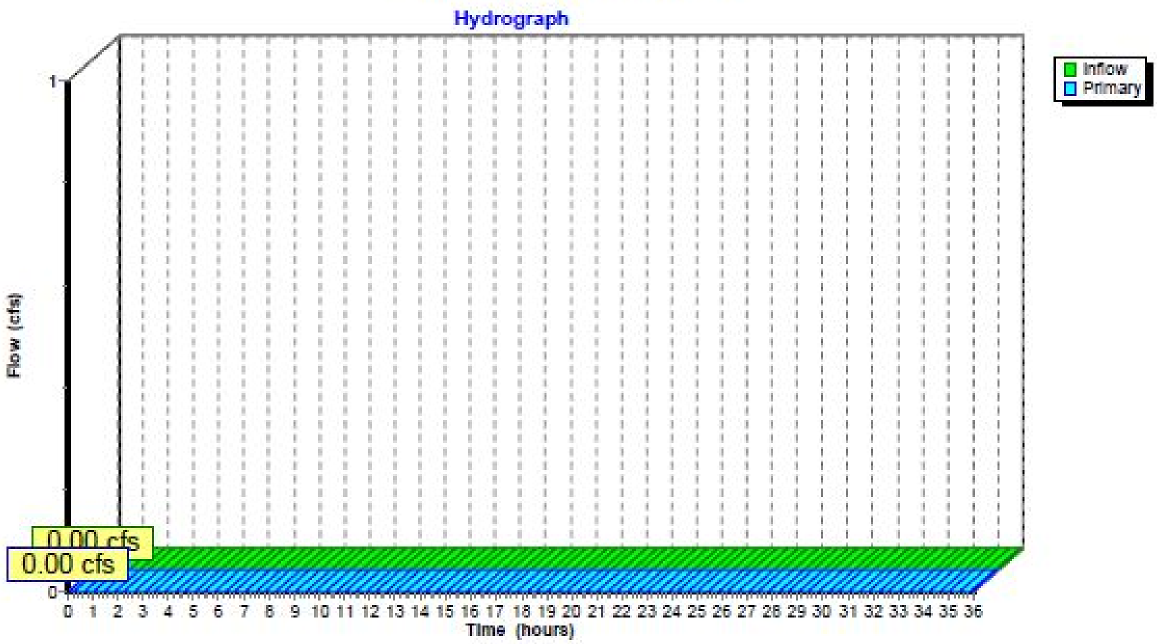


Summary for Link 8L: Over Flow Weir

Inflow	=	0.00 cfs @	0.00 hrs, Volume=	0.000 af
Primary	=	0.00 cfs @	0.00 hrs, Volume=	0.000 af, Atten= 0%, Lag= 0.0 min

Primary outflow = Inflow, Time Span= 0.00-36.00 hrs, dt= 0.05 hrs

Link 8L: Over Flow Weir

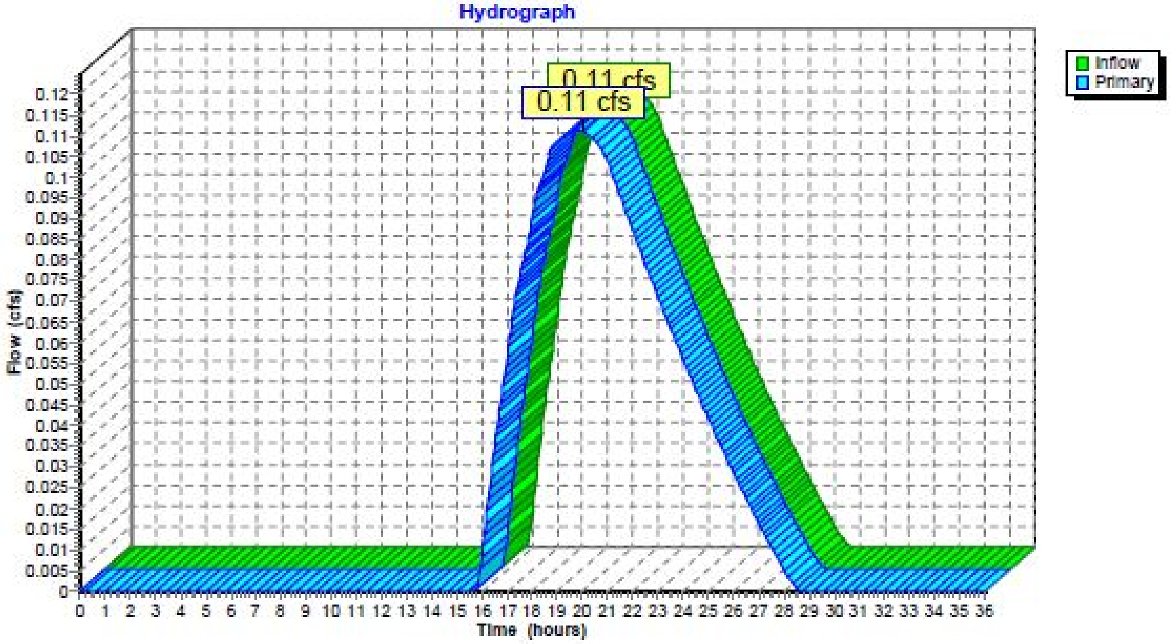


Summary for Link 9L: Outflow

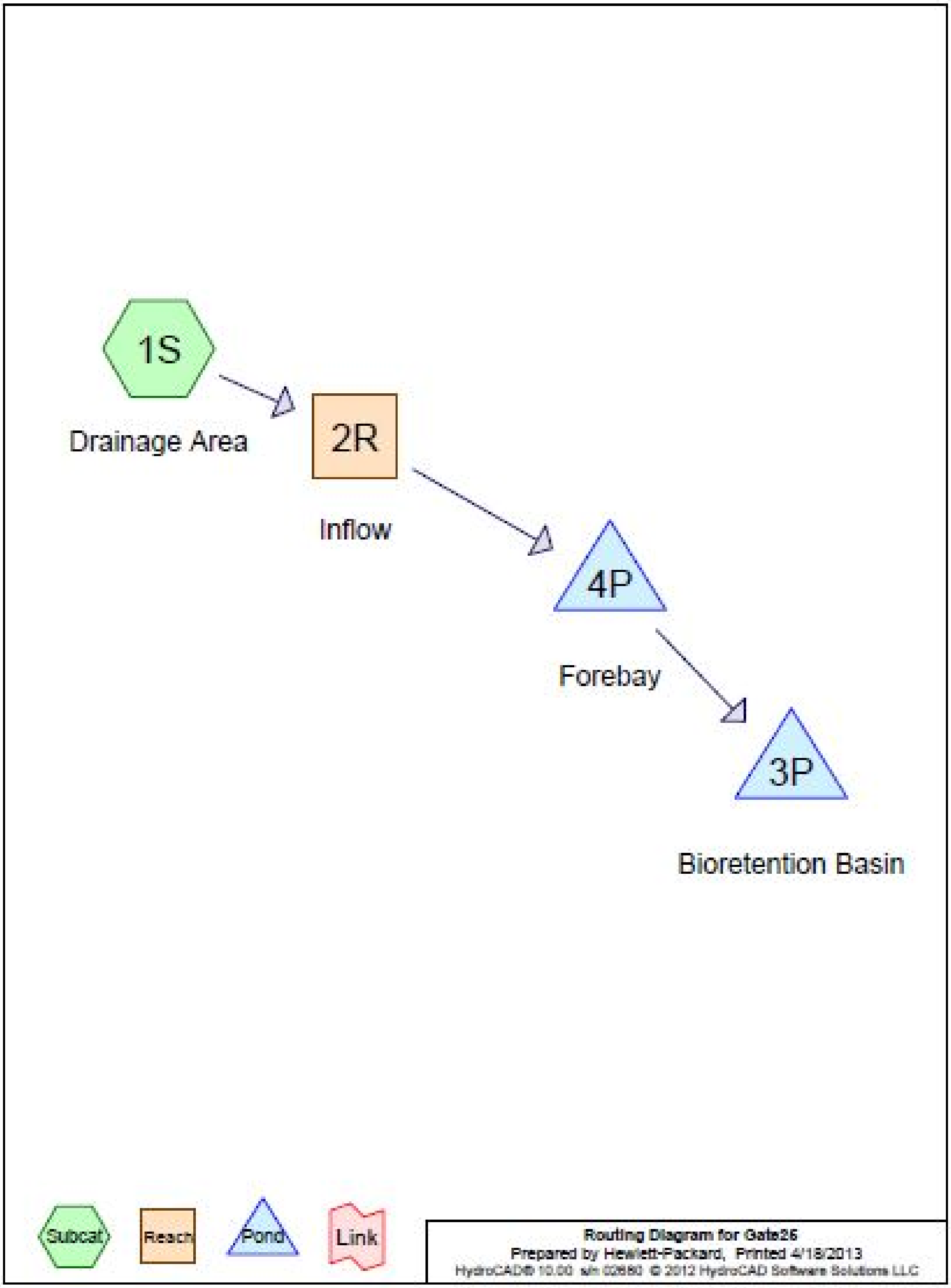
Inflow	=	0.11 cfs @	20.03 hrs, Volume=	0.065 af
Primary	=	0.11 cfs @	20.03 hrs, Volume=	0.065 af, Atten= 0%, Lag= 0.0 min

Primary outflow = Inflow, Time Span= 0.00-36.00 hrs, dt= 0.05 hrs

Link 9L: Outflow



9.5 Appendix E: Final Gate 25 HydroCAD Model Report



Gate25
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Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
19.900	46	2 acre lots, 12% imp, HSG A (1S)
19.900	**46**	**TOTAL AREA**

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Soil Listing (all nodes)

Area (acres)	Soil Group	Subcatchment Numbers
19.900	HSG A	1S
0.000	HSG B	
0.000	HSG C	
0.000	HSG D	
0.000	Other	
19.900		**TOTAL AREA**

Gate25
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Ground Covers (all nodes)

HSG-A (acres)	HSG-B (acres)	HSG-C (acres)	HSG-D (acres)	Other (acres)	Total (acres)	Ground Cover	Subcatchment Numbers
19.900	0.000	0.000	0.000	0.000	19.900	2 acre lots, 12% imp	1S
19.900	**0.000**	**0.000**	**0.000**	**0.000**	**19.900**	**TOTAL AREA**	

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Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Diam/Width (inches)	Height (inches)	Inside-Fill (inches)
1	2R	412.91	402.50	150.0	0.0694	0.012	15.0	0.0	0.0

Time span=11.00-17.00 hrs, dt=0.05 hrs, 121 points
Runoff by SCS TR-20 method, UH=SCS
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment 1S: Drainage Area Runoff Area=19.900 ac 12.00% Impervious Runoff Depth>0.85"
Flow Length=1,392' Slope=0.0639 '/' Tc=40.5 min CN=46 Runoff=9.18 cfs 1.408 af

Reach 2R: Inflow Avg. Flow Depth=0.62' Max Vel=15.00 fps Inflow=9.18 cfs 1.408 af
15.0" Round Pipe n=0.012 L=150.0' S=0.0694 '/' Capacity=18.44 cfs Outflow=9.16 cfs 1.408 af

Pond 3P: Bioretention Basin Peak Elev=399.06' Storage=28,358 cf Inflow=9.15 cfs 1.346 af
Discarded=1.64 cfs 0.620 af Primary=0.78 cfs 0.084 af Outflow=2.42 cfs 0.704 af

Pond 4P: Forebay Peak Elev=402.19' Storage=0.062 af Inflow=9.16 cfs 1.408 af
Outflow=9.15 cfs 1.346 af

Total Runoff Area = 19.900 ac Runoff Volume = 1.408 af Average Runoff Depth = 0.85"
88.00% Pervious = 17.512 ac 12.00% Impervious = 2.388 ac

