Project Number: MQP-SL1-DCR1

STORMWATER MANAGEMENT PLAN FOR THE WEST BOYLSTON BROOK SUBBASIN

A Major Qualifying Project
Submitted to the faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the Requirements for the
Degree of Bachelor of Science

Date: December 15th 2011

Submitted by:

____
Lucas Smith-Horn

____
Chris Stanton

____
David Warfel

Approved by:

____
Professor Suzanne LePage, Co-Advisor

____
Professor Paul Mathisen, Co-Advisor

Abstract

This goal of this project was to create a stormwater management plan for the West Boylston subbasin in the Wachusett Reservoir watershed. Existing conditions were determined using field observations, GIS mapping, laboratory testing, and pollutant loading calculations. Computer modeling predicted the effectiveness of potential improvements and solutions were prioritized through a weighting system. The management plan included conceptual designs for retrofitting structural and non-structural best management practices, including bioretention and a pet waste program, to improve the subbasin's stormwater infrastructure.

Capstone Design Statement

In order to meet the capstone requirement of this project, an integrated stormwater management plan was designed for the West Boylston subbasin. The development of this plan consisted of many steps designed by the team which included site assessments, development of a sampling plan, and configuration of a model for existing and future conditions. The plan consisted of suggestions to implement various structural BMPs at different locations, along with programs which when implemented correctly would educate the residents and stop pollution at the source. The model was used to help estimate the effectiveness of different BMPs in the subbasin and was critical to the design of the final plan.

This project took realistic constraints into consideration by addressing economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political issues in the following manner:

Economic: A BMP design had to be economically feasible; while there are many effective large scale BMPs, some are very expensive and would not be economically possible for this project. As a result, cost-benefit assessments were an important consideration in the selection of BMPs.

Environmental: The primary focus of this project is on improving the water quality in West Boylston brook, therefore environmental constraints were at the forefront of the project.

Sustainability: This constraint was considered throughout many phases of the project and is evident primarily in the stormwater management plan. The plan suggests both short and long-term stormwater solutions that were measured using metrics of sustainability.

Manufacturability**:** The conceptual design of the sediment forebay accounts for some material and maintenance demands. Also, the methodology of this project was designed with the intent that it could be used by the DCR to devise stormwater solutions in other subbasins.

Ethical: The project team carried out research, report writing, field visits, and designs, in a morally acceptable manner and prioritized ethical behavior throughout the project.

Health and Safety: The focus of this project was on improving water quality of the West Boylston Brook which enters the Wachusett Reservior and is used as a drinking supply for the city of Boston. Therefore, this project directly relates to improving public health and safety.

Social and Political: A metric used to devise solutions was directly related to social impact. The project team acknowledged the importance of politics in implementation of the proposed plans and designed accordingly.

Executive Summary

The West Boylston Brook is a tributary of the Wachusett Reservoir, the drinking water supply for the city of Boston. The Massachusetts Water Resources Authority and the Department of Conservation and Recreation strive to protect the reservoir and the surrounding areas to provide clean drinking water. High concentrations of pollutants contributed by untreated stormwater runoff in the West Boylston subbasin has caused concern about the potential impacts it may have on the reservoir if not improved.

The goal of this project was to provide a realistic stormwater management plan, which when implemented, would decrease the overall pollutant contribution leaving the subbasin. In the plan, best management practices would be used to prevent pollution, reduce runoff, and treat runoff. Four main steps were taken in the development of the plan. First, an analysis of the existing conditions in the brook was performed. Second, areas and specific sites of concern were identified to help in determining where BMPs should be placed. Third, appropriate BMPs were selected accounting for costs, size, maintenance, and social impact. With these three steps, the final step of creating an integrated plan was accomplished. In this plan, all BMPs were presented and a conceptual design for a sediment forebay was included.

The results of field observations, GIS mapping, a hydrologic analysis, water quality sampling, and subbasin modeling were used to establish the existing conditions of the subbasin. From field observations, the MQP team observed the general condition of the West Boylston Brook and the surrounding area and also identified some preliminary sites which could be pollutant contributors. Some of these preliminary areas included the DPW lot and the impervious intersection of Central and Prospect Streets. GIS mapping in combination with AutoCAD drawings provided by DCR helped the team to map the natural and manmade drainage of the subbasin. Using the topography, the team divided the subbasin into six sampling areas; each area focused on obtaining water quality data to determine the source of pollutant loadings.

Sampling and laboratory testing at six locations along the brook revealed that E. coli bacteria, phosphorus, ammonia, and sediment concentrations all increased as a result of stormwater runoff. Given the high concentrations for some of these parameters, it would appear that stormwater management actions would be warranted. Estimated loadings, from NRCS and Simple Method calculations, and instantaneous pollutant loadings were used as comparisons to the Watershed Treatment Model's existing pollutant loadings. The Watershed Treatment Model

is a spreadsheet-based model for the rapid assessment of yearly pollutant loadings from various sources and the prediction of pollutant reductions from structural and non-structural practices (CWP, 2002). From this, the model was calibrated so that it calculated pollutant loadings to provide a base for BMP implementation.

The results of the existing conditions confirmed the stormwater problem in the brook, which could be addressed through best management practices. Using these results, three of the sampling areas were classified as being pollutant contributors. The three sites chosen were downstream locations in the more residential, commercial, and impervious areas of the subbasin. Additional site visits in these three areas provided the team with specific sites which were possible pollutant contributors. In some cases, physical evidence of pollutant sources was noted. The team used this information to brainstorm possible BMPs focusing on the fact that most sites were small.

With this pre-analysis, the integrated plan was created where various BMP's were brainstormed and developed through placement in the subbasin and cost analysis. The BMPs chosen were selected to treat the pollutants found to be stormwater problems from sampling in the areas which were identified as likely pollutant contributors. Many of the BMPs were non-structural which could be implemented throughout the subbasin. The structural BMPs were chosen on a more site specific level due to more constraints such as cost and size. For example, bioretention was used in a few areas because of its small size and ability to treat most pollutants. A sediment forebay and a series of tree box filters were also suggested for treating sediment. Each BMP was added to the model to produce a predicted pollutant reduction. A separate analysis was conducted to rank and prioritize each practice base on realistic constraints including community impact, cost, maintenance, and their removal efficiency.

The team suggested to the DCR that every BMP developed be implemented because the final pollutant removals with all BMPs were less than 25% for each pollutant estimated by the model. However it is possible that the BMPs could outperform the predictions because of the conservative nature of the model. The BMPs do not have to be implemented all at once, so an initial phase of four BMPs was created as a first step. These include the raccoon removal, covering the sand at DPW, the sediment forebay, and the bioretention area near Darby's Bakery. The other non-structural BMPs should be finalized and implemented soon after the initial phase as many of them had higher pollutant removals than structural BMPs. Overall, the plan accomplished its job of predicting a decrease in pollutants with proper implementation.

The process used in this report can be replicated in other subbasins to produce a rapid, but detailed, assessment of a subbasin and predict the reduction of pollutant loads with BMPs. It is hoped that the methodology will be duplicated by the DCR to assess other subbasins which have pollutant problems similar to the West Boylston Brook. Included in this report are some recommendations which were developed to ease the process and prevent some of the complications encountered in this project.

Acknowledgements

We would like to express our gratitude to those who provided the required assistance necessary to complete the Major Qualifying Project (MQP). First and foremost we would like to thank our project advisors, Professor LePage and Professor Paul Mathisen, for the insight and guidance they provided to us throughout the duration of the project. We would also like to thank Lab Manager Don Pellegrino for helping to calibrate laboratory equipment and run various water quality tests.

A number of individuals at the Massachusetts Department of Conservation and Recreation (DCR) provided us with special localized information on the West Boylston subbasin which proved to be an enormous help to us. We would like to acknowledge the assistance provided to us by Larry Pistrang during the early stages of the project and throughout the development of the sampling plan. We would like to thank Steven Sulprizo for providing us with weather data and helping us forecast weather for stormwater sampling. We appreciate the help received from Patricia Austin in the preliminary stages of the project and Craig Fitzgerald's help with providing GIS layers to us. Lastly, we would like to thank Ross Goodale for the engineering insight he gave to us.

Table of Authorship

Section	Author	Editor
1.0 Introduction	David	Lucas
1.1 Capstone Design Statement	Chris	Lucas
2.0 Background	All	All
2.1 Stormwater Quality Concerns	Lucas	David
2.1.1 Point vs. Non-point Sources	Lucas	David
2.1.2 Agricultural Quality Concerns	Lucas	David
2.1.3 Residential and Commercial Quality Concerns	Lucas	David
2.2 Stormwater Hydrology	Chris	David
2.3 Wachusett Reservoir and the West Boylston Subbasin	Lucas	David
2.3.1 Wachusett Reservoir	Lucas	David
2.3.2 West Boylston Brook	Lucas	David
2.4 Stormwater Management and Planning	David	Chris
2.4.1 Structural BMPs	Chris	David
2.4.2 Non-Structural BMPs	Chris	Lucas
2.4.3 Selecting and Designing BMPs	Chris	Lucas
2.5 Watershed Treatment Model (WTM)	Chris	Lucas
2.6 Case Studies	David	Chris
2.6.1 Silver Lake Beach LID Retrofit	David	Chris
2.6.2 Silver Lake Neighborhood LID Retrofit	David	
3.0 Methodology	All	All
3.1 Analysis of Subbasin	All	All
3.1.1 General Field Observations	David	Lucas
3.1.2 GIS Mapping and Analysis	David	Lucas
3.1.3 Sampling and Lab Testing	Lucas	Chris
3.1.4 Current Hydrology	Chris	David

3.2 Development of the Watershed Treatment Model (WTM)	David	Lucas
3.2.1 Initial Configuration	David	Lucas
3.2.2 Comparison	David	Lucas
3.2.3 Calibration and Refinement	David	Lucas
3.2.4 Calculate Loading Reductions	David	Lucas
3.3 Identify Areas of Concern and Potential Improvement	David	Lucas
3.4 Select Appropriate Best Management Practices	Chris/Lucas	David
3.4.1 Brainstorming BMPs	Chris/Lucas	David
3.4.2 BMP Modeling	Chris/Lucas	David
3.4.3 BMP Ranking	Chris/Lucas	David
3.5 Create Integrated Plan	Lucas	Chris
4.0 Analysis of Existing Conditions	All	All
4.1 Field Observations	Lucas	Chris
4.1.1 September 7th Visit	Lucas	Chris
4.1.2 September 25th Visit	Lucas	Chris
4.2 Subbasin Drainage	David	Lucas
4.3 Sampling Results and Analysis	Lucas	Chris
4.4 Hydrology and Pollutant Loadings	Chris/David	Chris/David
4.5 Subbasin Initial Loadings	Lucas	Chris
4.6 Identification of Contributing Areas and Sites	Lucas	David
4.6.1 Identifying Areas	Lucas	David
4.6.2 Screening	Lucas	David
4.6.3 Identifying Sites	Lucas	David
5.0 Integrated Plan	All	All
5.1 BMPs to Implement	All	All
5.1.1 Retrofit Site 1: Department of Public Works	Chris/Lucas	Chris
5.1.2 Retrofit Site 2: Worcester Street Bioretention	David/Lucas	Chris

5.1.3 Retrofit Site 3: Central, Newton, and Prospect Street Bioretention	David	Lucas
5.1.4 Non-structural BMPs	Chris	Lucas
5.2 Suggested Solution	Lucas	Chris
6.0 Conclusions and Recommendations	Lucas	David
6.1 Conclusion of Findings	Lucas	David
6.2 Modifications to Approach	Lucas	David
6.2.1 Model Recommendations	Lucas	David
6.2.2 Sampling Recommendations	Lucas	David
6.2.3 Hydrology Recommendations	Lucas	David
6.2.4 Plan Recommendations	Lucas	David
6.3 Future Research Suggestions	Lucas	David

Table of Contents

Table of Figures

Table of Tables

List of Abbreviations

BMP- Best Management Practices

CAD- Computer Aided Design

CFS- Cubic Feet per Second

CN- Curve Number

CRWA- Charles River Watershed Association

CSO- Combined Sewer Overflow

DCR- Department of Conservation and Recreation

DO- Dissolved Oxygen

DPW- Department of Public Works

EPA- Environmental Protection Agency

GIS- Geographic Information system

IC- Ion Chromatography

IRWA- Ipswich River Watershed Association

LID- Low Impact Development

Mass DEP- Massachusetts Department of Environmental Protection

MPN- Most Probable Number

MQP- Major Qualifying Project

MWRA- Massachusetts Water Resource Authority

NPDES- National Pollution Discharge Elimination System

NPS- Non- Point Source

NRCS- National Resources Conservation Service

NTU- Nephelometric Turbidity Units

SSO- Sanitary Sewer Overflow

TN- Total Nitrogen

TP- Total Phosphorus

TSS- Total Suspended Solids

USGS- United States Geologic Survey

WPI- Worcester Polytechnic Institute

WQV- Water Quality Volume

WTM- Watershed Treatment Model

1.0 Introduction

Although traditional stormwater conveyance systems provide an efficient means of preventing flooding and transporting runoff away from developed sites, they often disrupt the hydrologic cycle and pose long-term threats to managing stormwater. Conveying stormwater solely through underground conduits inhibits groundwater recharge while increasing runoff velocities, volumes, and discharge rates. These combined factors may lead to various adverse impacts such as erosion, flooding, and degradation of water quality (EPA, 2003). The result of such consequences creates risk to ecosystems, public health, and economic costs.

Low Impact Development (LID) principles, applied in conjunction with stormwater Best Management Practices (BMPs), have proven to be sustainable alternatives to conventional stormwater systems. The use of LID principles with BMPs helps to control stormwater at the source, along with a goal of maintaining or replicating pre-development hydrologic site conditions. LID principles also offer economic benefits in the form of cost savings for initial construction and long-term maintenance (EPA, 2003). Structural BMPs designed with LID principles, such as rain gardens, green roofs, and porous pavement, help recycle water and filter pollutants before they enter surface water bodies and public water supplies.

A major goal of stormwater BMPs is to improve water quality of large water resources for a population. The Quabbin and Wachusett reservoirs supply water for more than two million people in the metropolitan Boston area and are thus some of the most significant water resources in New England (DCR, 2008). The Department of Conservation and Recreation (DCR) and the Massachusetts Water Resource Authority (MWRA) regularly monitor the water quality in the reservoir watersheds and implement solutions to combat threats to water quality. Unfortunately, most stormwater runoff from residential and commercial sites throughout the Wachusett watershed continues to flow untreated into the streams and rivers that lead into the reservoir.

One area of particular concern is the West Boylston subbasin and the brook that flows through it. The water quality of the West Boylston Brook is one of the poorest in the watershed with pollutants such as bacteria and excess nutrients being the greatest known problems. This subbasin also has one of the highest percentages of impervious area in the watershed and possesses an aged stormwater infrastructure that poses potential threats to the brook unless improvements can be implemented.

As stormwater regulations increase and the drainage systems of the towns neighboring the reservoir begin to age, the importance of sustainable stormwater management will become an indisputable necessity in order for the Wachusett Reservoir to maintain acceptable water quality. While many subbasins are too small to have a noticeable impact on the quality of the reservoir, it is important to take a proactive stance and implement stormwater solutions in subbasins that do have water quality concerns so the number of problems in the watershed does not increase.

The goal of this project was to develop an integrated stormwater management plan which could be implemented within the West Boylston subbasin by the DCR to improve the overall quality of stormwater discharge in the West Boylston Brook. First, research was conducted on the Wachusett Reservoir, West Boylston Brook, and other relevant topics such as stormwater quality, stormwater management, the Watershed Treatment Model and past case studies. By combining research, field observations, GIS software, a hydrologic analysis, sampling, and lab testing, an analysis was performed on the existing conditions of the subbasin to determine the water quality concerns related to stormwater. In addition to establishing these initial conditions, computer modeling was used to estimate pollutant loadings being discharged from the brook. Using the results of the initial analysis, areas of concern were determined which should be addressed by the implementation of BMPs. Additional field observations were performed to narrow down the areas to specific sites. Next, stormwater BMPs which were suitable to the sites were brainstormed and a conceptual design was made for one of the BMPs. All BMPs were ranked according to pollutant removal efficiency, cost, maintenance, and social impact.

The results of this project were presented to the DCR with intent that the new stormwater management plan will be implemented in the West Boylston Brook Subbasin. The project was not continued beyond the planning and design stages, but the designs and recommendations from this project will hopefully be successful as predicted by the report and projected by the computer model. While this plan only addresses the West Boylston Brook, a small subbasin compared to the much larger watershed it is contained in, the team and DCR hopes the methodology of this project can be replicated for use with other subbasins in the Wachusett Reservoir watershed. The team included many recommendations to supplement the used methodology so this project could indirectly extend to improving the water quality of the whole watershed in future research, projects, and designs.

2.0 Background

The purpose of this background chapter is to achieve a greater understanding of the key topics of this project and to highlight the research that was done in order to develop the methodology. First, the water quality concerns of stormwater will be discussed followed by a brief background on stormwater hydrology. Then, the examination of the characteristics and significance of both the Wachusett Reservoir and the West Boylston subbasin will be discussed. The background chapter will conclude with a discussion of stormwater management techniques including structural and non-structural best management practices, the description of a model used to estimate BMP effectiveness, and two low impact development case studies. The process of investigating these topics and summarizing them in the chapter were crucial to enhancing the project team's understanding of how to continue the progression of the project.

2.1 Stormwater Quality Concerns

Water quality is a generalized term for the overall measurement of water's characteristics. Quality is a comparable attribute which can be determined by meeting pre-set standards. Because water has physical, chemical, and biological properties, the quality of a water sample cannot be determined through one method. For example, drinking water cannot be determined clean just because it has a clear appearance. There could be pathogens in the water which are not apparent by simply looking at the water. Therefore, water is tested through various methods and then compared to standards to determine the quality of the water (USGS, 2001).

Natural and human processes cause substances to be released into water and impair quality. By natural processes, water flows in soil, over rocks, and through other vegetation on the ground. Nutrients, sand, and other debris can flow with the water affecting its overall quality. These natural substances will not normally be harmful to animal and human health, but too much of certain nutrients can have negative impacts. Human activity causes many pollutants to affect the quality of surface and ground waters (USGS, 2001).

2.1.1 Point vs. Non-point Sources

Pollutants can reach water through point and non-point sources. A point source is a direct discharge from an industry or wastewater plant which directly inputs its waste into the water system. Point sources are regulated by permits and have specific discharge limits for flow and concentration. Non-point sources (NPS) differ in they are the runoff from rainfall or snowmelt as it flows over developed areas and discharges into surface and ground waters at any point instead of one specific location. Stormwater is an NPS which can pick up many different types of pollutants (EPA, 2003).

2.1.2 Agricultural Quality Concerns

Agriculture is considered to be the largest NPS contributor of pollution to lakes and rivers. Loose soil is picked up by rain runoff and deposits sediment into the natural water system causing an increase in turbidity. Fertilizers that are over-applied or applied right before a storm are washed away causing increased nutrient loads of nitrogen, phosphorus, and potassium. High nutrient loads support the growth of algae blooms and can have negative health impacts at high concentrations. In addition, livestock waste can enter runoff and carry bacteria and viruses into surface and ground waters. Finally, pesticides that are applied to plants are also picked up by stormwater and can contaminate wildlife. All of these sources of pollution are commonly used in agricultural practices and can severely affect the water quality of stormwater runoff (EPA, 2005).