Summary for Subcatchment 1S: Drainage Area

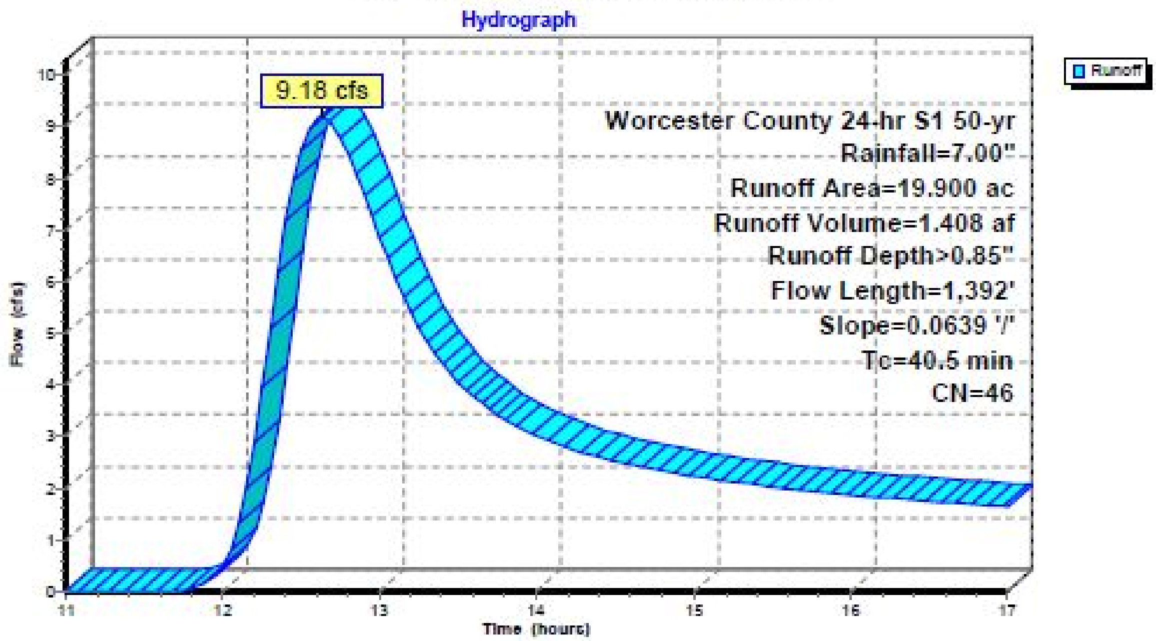
Runoff = 9.18 cfs @ 12.63 hrs, Volume= 1.408 af, Depth> 0.85"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 11.00-17.00 hrs, dt= 0.05 hrs
Worcester County 24-hr S1 50-yr Rainfall=7.00"

Area (ac)	CN	Description
19.900	46	2 acre lots, 12% imp, HSG A
17.512		88.00% Pervious Area
2.388		12.00% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
40.5	1,392	0.0639	0.57		**Lag/CN Method,**

Subcatchment 1S: Drainage Area



Summary for Reach 2R: Inflow

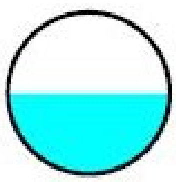
[52] Hint: Inlet/Outlet conditions not evaluated

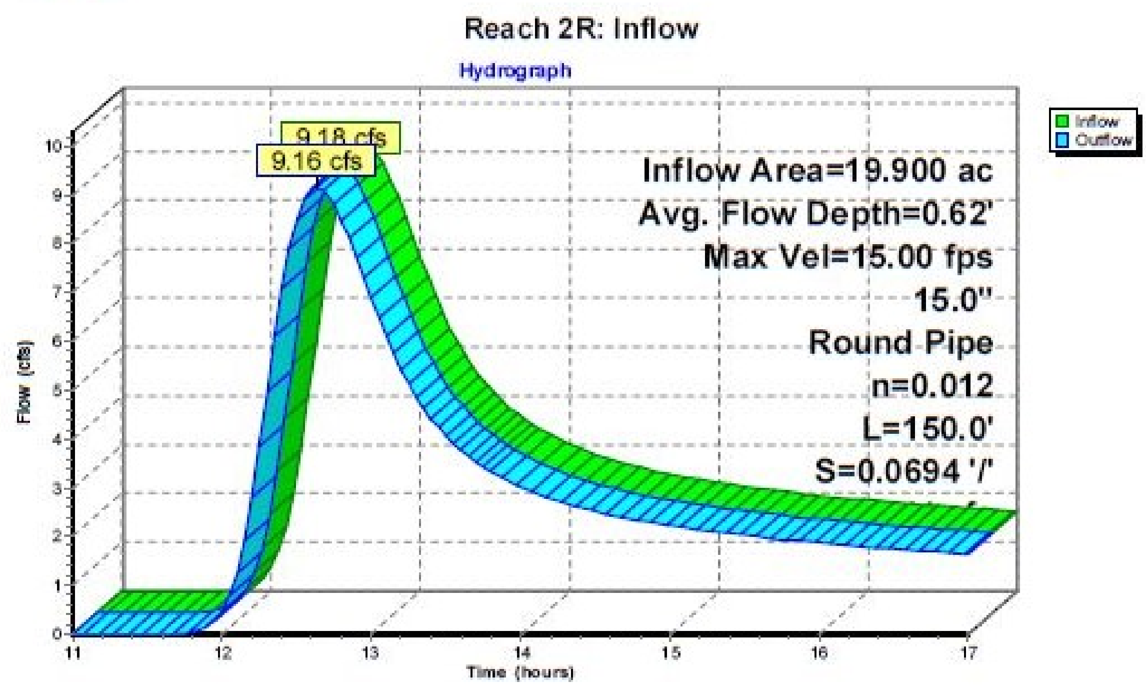
Inflow Area = 19.900 ac, 12.00% Impervious, Inflow Depth > 0.85"
Inflow = 9.18 cfs @ 12.63 hrs, Volume= 1.408 af
Outflow = 9.16 cfs @ 12.64 hrs, Volume= 1.408 af, Atten= 0%, Lag= 0.3 min

Routing by Stor-Ind+Trans method, Time Span= 11.00-17.00 hrs, dt= 0.05 hrs / 2
Max. Velocity= 15.00 fps, Min. Travel Time= 0.2 min
Avg. Velocity = 10.41 fps, Avg. Travel Time= 0.2 min

Peak Storage= 92 cf @ 12.63 hrs
Average Depth at Peak Storage= 0.62'
Bank-Full Depth= 1.25' Flow Area= 1.2 sf, Capacity= 18.44 cfs

15.0" Round Pipe
n= 0.012 Concrete pipe, finished
Length= 150.0' Slope= 0.0694 '/'
Inlet Invert= 412.91', Outlet Invert= 402.50'





Summary for Pond 3P: Bioretention Basin

Inflow Area = 19.900 ac, 12.00% Impervious, Inflow Depth > 0.81"
Inflow = 9.15 cfs @ 12.64 hrs, Volume= 1.346 af
Outflow = 2.42 cfs @ 14.65 hrs, Volume= 0.704 af, Atten= 73%, Lag= 120.4 min
Discarded = 1.64 cfs @ 14.65 hrs, Volume= 0.620 af
Primary = 0.78 cfs @ 14.65 hrs, Volume= 0.084 af

Routing by Stor-Ind method, Time Span= 11.00-17.00 hrs, dt= 0.05 hrs / 2
Peak Elev= 399.06' @ 14.65 hrs Surf.Area= 6,989 sf Storage= 28,358 cf

Plug-Flow detention time= 114.2 min calculated for 0.698 af (52% of inflow)
Center-of-Mass det. time= 51.8 min (887.5 - 835.7)

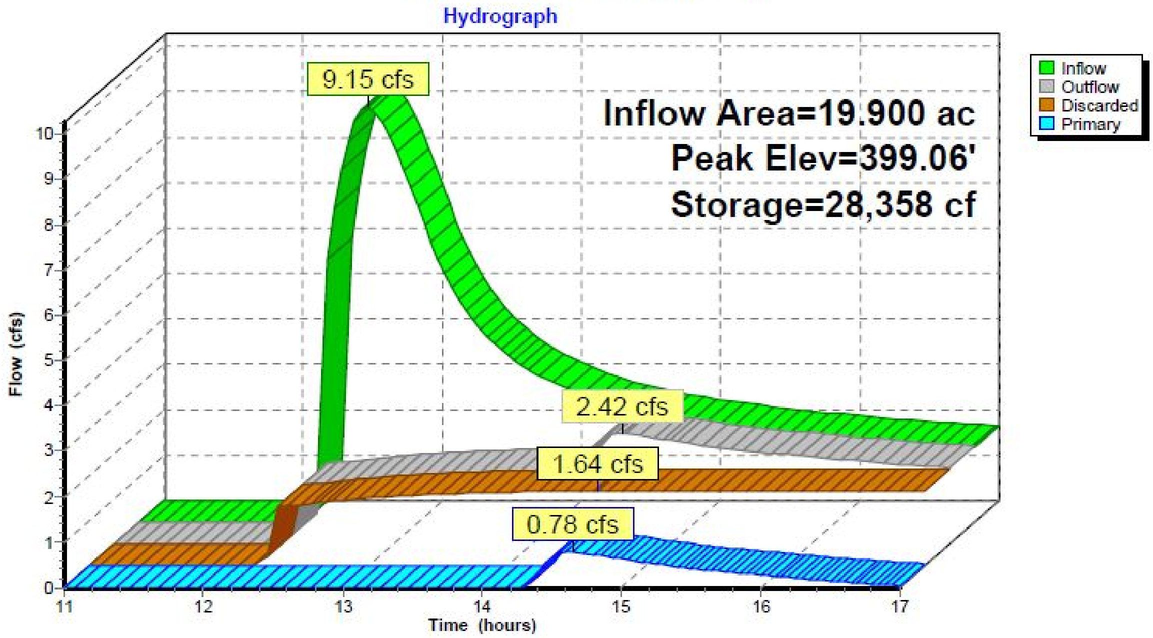
Volume	Invert	Avail.Storage	Storage Description
#1	395.00'	29,703 cf	**83.60'W x 83.60'L x 4.25'H Prismatoid**

Device	Routing	Invert	Outlet Devices
#1	Discarded	395.00'	**8.000 in/hr Exfiltration over Surface area** Conductivity to Groundwater Elevation = 380.00'
#2	Primary	399.00'	**20.0' long x 1.0' breadth Broad-Crested Rectangular Weir** Head (feet) 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00 2.50 3.00 Coef. (English) 2.69 2.72 2.75 2.85 2.98 3.08 3.20 3.28 3.31 3.30 3.31 3.32

Discarded OutFlow Max=1.64 cfs @ 14.65 hrs HW=399.06' (Free Discharge)
└─**1=Exfiltration** (Controls 1.64 cfs)

Primary OutFlow Max=0.74 cfs @ 14.65 hrs HW=399.06' (Free Discharge)
└─**2=Broad-Crested Rectangular Weir** (Weir Controls 0.74 cfs @ 0.65 fps)

Pond 3P: Bioretention Basin



Summary for Pond 4P: Forebay

Inflow Area = 19.900 ac, 12.00% Impervious, Inflow Depth > 0.85"
Inflow = 9.16 cfs @ 12.64 hrs, Volume= 1.408 af
Outflow = 9.15 cfs @ 12.64 hrs, Volume= 1.346 af, Atten= 0%, Lag= 0.4 min
Primary = 9.15 cfs @ 12.64 hrs, Volume= 1.346 af

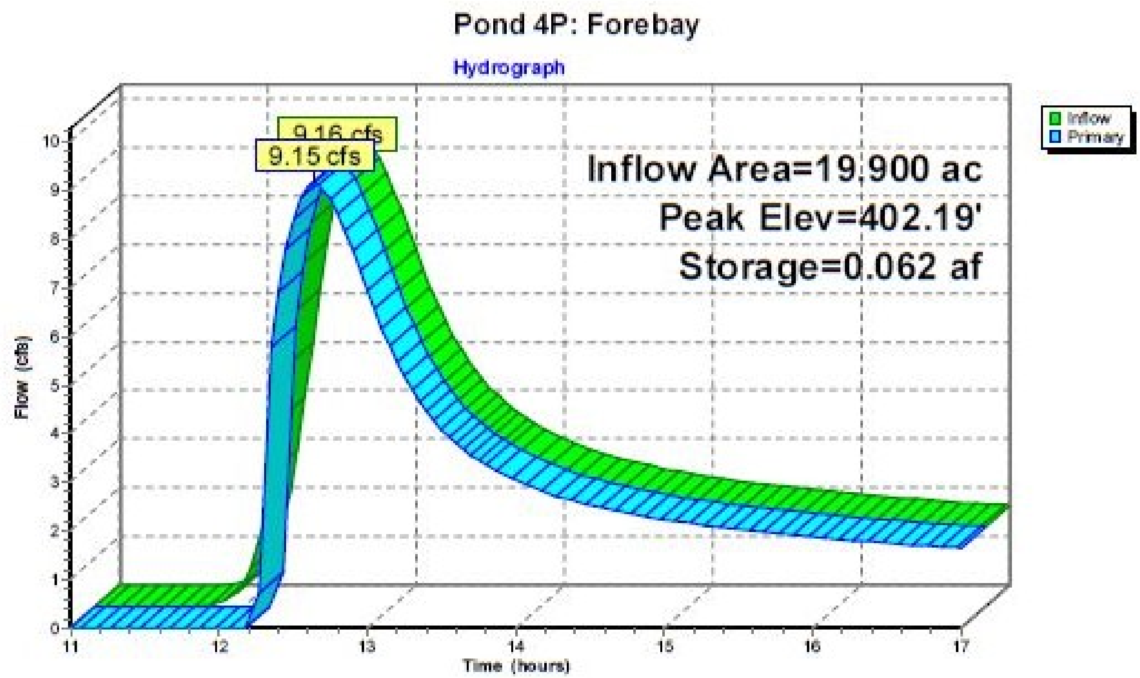
Routing by Stor-Ind method, Time Span= 11.00-17.00 hrs, dt= 0.05 hrs / 2
Peak Elev= 402.19' @ 12.64 hrs Surf.Area= 0.037 ac Storage= 0.062 af

Plug-Flow detention time= 12.8 min calculated for 1.346 af (96% of inflow)
Center-of-Mass det. time= 4.8 min (835.7 - 830.9)

Volume	Invert	Avail.Storage	Storage Description
#1	400.50'	0.073 af	**40.00'W x 40.00'L x 2.00'H Prismatoid**

Device	Routing	Invert	Outlet Devices
#1	Primary	402.00'	**40.0' long x 1.0' breadth Broad-Crested Rectangular Weir** Head (feet) 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00 2.50 3.00 Coef. (English) 2.69 2.72 2.75 2.85 2.98 3.08 3.20 3.28 3.31 3.30 3.31 3.32

Primary OutFlow Max=9.13 cfs @ 12.64 hrs HW=402.19' (Free Discharge)
↑—**1=Broad-Crested Rectangular Weir** (Weir Controls 9.13 cfs @ 1.18 fps)



9.6 Appendix F: Weir

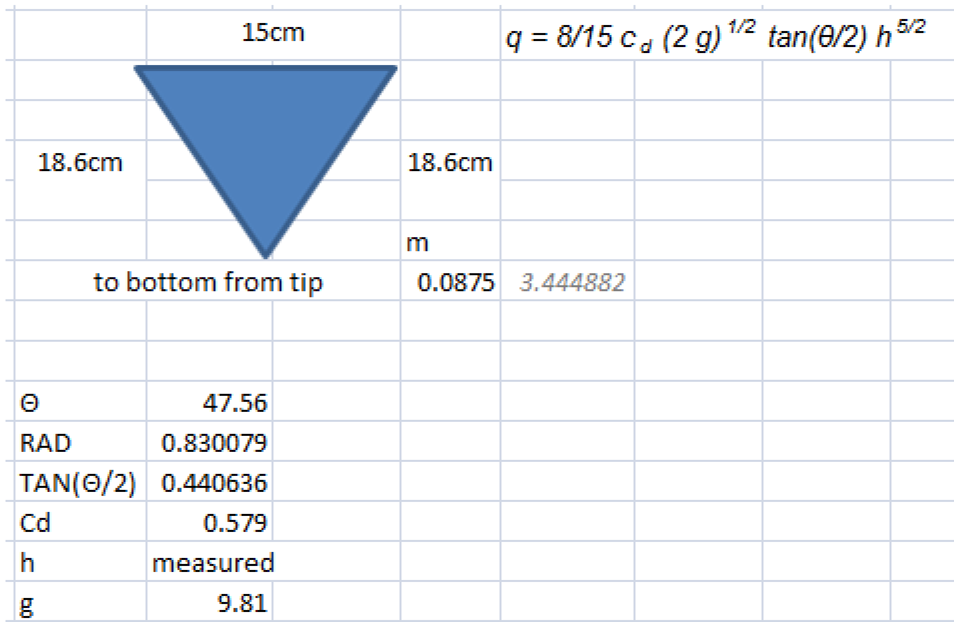
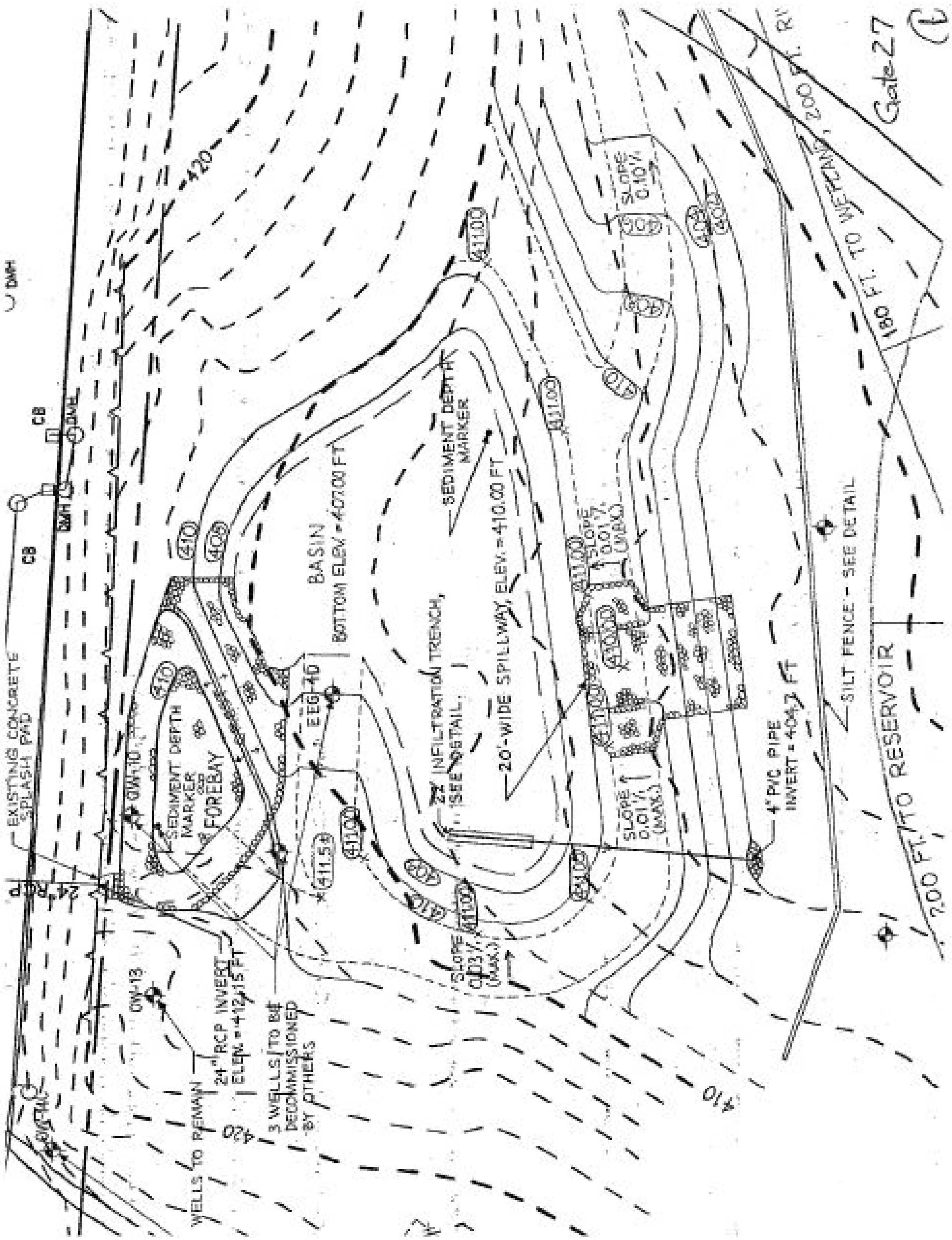
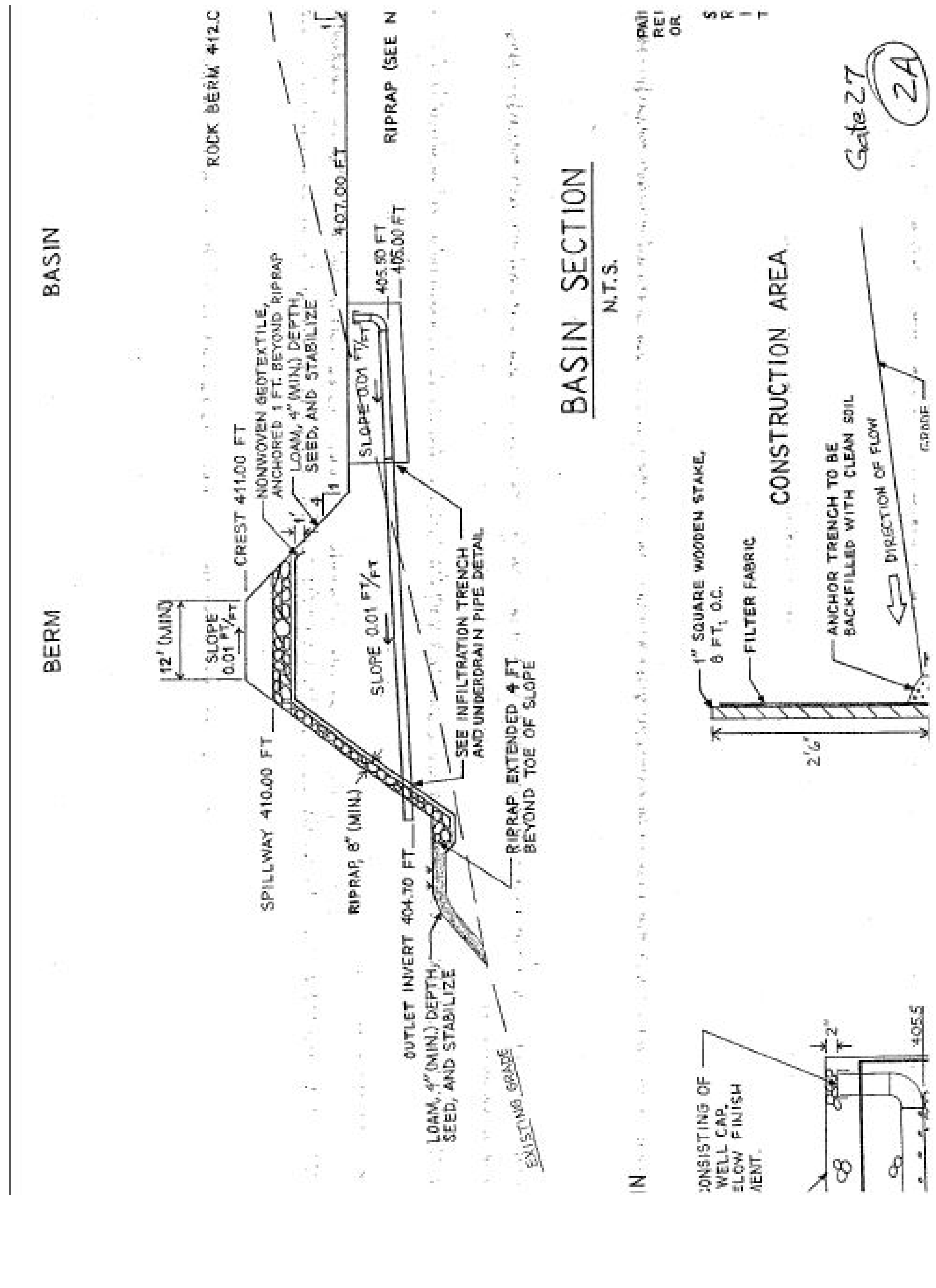