2.1.3 Residential and Commercial Quality Concerns

Residential and commercial areas also contribute to poor stormwater quality. These urbanized areas have more impervious surface which causes rainwater to not flow into the ground, but instead flow over these nonporous surfaces until it enters a stormwater sewer system or enters a porous surface. As the water flows over the impervious area, the stormwater can pick up any of the following pollutants: sediments, oils and other organic chemicals, pesticides, bacteria, nutrients, and heavy metals. Most stormwater sewers will eventually discharge into a natural environment where the water will flow into surface waters or infiltrate into ground water (EPA, 2003).

The quality of stormwater does not have to be nearly as high as the quality of drinking water, but stormwater runs into streams, rivers, lakes, and groundwater. This water will most likely end up flowing into a body of water which will be used for recreation or even as a drinking water source. Therefore, the quality of stormwater should be good enough so that it does not negatively impact wildlife, natural vegetation, ecosystems, or human health.

2.2 Stormwater Hydrology

Hydrology is the study of water and its movements through and over earth's surfaces. The hydrology of a subbasin can be characterized by determining peak flows and volumes of stormwater runoff throughout various points in a watershed. There exists several methods for conducting a hydrologic analysis but the Rational and The National Resources Conservation Services (NRCS) methods are the most commonly used procedures. Table 1 shows some of the fundamental uses and differences between the two procedures.

Table 1: Rational and NRCS Methods (ISU: Institute for Transportation, 2008)

Method	Size Limitations	Comments
Rational	<160 acres	Used for estimating peak flows and to design small site or subdivision storm sewer systems. *Should not be used for storage design*
NRCS	0-2000 acres	Used for estimate peak flows and hydrographs for all design applications. Can be used for low impact development hydrology analysis

The Rational Method is generally used when designing small impervious lots or subdivisions. This method is based on Equation 1:

$$Q = c * i * A \qquad \text{(Equation 1)}$$

Where:

Q= the maximum rate of runoff in cubic feet per second (cfs)

c = runoff coefficient and represents the runoff producing conditions of the subject land area.

i= Average rainfall intensity in inches per hour for a duration equal to the time of concentration.

A= contributing basin area in acres.

(CCRFCD, 1999)

The NRCS method is an effective way to determine many hydrological characteristics of a small urban subbasin. One of the major components in this analysis is the estimation of runoff. The NRCS method uses soil information, land use and vegetative cover, treatment, antecedent runoff conditions and hydrologic conditions to determine a curve number (CN) for the watershed (NRCS, 1986). A composite CN value is used to calculate storage, the potential maximum retention after runoff begins. It is important to determine a CN value for the entire area because it provides an idea of the overall imperviousness and abstraction of the area. Equation 2 is used to calculate the overall "composite" CN value.

$$\text{Composite CN} = \frac{\Sigma(\text{CN}_i * \text{A}_i)}{\text{A}} \qquad \text{(Equation 2)}$$

After the composite CN the subbasin is determined, the potential maximum retention after runoff must be calculated. This parameter is also known as storage and is denoted by the letter S using the Equation 3.

$$S = \frac{1000}{CN} - 10 \qquad \text{(Equation 3)}$$

The runoff depth (Q) in inches is then calculated using Equation 4 where P represents the precipitation in units of inches. The precipitation for a given area is determined from a graph which depicts rainfall as type I, II, or III distribution; this distribution is based on region of the country. An example of a precipitation graph for a 2-year 24 hour storm is shown in Figure 1.

$$Q = \frac{(P-0.2*S)^2}{(P+0.8*S)} \qquad \text{(Equation 4)}$$

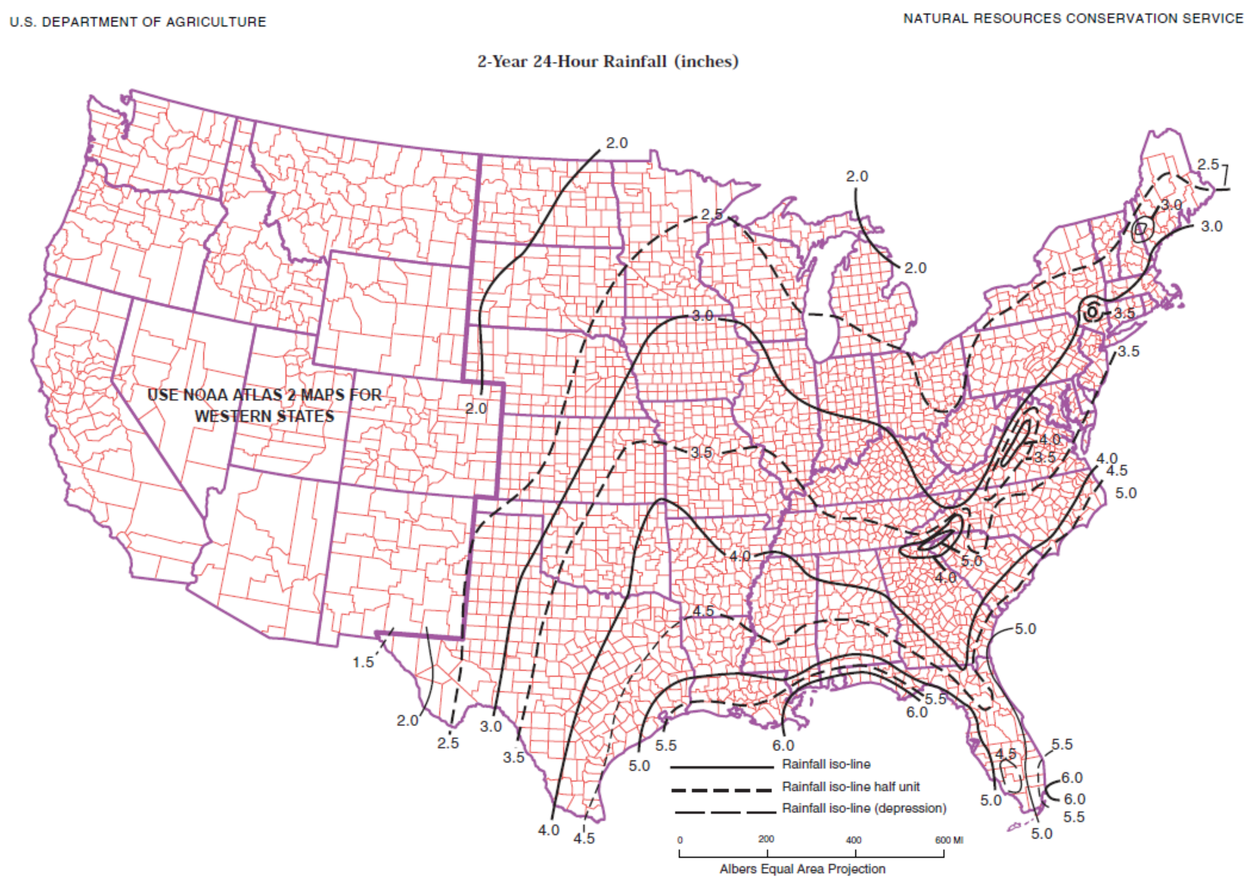


Figure 1: Rainfall Distribution for 2-year 24-hour Storm (NRCS, 1986)

The travel time is the time it takes for water to travel from one location to another. The time of concentration is the sum of the travel times for runoff to travel from the furthest point of the watershed to a point of interest in the watershed (NRCS, 1986). Time of concentration is also the point in the storm where runoff from all portions of the watershed is contributing to the outflow. This time is important to determine the response time of the watershed and speed pollutants are traveling from one area of the watershed to another area. Many factors can influence the time of concentration including surface roughness, slopes, and flow patterns. Water can travel as sheet flow, shallow concentrated flow, or open channel flow. Different equations can be used to calculate the travel time for each type of flow. However, in general the travel time can be calculated with Equation 5 (NRCS, 1986) where L is the flow length (ft.), v is the average velocity (ft. /s), and 3600 is a conversion factor:

$$T_t = {}^{L}/_{3600 * v} \qquad \text{(Equation 5)}$$

After these factors are determined, a hydrograph can be made to represent the flow and duration of a storm event. A visual example of a basic hydrograph can be seen below in Figure 2.

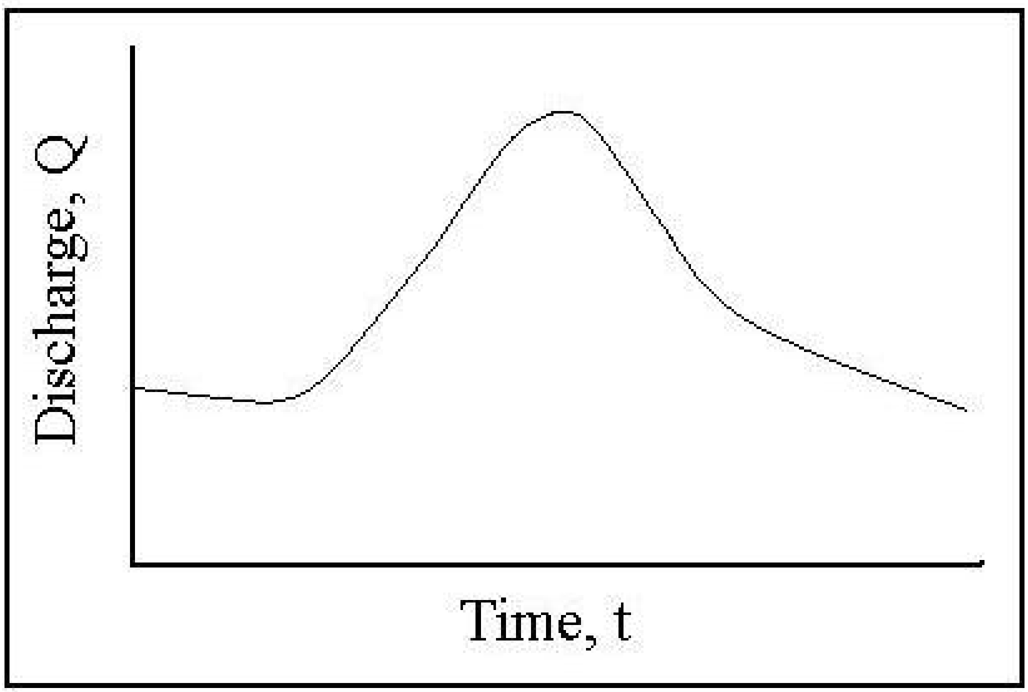


Figure 2: Typical Stormwater Hydrograph (Figure retrieved from engineeringexcelspreadsheets.com)

Loadings can also be calculated to show the amount of contaminants that are entering the stream in a given time period. The SIMPLE method is one method that is often used to assess the water quality of the watershed in order to formulate effective treatment recommendations (CWP, 2002). As with any "simple" model, precision is sacrificed for the sake of simplification and generalization. Nevertheless, the SIMPLE method is still reliable enough to use as a foundation for making pollution management decisions at the site level. Equation 6 is used to compute loadings for Total Suspended Solids and nutrient pollutants:

$$L = 0.226 * R * C * A \qquad \text{(Equation 6)}$$

Where:

L = Annual runoff load (pounds)

0.226 = Conversion factor

R = Runoff (inches)

C = Flow-weighted mean concentration of the pollutant in urban runoff (mg/L or ppm)

A = Contributing Area (acres)

Equation 7 is used to compute bacteria loads:

$$L = 1.03 * 10^{-3} * R * C * A \qquad \text{(Equation 7)}$$

Where:

L = Annual loads (Billion Colonies)

1.03 * 10-3 = Unit conversion factor

R = Annual runoff (inches)

C = Bacteria concentration (col/100ml)

A = Area (acres)

(New Hampshire Department of Environmental Services, 2008)

2.3 Wachusett Reservoir and the West Boylston Subbasin

The area of particular concern for this project is the West Boylston subbasin, which is located within the Wachusett Reservoir watershed. This chapter of the background will provide the reader with an understanding of the characteristics and significance of both the Wachusett Reservoir and the West Boylston subbasin. The first section describes the reservoir's role as a component of metropolitan Boston's water supply and reveals the various land uses within its area. This section then transitions into an explanation of the water quality concerns and land use characteristics of the West Boylston subbasin.

2.3.1 Wachusett Reservoir

As shown in Figure 3, the Wachusett Reservoir is the last water body in a series of reservoirs that provides drinking water to the city of Boston and its surrounding metropolitan communities. Water from the Quabbin Reservoir, the Ware River Watershed, and connecting tributaries is fed into the Wachusett Reservoir where it is piped to Boston for treatment and distribution (DCR, 2008).

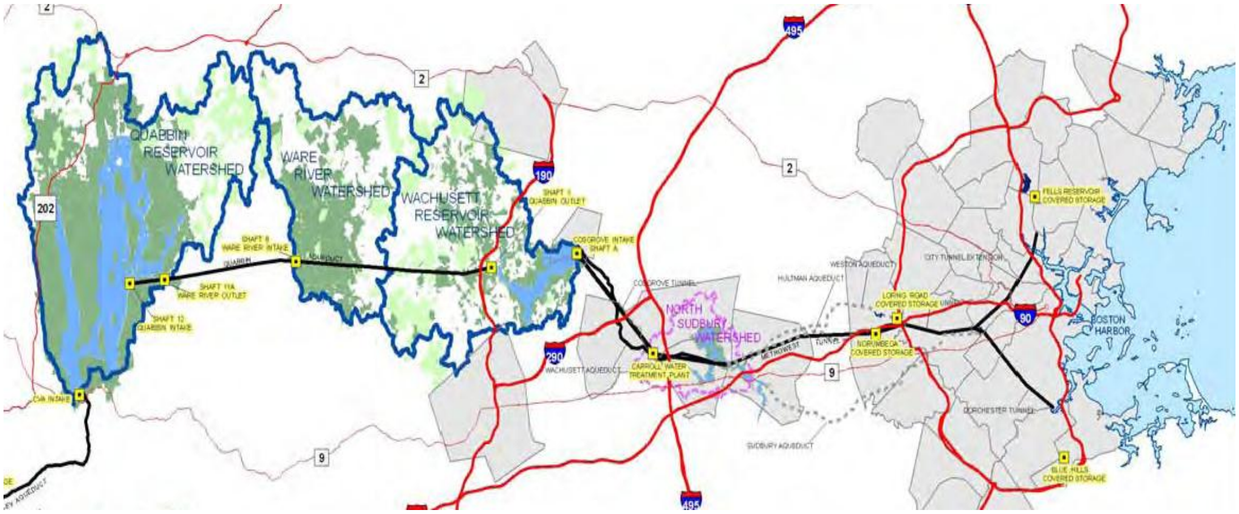


Figure 3: Map of Boston's Water Supply (DCR, 2008)

The Wachusett watershed is located north of the city of Worcester and shares area with many surrounding towns including Holden, West Boylston, Boylston, Clinton, Sterling, Princeton, and Rutland. In addition to the piped inflow from the Shaft 8 Ware River Intake, the reservoir receives much of its water from the Quinapoxet and Stillwater Rivers. Figure 4 shows the Wachusett watershed boundary along with the surrounding towns and contributing surface water bodies.

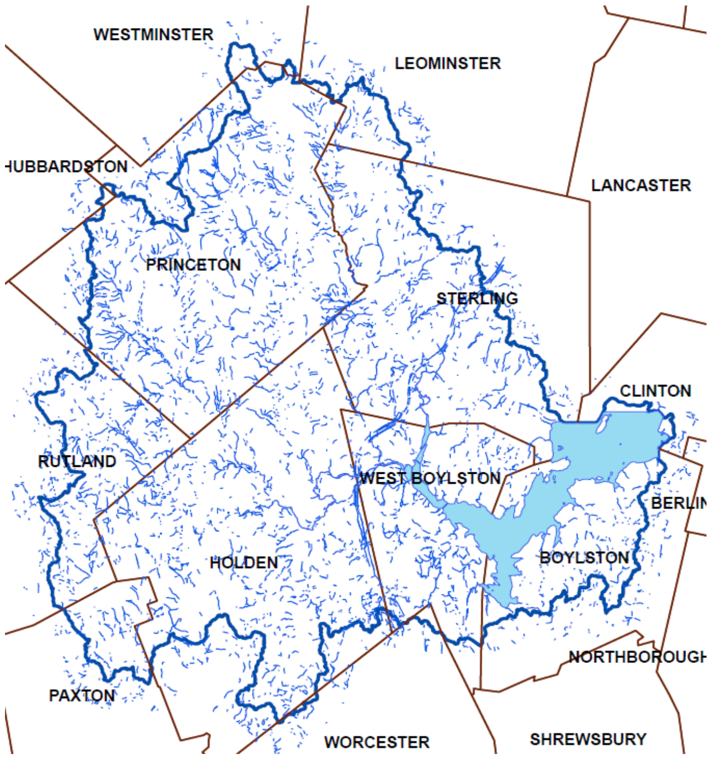


Figure 4: Towns and Streams in the Wachusett Reservoir

The watershed covers over 74,000 acres of land with just over 4,000 of that containing the reservoir itself. Table 2 shows the land use data from 1999; this is the most recent summary available for the whole reservoir. However, in the past twelve years, it is estimated that data for commercial/industrial and agricultural land has stayed the same or decreased. The largest change is estimated to be an increase in residential land use due to the overall increase in populations in the watershed communities (DCR, 2008). DCR has protected development as much as possible by buying unused land and promoting undeveloped land through tax breaks. Combining that land with land controlled by other conservation groups accounts for 44.5% of protected watershed land (DCR, 2008). Further discussion on West Boylston land use is in Section 2.3.2.

Table 2: Percent Land Use 1999 (DCR, 2008; DCR 2007)

	Forest and Open	Residential	Agricultural	Commercial/ Industrial	Wetland and Open Water	Other
Watershed	75.1	13.4	5.2	0.7	3.3	2.3
West Boylston Brook	35.0	44.0	11.0	5.0	7.0	0

Protection of the watershed is a priority because the first line of defense in delivering clean water is maintaining potable water at the source. Most drinking water treatment systems are required to filter and disinfect their water. However, Boston does not have to filter its water because of a lawsuit in 2000 in which a judge declared that the protection and treatment of water was sufficient to satisfy the Safe Water Drinking Act. In the case, the judge noted that the high water quality at the source and strict protection plan were more than enough to overcome the need for filtration (EPA vs. MWRA, 2000). Therefore, it is important for the Wachusett Reservoir to maintain its excellent water quality.

2.3.2 West Boylston Brook

Within the Wachusett Watershed, 57 subbasins encompass areas over eleven towns (DCR, 2008). The West Boylston Brook subbasin is located on the southwest side of the reservoir and is focused around the brook, which the basin is named after. A map of the 275-acre subbasin is shown in Figure 5.

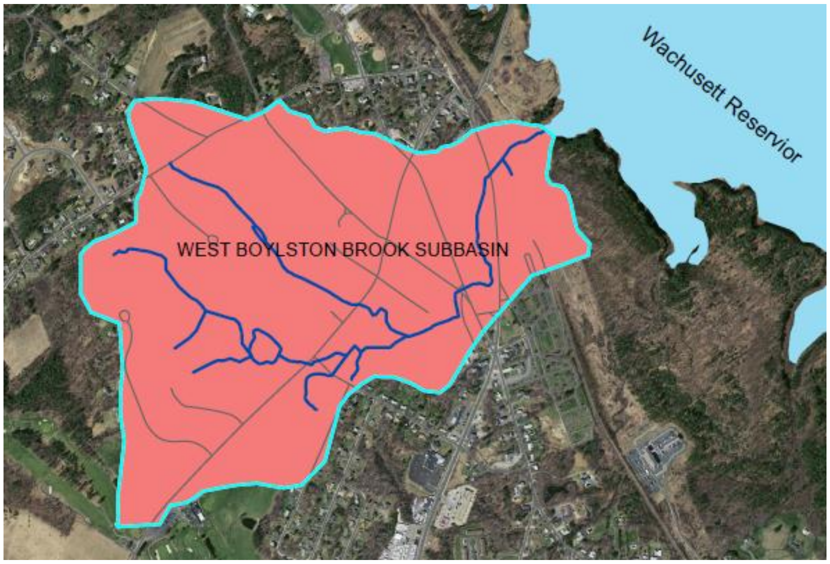


Figure 5: Map of West Boylston subbasin

The land use of this subbasin differs from that of the watershed as a whole. As shown in Table 1, there is significantly more residential, agricultural, and commercial land by percent. This subbasin has more residential land than any other subbasin in the Reservoir Sanitary District. The data suggests that there is a lot of agriculture; however, DCR has noted that of the six sites that contributed to this data in 1999, only one remains in operation and it does not house any livestock or animals (DCR, 2007).