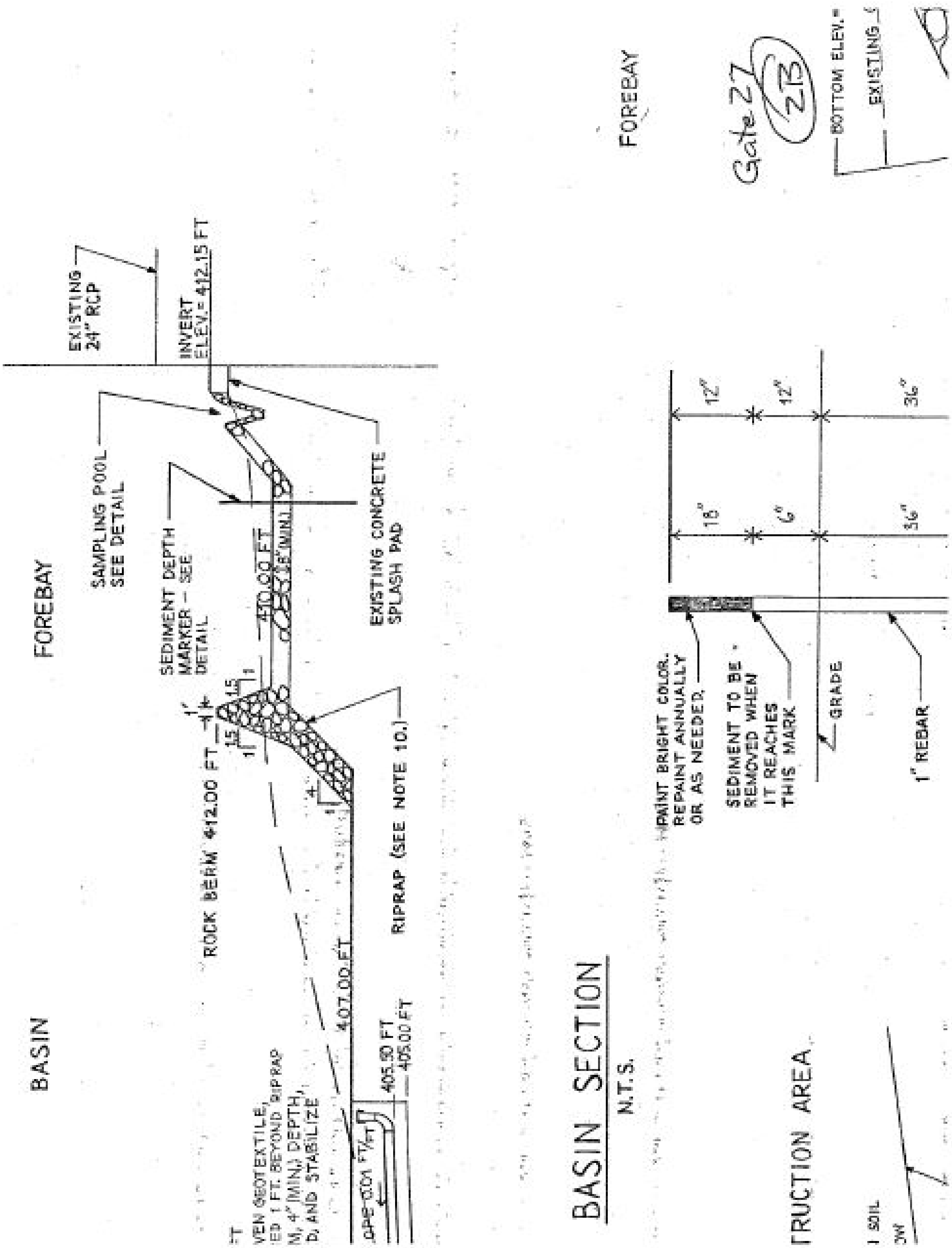
Table 40: Observations and Calculations for Gate 27 Outflow Weir

Date	Time	Height (in)	Height (m)	Q(m3/s)	Q (cfs)
12/10/2012	9:10 AM	1.5	0.0381	0.000171	0.006031
12/10/2012	10:35 AM	1.375	0.034925	0.000137	0.004852
12/10/2012	8:20 AM	2.2	0.05588	0.000445	0.015711

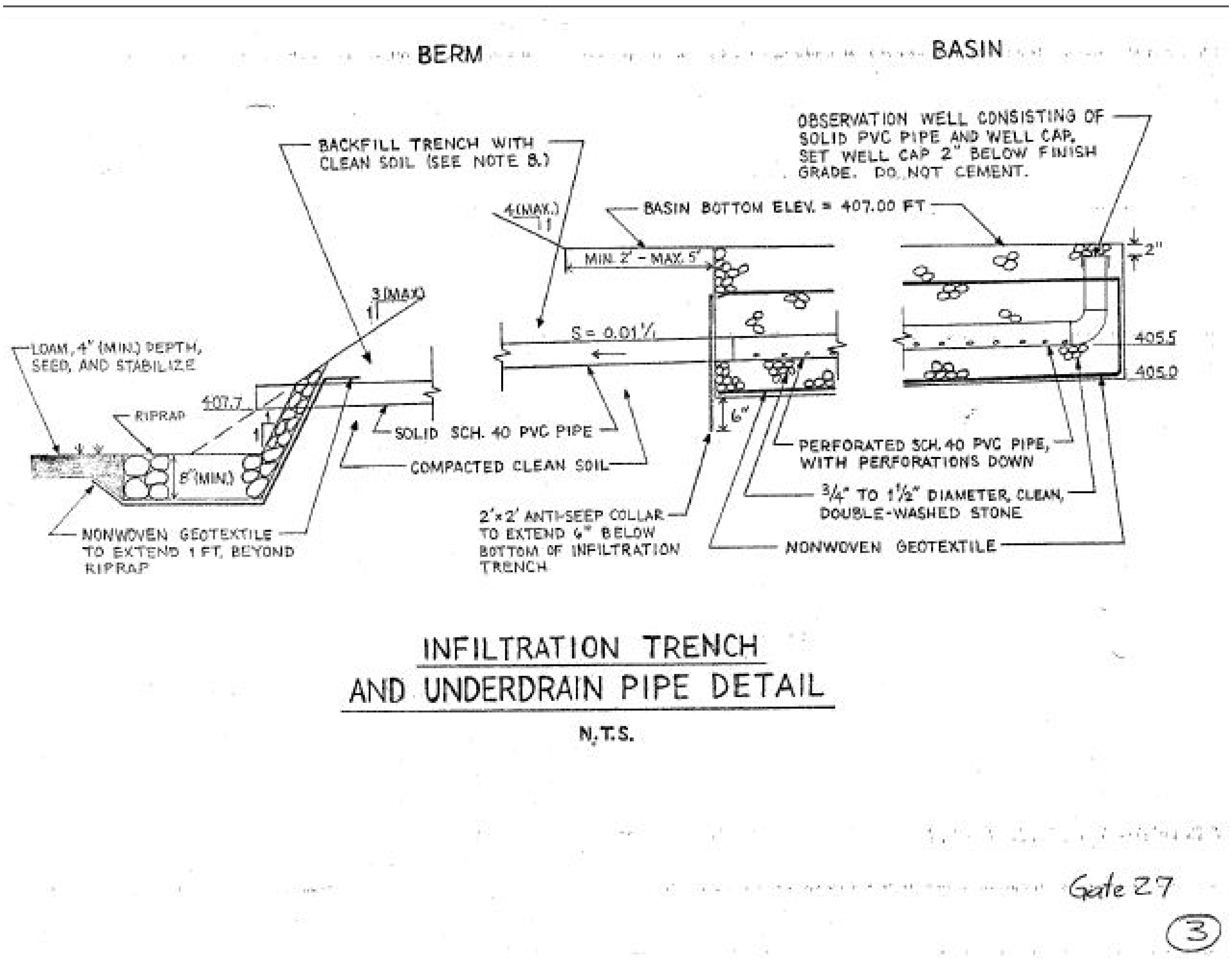
9.7 Appendix G: Gate 27 Designs




BERM
BASIN
12' (MIN.)
SLOPE 0.01 FT/FT
CREST 411.00 FT
NONWOVEN GEOTEXTILE, ANCHORED 1 FT. BEYOND RIPRAP
LOAM, 4" (MIN.) DEPTH, SEED, AND STABILIZE
ROCK BERM 412.C
407.00 FT
SLOPE 0.01 FT/FT
405.90 FT
405.00 FT
RIPRAP (SEE N
SPILLWAY 410.00 FT
SLOPE 0.01 FT/FT
SEE INFILTRATION TRENCH AND UNDERDRAIN PIPE DETAIL
RIPRAP, 8" (MIN.)
OUTLET INVERT 404.70 FT
RIPRAP EXTENDED 4 FT BEYOND TOE OF SLOPE
LOAM, 4" (MIN.) DEPTH, SEED, AND STABILIZE
EXISTING GRADE
BASIN SECTION
N.T.S.
1" SQUARE WOODEN STAKE, 8 FT. O.C.
FILTER FABRIC
CONSTRUCTION AREA
ANCHOR TRENCH TO BE BACKFILLED WITH CLEAN SOIL
DIRECTION OF FLOW
GRADE
2'6"
Gate 27
2A
405.5
2"



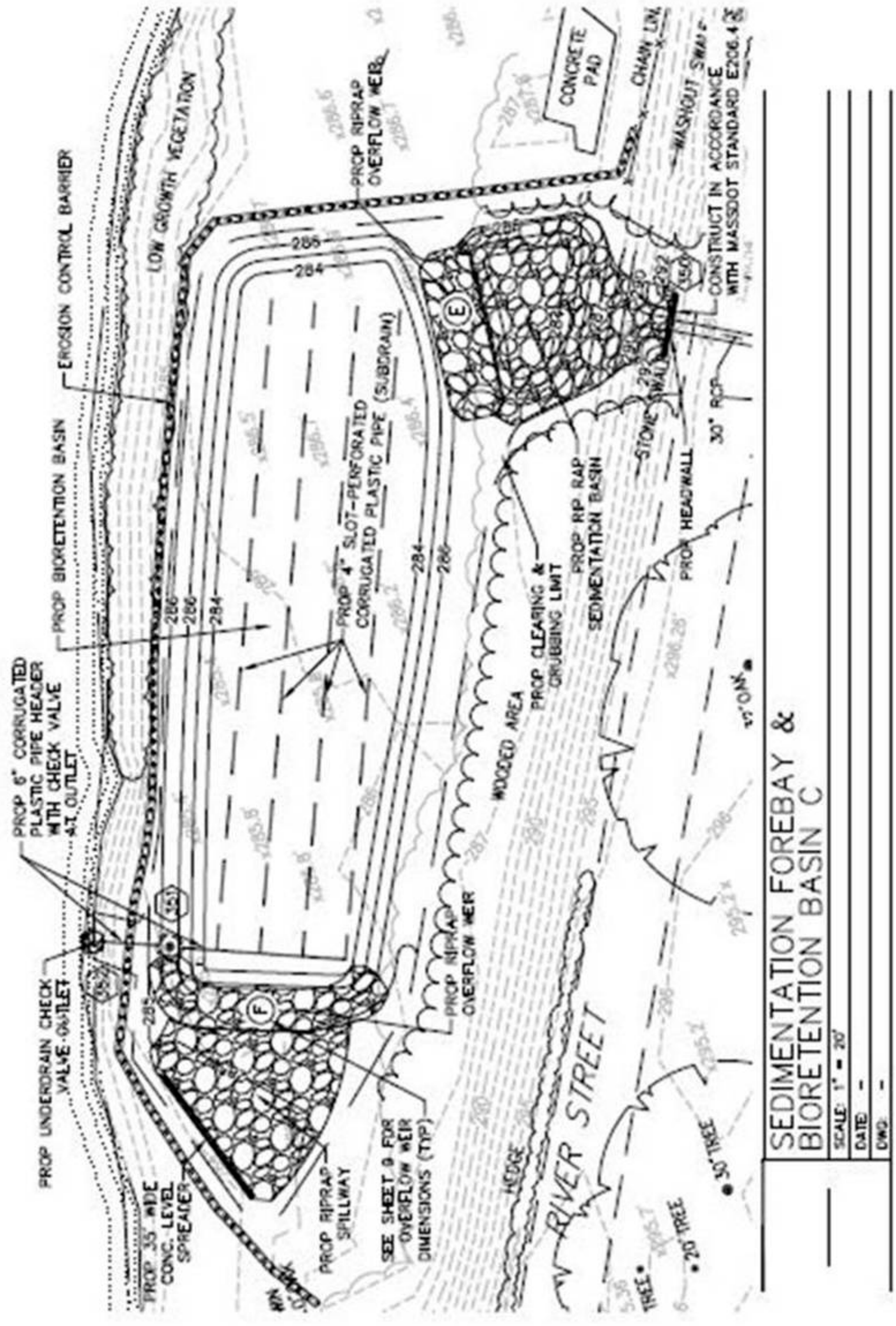
BASIN
FOREBAY
ROCK BERM 412.00 FT
1'
1.5
1
4
407.00 FT
405.50 FT
405.00 FT
RIPRAP (SEE NOTE 10.)
SEDIMENT DEPTH MARKER – SEE DETAIL
SAMPLING POOL SEE DETAIL
410.00 FT
EXISTING CONCRETE SPLASH PAD
EXISTING 24" RCP
INVERT ELEV.= 412.15 FT
BASIN SECTION
N.T.S.
PAINT BRIGHT COLOR. REPAINT ANNUALLY OR AS NEEDED.
SEDIMENT TO BE REMOVED WHEN IT REACHES THIS MARK
GRADE
1" REBAR
12"
18"
6"
36"
FOREBAY
Gate 27
2B
BOTTOM ELEV.=
EXISTING