Historically, West Boylston Brook has had the worst water quality in the district and at one point had the worst fecal bacteria samples in the watershed. From 1991 to 1996, the brook exceeded the fecal coliform limit of 20 colonies per 100mL for more than 80% of all samples taken. Levels began to decrease prior to 2003, coinciding with the installation of a public sewer system. It was thought that this would reduce the coliform levels as less septic systems would be used. Despite these improvements, this did not help, as coliform levels have continued to rise since then. In 2006, the median sample was 70 colonies per 100mL with 74% of samples exceeding the limit set by the Surface Water Quality Standard. Nutrient levels for nitrate-nitrogen have also been high, while phosphorous levels have generally been low compared to the rest of the district (DCR, 2007).

Starting in 2008, measurements for bacteria were accomplished by measuring for E. coli coliform instead of fecal bacteria. This was done to follow the new standards for the federal Surface Water Treatment Rule. Under this change the E. coli coliform geometric mean should not exceed 126 colonies per 100mL. Also, the count should not occasionally exceed 235 colonies per 100mL; if it does, then the tributary is put on a watch list (DCR, 2008). The actual frequency associated with occasionally is not defined and is left open for interpretation. Table 3 shows the E. coli means from 2008 to 2010 and the percentage of samples over 235 colonies per 100mL. The brook does not cross the geometric mean of 126, but it does occasionally have samples greater than 235 colonies per 100mL. Therefore, West Boylston Brook still has poor bacteria water quality which should be addressed.

Table 3: West Boylston Brook E. coli Samples from 2008 to 2010

Year	Geometric Mean Colonies per 100mL	Percent > 235 Colonies per 100mL
2008	73	27
2009	50	19
2010	107	24

The impact of stormwater is considered a major concern for West Boylston Brook. This can be shown by the 300% increase in turbidity as a result of runoff in 2006. The subbasin had 20.9% impervious land in 1999 compared to the overall 8.9% in the watershed (DCR, 2007). The high amount of impervious surface could link to the increase in turbidity pollution. Previous studies have recommended practices that would attempt to address the stormwater pollution. One idea was to install a wet pond to allow sediments and associated pollutants to settle out; however, the project was never implemented because there was insufficient land on which to construct it (DCR, 2007). In the 2008 Watershed Protection Plan Update the report states, "stormwater management is likely the most important program for the immediate future in the Wachusett Reservoir watershed" (DCR, 2008). This statement applies to the whole watershed, but it also has a direct relation to the West Boylston Brook.

There is low potential for growth in the subbasin because most areas that could be developed already have been. From 1997 to 2007, there were only two applications made with the DCR for the construction of new buildings, both single-family homes. Under the Watershed Protection Act, any new construction or alteration must be approved by the DCR to prevent building too close to the reservoir or its tributaries. Even without a concern of growth, DCR is still watching this brook. The DCR wants to determine where contamination is occurring and treat the problem. They also want to determine if the municipal sewers are having any effect on improving the water quality. Finally, they need a solution to improve the water quality before it flows into the reservoir (DCR, 2007).

2.4 Stormwater Management and Planning

Traditional stormwater management systems provide an efficient means of conveying stormwater and preventing flooding by transporting runoff away from developed sites. However, they often disrupt the hydrologic cycle and pose long-term threats to managing stormwater. Impervious areas and pipes effectively transport stormwater, but can lead to a poor quality of water, due to the lack of treatment by natural buffers. It also inhibits groundwater recharge while increasing runoff velocities, volumes, and discharge rates. These combined factors may lead to various adverse impacts such as erosion, flooding, and degradation of water quality (EPA, 2003). The result of such consequences creates risk to ecosystems, public health, and economic costs. This is why new developments have been made to improve treatment of stormwater quality and quantity. Best management practices (BMPs) use a variety of techniques to naturally treat and delay stormwater. When there is redevelopment, techniques called Low Impact Development (LID) can be used to achieve the same goal as structural BMPs. LID is useful in redevelopment because it is easy to implement when construction is already occurring. Retrofitting can also be used to improve the efficiency of already existing BMPs; this also has the benefit of lower cost and less planning.

There are many types of BMPs which can be used to decrease and treat stormwater runoff. The following sections will discuss structural BMPs, non-structural BMPs, and the process of selecting BMPs.

2.4.1 Structural BMPs

Structural BMPs are designed treatment systems that can be engineered to treat and control water through natural processes or manufactured mechanisms. Structural BMPs that undergo natural filtration processes abide by LID principles. Some examples are vegetated filter strips, rain gardens, and water quality swales. Examples of manufactured BMPs are deep-sump catch basins, proprietary separators, dry wells, and subsurface infiltration chambers. Structural BMPs can also be classified as construction or post-construction BMPs. Since the objectives in this project are primarily based on planning and design of a stormwater treatment plan in a subbasin with limited potential for growth, only post-construction BMPs will be discussed.

Terminology and categorization of post-construction structural BMPs differs throughout literature on the subject. This report will use the Massachusetts Department of Environmental Protection (Mass DEP) classification which is divided into five main classes according to function. This includes pretreatment, treatment, conveyance, infiltration, and other BMPs (Mass DEP, 2008). The comprehensive list of BMPs according to Mass DEP can be seen in Table 4.

Table 4: Comprehensive List of BMPs (Mass DEP, 2008)

Post-Construction Structural BMPs	
Pre-treatment	**Conveyance**
• Deep sump catch basin	• Drainage channels
• Oil grit separator	• Grass channels
• Proprietary separators	• Water quality swale-dry
• Sediment forebay	• Water quality swale-wet
• Vegetated filter strip	**Infiltration**
Treatment	• Dry wells
• Bioretention area/rain gardens	• Infiltration basins
• Constructed stormwater wetlands	• Infiltration trenches
• Extended dry detention basin	• Leaching catch basins
• Gravel wetlands	• Subsurface structures
• Proprietary media filters	**Other**
• Sand/Organic filters	• Green roofs
• Tree box filters	• Porous pavement
• Wet basins	• Rain barrels & cisterns

It is important to note that some BMPs fit into more than one class because they serve multiple functions. BMPs can be configured as “on-line” systems that treat the entire water quality volume (e.g. when water flows first into a sediment forebay then to a wet basin) or “off-line” systems that function alone (e.g. subsurface infiltration chambers that collect roof runoff).

2.4.1.1 Pretreatment

The primary function of pretreatment BMPs is to remove large debris and coarse sediments. For this reason they are almost always used as the first BMPs in an on-line treatment train and require more maintenance than other BMP categories. Deep-sump catch basins, oil grit separators, and proprietary separators are often placed in lots because they are capable of settling or removing oil, grease, and hydrocarbons. A sediment forebay is designed to slow incoming stormwater runoff to facilitate the separation of suspended solids before discharging to an extended detention basin, wet basin, stormwater wetland, or infiltration basin. This is accomplished by detaining the runoff in a forebay temporarily before allowing water to enter another BMP (Mass DEP, 2008). A section view of a sediment forebay can be seen below in Figure 6.

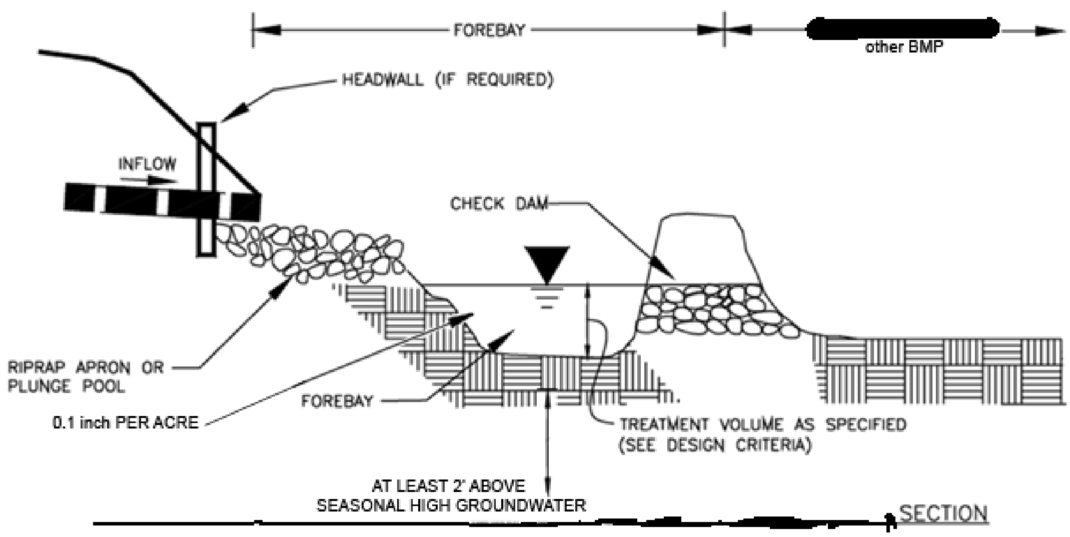


Figure 6: Sediment Forebay (Mass DEP, 2008)

The pretreatment BMP that best embodies LID principles are vegetated filter strips (also known as grass buffers or filters). These BMPs help reduce runoff volumes by slowing runoff velocities, trapping sediment, and increasing infiltration. The ideal configurations for vegetated filter strips are residential settings and small parking lots and roads which yield sheet flow or small concentrated flows along the width of the strips. Some limitations of vegetated filter strips are their physical size and ineffectiveness on slopes greater than 6 percent. An example of this BMP can be seen below in Figure 7.

Figure 7: Vegetated Filter Strips, (Retrieved from: http://www.lakesuperiorstreams.org/stormwater/toolkit/filterstrips.html)

The effectiveness and uses of pretreatment BMPs are summarized below in Table 5.

Table 5: Pretreatment BMPs, (Mass DEP, 2008)

Pretreatment BMPs	Suitable for Redevelopment	Peak Flow Attenuation	Groundwater Recharge	Total Suspended Solids (TSS) Removal
Deep sump catch basin	Yes	No	No	Yes
Oil grit separator	Yes	No	No	Yes
Proprietary separators	Yes	No	No	Varies by unit
Sediment forebay	Yes	No	No	Yes
Vegetated filter strip	Yes	Some with careful design	No	Yes

2.4.1.2 Treatment

Treatment BMPs are much more varied, and are used to accomplish different goals. Many of the treatment BMPs mentioned in this section require a pretreatment BMP to precede it in the treatment process to be effective. Mass DEP further classifies treatment BMPs as either Stormwater Treatment Basins, Constructed Stormwater Wetlands, or Filtration BMPs.

Stormwater treatment basins provide peak rate attenuation and settling of suspended solids. Stormwater basins include extended dry detention basins and wet basins. Detention basins are designed to hold stormwater for at least 24 hours whereas wet basins hold a permanent pool of water. Both basins are voluminous in size and enhance pollutant removal when more vegetation is incorporated into the design. An image of a wet basin is shown below in Figure 8.

Figure 8: Wet Basin (Mass DEP, 2008)

Constructed Wetlands are used to maximize the removal of pollutants from stormwater runoff by mimicking a natural wetland. Wetlands act as an effective biofilter for pollutants and nutrients, with the potential for promoting wildlife habitats. A gravel wetland is an example of a constructed wetland. A figure of this BMP is shown below in Figure 9.

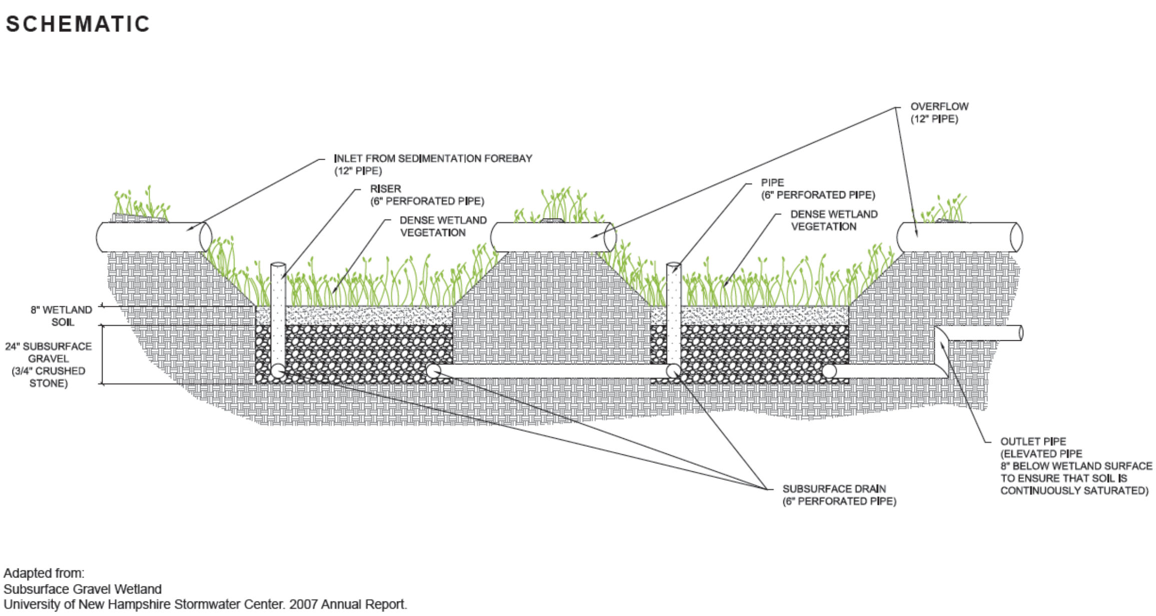


Figure 9: Gravel Wetland (CRWA, 2009)

Stormwater flows horizontally through the sediment forebays and into gravel layered wetland cells. The gravel supports the growth of algae and other microbes which promotes biological treatment (CRWA, 2009). A major limitation of stormwater wetlands are land requirements and implementation costs.

Treatment BMPs classified as Filtration BMPs act as filters and use media to remove solids from runoff. This BMP is more common in urban areas, because they are smaller than constructed wetlands, and are more effective in capturing industrial waste and pollutants. Examples that incorporate LID principles include rain gardens, and tree box filters. Rain gardens are landscaping designs which are modified to treat stormwater. Depressions are usually designed to lead runoff into the gardens which are fitted with plants that have high pollutant removal characteristics. The water than filters through the soil and gravel blanket were it is treated further than collected in a drain and returned to the storm drain system (EPA, 2006). A rain garden diagram is shown below in Figure 10.

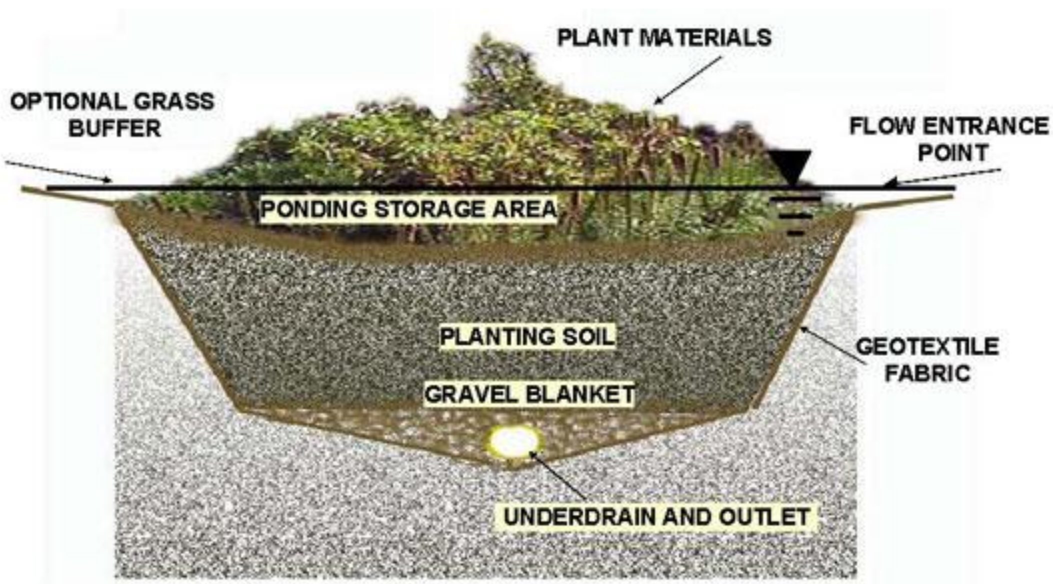


Figure 10: Rain Garden (Retrieved from http://www.mdsg.umd.edu/CQ/V04N4/side2/)

The effectiveness and uses of treatment BMPs are summarized below in Table 6.

Table 6: Treatment BMPs (Mass DEP, 2007)

Treatment BMPs	Suitable for Redevelopment	Peak Flow Attenuation	Groundwater Recharge	Total Suspended Solids (TSS) Removal
Bioretention area/rain gardens	Yes	No	Depends on design	Yes
Constructed stormwater wetlands	As retrofit for dry detention basin	Yes	No	Yes
Extended dry detention basin	As retrofit for dry detention basin	Yes	No	Yes
Gravel wetlands	As retrofit for dry detention basin	Yes	No	Yes
Proprietary media filters	Yes	No	No	Yes
Sand/Organic filters	Yes	No	No	Yes
Tree box filters	Yes	No	No	Yes
Wet basins	As retrofit for dry detention basin	Yes	No	Yes

2.4.1.3 Conveyance

Conveyance BMPs are used to collect and transport stormwater to other BMPs for treatment and are effective in slowing the flows during transportation. These also can be used to treat water through infiltration or temporary storage. Different conveyance options include swales, furrows, gardens, and gravel-filled trenches. Specific examples of Conveyance BMPs are Drainage Channels, and Grass channels. Grass channels are vegetated open channels that filter runoff while slowing the flow of stormwater. The stormwater emerges from a pipe and flows through the open channel to the next BMP. A diagram of a grass channel is shown below in Figure 11.

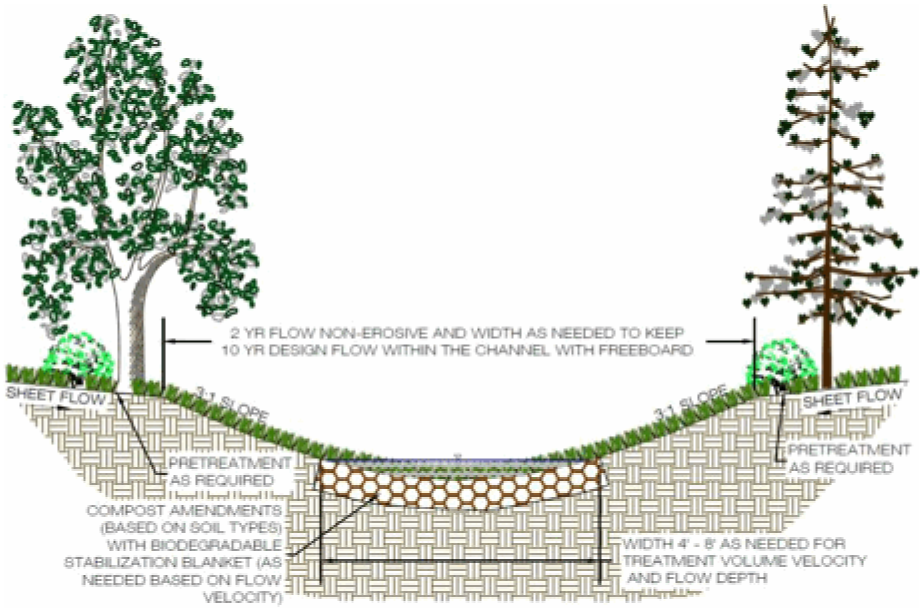


Figure 11: Grass channel (Virginia DCR, 2011)

The effectiveness and uses of conveyance BMPs are summarized below in Table 7.

Table 7: Conveyance BMPs (Mass DEP, 2007)

Conveyance BMPs	Suitable for Redevelopment	Peak Flow Attenuation	Groundwater Recharge	Total Suspended Solids (TSS) Removal
Drainage channels	Yes	No	No	No
Grass channels	Yes	No	No	Yes
Water quality swale-dry	Yes	With careful design	No	Yes
Water quality swale-wet	May not be practicable because of site constraints	N/A	N/A	N/A

2.4.1.4 Infiltration

Infiltration BMPs are designed to allow runoff to be absorbed into the ground. This means that the right soil type is imperative for this BMP to be effective. They are effective at reducing the overall surface flow, but they cannot provide channel protection during times of extreme flooding. Examples include dry wells and infiltration trenches. Infiltration trenches are deep trenches backfilled with stone aggregate and lined with a filter fabric. A portion of the runoff is diverted to the trench where it is treated and can provide effective groundwater recharge (EPA, 1999). A diagram of an infiltration trench is shown below in Figure 12.

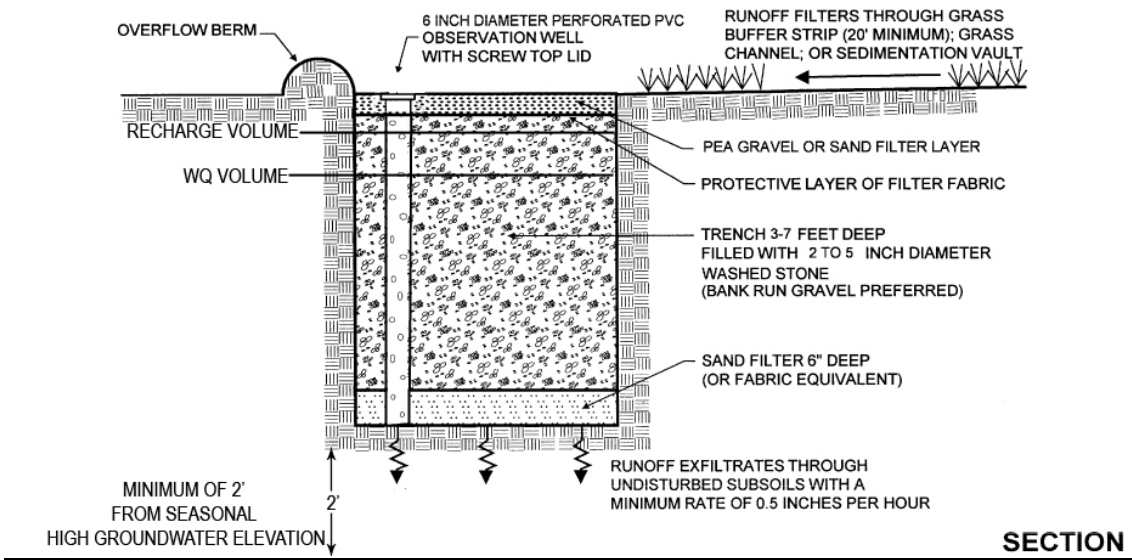


Figure 12: Example of Infiltration Trench (Mass DEP, 2008)

The effectiveness and uses of infiltration BMPs are summarized below in Table 8.

Table 8: Infiltration BMPs (Mass DEP, 2007)

Infiltration	Suitable for Redevelopment	Peak Flow Attenuation	Groundwater Recharge	Total Suspended Solids (TSS) Removal
Dry wells	Yes, runoff from nonmetal roofs and metal roofs outside Zone II, IWPA, and industrial sites	No	Yes	Yes
Infiltration basins	May not be practicable because of site constraints	N/A	N/A	N/A
Infiltration trenches	Yes, w/pretreatment	Yes Full Exfiltration System Trenches	Yes	Yes
Leaching catch basins	Yes, w/pretreatment	Yes if sufficient catch basins	Yes	Yes
Subsurface structures	Yes w/pretreatment	No	Yes	Yes

2.4.1.5 Other BMPs

The last category of structural BMPs is anything that does not specifically fit into the above categories; these include LID practices such as green roofs and porous pavement. Below is Table 9 summarizing their uses.

Table 9: Other BMPs (Mass DEP, 2007)

Other BMPs	Suitable for Redevelopment	Peak Flow Attenuation	Groundwater Recharge	Total Suspended Solids (TSS) Removal
Green roofs	Yes	Some with careful design	No	No
Porous pavement	Yes	Some with careful design	Yes	Yes
Rain barrels & cisterns	Yes	Some for cisterns with careful design	No	No

2.4.2 Non-Structural BMPs

Structural BMPs are very effective means of reducing flows and treating stormwater runoff. However, non-structural methods can be just as effective and much cheaper. Methods such as public education, street sweeping, and implementing local bylaws and regulations can be just as effective because this can prevent pollution before it begins by managing stormwater at its source. Other methods such as re-vegetation help restore the environment naturally and help prevent large amounts of runoff. For example, a study by Breault in 2005 indicated that if street sweeping is used correctly, high amounts of total solids are removed before it enters surface water (Mass DEP, 2008). This study also explains that in order to be effective, street sweeping must be used more frequently and must be accompanied by parking regulations. This is one example of a non-structural practice being highly effective. For businesses, municipalities and industries, there is a legal obligation to follow a pollution prevention plan; however, individuals must also take it upon themselves to reduce pollution. When these BMPs are implemented correctly, the size and expense of structural BMPs can be avoided.

There are several types of non-structural BMPs, each designed to prevent a certain pollutant from entering runoff or protecting a certain area. The first type of non-structural BMPs are natural BMPs by protecting the natural resources threat stormwater. This includes protection of wetlands, riparian buffers, and natural flow pathways. This improves natural filtering of stormwater and helps groundwater recharge, while keeping the habit safe for organisms.

Smart growth BMPs aim to protect the future of a subbasin by preventing stormwater from being an issue in future developments. One example of this is to protect current open area by clustering houses closer to each other. Also, minimizing soil compaction and re-vegetation of sites using plants that do not require significant amounts of fertilizers will help manage stormwater. Re-vegetation helps slow runoff and improves filtration, and reduces nutrient loading from the absence of fertilizers. In addition, minimizing impervious cover from streets and parking lots by reducing street widths and lengths can effectively reduce the flow of stormwater. Last, disconnection from rooftops and storm sewers can also improve overall infiltration. This can be done by simply directing stormwater into a side yard or by redirecting runoff to vegetation or swales, increasing time of concentration and infiltration (Pennsylvania Stormwater, 2006).

Routine maintenance for municipal operations and public education practices can also be used to improve water quality at a low cost. A good source control practice can be street sweeping, and while many towns already have a program, increasing its frequency and time of sweeping will help reduce pollutants to receiving water bodies. Increasing the frequency of catch basin cleanouts will help prevent the frequency of overflowing drains and prevent an increase in pollutants. Pet waste programs can be utilized to educate the local population of the hazards pet waste poses. One way to address this is municipalities can enact an ordinance to fine pet owners that do not pick up after their pet. Also, education on lawn care can help the community realize the impact that fertilizer has on water quality.

While many non-structural BMPs require lots of planning and time to fully implement, they can be a very economical option to decreasing stormwater pollution by avoiding the large up-front cost of many structural BMPs.

2.4.3 Selecting and Designing BMPs

The selection of BMP(s) is very important to the success of a stormwater management plan. The chosen BMP(s) must meet stormwater standards, be effective in removing undesired pollutants, and be cost effective. In addition, site suitability, design specifications, construction methods, and maintenance requirements must all be considered in the selection process (Mass DEP, 2008).

Before structural BMPs can be selected, non-structural BMPs should be considered as they are usually more cost efficient and can have the similar results as structural BMPs. This consideration should include plans to address site planning, pollution prevention, and source control measures.

In the selection of structural BMPs, there are many possible considerations based on the characteristics of the site, target pollutants, cost, and required maintenance. The following properties of the BMP site must be considered in selection:

- Land uses on the site and close to the site
- Size limitations
- Soil types
- Volume of runoff to be treated
- Slope of land
- Proximity to animals habitats
- Ownership of land
- Proximity to underground utilities such as water mains, sewer pipes, and electrical lines

Each of these properties must be considered to obtain the maximum efficiency of the BMP. For example, if the soils on the proposed site have low permeability, many infiltration BMPs cannot be used. Also, special consideration should be taken when considering an urbanized site because they will usually have higher pollutant concentrations and limited space to implement solutions (Mass DEP, 2008).

Because some BMPs do not treat all pollutants, knowledge of the specific pollutants creating problems can greatly assist in the selection of the BMP. An example of this is in the removal of bacteria from stormwater. If bacteria are the only concern, then any BMP which only treats total suspended solids can be immediately removed from consideration.

Cost is always a constraint on BMPs as a budget could restrict the implementation of some BMPs because of up front construction. In addition to the initial costs, the long term maintenance requirements must be considered during the selection process. Keeping this into perspective can eliminate the consideration of certain BMPs. For example, BMPs above ground are easier and cheaper to maintain than those below ground and BMPs that utilize natural cover are cheaper than manmade alternatives. While each BMP needs its own maintenance plan, they should be designed to have the least maintenance possible while not violating any stormwater standards as specified by the Massachusetts DEP Stormwater Technical Handbook (Mass DEP, 2008).

Also, public acceptance can be a major constraint, because many BMPs must be placed on private property or in popular public areas. BMPs should be aesthetically pleasing to not prevent negative feedback from the public and, if possible, public education can be combined with the BMP to promote future implementation of other BMPs (Mass DEP, 2008).

When accounting for these many considerations, it may be more feasible to utilize a system of many BMPs as opposed to a single BMP. This step is facilitated if site planning is done prior to BMP selection and sizing. Once the BMPs are selected, the design process can begin to determine the specifications of the BMPs.

2.5 Watershed Treatment Model (WTM)

There are many computer models available which can be useful in replicating the characteristics of runoff in a subbasin. These models can also include BMP modeling to estimate the reduction of pollutant loadings if the BMP was added to the subbasin. The Watershed Treatment Model or WTM is a spreadsheet model which is used for the rapid assessment of watershed treatment options (CWP, 2002). It is primarily used as a starting point to allow users to view a wide range of multiple alternatives for watershed treatment. The model uses many assumptions which allow the user to include variables that are not commonly taken into consideration such as public involvement in educational programs. The spreadsheet uses default data from a wide range of studies to assume values of many possible constraints including maintenance discounts and community impact, but allows for user adjustment if more accurate information is available.

The model is composed of pollutant sources and treatment options. The pollutant sources are the first step of WTM, and allow users to identify the existing loads in the watershed without any treatment options. Land uses and secondary sources are used to assess the current pollutant loadings; Table 10 displays the different categories used in the calculation of these two sections. The loadings are calculated in pounds per year.

Table 10: Pollutant Sources in the WTM model (CWP, 2002)

Primary Land Uses	Secondary Sources
• Residential Land • Commercial Land • Roadway • Industrial Land • Rural Land • Forest • Open Water	• Septic Systems • Sanitary Sewer Overflows • Combined Sewer Overflows • Illicit Connections • Active Construction • Managed Turf • Channel Erosion • Hobby Farms/Livestock • Marinas • Road Sanding • NPDES Dischargers

Treatment options determine the efficiency of various future practices. This is broken down into structural and non-structural options or as listed in the WTM stormwater treatment practices and stormwater control programs. Table 11 shows these practices and programs presented in the model.

Table 11: Treatment options (CWP, 2002)

Stormwater Treatment Practices	Stormwater Management Programs
• Stormwater Treatment Practices for New Development • Stormwater Retrofits	• Lawn Care Education • Pet Waste Education • Erosion and Sediment Control • Street Sweeping • Impervious Cover Disconnection • Land Reclamation • Impervious Cover Reduction • Riparian Buffers • Better Site Design • Catch Basin Clean Outs • CSO Repair/Abatement • SSO Repair/Abatement • Illicit Connection Removal • Septic System Education • Septic System Inspection/Repair • Septic System Upgrade • Marina Pump out • Point Source Treatment

The WTM also takes into account the realistic constraints of these treatment options by adding discount factors. The discount factors decrease the BMP efficiency based on the detail of design and quantity of maintenance expected to be done on the BMP. For non-structural, educational BMPs, awareness factors are included which represent the percentage of residents who would hear and follow the suggested message.

Future Loadings can also be determined from the WTM. This section determines the effectiveness of the treatment options in the future with redevelopment.

While the WTM model is very useful for a quick assessment of a watershed, there are some limitations. First, because it is a simplified model, the loading calculations are simplified and based on "informed judgments" (CWP, 2002). Most of the loadings are very conservative, which leaves adjustment up to the user. Also, this version only accounts for total suspended solids, fecal bacteria, total nitrogen, and total phosphorous, which excludes the analysis of other important pollutants. Lastly, the stormwater management programs depend largely on assumed values of public participation which could vary between watersheds.

2.6 Case Studies

Using stormwater BMPs and LID in areas that have already been developed using conventional drainage systems presents different challenges than starting with an empty parcel of land. Retrofits may cost more than newly developed construction if it becomes necessary to upgrade existing subsurface drainage infrastructure. The benefits that arise from retrofitted BMPs and LID are usually worth the effort of overcoming the challenges. The two case studies presented in this section are successful examples of stormwater retrofit projects that incorporate LID design. All the information and figures presented in these case studies were retrieved from the Ipswich River Targeted Watershed Grant Fact Sheet written by the Ipswich River Watershed Association (IRWA) and the Massachusetts Department of Conservation and Recreation (DCR).

2.6.1 Silver Lake Beach LID Retrofit

Silver Lake is a 28-acre pond located in Wilmington, Massachusetts that serves as the town's beach. The beach faced frequent closures throughout the 8 years preceding redevelopment due to high levels of E. coli believed to be from stormwater runoff. In 2005, the town partnered with the DCR to redevelop the parking lot with LID practices to reduce the volume of runoff and improve the quality.

The last sections of two subsurface drainage pipes that conveyed stormwater from the beach parking lot and surrounding area were replaced with vegetated swales. The swales were designed to filter stormwater and the steep sides of the swale helped discourage geese from gathering and feeding in the area, which helped prevent bacteria growth.

In addition to the swales, the town replaced half of the old impervious parking lot with various porous surfaces and bioretention cells that increase groundwater recharge and allow pollutants to be broken down naturally. Permeable paving stones were placed in the parking spaces and porous asphalt was put in the driving lane. The other half of the lot was repaved with conventional impervious asphalt but graded so that runoff would efficiently drain to the porous areas or to the various bioretention cells. Two different types of pervious surfaces were built in the overflow parking area to the east of the main lot.

Promising findings were reported after five years of monitoring the LID site. There were no beach closures due to E. coli and only one closure following a bloom of blue-green algae which can be associated with excess phosphorous or nitrogen nutrients. All four pervious surfaces infiltrated as expected or better. The infiltration rates ranged from 49 to 10,000 inches per hour depending on the material. The monitoring also showed no evidence of groundwater contamination (DCR-IPWA, 2005).

Figure 13: Silver Lake Beach

2.6.2 Silver Lake Neighborhood LID Retrofit

Another project was completed by the DCR and town of Wilmington in a 3-acre residential area bordering Silver Lake. Flooding was known to be a frequent problem in the neighborhood so twelve rain gardens and two permeable pavers were implemented in the public right-of-way in front of homes along two streets in the neighborhood. Stormwater that previously flowed into catch basins and discharged into Silver Lake was now going into rain gardens and permeable pavers that provide water quality and recharge benefits.

The USGS was contracted by DCR to monitor the volume and quality of stormwater going into the lake through the neighborhood storm drain. Rainfall and runoff volumes were continuously monitored for 14 months to arrive at the following findings.

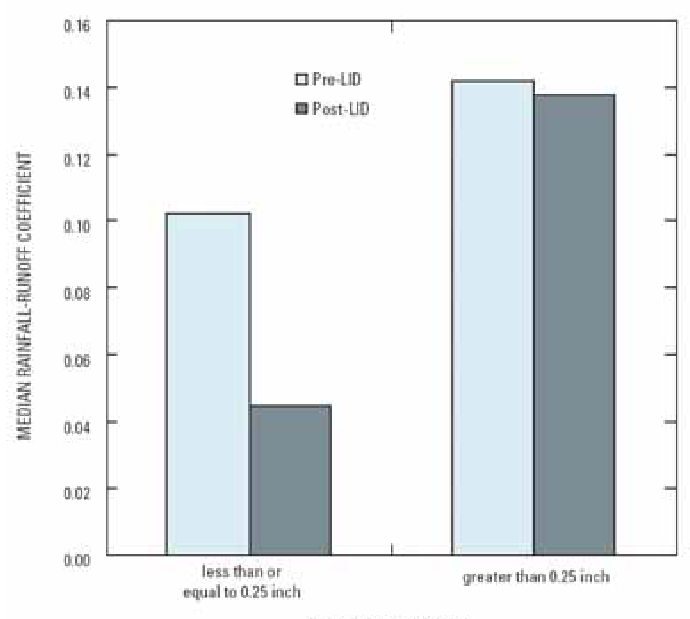


Figure 14: Runoff change before and after LID

Figure 14 shows that the LID practices were able to reduce the runoff coefficient for small storms of less than or equal to 0.25 inches. Lower runoff coefficients result in lower runoff volumes and greater infiltration. Following the LID retrofits, 33% of small storms produced no runoff at all. Nevertheless, in large storms there was no noticeable difference. There are various reasons for this finding- none of which have been confirmed. Debris and sediment could be clogging the BMPs or perhaps they were insufficiently designed. Another possibility is the storage capacity was being reached in larger storms. The water quality data was also found to be inconclusive for this case study (DCR-IPWA, 2005).

3.0 Methodology

The goal of this project was to develop an integrated stormwater management plan for the West Boylston Brook Subbasin that included a set of preliminary designs for structural and non-structural stormwater Best Management Practices (BMPs). To accomplish this, a series of tasks were executed. First, an analysis of the subbasin was completed to gain an understanding of the brook and determine existing conditions on water quality and hydrology. This analysis included general field observations, GIS mapping, current hydrologic analysis, and water sampling and laboratory testing. With this initial data, and an initial run with a computer model, critical areas were identified by the significant contributions of pollutants. Then, BMPs were selected and ranked by the team with assistance from the model. Finally, an integrated plan was created to address the needs of the subbasin and the recognized critical areas. With this plan, the subbasin was modeled to predict an overall change if the plan were to be implemented as specified. Figure 15 displays a basic flowchart of this process. For a more detailed flowchart, please see Appendix A.