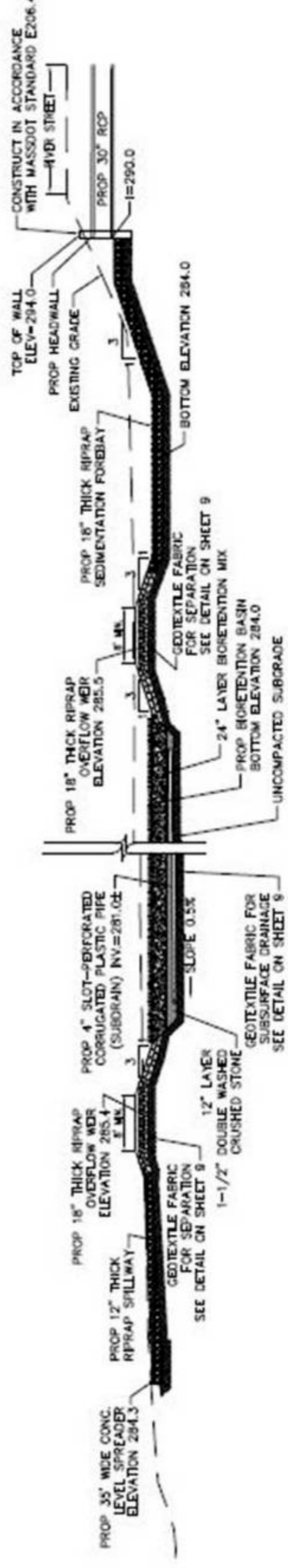


INFILTRATION TRENCH AND UNDERDRAIN PIPE DETAIL

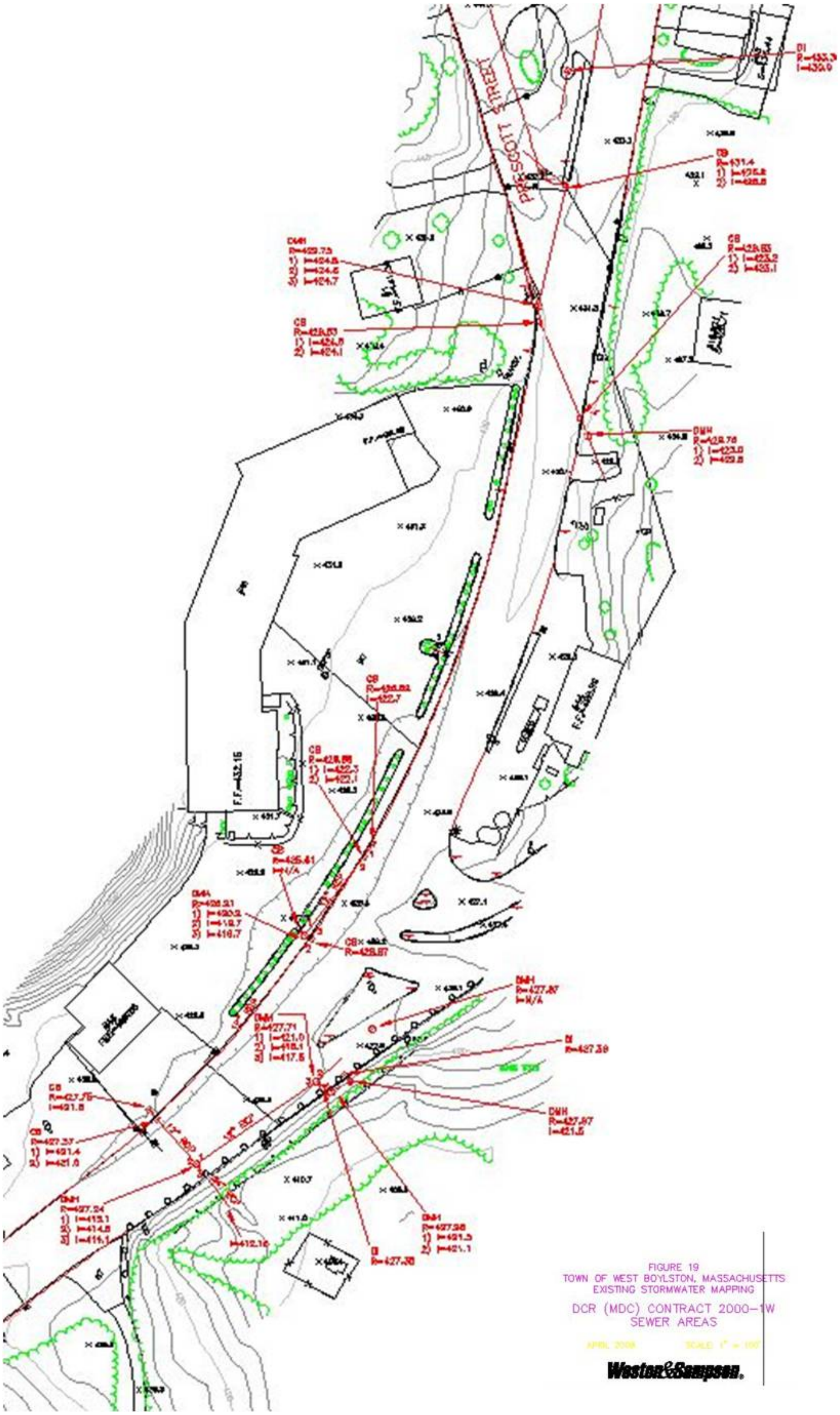
N.T.S.

9.8 Appendix H: River Street Designs




CONSTRUCT IN ACCORDANCE WITH MASSDOT STANDARD E206.4
PROP 30" RCP
I=290.0
TOP OF WALL ELEV=294.0
PROP HEADWALL
EXISTING GRADE
BOTTOM ELEVATION 284.0
PROP 18" THICK RIPRAP SEDIMENTATION FOREBAY
GEOTEXTILE FABRIC FOR SEPARATION SEE DETAIL ON SHEET 9
PROP 18" THICK RIPRAP OVERFLOW WEIR ELEVATION 285.5
24" LAYER BIORETENTION MIX
PROP BIORETENTION BASIN BOTTOM ELEVATION 284.0
UNCOMPACTED SUBGRADE
PROP 4" SLOT-PERFORATED CORRUGATED PLASTIC PIPE (SUBDRAIN) INV=281.0±
SLOPE 0.5%
GEOTEXTILE FABRIC FOR SUBSURFACE DRAINAGE SEE DETAIL ON SHEET 9
12" LAYER 1-1/2" DOUBLE WASHED CRUSHED STONE
PROP 18" THICK RIPRAP OVERFLOW WEIR ELEVATION 285.4
GEOTEXTILE FABRIC FOR SEPARATION SEE DETAIL ON SHEET 9
PROP 12" THICK RIPRAP SPILLWAY
PROP 35' WIDE CONC. LEVEL SPREADER ELEVATION 284.3

9.9 Appendix I: West Boylston Stormwater System



9.10 Appendix J: Depth Probe Data

Table 41: Depth Probe Data for Gate 27 11/7/2012 Storm

Date and Time	Seconds	Pressure (PSI)	Temperature (°F)	Level Surface Elevation (in)
11/7/2012 15:03	0	0.006	38.725	0.218
11/7/2012 15:08	300.001	0	38.438	0.062
11/7/2012 15:13	600.001	0.003	38.512	0.14
11/7/2012 15:18	900.001	0.005	38.635	0.196
11/7/2012 15:23	1200.001	0.003	38.042	0.143
11/7/2012 15:28	1500.001	0.005	37.984	0.187
11/7/2012 15:33	1800.001	0.004	37.248	0.171
11/7/2012 15:38	2100.001	0.003	37.319	0.13
11/7/2012 15:43	2400.001	0.003	36.818	0.132
11/7/2012 15:48	2700.001	0.004	35.782	0.167
11/7/2012 15:53	3000.001	0.002	35.735	0.118
11/7/2012 15:58	3300.001	0.003	35.43	0.148
11/7/2012 16:03	3600.001	0.004	35.622	0.163
11/7/2012 16:08	3900.001	0.005	35.432	0.185
11/7/2012 16:13	4200.001	0.002	35.28	0.115
11/7/2012 16:18	4500.001	0.004	35.854	0.174
11/7/2012 16:23	4800.001	0.006	35.76	0.211
11/7/2012 16:28	5100.001	0.003	36.019	0.128
11/7/2012 16:33	5400.001	0.005	36.334	0.195
11/7/2012 16:38	5700.001	0.005	36.007	0.188
11/7/2012 16:43	6000.001	0.004	35.479	0.153
11/7/2012 16:48	6300.001	0.004	35.327	0.176
11/7/2012 16:53	6600.001	0.004	35.692	0.163
11/7/2012 16:58	6900.001	0.005	36.457	0.183
11/7/2012 17:03	7200.001	0.004	36.72	0.153
11/7/2012 17:08	7500.001	0.004	37.416	0.162
11/7/2012 17:13	7800.001	0.005	37.202	0.184
11/7/2012 17:18	8100.001	0.005	37.296	0.198
11/7/2012 17:23	8400.001	0.004	37.294	0.16
11/7/2012 17:28	8700.001	0.004	37.302	0.162
11/7/2012 17:33	9000.001	0.007	37.147	0.233
11/7/2012 17:38	9300.001	0.004	36.82	0.163
11/7/2012 17:43	9600.001	0.005	37.105	0.188
11/7/2012 17:48	9900.001	0.005	37.01	0.18
11/7/2012 17:53	10200.001	0.005	37.007	0.181
11/7/2012 17:58	10500.001	0.003	36.717	0.129
11/7/2012 18:03	10800.001	0.006	36.492	0.213