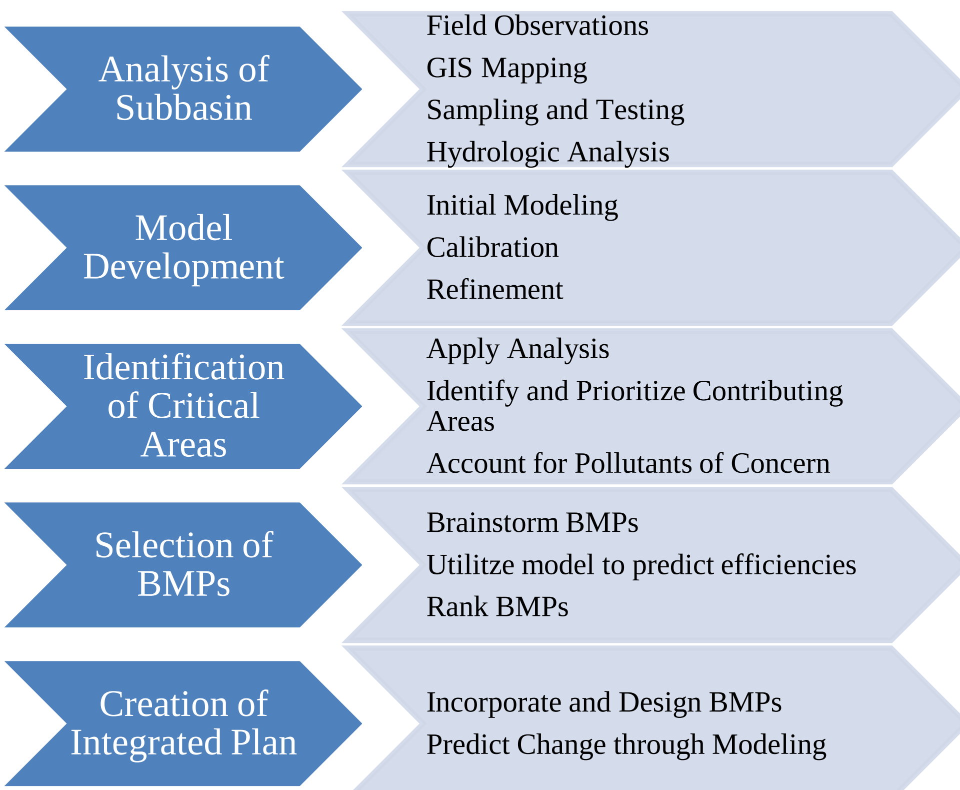


Figure 15: Basic Methods Flowchart

A goal was to develop a methodology of this project that can be replicated for use with other subbasins in the Wachusett Reservoir watershed. By applying this methodology elsewhere, the project can indirectly extend to improving the water quality of the whole watershed in future research, projects, and designs.

3.1 Analysis of Subbasin

The first step of the methodology was to analyze the current state of the subbasin. This examination would provide the team with an understanding of the subbasin and give a base to create an integrated stormwater plan from. The team completed a variety of independent tasks which contributed to the overall analysis.

3.1.1 General Field Observations

To develop an overall understanding of the subbasin, the team performed field observations on the West Boylston Brook and the surrounding neighborhoods and roads. These observations helped accomplish the following tasks:

- Determine existing qualitative conditions of brook
- Observe stormwater drainage during a few storms
- Connect facts and data from reports and GIS mapping to actual subbasin

The research performed by the team provided a good concept of the conditions of the brook. However, the reports referenced are based on past conditions. The team visited the subbasin multiple times throughout the project to gain a visual perspective of the problem, sometimes with DCR staff to locate access points to the brook. At all times, the team was careful to avoid crossing into private property.

The group visited as many sections of the brook as possible to get a full understanding of how the brook flows through the subbasin especially during wet weather conditions to see the flow of stormwater runoff. Site visits were also performed during dry weather to see the difference in brook conditions as well as complete a preliminary scouting of possible BMP locations. The team observed the qualitative water quality, noticeable stormwater culverts which feed into the brook, and general conditions of the terrain around the brook. In the whole subbasin, the team examined neighborhood trends, locations of catch basins, and road conditions.

3.1.2 GIS Mapping and Analysis

Geographic Information Software (GIS) proved to be an ideal tool for storing and organizing geographic data pertaining to the West Boylston subbasin. ArcMap 10.0 was used to evaluate many types of data simultaneously by utilizing multiple data layers. Table 12 lists the GIS data layers used throughout the project as well as the significance of each in the preliminary assessment of the subbasin.

Table 12: GIS Mapping Layers

Layers	Purpose(s)	Source
Land Use	Provides land information that can be used to assess runoff characteristics. Especially useful for hydrologic analysis.	MassGIS
Topography	Topographical lines approximate the drainage profile of subbasin and help obtain an understanding of flow patterns	USGS
Streams	The geographic location of West Boylston brook is crucial to know since it is the water resource of concern	DCR
Wetlands	Important hydrologic feature	DCR
Watershed/Subbasin boundaries	Essential geographic data to determine drainage and other hydrologic characteristics	DCR
Parcels	Determine land ownership and property sizes. Used in the development of the management plan.	DCR
Orthophotographs	Provides comprehensive view of area. Aerial images help quickly identify land uses and other geographic information	MassGIS
Storm drain network	Locations of culverts, catch basins, and manholes, help determine how water is conveyed throughout the subbasin	DCR
Roadways	(From Parcels) A critical component of land use in the subbasin and influences drainage	DCR
Soils	Shows soil types throughout subbasin. Useful for hydrologic calculations	MassGIS

GIS mapping also was useful in dividing the subbasin, as shown in Figure 16, into six sub-areas which proved helpful in the preparation of sampling and the hydrologic analysis. The six sub-areas were delineated according to the six sampling locations discussed later in Section 3.1.4.2. This delineation was created into a layer which was used to clip other layers as needed.

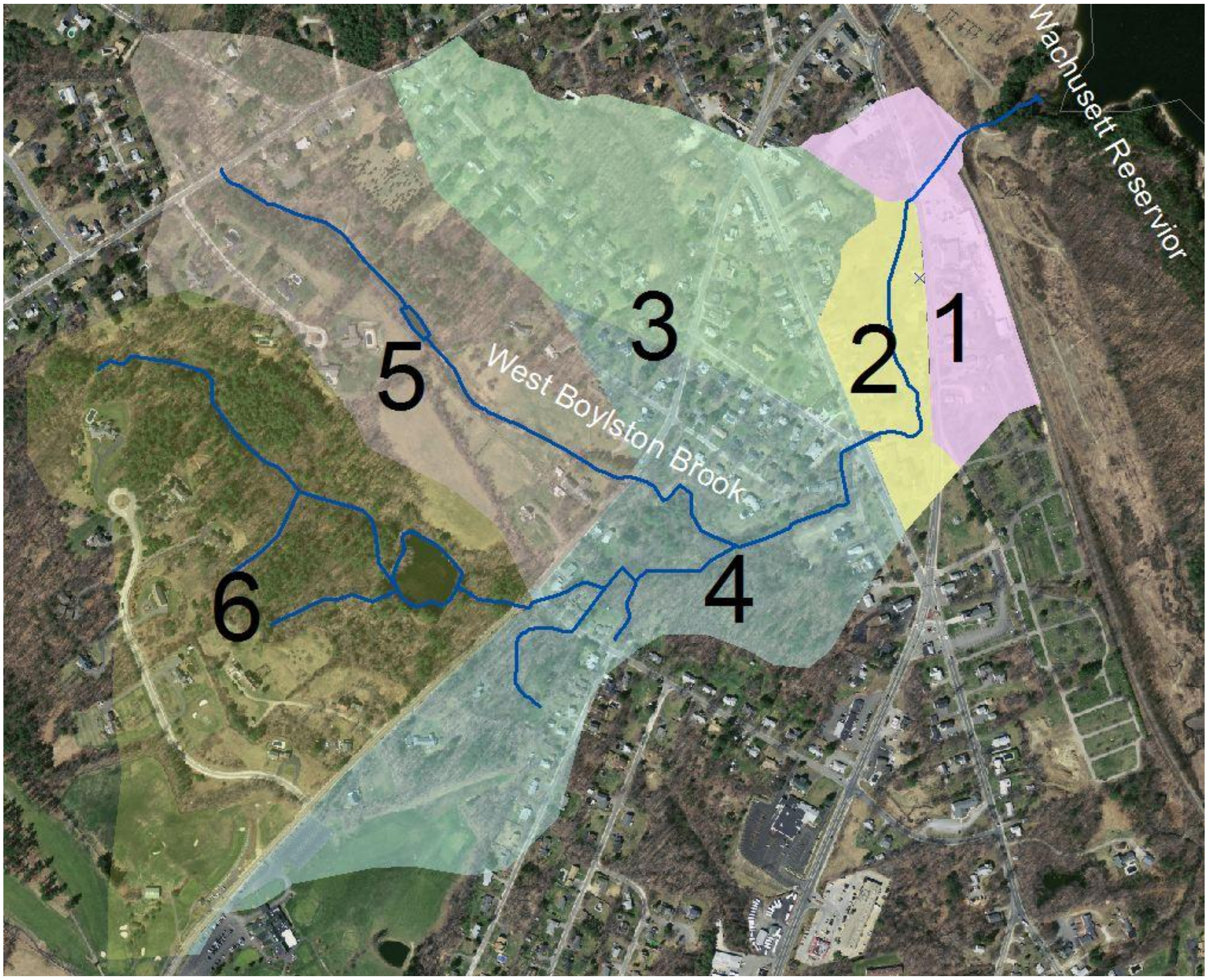


Figure 16: Subbasin Delineation

The data from GIS mapping was useful in the calculation of various hydrologic aspects of the subbasin. For example, the soil type and land use layers were critical to the calculation of curve numbers (CNs). The specific data used and the calculations used can be found in the Hydrology methodology section.

3.1.3 Sampling and Lab Testing

Water quality data is currently only obtained by the DCR from the outfall of the West Boylston Brook near the reservoir. These data are very useful for generalizing the water quality for the whole subbasin, but it does not provide sufficient information to determine sources of pollutant loading. A set of samples taken at various locations throughout the brook could reveal the source(s) or pollution in the subbasin. Therefore, a sampling plan was designed to accomplish the following tasks:

- Determined pollutant concentrations at various locations in the subbasin
- Measured flows at outfall and selected locations
- Observed differences in brook between wet and dry conditions

Three sets of six samples were taken from the brook; one set was obtained during dry weather and the other two were collected during a storm. The dry weather samples were originally planned to take place before wet weather samples to practice the sampling technique in non-storm conditions. However, wet weather samples were taken first because a measurable storm occurred before a very dry day occurred. The first wet weather samples were taken to attempt to capture the first flush of the storm, within the first hour, to measure the pollutant concentrations close to their peak. The second wet weather set was taken about an hour after the completion of the first set to capture data after the first flush. A relative reduction in pollutants over the course of the storm was observed from the second wet sample. A map of the six sample locations is shown in Figure 17.

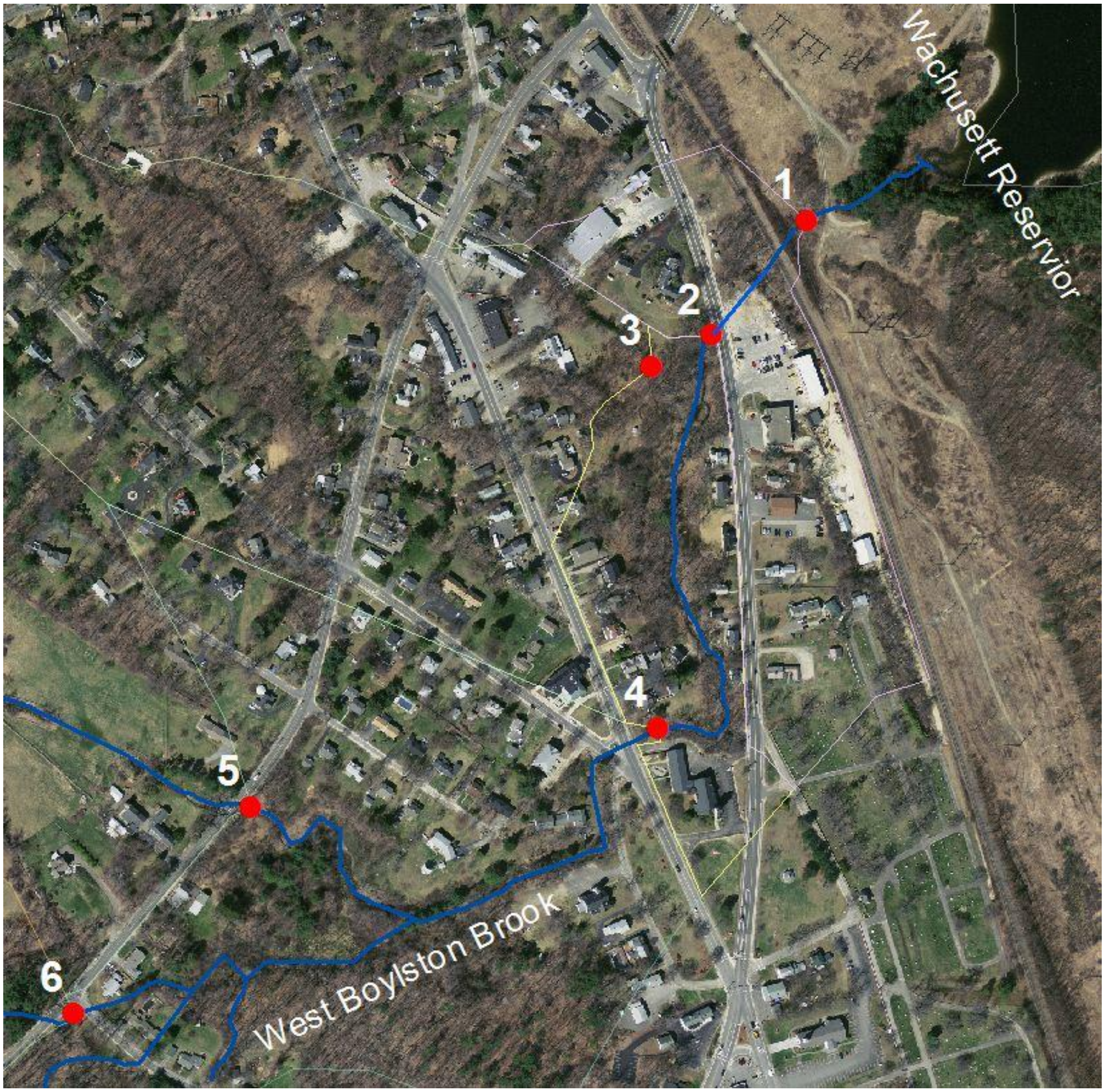


Figure 17: Sampling Locations

3.1.3.1 Storm Qualifications

EPA's *NPDES Storm Water Sampling Guidance Document* states that a storm must meet the following conditions for it to be considered acceptable for sampling (1992):

- The storm must accumulate at least 0.1 inches of rainwater
- The storm must be preceded by at least three full days of dry weather
- The depth of rain and the duration of the storm should not vary by more than 50% from the past year's average depth and duration based on the closest data collection station.

Because this brook does not have to comply with a NPDES permit and because there were only two sets of sampling during the storm, the third condition was not considered in the team's selection of a storm. Instead, the team looked for a steady storm which was predicted to produce close to or more than the average storm depth. For the month of October, the time period when the team sampled, the average storm depth from the past five years was 0.77 in (NOAA, 2011). Considering project time constraints, the team attempted to sample any storm which appeared to be acceptable as they wanted to complete sampling and testing as soon as possible.

3.1.3.2 Sampling Locations

The team collected samples from the following six locations as shown in Figure 17. Each location was selected to try to determine the concentrations of pollutants coming from different areas. With this, the team could identify possible areas of concern.

Location 1. DCR's Sampling Location

This location was east of Route 12/140 and northeast of the DPW parking lot. Downstream of this point contained no stormwater discharges and drained directly into the reservoir. Directly upstream was the drainage from the DPW yard. Location 1 was selected because it provided a comparison to DCR's sampling data and in combination with Location 2 will show the effect of the runoff from DPW.

Location 2. Culvert Entrance opposite of DPW

On the west side of Route 12/140 was a culvert running under the road toward Location 1. From here samples were collected. Upstream, the brook turned south, while to the west was a stormwater discharge that formed a channel into the brook. This location was selected to see the water quality as a combination of the brook with the runoff from Location 3.

Location 3. Stormwater Discharge Culvert

Runoff from sections of Newton, Prospect, and Central streets collected into a culvert which discharged just west of Location 2. Location 3 was selected to capture the direct runoff from these streets. This culvert opening was Location 3 and was the only site not to have in-brook samples. Therefore, this location was not sampled in dry weather conditions.

Location 4. First Congregational Church

Just north of the church was a sharp downhill wooded area where the brook ran between Central Street and Route 12/140. Samples were collected at the outfall of the culvert which ran upstream under Central Street to measure the water quality after the two splits of the brook join together.

Location 5. Prospect Street #1 (North)

A wetland area was located in the center of the subbasin where the brook split into two directions, both heading west. This location was on the east side of Prospect Street after the brook runs under the road. Upstream of this location, the brook ran northwest toward Goodale Street.

Location 6. Prospect Street #2 (South)

Right down the road from Location 5 was Location 6, the other split from the wetland. This location was also on the east side of Prospect Street after the brook flows under the road. Upstream were Carroll's Pond and the continuation of the brook to the west. Locations 5 and 6 were sampled to determine the water quality in the two splits of the brook before they join in the wetland.

3.1.3.3 Sampling Procedure

The team had collection materials prepared ahead of time to be ready for storm sampling. Because all sampling locations were very close to one another, the samples were taken to replicate a snapshot of the brook concentrations during the storm. Therefore, the order of samples was not as important as obtaining them in an efficient matter.

At each location, the samples were manually collected into plastic bottles which were cleaned in the laboratory prior to sampling. Care was taken not to take samples too close to the bottom of the brook or to contaminate samples once collected. The volume collected for each constituent is shown in Table 13. Additionally, the velocity of the brook was measured using a flow meter. The flow was approximately calculated by using a tape measure to measure the depth and width of the brook. Samples were immediately stored in an iced cooler to preserve the samples through transportation to the laboratory. *Standard Methods for Examination of Water and Wastewater* states the minimum holding time for some of the tests the team performed is 24 hours (2005). Therefore, samples were analyzed as soon as possible following collection.

Table 13: Sample Volume Required (Standard Methods, 2005)

Constituent	Volume Required (mL)
Coliform Bacteria	500
Anions	30
Total Suspended Solids	1000
Specific Conductance/pH	250
Turbidity	125
Total Phosphorus	60
Ammonia	60
DO	300 (glass)

The volume specified by *Standard Methods* was sometimes larger than what was actually required for testing. Bacteria samples were collected in 100 mL bottles provided by the DCR. The samples needed for the anion testing had to only be 3 mL so a separate bottle was not needed for the test. The 3 mL required was taken from either the sample for total phosphorus or the sample for ammonia as both those tests require only 25 mL each.

In addition to the above sampling, one of WPI's Hydrolabs, water quality measuring sonde, was used at Location 1 to create a hydrograph for the storm during wet weather conditions. The Hydrolab measured the depth every minute throughout the entire duration of sampling effort. The depth was used with the USGS discharge relationship curve for the brook to determine the flow at each minute. Turbidity, pH, DO, and specific conductance were also measured by the Hydrolab. A second Hydrolab was placed in the brook at each sampling location when collecting samples. This Hydrolab took the same measurements and was used to compare the findings of sampling and testing.

3.1.3.4 Testing Procedures

The team tested its samples for E. coli coliform bacteria, various nutrients, total suspended solids, specific conductance, turbidity, and dissolved oxygen. All procedures were performed for all samples at WPI's Environmental Engineering Laboratory unless otherwise specified. The following sections describe each procedure utilized. Full details of each procedure can be found in step by step instructions found in Appendix D.

Coliform Bacteria

Bacteria procedures test for coliform as they are a high indicator for the presence of bacteria. The coliform bacteria samples were measured because the brook has a history of high fecal and E. coli coliform concentrations. Sampling for coliform may reveal the source or the sources or these high concentrations such as pet waste, septic system failures, livestock waste, wild animal droppings, or wastewater discharges (NHVRAP, 2011). *Standard Methods* suggests using procedure 9221, Multiple Tube Fermentation, or 9222 Membrane Filtration Technique. Both require a holding time of less than six hours and overnight incubation. Because of these specifications, the DCR sent samples for coliform testing to MWRA's EPA certified lab.

Nutrients

Test(s) for nutrients were conducted because the DCR has expressed concern in the nutrient levels of the brook. High levels of nutrients suggest the presence of animal or human waste, fertilizers, erosion, or detergents (NHVRAP, 2011). *Standard Methods* procedure 4110 for Ion Chromatography (IC) was used to measure anion concentrations in the samples. Samples were filtered through a 0.45-micron filter before injecting into the IC. The results from this procedure yielded concentrations of dissolved phosphate, nitrate, and nitrite. The chromatography system also yielded concentrations of chloride, bromide, fluoride, and sulfate.

A test for ammonia and a test for total phosphorus were also performed using a color spectrophotometer according to WPI's testing procedures. Total phosphorus was measured to determine the total amount of phosphorus that includes phosphorus attached to any sediment that was filtered out in the test for the phosphate ion. The ammonia test was performed to determine the amount of ammonia, the third form of nitrogen which can be of concern in surface waters.

Total Suspended Solids

As a measure of the sediment loadings in the water and the overall water quality, a test for total suspended solids was conducted. High levels of total suspended solids are the result of organic matter and sediment getting into the water through runoff (NHVRAP, 2011). Sources of this sediment can be sand or soil in non-vegetated areas or erosion. To test for TSS, *Standard Methods* procedure 2540D dried at 103 to 105 °C was performed to determine total suspended solids. In this procedure, a volume of the sample was pipetted into a vacuum filter. The filter was washed with laboratory E-pure water three times. Then the filter was transferred to a plate and dried in an oven for one hour. The sample was measured for mass and the heating process was repeated until the mass did not change by more than four percent. A simple calculation was used to calculate the concentration of suspended solids using Equation 8.

$$TSS\left({}^{mg}/_{L}\right) = \frac{(W_f - W_i(mg))}{V(L)} \qquad \text{(Equation 8)}$$

Turbidity, Conductance, and Dissolved Oxygen

All three of these constituents were measured as determinants for overall water quality in all samples. A conductivity meter was used to measure specific conductance which can indicate pollution from septic system failures and road salting (NHVRAP, 2011). Turbidity, another way of estimating solid concentrations in water, was measured using the Hach 2100N Turbidimeter in the laboratory and dissolved oxygen (DO) was measured using a probe in the laboratory. Low DO levels can be the result of high bacteria or can be the result of high turbidity levels (NHVRAP, 2011).

3.1.3.5 Analysis of Test Results

After recording the results for the stormwater samples, the team created bar graphs to visually evaluate water quality trends throughout the subbasin. A bar graph was created for each measured pollutant with values of concentrations in mg/L on the y-axis and each of the six sampling locations on the x-axis as presented in Section 4.3. The sampling locations were listed from left to right in an increasing numerical order to more easily interpret the changes in concentrations at different locations throughout West Boylston Brook.

The group analyzed how concentrations for each pollutant changed throughout the six subbasin sampling locations by noting isolated peaks in the data. The team assumed that a particular pollutant was prominent in the sample location where large pollutant values were observed and the concentrations at the immediate downstream and upstream sample locations remained low or relatively stable. This data served as an indication that the pollutant was being transported from the stormwater runoff of a nearby site and not from accumulated pollutant concentrations from upstream sources.

In addition to identifying peak concentration values, the team considered the influence of geographical and hydrological features such as wetlands, topography, and stream confluences in the results. For instance, ponds and wetlands are known to treat pollutants so the team expected that sampling locations following these natural features would have lower concentrations. The team also used the concept of mass balance to claim that the individual pollutant loadings in two converging streams accumulate to the summation of the two loadings when finally joined. This was evident in the area downstream of sample locations 5 and 6 where the two streams join to become West Boylston Brook.

The team compared the stormwater sample results to other historical water quality concentration values to quantify the significance of the data. DCR's stormwater and dry weather data for West Boylston Brook were compared to the team's sample results to acquire a reliable baseline on which to assess our data. Research was also conducted to discover common ranges of pollutant concentrations as presented by EPA in a variety of sources (EPA 2011a, EPA 2011b, EPA 2011c).

The stormwater concentrations at both collection times were compared to one another to help achieve a greater understanding of how pollutant concentrations may change during the duration of the storm. The first set of wet samples was intended to be collected at the beginning of the storm in time to capture the first-flush. First flush concentrations are generally higher than those collected later in the storm since the first flush concentrations are likely affected by pollutants that accumulated during dry weather periods (Kayhanian and Stenstrom, 2008)

The team compared the first and second set of data to determine if the first-flush was captured and whether the pollutant concentrations at could have possibly diluted over time. All pollutants were analyzed individually to take into consideration the unique characteristics of each.

Analysis of Dry Weather Sample Data

The results from the dry weather samples were compared to the stormwater results to help assess the level of stormwater contributions to observed pollutant concentrations in wet weather. If a particular wet weather pollutant concentration was found to be significantly higher than the concentration during dry weather conditions then the team concluded that runoff was the primary source of the pollutant in the stream. If the dry weather concentration was higher than the stormwater concentration then the team reasoned that the pollutant was most likely being diluted during the storm event and that the higher concentrations could possibly be attributed to base flows from groundwater. This determination was confirmed by looking at the concentrations at Location 3 during wet weather because this location was direct runoff without any baseflow. If this location had low concentrations compared to others and the dry samples were higher, then it was even more likely that the high concentrations were not a result of stormwater. The instantaneous loadings of wet and dry conditions were also compared to determine if the pollutant was a result of stormwater.

3.1.4 Current Hydrology

An analysis on the hydrology of the subbasin and the sampling areas was done using information from field monitoring data and hand calculations to accomplish the following:

- Complete a hydrograph for the storm sampled
- Determine the runoff curve number (CN) for each sub-area
- Approximate flows at each sample location and loadings of pollutants for each sub-area

A hydrograph was made for the entire subbasin by using depth measurements from the Hydrolab at Location 1. The Hydrolab was a Hach water quality sonde which measured depth, turbidity, conductivity, temperature, pH, and dissolved oxygen. The Hydrolab data was found to be approximately 0.1 feet less than the readings taken from the USGS gage on site. Therefore this difference was added to all measurements and then the depths were converted to flows by using the USGS discharge relationship chart provided by DCR. Appendix B shows a copy of this chart. The flows were plotted versus time to develop the hydrograph.

A runoff curve number (CN) was calculated for each of the six sub-areas using the soil types and land use layers from GIS along with the areas of each sub-area. It was assumed that the antecedent moisture condition number was II for all calculations. The antecedent moisture condition represents the variance in the CN value at sites between storms. A value of II is the most commonly used value as it is the median.

For the storm, the pollutant loadings were calculated by multiplying the flows at each sampling location by the calculated event mean concentrations. An event mean concentration was calculated between the two concentrations measured during the storm by taking a weighted average. The time when the sample was obtained, was used with the hydrograph to determine the weighting by splitting the hydrograph in half between the two sample times. The volume of water under each hydrograph was used for the weighting. Equation 9 was used to calculate the event mean concentration. A sample calculation is shown following the equation.

$$Event\ mean\ concentration = \frac{(C_1 * V_1 + C_2 * V_2)}{total\ V} \qquad \text{(Equation 9)}$$

$$Example: C_1 = 1.0\frac{mg}{L}, C_2 = 2.0\frac{mg}{L}, V_1 = 1000\ ft^3, V_2 = 1500\ ft^3$$

$$Event\ mean\ concentration = \frac{(1.0 * 1000 + 2.0 * 1500)}{2500} = 1.6\ mg/L$$

The full methods for calculating the event mean concentration can be found in Appendix C. The team used Simple Method calculations in Microsoft Excel to loadings from each area by using the equation 10.

$$L = 0.226 * R * C * A \qquad \text{(Equation 10)}$$

In this equation, L is the loading, R is the runoff volume, C in the event mean concentration, and A equals the area. The runoff volume was determined from the NRCS method to estimate flow using equation 11. The P value is precipitation and the S value is storage which was determined from the CN of the sub-area.

$$Q = \frac{(P - 0.2*S)^2}{(P + 0.8*S)} \qquad \text{(Equation 11)}$$

As an alternative, instantaneous loadings were also calculated by multiplying the flow in the brook by the concentration at the time of that flow. The flow was calculated by multiplying the velocity of the brook by the area, both of which were measured in the field. The area was assumed to be rectangular by taking the average of three depths evenly spaced along the bottom of the stream. Both methods of calculating loadings were done to provide a comparison to loadings calculated by the model.

3.2 Development of the Watershed Treatment Model (WTM)

The Watershed Treatment Model (WTM) was used as a tool to quantify pollutant loadings and assess various treatment options in the West Boylston subbasin. Several stages of development were established to effectively utilize the model. A table of the model development process is shown in Table 14.

Table 14: Modeling Steps

Major Step	Minor Steps	Purpose
Initial Configuration	•Determine primary model inputs •Determine secondary pollutant sources and existing management practices	•Gain familiarity with model •Calculate first-run pollutant loadings for existing conditions
Comparison	•Compare WTM to Simple Method and historical loadings	•Determine accuracy of model results
Calibration and Refinement	•Make further adjustments to model	•Improve accuracy of results for existing conditions
Calculate Loading Reductions	•Incorporate suitable BMPs •Compare results to existing loadings	•Quantify effectiveness of recommended BMPs

3.2.1 Initial Configuration

The most fundamental inputs required in the WTM were the primary sources or the inputs which would calculate the loadings from runoff. Information needed for primary sources included land use, annual rainfall, and soil type. Since there were many more MassGIS land use categories than WTM categories, MassGIS land uses that shared common runoff curve numbers (CN) and average percent impervious area were grouped together and categorized into one of the WTM land uses. The team used a table of CN values for various land uses found in the Natural Resources Conservation Service (NRCS) Technical Report 55 to group and categorize the land uses. A complete list of MassGIS and the WTM land uses for the West Boylston subbasin can be found in Appendix E. Annual rainfall was obtained from the Worcester Regional Airport through the National Oceanic and Atmospheric Administration database and soil type data for soil groups A, B, C, and D was available through MassGIS.

Information for secondary pollutant sources and existing management practices in the subbasin were also found to complete the initial configuration of the spreadsheet model. Secondary sources were practices, when applicable to the subbasin, which could have an additional pollutant loading impact. Some of the relevant inputs for the secondary sources were the number of dwellings connected to sewage systems, road sand application (lb/yr), and non-stormwater point sources. Inputs for existing management practices included but were not limited to current effectiveness of pet waste programs, sediment controls, BMPs, street sweeping, and catch basin cleanouts. As much information as possible was gathered in order to increase the accuracy of the model output. A full list of inputs and sources can be found in Appendix F.

The WTM automatically calculated the annual pollutant loadings for existing conditions once all crucial inputs were added to the model for primary sources, secondary sources, and existing management practices. Conducting this first run-through of the model helped increase familiarity with the various inputs and variables in the WTM and provided a base for comparison once future BMPs were implemented.

3.2.2 WTM and NRCS Comparison

The team reasoned that it was necessary to compare the WTM loadings to those obtained using a different method to achieve a degree of confidence in the model results. The loading results from the WTM were compared to the team's calculations from the NRCS method to calculate runoff instead of the Simple Method formula used in the WTM. For this calibration, the model was modified to a 24-hour storm rainfall to match the NRCS calculation. To do this, the annual rainfall value was changed to the total rainfall for the storm the team sampled.

WTM uses default pollutant concentrations based on historical stormwater data from numerous research reports; whereas the team used concentrations derived from the storm that was sampled. Table 15 depicts how each approach differs in the use of parameters applied in the pollutant loading calculation. For more information on the formulas in Table 15, please refer to Section 2.2.

Table 15: WTM and NRCS Calculation Comparisons

Parameters	WTM Method (CWP, 2002)	NRCS Runoff Method
L= Loading (lb/time)	L = 0.226 * R * C * A Loads are calculated for each land use and summed to obtain one loading Secondary Pollutant Sources and Existing Management Practices normally included	L = 0.226 * Q * C * A One loading is computed using the Q value for the given sub-area. C is the only variable that changes from one pollutant loading to another
R=Q= Runoff (inches)	Runoff calculated for each land use using the formula: R = P * P_j * Rv Where: R = Annual runoff (inches) P = Annual rainfall (inches) P_j = Fraction of annual rainfall events that produce runoff (usually 0.9) Rv = Runoff coefficient	One Q value is calculated for each sub-area using the following formula: $Q = \frac{(P - 0.2 * S)^2}{(P + 0.8 * S)}$ One composite CN is calculated for each sub-area which represents a weighted average of CN values for the various land uses. $S = \frac{1000}{CN} - 1$
C= Pollutant Concentration (mg/L)	Defaults values derived from nationwide data. See Appendix O for the full table	Event Mean Concentration derived using stormwater sample concentrations and the process explained in Appendix J

One step to reduce variability in pollutant loadings during the calibration process was to ignore the effects of secondary pollutant sources and existing management practices from the WTM because they could not be included in NRCS calculations. In addition, only loadings from sub-areas 5 and 6 were used in the calibration. The respective sub-areas are located upstream and are isolated from the effects of downstream wetlands, which allowed for less interference in the pollutant loading calculations.

The pollutant loading results for sub-areas 5 and 6 were analyzed using the WTM and the NRCS methods. If differences existed, then the model could be determined to be imprecise; however, this determination is limited because they were compared for only one storm. Therefore the differences were analyzed to see if the model had a level of accuracy good enough to provide a basic comparison between the existing conditions and post BMP implementation conditions.

3.2.3 Model Calibration and Refinement

Once some confidence was established in the model results, the model was adjusted back from a 24-hour model to produce annual loadings and the input values for the secondary pollutant sources and existing management practices in the West Boylston subbasin were further refined. The website for the town of West Boylston and its affiliated departments was researched to acquire more recent and reliable data. DCR and the town's Department of Public Works were further consulted to update the model inputs. Once the refinement process was complete, the existing loads of the subbasin were determined and could be used as a baseline on which to measure suggested improvements.

3.2.4 Loading Reduction Calculations

Once BMPs were selected, the model was used to predict BMP removal efficiencies. This step is described further in the Section 3.4 of the methodology.

3.3 Identification of Contributing Areas

Identifying the areas that need the most water quality improvement is a prerequisite to determining potential locations for BMPs and the eventual development of a stormwater management plan. Several tasks were completed which, when analyzed together, helped locate the areas of concern. Figure 18 depicts these tasks in the flow chart below. Once the general sub-areas of concern were determined, specific sites within those sub-areas were found through additional screening of land and properties.

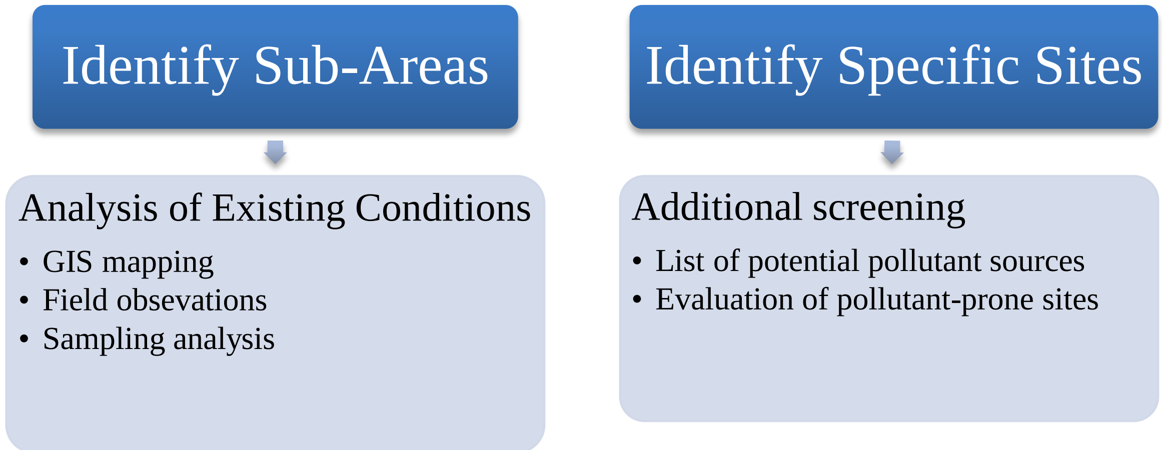


Figure 18: Identifying Areas Tasks

The problematic pollutants and the general locations in which they were most prominent were identified through the analysis of the subbasin's existing conditions. GIS mapping and knowledge received from field observations were used in conjunction with the laboratory analysis to determine the sub-areas (1-6) of greatest concern. The significant data from the lab analysis were organized and highlighted as portrayed in the Section 3.1.3 of the methodology. The field observations and GIS mapping helped provide the geographic and visual understanding necessary to interpret the quantitative data received from the sample analysis. Determining the impaired water quality sub-areas helped establish the focus for the rest of the project.

An additional screening process was necessary to identify specific problem sites in the larger sub-areas of concern. A list of potential sources and indicators of each pollutant was made to narrow the search for sites where pollutant runoff could be expected. Next, the sites or specific areas that contained indicators of pollutants were listed. For example, if E. coli were a pollutant of concern, attention would be concentrated on specific areas where wildlife were known to roam since these areas are more susceptible to E. coli contamination. Internet research and coordination with DCR was utilized to screen particular properties to determine the likelihood of pollutant runoff at the given site. Table 28 in Section 4.6.3 was made to organize this information to be easily understood. Identifying the specific sites helped lay a foundation for selecting potential locations for BMP retrofits.

3.4 Selection of Appropriate Best Management Practices

With specific sites of concern identified, appropriate best management practices were selected by the team. The selection process began with an overall brainstorming of BMPs, both structural and non-structural, for specific sites. Next, all BMPs were placed into the WTM individually to predict pollutant removal efficiencies. Last, with additional consideration into physical size, approximate cost, and community impact, the BMPs were ranked using a weighted system. The top ranked BMPs were chosen for suggestion in the integrated plan.

3.4.1 Brainstorming BMPs

After completing additional site visits, the team brainstormed a variety of BMPs that could be implemented in the subbasin. No restrictions were placed on ideas besides trying to target pollutants at specific sites. A list was created with all BMPs, including non-structural ideas as they provide a cheaper alternative to the high-up-front cost of many structural BMPs.

3.4.2 BMP Modeling

All BMPs were then entered into the model one at a time to predict a pollutant removal from the subbasin for total phosphorus, total nitrogen, total suspended solids, and fecal coliform bacteria. In addition to the type of BMP, the drainage area, impervious percent of area, majority soil type, and maintenance factors were inputted into the model. GIS was used to obtain many of these values. The WTM used the inputted values and predetermined removal efficiencies to get a pollutant removal for each BMP. This value may not have been accurate because of the assumptions that the model makes, but the value was still useful in a relative sense to compare different BMPs. These efficiencies were important as the BMPs needed to have high enough values to make a difference in the pollutant loadings. Research showed a lot of estimates for pollutant removals from BMPs, but they were often presented with large ranges. Modeling a BMP provided a solid percentage based on the area treated and the general characteristics of that area, which was comparable to the other BMPs.

In some cases, the WTM did not have a BMP that the group had considered. In these situations, the group tried to approximate the reduction as best as possible by using another BMP similar to it or by using research to determine a reduction percent.

3.4.3 BMP Ranking

Each BMP was compared based on the percent removal of the four pollutants: TSS, TN, TP, and fecal coliform, as estimated from the model. Additional factors included the up-front cost, the required maintenance, and the community impact. The next few sections describe these additional considerations followed by the ranking process.