11/7/2012 18:08	11100.001	0.004	36.915	0.174
11/7/2012 18:13	11400.001	0.005	37.575	0.2
11/7/2012 18:18	11700.001	0.004	37.136	0.162
11/7/2012 18:23	12000.001	0.006	37.02	0.225
11/7/2012 18:28	12300.001	0.006	36.539	0.216
11/7/2012 18:33	12600.001	0.003	36.613	0.136
11/7/2012 18:38	12900.001	0.004	36.578	0.164
11/7/2012 18:43	13200.001	0.005	36.984	0.201
11/7/2012 18:48	13500.001	0.007	36.895	0.243
11/7/2012 18:53	13800.001	0.006	36.921	0.213
11/7/2012 18:58	14100.001	0.003	36.526	0.144
11/7/2012 19:03	14400.001	0.006	35.96	0.205
11/7/2012 19:08	14700.001	0.005	35.697	0.183
11/7/2012 19:13	15000.001	0.004	35.275	0.156
11/7/2012 19:18	15300.001	0.004	34.833	0.163
11/7/2012 19:23	15600.001	0.004	35.239	0.155
11/7/2012 19:28	15900.001	0.003	35.102	0.146
11/7/2012 19:33	16200.001	0.004	35.277	0.153
11/7/2012 19:38	16500.001	0.005	35.389	0.184
11/7/2012 19:43	16800.001	0.005	35.613	0.181
11/7/2012 19:48	17100.001	0.005	35.095	0.2
11/7/2012 19:53	17400.001	0.005	34.925	0.196
11/7/2012 19:58	17700.001	0.005	35.245	0.195
11/7/2012 20:03	18000.001	0.006	35.483	0.209
11/7/2012 20:08	18300.001	0.004	35.135	0.169
11/7/2012 20:13	18600.001	0.005	35.735	0.181
11/7/2012 20:18	18900.001	0.006	35.994	0.212
11/7/2012 20:23	19200.001	0.008	36.455	0.268
11/7/2012 20:28	19500.001	0.006	36.181	0.211
11/7/2012 20:33	19800.001	0.003	36.602	0.126
11/7/2012 20:38	20100.001	0.006	36.821	0.227
11/7/2012 20:43	20400.001	0.005	36.917	0.198
11/7/2012 20:48	20700.001	0.005	36.992	0.181
11/7/2012 20:53	21000.001	0.005	36.306	0.198
11/7/2012 20:58	21300.001	0.006	36.202	0.207
11/7/2012 21:03	21600.001	0.002	43.945	0.113
11/7/2012 21:08	21900.001	0.003	51.005	0.127
11/7/2012 21:13	22200.001	0.002	52.261	0.096
11/7/2012 21:18	22500.001	0.001	52.499	0.08
11/7/2012 21:23	22800.001	0.001	52.121	0.091
11/7/2012 21:28	23100.001	0.001	51.567	0.093

11/7/2012 21:33	23400.001	0.002	51.472	0.096
11/7/2012 21:38	23700.001	0.003	51.082	0.133
11/7/2012 21:43	24000.001	0.002	50.829	0.108
11/7/2012 21:48	24300.001	0.001	50.357	0.075
11/7/2012 21:53	24600.001	0.002	49.872	0.122
11/7/2012 21:58	24900.001	0.001	50.241	0.077
11/7/2012 22:03	25200.001	0	50.52	0.058
11/7/2012 22:08	25500.001	0.003	50.391	0.138
11/7/2012 22:13	25800.001	0.002	49.946	0.1
11/7/2012 22:18	26100.001	0.003	49.787	0.129
11/7/2012 22:23	26400.001	0.002	49.278	0.122
11/7/2012 22:28	26700.001	0.003	48.943	0.138
11/7/2012 22:33	27000.001	0.002	48.58	0.122
11/7/2012 22:38	27300.001	0.002	48.947	0.111
11/7/2012 22:43	27600.001	0.001	49.057	0.079
11/7/2012 22:48	27900.001	0.001	49.607	0.094
11/7/2012 22:53	28200.001	0.003	50.251	0.147
11/7/2012 22:58	28500.001	0.006	50.156	0.213
11/7/2012 23:03	28800.001	0.011	49.713	0.343
11/7/2012 23:08	29100.001	0.013	49.169	0.4
11/7/2012 23:13	29400.001	0.014	48.528	0.439
11/7/2012 23:18	29700.001	0.014	47.674	0.441
11/7/2012 23:23	30000.001	0.009	47.11	0.306
11/7/2012 23:28	30300.001	0.009	46.949	0.314
11/7/2012 23:33	30600.001	0.011	46.917	0.348
11/7/2012 23:38	30900.001	0.01	46.896	0.316
11/7/2012 23:43	31200.001	0.009	46.843	0.294
11/7/2012 23:48	31500.001	0.01	46.847	0.328
11/7/2012 23:53	31800.001	0.007	46.835	0.256
11/7/2012 23:58	32100.001	0.007	46.941	0.253
11/8/2012 0:03	32400.001	0.007	46.967	0.255
11/8/2012 0:08	32700.001	0.004	47.108	0.176
11/8/2012 0:13	33000.001	0.004	47.16	0.173
11/8/2012 0:18	33300.001	0.003	47.228	0.134
11/8/2012 0:23	33600.001	0.003	47.417	0.146
11/8/2012 0:28	33900.001	0	47.601	0.061
11/8/2012 0:33	34200.001	0.003	47.698	0.126
11/8/2012 0:38	34500.001	0.004	47.946	0.169
11/8/2012 0:43	34800.001	0.002	47.979	0.114
11/8/2012 0:48	35100.001	0	48.032	0.046
11/8/2012 0:53	35400.001	0	47.96	0.068

11/8/2012 0:58	35700.001	-0.001	47.979	0.033
11/8/2012 1:03	36000.001	-0.001	47.973	0.026
11/8/2012 1:08	36300.001	-0.001	48.054	0.015
11/8/2012 1:13	36600.001	0.001	48.029	0.082
11/8/2012 1:18	36900.001	-0.001	48.035	0.02
11/8/2012 1:23	37200.001	-0.001	47.968	0.029
11/8/2012 1:28	37500.001	-0.001	47.878	0.019
11/8/2012 1:33	37800.001	0	47.8	0.047
11/8/2012 1:38	38100.001	-0.001	47.831	0.029
11/8/2012 1:43	38400.001	0.001	48.18	0.078
11/8/2012 1:48	38700.001	0.001	48.627	0.072
11/8/2012 1:53	39000.001	-0.001	49.128	0.038
11/8/2012 1:58	39300.001	-0.001	49.273	0.031
11/8/2012 2:03	39600.001	-0.001	49.346	0.04
11/8/2012 2:08	39900.001	-0.001	49.44	0.019
11/8/2012 2:13	40200.001	0.017	49.752	0.527
11/8/2012 2:18	40500.001	0.03	48.893	0.884
11/8/2012 2:23	40800.001	0.04	44.752	1.145
11/8/2012 2:28	41100.001	0.031	42.185	0.894
11/8/2012 2:33	41400.001	0.029	40.677	0.86
11/8/2012 2:38	41700.001	0.03	40.234	0.88
11/8/2012 2:43	42000.001	0.03	40.091	0.865
11/8/2012 2:48	42300.001	0.028	39.986	0.812
11/8/2012 2:53	42600.001	0.035	39.784	1.02
11/8/2012 2:58	42900.001	0.039	39.079	1.11
11/8/2012 3:03	43200.001	0.038	38.288	1.097
11/8/2012 3:08	43500.001	0.039	37.753	1.127
11/8/2012 3:13	43800.001	0.036	37.322	1.044
11/8/2012 3:18	44100.001	0.033	37.174	0.964
11/8/2012 3:23	44400.001	0.03	37.281	0.878
11/8/2012 3:28	44700.001	0.032	37.486	0.923
11/8/2012 3:33	45000.001	0.027	37.758	0.79
11/8/2012 3:38	45300.001	0.019	38.146	0.578
11/8/2012 3:43	45600.001	0.023	38.592	0.686
11/8/2012 3:48	45900.001	0.022	38.777	0.667
11/8/2012 3:53	46200.001	0.022	38.827	0.644
11/8/2012 3:58	46500.001	0.023	38.85	0.678
11/8/2012 4:03	46800.001	0.026	38.854	0.771
11/8/2012 4:08	47100.001	0.028	38.867	0.829
11/8/2012 4:13	47400.001	0.032	38.793	0.921
11/8/2012 4:18	47700.001	0.03	38.641	0.866

11/8/2012 4:23	48000.001	0.034	38.415	0.978
11/8/2012 4:28	48300.001	0.034	38.245	0.978
11/8/2012 4:33	48600.001	0.033	38.227	0.955
11/8/2012 4:38	48900.001	0.034	38.179	0.989
11/8/2012 4:43	49200.001	0.031	38.065	0.914
11/8/2012 4:48	49500.001	0.035	37.898	1.015
11/8/2012 4:53	49800.001	0.03	37.801	0.882
11/8/2012 4:58	50100.001	0.029	37.945	0.85
11/8/2012 5:03	50400.001	0.026	38.233	0.779
11/8/2012 5:08	50700.001	0.03	38.404	0.872
11/8/2012 5:13	51000.001	0.025	38.536	0.745
11/8/2012 5:18	51300.001	0.025	38.792	0.725
11/8/2012 5:23	51600.001	0.023	39.03	0.687
11/8/2012 5:28	51900.001	0.024	39.271	0.7
11/8/2012 5:33	52200.001	0.02	39.526	0.599
11/8/2012 5:38	52500.001	0.021	39.789	0.618
11/8/2012 5:43	52800.001	0.02	40.018	0.606
11/8/2012 5:48	53100.001	0.023	40.221	0.677
11/8/2012 5:53	53400.001	0.018	40.407	0.535
11/8/2012 5:58	53700.001	0.02	40.529	0.599
11/8/2012 6:03	54000.001	0.019	40.693	0.563
11/8/2012 6:08	54300.001	0.019	40.808	0.587
11/8/2012 6:13	54600.001	0.019	40.975	0.586
11/8/2012 6:18	54900.001	0.017	41.182	0.53
11/8/2012 6:23	55200.001	0.016	41.37	0.488
11/8/2012 6:28	55500.001	0.018	41.451	0.555
11/8/2012 6:33	55800.001	0.022	40.728	0.651
11/8/2012 6:38	56100.001	0.032	40.34	0.926
11/8/2012 6:43	56400.001	0.033	40.262	0.962
11/8/2012 6:48	56700.001	0.051	39.458	1.455
11/8/2012 6:53	57000.001	0.05	38.086	1.417
11/8/2012 6:58	57300.001	0.053	37.133	1.492
11/8/2012 7:03	57600.001	0.055	36.211	1.555
11/8/2012 7:08	57900.001	0.055	35.63	1.549
11/8/2012 7:13	58200.001	0.059	35.476	1.658
11/8/2012 7:18	58500.001	0.056	35.494	1.591
11/8/2012 7:23	58800.001	0.06	35.46	1.691
11/8/2012 7:28	59100.001	0.056	35.482	1.58
11/8/2012 7:33	59400.001	0.054	35.534	1.542
11/8/2012 7:38	59700.001	0.053	35.671	1.511
11/8/2012 7:43	60000.001	0.053	35.745	1.504