3.4.3.1 Cost

The cost refers to all up-front costs needed to construct and/or implement the BMP. Because cost was a limitation, it was useful to estimate the approximate costs of preliminary solutions. Therefore BMPs that were less expensive were more desirable. However, this did not mean that pollutant removal percentage was necessarily sacrificed for a lower cost. The team calculated the percent removal per dollar for the target pollutant of the BMP. Another way to quickly compare the value of a BMP was to calculate the cost per cubic feet of stormwater treated. These figures were readily available in stormwater reports, such as the *Urban Subwatershed Restoration Manual Series* written by the Center for Watershed Protection in 2007. Each BMP was given a cost score from 0 to 10 where 0 was the least cost effective and 10 was the most cost effective. The score was either agreed upon by the group or an average of individual group member scores.

Size was originally considered as a criterion for BMP selection, but because an increase in size usually meant an increase in cost, the team eliminated this criterion to avoid a double count. However, size was still a role in the decision making process as some BMPs may have been too large with space limitations. DCR had previously made it clear that large and expensive BMPs may not be feasible, but some were brainstormed and were considered subject to the scoring of the ranking process.

3.4.3.2 Maintenance and Upkeep

Maintenance and upkeep refers to the future costs associated with ensuring that the BMP will continue to function properly, making repairs as needed, and providing routine service if necessary. Many BMPs require some servicing after implementation and this was considered in the ranking of BMPs. For example, rain gardens and bioretention areas must be landscaped routinely. A concern for all BMPs in this project was who would service BMPs, especially if they were on private property. Associated with this, is the cost to maintain a BMP through supplies or labor. Because cost was a concern and because high maintenance was not desired, it was preferred to have BMPs with as low upkeep as possible. Each BMP was given a score from 0 to 10 where 0 required frequent and extensive, costly maintenance and 10 required no maintenance.

3.4.3.3 Community Impact

Assessing the impacts of stormwater retrofits on the surrounding community is essential to the long-term success of any proposed solutions. Some of the common concerns that arise when retrofits are proposed are construction issues and BMP appearance (Urban Stormwater, 2007). The DCR proved to be very helpful in assessing community impact since they have had experience dealing with such issues. GIS was also used with this criterion. Assessing the sites surrounding the proposed on-site BMP helped determine what effect it may have on neighboring residents and businesses. Each BMP was given a score from 0 to 10 where 0 represented a BMP which would not be accepted by the public and was likely to receive negative feedback and 10 represented a BMP that would not receive negative feedback or would not even be seen by the public.

3.4.3.4 Ranking Process

Each BMP was given a total weighted score based on the pollutant removals and the above considerations according to the weightings in Table 16. The weightings were determined by group agreement as they viewed each consideration to be equally important. If desired, the distribution may be changed by adjusting the values in the ranking spreadsheet, located in Appendix G.

Table 16: Weighting for Rankings

Consideration	Percent Weighting
Cost	25 %
Maintenance	25 %
Community Impact	25 %
Total Relevant Pollutant Removal	25 %

The total relevant pollutant removal was an average of the pollutant removal percentages that were relevant to the BMP. For example, if the BMP was considered just to target TSS, then only the TSS removal percentage was factored into the ranking. If more than one relevant pollutant was considered then each pollutant was weighted equally within that 25%. The total weighted score was on a scale from 0 to 10 where 0 score was a BMP which was unlikely to be considered and 10 score was a BMP which would be a perfect solution for the entire subbasin. The team ordered the BMPs by score and selected those which had high scores and in combination would treat all pollutants.

3.5 Creation of Integrated Management Plan

With the existing conditions of the subbasin analyzed and appropriate BMPs selected, the next step of the methodology was to create the integrated stormwater plan. This plan outlined the steps needed to decrease pollutant loadings going into the brook. The plan presented many options to improve the subbasin, but also included a final suggestion on how to implement the plan. The plan was designed to be implemented over no specific time period; because, while implementing every BMP would decrease pollutant loadings, it may not be economically feasible to implement them all. Each BMP should be implemented as soon as possible with a few exceptions as noted in the plan. The following components are included in the plan: Suggested BMPs and their Implementation, Conceptual Design of a structural BMP, and Predicted Performance.

In the first component, three sites were presented with the suggested BMPs for that area. The BMPs were presented with as much detail to describe where and how they should be implemented. The sizing and specifications were not determined in this report. The estimated cost and efficiency as estimated by the WTM were also presented with each BMP. The efficiency was found by selecting the BMP in WTM and inputting the area of the subbasin that it would treat along with the most frequent soil type in the treated area. The WTM calculated the final pollutant loadings with the BMP implementation and gave a percentage output which was used in the plan. This section simply presents the options available to treat the runoff going into the brook and the maintenance required for the future.

The second component details a conceptual design for one BMP near the DPW yard. The design was determined by sizing it according to the standards set forward by the *Massachusetts Stormwater Handbook.* The design provided basic specifications for the BMP to allow for an easier implementation since the sizing is already complete. Because of time constraints, the specifications for the other BMPs were not determined.

The last component focused on using the WTM to combine the implementation of various BMPs to observe the expected pollutant decrease. The model was used to input multiple BMPs at once to determine the most effective method. In addition to the effectiveness determined by the WTM, the costs of upfront construction and long term maintenance were considered. The final solution, presented in the next chapter, will be a suggested solution with suggestions for additional BMPs to be implemented in the future.

4.0 Analysis of Existing Conditions

The following sections present the results and analysis of all tasks accomplished to establish the existing conditions of the subbasin. These sections include field observations, subbasin drainage analysis, the analysis of sampling and laboratory testing, the hydrologic analysis of the subbasin, the initial loading results from the WTM, and the identification of contributing areas and sites.

4.1 Field Observations

Two initial site visits were completed prior to sampling. The first was on September 7th, 2011 and the second was on September 25th, 2011. Detailed records of both visits can be found in Appendix H. The following sections describe the major findings from the two visits.

4.1.1 September 7th Visit

The first visit was on a rainy day in early September. From this visit, the team got to see the brook for the first time and observe the flow of runoff. The team was guided by two DCR employees who were familiar with the area. First, the group visited the sampling point for DCR which later would become sampling Location 1 as shown in Figure 19. There was some noticeable turbidity in the water.

Figure 19: DCR Sampling Location

Next, the team went upstream to the DPW parking lot where it was observed that there was runoff from the lot channeling down right toward the brook. The DCR staff commented on the spot believing it could be a possible source of pollutants. The team noted the DPW area as being a preliminary spot where a BMP could be placed.

The team proceeded across the street to look at the culvert which passes underneath the road. There, the team saw the brook run into the culvert and the addition of a large amount of runoff coming from a culvert to the west. The DCR staff was unsure what streets contributed to this runoff, but suggested the team consult some AutoCAD files which might have the storm drain piping mapped. Of note, the channelized flow from the runoff had caused some very eroded areas as shown in Figure 20, a picture taken of the eroded area at a later time. Because of the volume of runoff coming from this area, the team considered this to be of interest.

Figure 20: Eroded Runoff Channel

Next, the team visited the brook near the church and the only observation of concern was that some of the curbing on the parking lot was broken or not complete, meaning runoff from the parking lot could flow right down the embankment into the brook.

As the team drove to the next location, they noticed the intersection of Prospect and Central Streets as having lots of commercial buildings and a lot of impervious area. The last part of the brook the team visited was after it splits in a wetland in the middle of the subbasin. The team saw the brook at the split near Carroll's Pond. No observations of importance were made except that the DCR staff did not view this area as being a major pollutant contributor because it was so far upstream. Overall, the team thought the visit successful as they saw four sections of the brook, much of the surrounding area, and got to observe light storm conditions.

4.1.2 September 25th Visit

The second visit was on a cloudy, but dry day a few weeks after the first visit. The team went alone with specific sites to visit. The first spot the team visited was the DPW parking lot again because of the emphasis the DCR staff had put on its potential source of pollutants. Nothing of additional importance was found besides a waste oil collection basin on the east side of the parking lot. Inquiry into this a few weeks later revealed that the waste oil is collected to heat the DPW building.

The team proceeded to a one road neighborhood, Lost Oak Rd. in the southeast corner of the subbasin. It was not included in the CAD drawings that the team had studied so the field visit was used to examine the neighborhood. The neighborhood consisted of large houses and lawns, but still had many natural trees and vegetation. There were many catch basins along the road. The team tried to determine where all the runoff drained and thought some of it might drain down Prospect Street and then enter the brook at the corner of Prospect and Franklin. In talking with DCR staff at a later time, it was also a possibility that some or all of the drains led to a detention basin north of the neighborhood and then drained upstream of Carroll's Pond.

Very close to Lost Oak Rd. was a golf course, some of which was in the subbasin. Using a map from the parking lot, the team concluded that most the runoff would not enter the subbasin, but some could.

Two more neighborhoods, Scarlett St. and Newton St., were visited by the team with no major observations.

Last, the team went to the highly impervious intersection of Prospect and Central Streets. The goal was to see where the runoff collected from these streets and a few nearby streets drained. According to the CAD files, it drained behind the building with Darby's Bakery. The team searched behind the building and into the vegetation behind the rear parking lot, but could not find any discharge. From this, the team assumed that the pipe is completely underground until the culvert opens and the runoff flows into the brook near the DPW.

This second visit was also successful as the team observed many of the areas it had previously not seen and obtained some of the physical drainage information that could not be determined in the CAD files.

4.2 Subbasin Drainage

The behavior of stormwater runoff throughout the subbasin was determined using GIS and CAD software. The topographic GIS layer was used to determine surface flow and DCR's drainage structures layer was used to determine manmade subsurface flow. A CAD file showing West Boylston's drainage network designed by engineers at Weston & Sampson Inc. was reviewed and compared to DCR's existing drainage layer to complement the drainage information missing from the DCR drainage structure layer. Drainage pipes were drawn onto the printed subbasin map to help the team visualize the subbasin drainage system. The drawn-in drainage pipes along Prospect and Central Street can be seen below in Figure 21.

Figure 21: Map with Subsurface Drainage

Upon early analysis of the subbasin drainage, it became evident that areas of surface and subsurface flow were more common in pervious and impervious areas respectively. This observation seemed valid since most of the subbasin land use is low density residential or forest, which allows for runoff to partially infiltrate into soil. All streets, with the exception of Scarlett Street, possessed some catch basins, though the catch basins in low-density residential streets such as Marsh Hawk Way and the east section of Newton Street drained out into nearby pervious areas instead of joining a larger drainage network. Long drainage pipes were found to be present in areas with more impervious area and along major roads such as Central Street, Prospect Street, and Worcester Street. Figure 22 shows an example of the drainage mapped at the intersection of Central Street and Prospect Street.

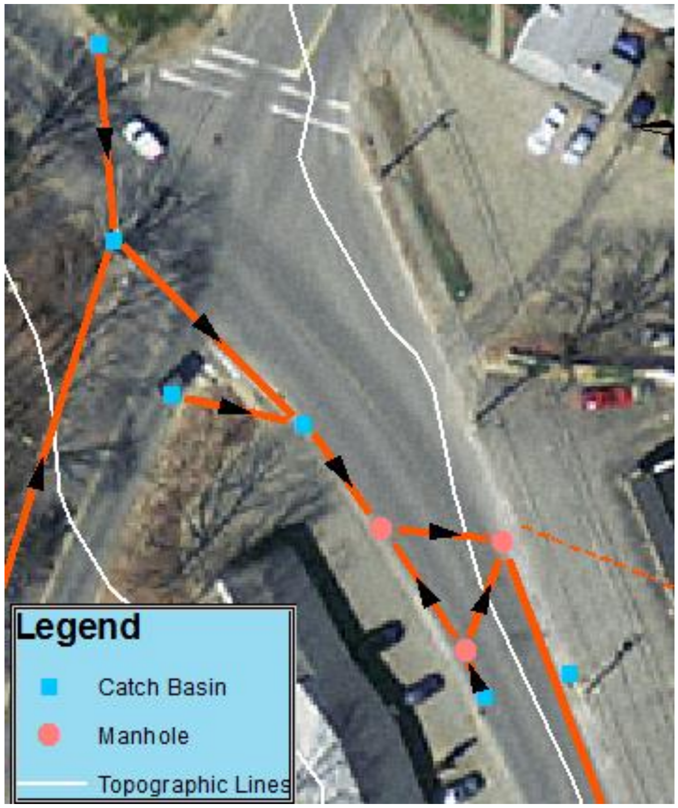


Figure 22: Subsurface Drainage for the Intersection of Prospect and Central Street

An important note to be made regarding the drainage assessment is that some of the GIS and CAD data were incomplete or indiscernible by the team. One area that posed a challenge was the intersection of Prospect Street and Central Street. One of the catch basins in CAD drawings was missing a connection and a manhole was falsely recorded as a catch basin. These details could have been investigated further by field inspection but due to the time constraints of the project some of the missing details were left unresolved. Nevertheless, the team was able to obtain a good enough understanding of the drainage characteristics to continue with the development of stormwater solutions in the subbasin.

4.3 Sampling Results and Analysis

The results of sampling and laboratory testing were used to determine the pollutant problems in the West Boylston Brook and the areas where these pollutants are originating. A summary of the peak wet and dry concentrations measured for each testing parameter can be found in Table 17. The location where the sample was obtained is in parentheses next to the concentration. These locations can be seen in Figure 17 of Section 3.1.3. All results in Table 17 are from sampling and testing.

Table 17: Summary of Sampling and Laboratory Testing

Testing Parameter	Peak Wet Weather Value	Peak Dry Weather Value
Turbidity (NTU)	39.8 (Location 1)	1.45 (Location 1)
TSS (mg/L)	93.50 (Location 1)	5.63 (Location 1)
E. coli (MPN/100mL)	14,100 (Location 2)	20 (Location 4)
Ammonia (mg/L)	1.111 (Location 2)	0.145 (Location 4)
Total Phosphorus (mg/L as P)	0.907 (Location 2)	0.056 (Location 1)
Nitrate (mg/L)	2.59 (Location 1)	4.52 (Location 1)
Phosphate-P (mg/L)	0.31 (Location 3)	0.13 (Location 1)
Conductivity (μS/cm)	508 (Location 1)	730 (Location 1)
pH	7.06 (Location 1)	7.16 (Location 4)
Dissolved Oxygen (mg/L)	10.91 (Location 5)	10.11 (Location 4)
Chloride (mg/L)	61.29 (Location 1)	95.29 (Location 1)
Sulfate (mg/L)	8.57 (Location 1)	14.03 (Location 1)
Fluoride (mg/L)	0.05 (Location 1)	0.05 (all locations)

The following sections describe the results for each parameter for both dry and wet conditions, the variations throughout the sampling locations, and how the results from the Hydrolab compared with the results from the laboratory. The values measured or determined by sampling may be compared to historical data from the brook or compared to standards obtained from other sources. Full tables with all data may be found in Appendix I.

Throughout these sections, it is important to recognize that there were some factors that may have affected the results. These factors do not diminish the value of the results, but they will be accounted for in the analysis when applicable. The first factor is that unlike the original plan, the wet samples were taken before the dry samples because of timing with a storm. In addition, the dry samples were taken three weeks after the wet because of continued wet conditions. In these three weeks, there was a snow storm, more leaves fell off trees, and the temperatures were overall colder. In wet weather sampling, the samples for one set were not all obtained at the same time. Therefore variations between samples could be present because of travel time between sites.

Conductivity

The results from the conductivity measurements in the laboratory and with the Hydrolab are shown in Figure 23. The locations are ordered from downstream (Location 1) to upstream (Locations 5 and 6).

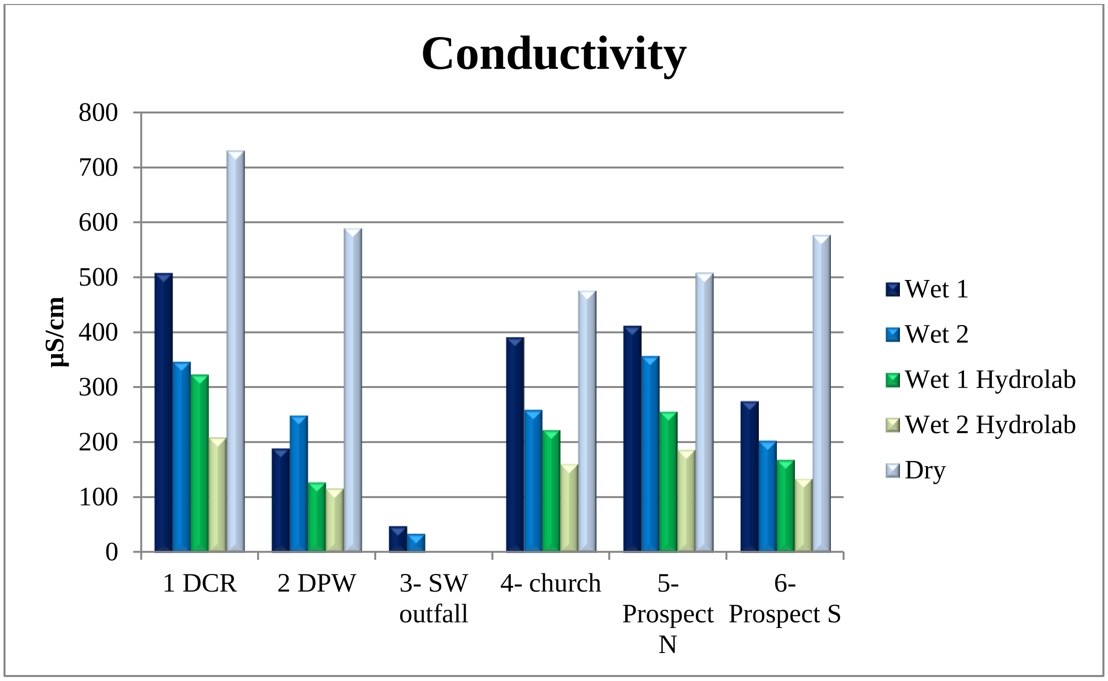


Figure 23: Conductivity Results

The highest conductivity value, 730 µS/cm, was found at Location 1 during dry sampling. The lowest measurements were obtained at the stormwater discharge point, Location 3, during both sets of wet samples. These values were both below 50 µS/cm. All the dry samples were higher than the wet samples at each location.

Because of this and the low values at Location 3, conductivity does not increase as a result of stormwater. The runoff has a much lower conductivity and dilutes the values because conductivity is a function of the stream's natural characteristics.

pH

Figure 24 shows the results for pH, both measured in the field and measured in the laboratory.