11/8/2012 7:48	60300.001	0.056	35.733	1.59
11/8/2012 7:53	60600.001	0.054	35.682	1.543
11/8/2012 7:58	60900.001	0.061	35.544	1.715
11/8/2012 8:03	61200.001	0.06	35.265	1.687
11/8/2012 8:08	61500.001	0.059	35.09	1.664
11/8/2012 8:13	61800.001	0.056	35.063	1.598
11/8/2012 8:18	62100.001	0.057	35.063	1.623
11/8/2012 8:23	62400.001	0.056	35.05	1.592
11/8/2012 8:28	62700.001	0.054	35.134	1.536
11/8/2012 8:33	63000.001	0.052	35.281	1.463
11/8/2012 8:38	63300.001	0.054	35.432	1.528
11/8/2012 8:43	63600.001	0.05	35.607	1.411
11/8/2012 8:48	63900.001	0.049	35.783	1.4
11/8/2012 8:53	64200.001	0.051	35.961	1.45
11/8/2012 8:58	64500.001	0.056	35.957	1.588
11/8/2012 9:03	64800.001	0.061	35.654	1.715
11/8/2012 9:08	65100.001	0.07	35.285	1.966
11/8/2012 9:13	65400.001	0.039	34.61	1.123
11/8/2012 9:18	65700.001	0.041	34.019	1.169
11/8/2012 9:23	66000.001	0.046	33.494	1.321
11/8/2012 9:28	66300.001	0.051	33.288	1.447
11/8/2012 9:33	66600.001	0.049	33.266	1.404
11/8/2012 9:38	66900.001	0.061	33.308	1.729
11/8/2012 9:43	67200.001	0.052	33.306	1.482
11/8/2012 9:48	67500.001	0.05	33.463	1.417
11/8/2012 9:53	67800.001	0.048	33.719	1.375
11/8/2012 9:58	68100.001	0.056	34.003	1.583
11/8/2012 10:03	68400.001	0.027	34.072	0.8
11/8/2012 10:08	68700.001	0.045	33.95	1.293
11/8/2012 10:13	69000.001	0.044	34.069	1.27
11/8/2012 10:18	69300.001	0.044	34.267	1.254
11/8/2012 10:23	69600.001	0.046	34.507	1.313
11/8/2012 10:28	69900.001	0.044	34.666	1.266
11/8/2012 10:33	70200.001	0.042	34.85	1.211
11/8/2012 10:38	70500.001	0.042	34.952	1.197
11/8/2012 10:43	70800.001	0.04	34.981	1.161
11/8/2012 10:48	71100.001	0.036	35.073	1.049
11/8/2012 10:53	71400.001	0.037	35.15	1.074
11/8/2012 10:58	71700.001	0.038	35.189	1.107
11/8/2012 11:03	72000.001	0.039	35.263	1.13
11/8/2012 11:08	72300.001	0.006	35.334	0.213

11/8/2012 11:13	72600.001	0.007	35.427	0.239
11/8/2012 11:18	72900.001	0.014	35.443	0.429
11/8/2012 11:23	73200.001	0.01	35.448	0.329
11/8/2012 11:28	73500.001	0.009	35.473	0.309
11/8/2012 11:33	73800.001	0.008	35.527	0.27
11/8/2012 11:38	74100.001	0.007	35.59	0.246
11/8/2012 11:43	74400.001	0.007	35.681	0.239
11/8/2012 11:48	74700.001	0.009	35.796	0.292
11/8/2012 11:53	75000.001	0.009	35.941	0.305
11/8/2012 11:58	75300.001	0.014	36.082	0.424
11/8/2012 12:03	75600.001	0.006	36.227	0.219
11/8/2012 12:08	75900.001	0.007	36.334	0.251
11/8/2012 12:13	76200.001	0.007	36.465	0.24
11/8/2012 12:18	76500.001	0.002	35.392	0.106
11/8/2012 12:23	76800.001	0	38.845	0.066
11/8/2012 12:28	77100.001	0.001	41.925	0.089
11/8/2012 12:33	77400.001	0.002	44.482	0.096
11/8/2012 12:38	77700.001	0.002	46.616	0.106
11/8/2012 12:43	78000.001	-0.002	48.253	0.005
11/8/2012 12:48	78300.001	-0.001	49.187	0.04
11/8/2012 12:53	78600.001	-0.003	50.263	-0.036
11/8/2012 12:58	78900.001	0	51.447	0.052
11/8/2012 13:03	79200.001	0	52.511	0.044
11/8/2012 13:08	79500.001	-0.002	53.183	0.006
11/8/2012 13:13	79800.001	-0.002	54.081	-0.012
11/8/2012 13:18	80100.001	-0.002	55.222	0.006
11/8/2012 13:23	80400.001	-0.003	56.343	-0.026
11/8/2012 13:28	80700.001	-0.004	56.587	-0.06
11/8/2012 13:33	81000.001	-0.005	55.802	-0.07
11/8/2012 13:38	81300.001	-0.003	54.862	-0.041
11/8/2012 13:43	81600.001	-0.002	53.787	-0.011
11/8/2012 13:48	81900.001	-0.003	53.512	-0.023
11/8/2012 13:53	82200.001	-0.003	53.905	-0.02
11/8/2012 13:58	82500.001	-0.004	54.633	-0.068
11/8/2012 14:03	82800.001	-0.003	55.524	-0.015
11/8/2012 14:08	83100.001	-0.002	56.459	-0.007
11/8/2012 14:13	83400.001	-0.003	57.37	-0.034
11/8/2012 14:18	83700.001	-0.006	58.208	-0.097
11/8/2012 14:23	84000.001	-0.004	58.971	-0.059
11/8/2012 14:28	84300.001	-0.004	59.665	-0.053
11/8/2012 14:33	84600.001	-0.004	60.295	-0.056

11/8/2012 14:38	84900.001	-0.004	60.873	-0.067
11/8/2012 14:43	85200.001	-0.004	61.399	-0.062
11/8/2012 14:48	85500.001	-0.005	61.896	-0.081
11/8/2012 14:53	85800.001	-0.004	62.343	-0.064
11/8/2012 14:58	86100.001	-0.006	62.748	-0.122
11/8/2012 15:03	86400.001	-0.003	63.112	-0.029
11/8/2012 15:08	86700.001	-0.004	63.438	-0.047
11/8/2012 15:13	87000.001	-0.006	63.723	-0.097
11/8/2012 15:18	87300.001	-0.004	63.983	-0.063
11/8/2012 15:23	87600.001	-0.004	64.214	-0.056
11/8/2012 15:28	87900.001	-0.005	64.432	-0.093
11/8/2012 15:33	88200.001	-0.005	64.653	-0.079
11/8/2012 15:38	88500.001	-0.004	64.851	-0.059
11/8/2012 15:43	88800.001	-0.005	65.041	-0.071
11/8/2012 15:48	89100.001	-0.004	65.222	-0.066
11/8/2012 15:53	89400.001	-0.006	65.393	-0.105
11/8/2012 15:58	89700.001	-0.004	65.547	-0.051
11/8/2012 16:03	90000.001	-0.005	65.7	-0.077
11/8/2012 16:08	90300.001	-0.005	65.844	-0.071
11/8/2012 16:13	90600.001	-0.005	65.98	-0.087
11/8/2012 16:18	90900.001	-0.004	66.108	-0.062
11/8/2012 16:23	91200.001	-0.003	66.221	-0.039
11/8/2012 16:28	91500.001	-0.005	66.335	-0.074
11/8/2012 16:33	91800.001	-0.005	66.435	-0.084
11/8/2012 16:38	92100.001	-0.005	66.531	-0.092
11/8/2012 16:43	92400.001	-0.006	66.626	-0.103
11/8/2012 16:48	92700.001	-0.003	66.707	-0.023
11/8/2012 16:53	93000.001	-0.004	66.8	-0.042
11/8/2012 16:58	93300.001	-0.006	66.887	-0.101
11/8/2012 17:03	93600.001	-0.005	66.97	-0.071
11/8/2012 17:08	93900.001	-0.005	67.055	-0.078
11/8/2012 17:13	94200.001	-0.003	67.135	-0.038
11/8/2012 17:18	94500.001	-0.006	67.222	-0.097
11/8/2012 17:23	94800.001	-0.006	67.304	-0.115
11/8/2012 17:28	95100.001	-0.004	67.39	-0.046
11/8/2012 17:33	95400.001	-0.004	67.471	-0.052
11/8/2012 17:38	95700.001	-0.005	67.547	-0.071
11/8/2012 17:43	96000.001	-0.006	67.614	-0.103
11/8/2012 17:48	96300.001	-0.005	67.691	-0.077
11/8/2012 17:53	96600.001	-0.004	67.766	-0.053
11/8/2012 17:58	96900.001	-0.003	67.834	-0.024

11/8/2012 18:03	97200.001	-0.003	67.902	-0.028
11/8/2012 18:08	97500.001	-0.002	67.968	0
11/8/2012 18:13	97800.001	-0.002	68.042	-0.006
11/8/2012 18:18	98100.001	-0.004	68.108	-0.065
11/8/2012 18:23	98400.001	-0.004	68.176	-0.065
11/8/2012 18:28	98700.001	-0.004	68.244	-0.064
11/8/2012 18:33	99000.001	-0.003	68.311	-0.031
11/8/2012 18:38	99300.001	-0.005	68.384	-0.075
11/8/2012 18:43	99600.001	-0.003	68.454	-0.04
11/8/2012 18:48	99900.001	-0.004	68.524	-0.068
11/8/2012 18:53	100200.001	-0.005	68.594	-0.076
11/8/2012 18:58	100500.001	-0.004	68.654	-0.051
11/8/2012 19:03	100800.001	-0.004	68.719	-0.064
11/8/2012 19:08	101100.001	-0.004	68.787	-0.044
11/8/2012 19:13	101400.001	-0.004	68.841	-0.045
11/8/2012 19:18	101700.001	-0.003	69.169	-0.033

Table 42: Depth Probe Data for River Street 12/9 - 12/10/2012 Storm

Date and Time	Seconds	Pressure (PSI)	Temperature (^{o}F)	Level Surface Elevation (in)
12/9/2012 22:15	0	0.008	50.059	0.242
12/9/2012 22:20	300.001	0.004	52.243	0.134
12/9/2012 22:25	600.001	0.007	54.21	0.197
12/9/2012 22:30	900.001	0.008	55.694	0.248
12/9/2012 22:35	1200.001	0.005	56.977	0.16
12/9/2012 22:40	1500.001	0.011	53.421	0.304
12/9/2012 22:45	1800.001	0.046	47.562	1.261
12/9/2012 22:50	2100.001	0.048	45.125	1.334
12/9/2012 22:55	2400.001	0.044	44.751	1.229
12/9/2012 23:00	2700.001	0.047	44.72	1.298
12/9/2012 23:05	3000.001	0.051	44.631	1.41
12/9/2012 23:10	3300.001	0.055	44.276	1.527
12/9/2012 23:15	3600.001	0.056	44.069	1.551
12/9/2012 23:20	3900.001	0.055	44.091	1.527
12/9/2012 23:25	4200.001	0.049	44.23	1.345
12/9/2012 23:30	4500.001	0.044	44.384	1.209
12/9/2012 23:35	4800.001	0.046	44.29	1.272
12/9/2012 23:40	5100.001	0.054	43.983	1.492
12/9/2012 23:45	5400.001	0.048	43.942	1.33
12/9/2012 23:50	5700.001	0.047	44.04	1.314
12/9/2012 23:55	6000.001	0.042	44.183	1.171
12/10/2012 0:00	6300.001	0.04	44.26	1.109

12/10/2012 0:05	6600.001	0.042	44.176	1.153
12/10/2012 0:10	6900.001	0.069	43.591	1.902
12/10/2012 0:15	7200.001	0.086	43.037	2.38
12/10/2012 0:20	7500.001	0.085	42.788	2.346
12/10/2012 0:25	7800.001	0.081	42.851	2.219
12/10/2012 0:30	8100.001	0.066	43.105	1.814
12/10/2012 0:35	8400.001	0.065	43.239	1.797
12/10/2012 0:40	8700.001	0.077	42.908	2.123
12/10/2012 0:45	9000.001	0.086	42.618	2.364
12/10/2012 0:50	9300.001	0.086	42.426	2.366
12/10/2012 0:55	9600.001	0.085	42.4	2.334
12/10/2012 1:00	9900.001	0.084	42.435	2.313
12/10/2012 1:05	10200.001	0.077	42.434	2.134
12/10/2012 1:10	10500.001	0.102	42.208	2.797
12/10/2012 1:15	10800.001	0.105	41.965	2.899
12/10/2012 1:20	11100.001	0.102	41.855	2.794
12/10/2012 1:25	11400.001	0.095	41.887	2.609
12/10/2012 1:30	11700.001	0.092	41.934	2.539
12/10/2012 1:35	12000.001	0.093	41.96	2.571
12/10/2012 1:40	12300.001	0.087	42.017	2.395
12/10/2012 1:45	12600.001	0.079	42.153	2.184
12/10/2012 1:50	12900.001	0.071	42.324	1.958
12/10/2012 1:55	13200.001	0.064	42.463	1.762
12/10/2012 2:00	13500.001	0.069	42.509	1.895
12/10/2012 2:05	13800.001	0.075	42.405	2.074
12/10/2012 2:10	14100.001	0.082	42.256	2.26
12/10/2012 2:15	14400.001	0.081	42.206	2.236
12/10/2012 2:20	14700.001	0.081	42.271	2.231
12/10/2012 2:25	15000.001	0.08	42.348	2.213
12/10/2012 2:30	15300.001	0.092	42.249	2.541
12/10/2012 2:35	15600.001	0.097	42.112	2.664
12/10/2012 2:40	15900.001	0.096	42.031	2.638
12/10/2012 2:45	16200.001	0.095	42.033	2.616
12/10/2012 2:50	16500.001	0.095	42.085	2.607
12/10/2012 2:55	16800.001	0.086	42.173	2.377
12/10/2012 3:00	17100.001	0.073	42.325	2.024
12/10/2012 3:05	17400.001	0.073	42.479	2.014
12/10/2012 3:10	17700.001	0.068	42.575	1.887
12/10/2012 3:15	18000.001	0.063	42.588	1.75
12/10/2012 3:20	18300.001	0.071	42.573	1.951
12/10/2012 3:25	18600.001	0.072	42.589	1.977

12/10/2012 3:30	18900.001	0.071	42.616	1.951
12/10/2012 3:35	19200.001	0.072	42.694	1.98
12/10/2012 3:40	19500.001	0.067	42.78	1.84
12/10/2012 3:45	19800.001	0.068	42.799	1.879
12/10/2012 3:50	20100.001	0.069	42.832	1.891
12/10/2012 3:55	20400.001	0.063	42.889	1.732
12/10/2012 4:00	20700.001	0.065	42.944	1.805
12/10/2012 4:05	21000.001	0.071	42.862	1.951
12/10/2012 4:10	21300.001	0.081	42.749	2.243
12/10/2012 4:15	21600.001	0.087	42.669	2.386
12/10/2012 4:20	21900.001	0.082	42.682	2.252
12/10/2012 4:25	22200.001	0.073	42.807	2.012
12/10/2012 4:30	22500.001	0.063	42.977	1.752
12/10/2012 4:35	22800.001	0.059	43.149	1.636
12/10/2012 4:40	23100.001	0.054	43.315	1.487
12/10/2012 4:45	23400.001	0.047	43.456	1.298
12/10/2012 4:50	23700.001	0.046	43.562	1.276
12/10/2012 4:55	24000.001	0.044	43.628	1.222
12/10/2012 5:00	24300.001	0.039	43.696	1.079
12/10/2012 5:05	24600.001	0.038	43.768	1.051
12/10/2012 5:10	24900.001	0.038	43.842	1.063
12/10/2012 5:15	25200.001	0.036	43.905	1.005
12/10/2012 5:20	25500.001	0.037	43.975	1.032
12/10/2012 5:25	25800.001	0.037	44.048	1.024
12/10/2012 5:30	26100.001	0.035	44.113	0.981
12/10/2012 5:35	26400.001	0.034	44.107	0.952
12/10/2012 5:40	26700.001	0.036	44.108	0.998
12/10/2012 5:45	27000.001	0.037	44.195	1.032
12/10/2012 5:50	27300.001	0.033	44.272	0.932
12/10/2012 5:55	27600.001	0.035	44.346	0.977
12/10/2012 6:00	27900.001	0.033	44.423	0.929
12/10/2012 6:05	28200.001	0.031	44.527	0.877
12/10/2012 6:10	28500.001	0.03	44.566	0.83
12/10/2012 6:15	28800.001	0.03	44.655	0.833
12/10/2012 6:20	29100.001	0.027	44.677	0.752
12/10/2012 6:25	29400.001	0.027	44.721	0.748
12/10/2012 6:30	29700.001	0.026	44.761	0.728
12/10/2012 6:35	30000.001	0.025	44.828	0.701
12/10/2012 6:40	30300.001	0.023	44.858	0.655
12/10/2012 6:45	30600.001	0.023	44.883	0.653
12/10/2012 6:50	30900.001	0.023	44.927	0.633

12/10/2012 6:55	31200.001	0.021	44.994	0.603
12/10/2012 7:00	31500.001	0.019	45.05	0.547
12/10/2012 7:05	31800.001	0.02	45.107	0.57
12/10/2012 7:10	32100.001	0.018	45.101	0.506
12/10/2012 7:15	32400.001	0.018	45.103	0.495
12/10/2012 7:20	32700.001	0.016	45.137	0.453
12/10/2012 7:25	33000.001	0.016	45.149	0.45
12/10/2012 7:30	33300.001	0.017	45.156	0.483
12/10/2012 7:35	33600.001	0.016	45.157	0.446
12/10/2012 7:40	33900.001	0.016	45.151	0.466
12/10/2012 7:45	34200.001	0.015	45.184	0.416
12/10/2012 7:50	34500.001	0.013	45.19	0.376
12/10/2012 7:55	34800.001	0.015	45.236	0.431
12/10/2012 8:00	35100.001	0.014	45.218	0.409
12/10/2012 8:05	35400.001	0.014	45.242	0.4
12/10/2012 8:10	35700.001	0.012	45.241	0.346
12/10/2012 8:15	36000.001	0.013	45.246	0.365
12/10/2012 8:20	36300.001	0.012	45.263	0.356
12/10/2012 8:25	36600.001	0.011	45.278	0.307
12/10/2012 8:30	36900.001	0.011	45.293	0.307
12/10/2012 8:35	37200.001	0.013	45.332	0.377
12/10/2012 8:40	37500.001	0.012	45.351	0.334
12/10/2012 8:45	37800.001	0.01	45.375	0.293
12/10/2012 8:50	38100.001	0.01	45.373	0.288
12/10/2012 8:55	38400.001	0.009	45.389	0.25
12/10/2012 9:00	38700.001	0.011	45.411	0.305
12/10/2012 9:05	39000.001	0.011	45.428	0.311
12/10/2012 9:10	39300.001	0.011	45.43	0.308
12/10/2012 9:15	39600.001	0.008	45.443	0.247
12/10/2012 9:20	39900.001	0.009	45.45	0.253
12/10/2012 9:25	40200.001	0.01	45.465	0.289
12/10/2012 9:30	40500.001	0.009	45.512	0.268
12/10/2012 9:35	40800.001	0.008	45.524	0.241
12/10/2012 9:40	41100.001	0.007	45.554	0.216
12/10/2012 9:45	41400.001	0.008	45.562	0.225
12/10/2012 9:50	41700.001	0.004	45.549	0.116
12/10/2012 9:55	42000.001	0.007	45.563	0.206
12/10/2012 10:00	42300.001	0.007	45.567	0.203
12/10/2012 10:05	42600.001	0.001	45.781	0.047
12/10/2012 10:10	42900.001	0.008	44.76	0.228
12/10/2012 10:15	43200.001	0.008	44.227	0.24

12/10/2012 10:20	43500.001	0.004	43.93	0.129
12/10/2012 10:25	43800.001	0.006	44.813	0.174
12/10/2012 10:30	44100.001	0.007	46.846	0.202
12/10/2012 10:35	44400.001	0.003	49.418	0.085
12/10/2012 10:40	44700.001	0.004	51.507	0.113
12/10/2012 10:45	45000.001	0.003	53.089	0.101
12/10/2012 10:50	45300.001	0.005	54.845	0.142
12/10/2012 10:55	45600.001	0.004	56.902	0.124
12/10/2012 11:00	45900.001	0.004	58.775	0.133
12/10/2012 11:05	46200.001	0.005	60.164	0.142
12/10/2012 11:10	46500.001	0.005	61.557	0.142
12/10/2012 11:15	46800.001	0.002	62.786	0.075
12/10/2012 11:20	47100.001	0.002	63.836	0.08
12/10/2012 11:25	47400.001	0.003	64.763	0.1
12/10/2012 11:30	47700.001	0.005	65.589	0.157
12/10/2012 11:35	48000.001	0.003	66.481	0.091
12/10/2012 11:40	48300.001	0.001	67.371	0.053
12/10/2012 11:45	48600.001	0.002	68.133	0.073
12/10/2012 11:50	48900.001	0.003	68.797	0.091
12/10/2012 11:55	49200.001	0.002	69.351	0.08
12/10/2012 12:00	49500.001	0.001	69.901	0.057
12/10/2012 12:05	49800.001	0.002	70.29	0.078
12/10/2012 12:10	50100.001	0.004	70.613	0.12
12/10/2012 12:15	50400.001	0.002	70.854	0.07
12/10/2012 12:20	50700.001	0.003	71.01	0.087
12/10/2012 12:25	51000.001	0.005	71.189	0.159
12/10/2012 12:30	51300.001	0.002	71.399	0.079
12/10/2012 12:35	51600.001	0.001	71.618	0.052
12/10/2012 12:40	51900.001	0.005	71.801	0.146
12/10/2012 12:45	52200.001	0.002	71.952	0.075
12/10/2012 12:50	52500.001	0.004	72.089	0.123
12/10/2012 12:55	52800.001	0.002	72.212	0.08
12/10/2012 13:00	53100.001	0.004	72.319	0.127
12/10/2012 13:05	53400.001	0.003	72.421	0.097
12/10/2012 13:10	53700.001	0.003	72.517	0.102
12/10/2012 13:15	54000.001	0.003	72.626	0.104
12/10/2012 13:20	54300.001	0.003	72.753	0.1
12/10/2012 13:25	54600.001	0.004	72.888	0.12
12/10/2012 13:30	54900.001	0.003	73.006	0.104
12/10/2012 13:35	55200.001	0.002	73.098	0.081
12/10/2012 13:40	55500.001	0.002	73.173	0.081

12/10/2012 13:45	55800.001	0.004	73.248	0.115
12/10/2012 13:50	56100.001	0.004	73.325	0.131
12/10/2012 13:55	56400.001	0.004	73.395	0.128
12/10/2012 14:00	56700.001	0.002	73.458	0.066
12/10/2012 14:05	57000.001	0.002	73.515	0.058
12/10/2012 14:10	57300.001	0.004	73.57	0.123
12/10/2012 14:15	57600.001	0.002	73.624	0.082
12/10/2012 14:20	57900.001	0.002	73.67	0.082
12/10/2012 14:25	58200.001	0.002	73.713	0.084
12/10/2012 14:30	58500.001	0.001	73.75	0.036
12/10/2012 14:35	58800.001	0.003	73.794	0.093
12/10/2012 14:40	59100.001	0.003	73.818	0.086
12/10/2012 14:45	59400.001	0.004	73.871	0.136
12/10/2012 14:50	59700.001	0.004	73.902	0.126
12/10/2012 14:55	60000.001	0.002	73.911	0.081
12/10/2012 15:00	60300.001	0.002	73.929	0.079
12/10/2012 15:05	60600.001	0.002	73.954	0.077
12/10/2012 15:10	60900.001	0.002	73.986	0.06
12/10/2012 15:15	61200.001	0.003	74.022	0.085
12/10/2012 15:20	61500.001	0.003	74.048	0.088
12/10/2012 15:25	61800.001	0.003	74.105	0.101
12/10/2012 15:30	62100.001	0.002	74.193	0.084
12/10/2012 15:35	62400.001	0.003	74.281	0.091
12/10/2012 15:40	62700.001	0.004	74.36	0.113
12/10/2012 15:45	63000.001	0.003	74.441	0.085
12/10/2012 15:50	63300.001	0.002	74.526	0.08
12/10/2012 15:55	63600.001	0.002	74.594	0.066
12/10/2012 16:00	63900.001	0.002	74.681	0.083
12/10/2012 16:05	64200.001	0.003	74.77	0.094
12/10/2012 16:10	64500.001	0.004	74.867	0.122
12/10/2012 16:15	64800.001	0.003	74.956	0.102
12/10/2012 16:20	65100.001	0.003	75.043	0.089
12/10/2012 16:25	65400.001	0.002	75.123	0.059
12/10/2012 16:30	65700.001	0.005	75.307	0.143