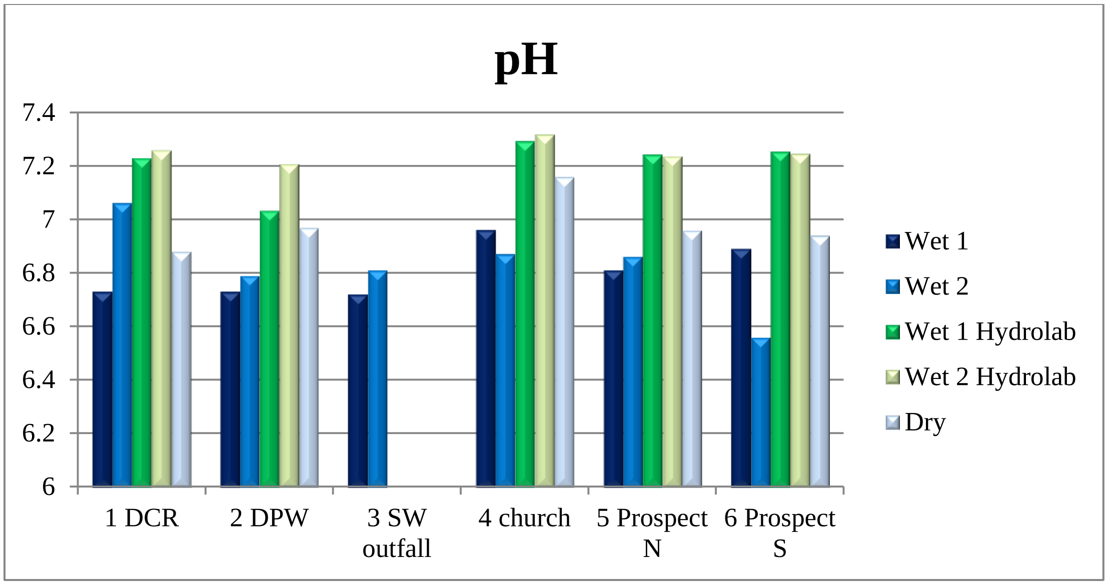


Figure 24: pH Results

The pH values obtained through sampling and Hydrolab readings ranged from 6.56 to 7.32. The Hydrolab had consistently higher values than the physical testing, but the difference was not much. EPA suggests that the pH should normally be between 6.5 and 8 for surface waters (EPA, 2011). Because all values measured fell in this range, there is no concern in the pH values of the brook.

Turbidity

In addition to the turbidity measurements at all locations during wet and dry conditions, turbidity was also measured by the Hydrolab during wet conditions at all locations except for Location 3. Figure 25 shows the comparison of turbidity measurements for all locations with both the laboratory and Hydrolab results.

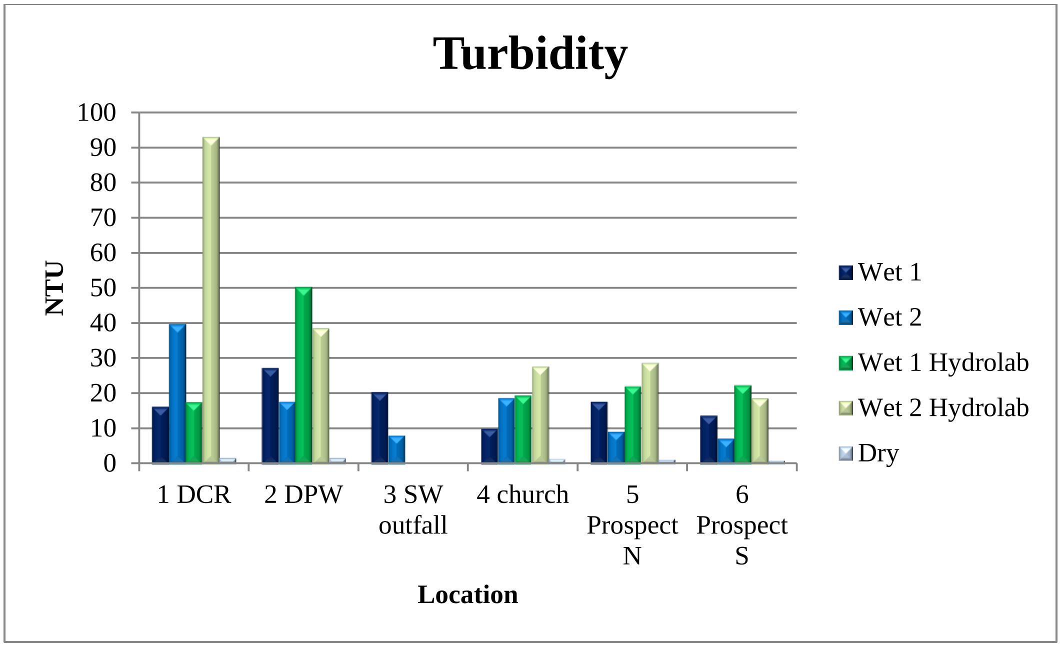


Figure 25: Turbidity Results

The highest value obtained from sampling, 93.0 NTU, for Turbidity was from the Hydrolab at Location 1. The highest sample measured in the lab was also from Location 1, but was only 39.8 NTU. The highest dry weather sample was 1.5 NTU at Location 1. From Figure 25 and these peak values, it is clear that turbidity increases in wet weather due to stormwater contributions. This can be assumed for two reasons. The first is that the dry samples tested very low for turbidity. Second, the historical median of the West Boylston Brook for 2010 was 0.76 NTU and for 2011 was 0.80 NTU. There is an obvious increase in turbidity in wet weather conditions, but Locations 1 and 2 have overall higher values than the other locations. Therefore, the runoff from areas contributing to flow at downstream Locations 1 and 2 are transporting more sediment, causing this increase.

The Hydrolab values were consistently higher than the laboratory values. It should be noted that the Hydrolab was placed in the bottom of the brook where sediment settles out and the turbidity could be higher.

Total Suspended Solids

Figure 26 shows the comparison of total suspended solids (TSS) results for all locations through laboratory testing.

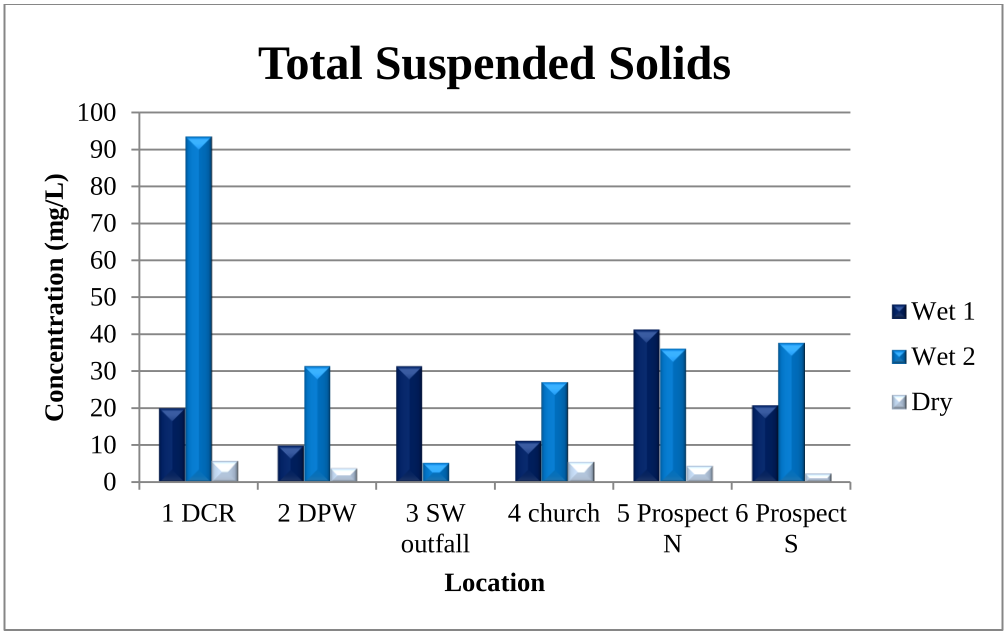


Figure 26: Total Suspended Solids Results

The first observation that can be made from this chart is that the TSS concentrations increase as a result of stormwater because the dry concentrations are much lower than wet weather concentrations. The highest value, 93.5 mg/l, was recorded at Location 1 during the second wet weather set, which indicates that there could be a lot of sediment coming off of this area. This turbidity of the stream was observed by the team and noted that the bottom of the pool in front of the v-notch weir was not visible. The Michigan Department of Environmental Quality uses general ranges of TSS concentrations to provide indications of water quality. Water under 20 mg/L can be judged as “clear”. A level from 40 to 80 mg/L is considered to have a “cloudy” appearance while any value over 150 mg/L has a “dirty” appearance (Michigan DEQ, 2002). A value over 150 mg/L does not mean the water is dirty, it just means that it has a dirty appearance to the average viewer. From this ranking, there are only two spots that would be considered in the middle category or worse; Location 1 as previously mentioned and Location 5 during the first wet set.

E. coli

Figure 27 displays the E. coli results from all laboratory testing through the MWRA.

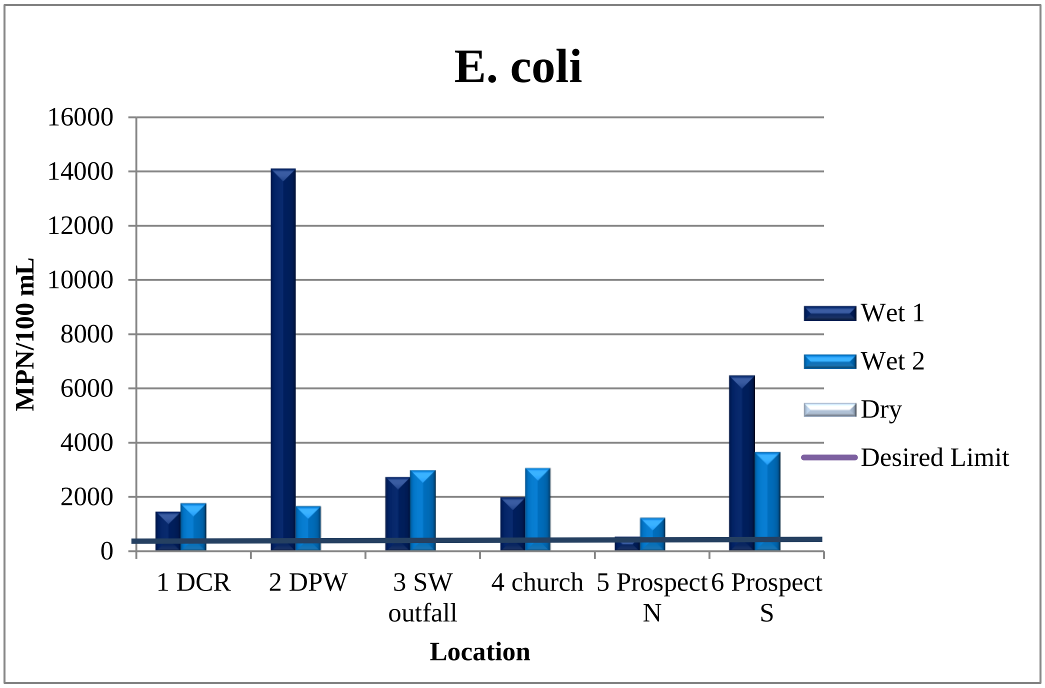


Figure 27: E. coli Results

The desired limit line on the chart represents the target for which all E. coli samples should be under. If samples occasionally exceed this value of 235 MPN/100 mL, then the brook should be placed under a watch list (DCR, 2008). In 2010, 24% of samples taken in both dry and wet weather exceeded this limit. In the storm sampled here, every value was above this limit with an extreme high of 14,100 MPN/100 mL at Location 2. This clearly shows that stormwater is a cause for the rise in bacteria levels as the dry samples did not break 30 MPN/100 mL. Even though an increase in levels is expected from stormwater, the levels here are very high and should be addressed.

Ammonia

Figure 28 shows the results of the ammonia testing obtained using the spectrophotometer for all samples during wet and dry conditions. The desired limit for ammonia is less than 1.0 mg/L as surface waters are typically under this level for ammonia and nitrate, the two most common forms of nitrogen in surface waters. At higher levels, ammonia can pose a physical threat for aquatic creatures (EPA, 2011). The 2010 mean was 0.012 mg/L which is much lower than all values found from sampling. The wet samples were significantly higher than dry samples showing that ammonia is likely a result of stormwater. The highest samples of ammonia were found at Locations 1, 2, and 3 including the only two samples which exceeded the 1.0 mg/L desired limit at Locations 2 and 3. From these values, it was likely that the areas draining into Locations 2 and 3 had wet weather sources of ammonia.

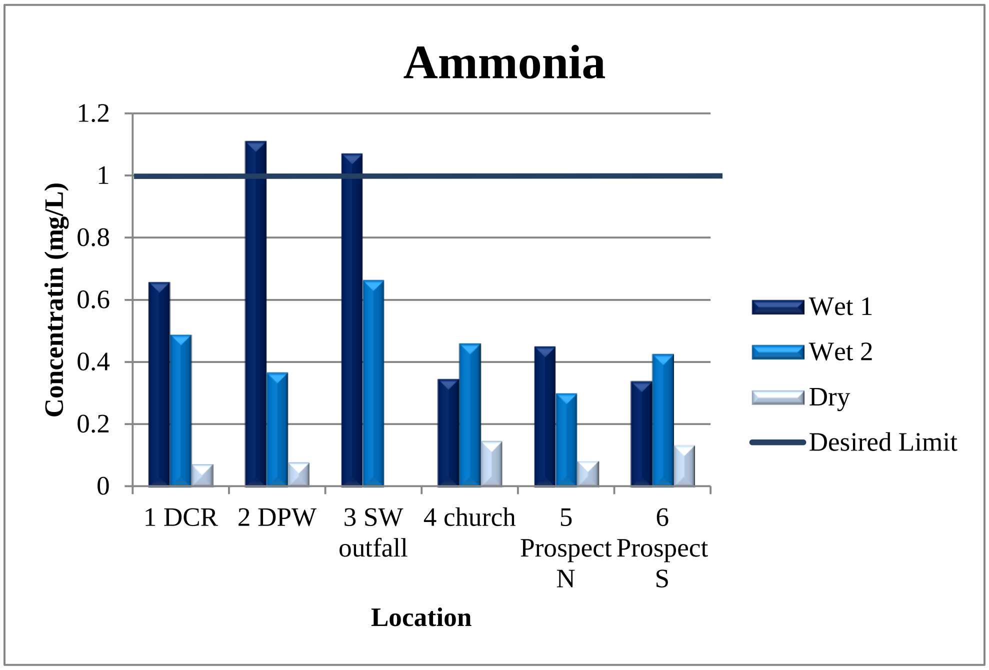


Figure 28: Ammonia Results

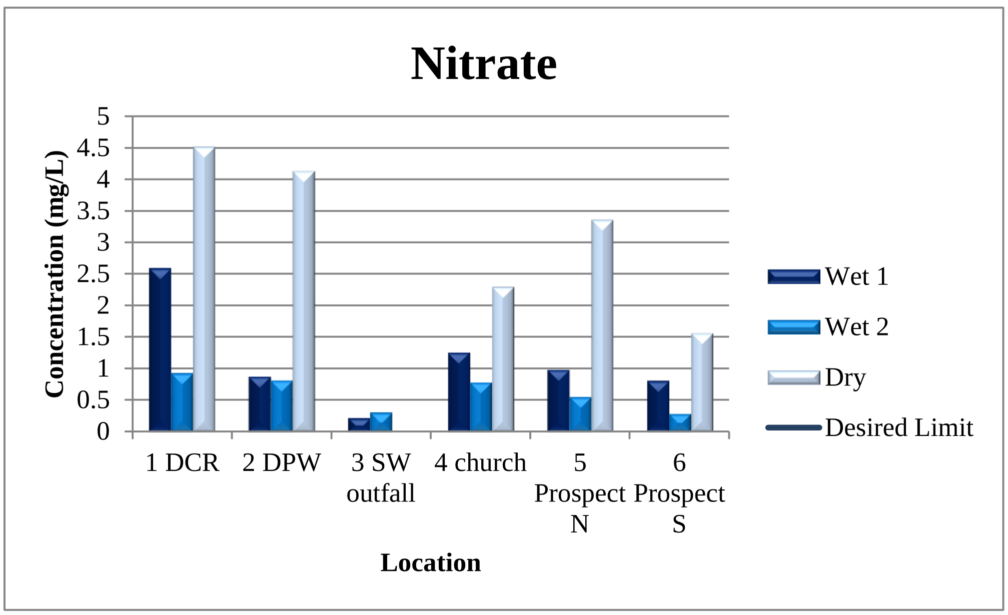


Figure 29: Nitrate Results

Nitrate

The concentrations of nitrate found from the Ion Chromatography system can found in Figure 29. As previously stated, nitrate concentrations in surface waters are usually under 1.0

mg/L. However, nitrate does not become toxic to aquatic creatures until a concentration around 10 mg/L (EPA, 2011). All samples were under this toxic limit for both dry and wet weather. The main finding from nitrate sampling was the nitrate levels during dry conditions were higher than wet weather conditions at all locations. The values during dry conditions exceed the 2010 average of 1.58 mg/L significantly at Locations 1 and 2. This means that nitrate levels are not high because of stormwater, but because of groundwater or natural steam conditions. This can be supported by the low nitrate values at Location 3, a location where samples are comprised primarily of stormwater. If anything, the stormwater was diluting the concentrations of nitrate. The concentrations of ammonia and nitrate in Figure 29 illustrate trends. Since these ions have different molecular weights, their concentrations should be converted to concentrations as nitrogen for direct comparisons and load analyses.

Total Phosphorus

The concentrations of total phosphorus found in wet and dry conditions can be found in Figure 30. All concentrations are in mg/L as phosphoris for comparison to the phosphate test.

According to DCR and EPA any water body which leads into a reservoir should not have a phosphorus concentration greater than 0.05 mg/L as phosphorus to prevent eutrophication (DCR, 2010). Therefore, the desired limit of total phosphorus is set at this limit. The dry samples were very close to this limit, but all the wet samples exceeded this limit including a few that were over ten times the desired limit. Because of these elevated levels, especially at Locations 1, 2, and 3, phosphorus limits are a problem as a result of stormwater.

Phosphate

Figure 31 shows the concentrations of phosphate as phosphorus found by the Ion Chromatography system. The results of the phosphate testing show that the highest values were at Locations 1 and 2, and 3. This matches with the highest values of the total phosphorus test. Wet 1 samples were almost always higher than Wet 2. Concentrations of dry samples were only detected at Locations 1 and 4. Because phosphate is included in the total phosphorus test, increases in phosphate levels were a result of stormwater.

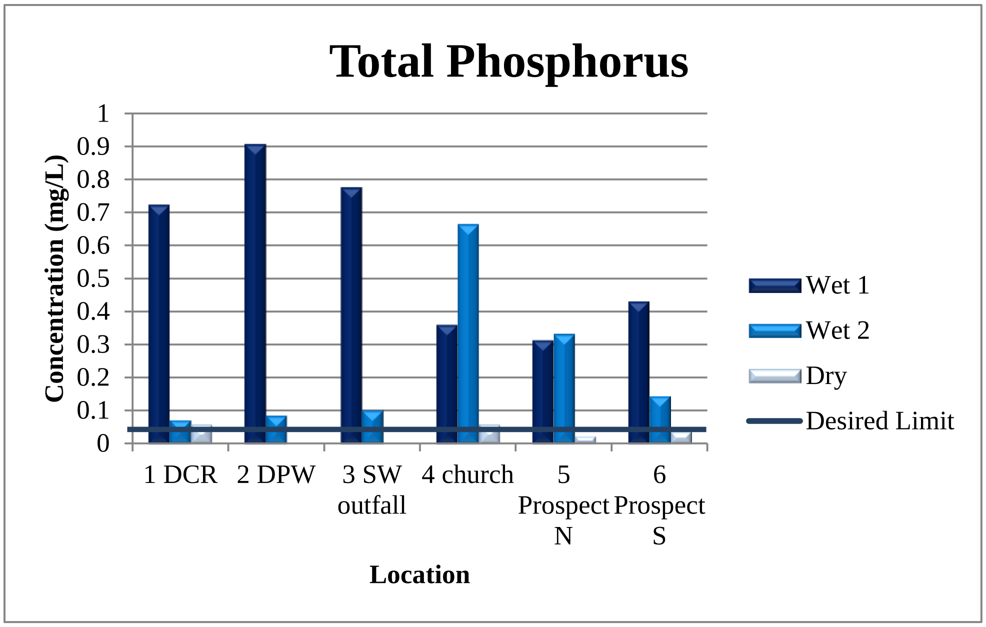


Figure 30: Total Phosphorus Results

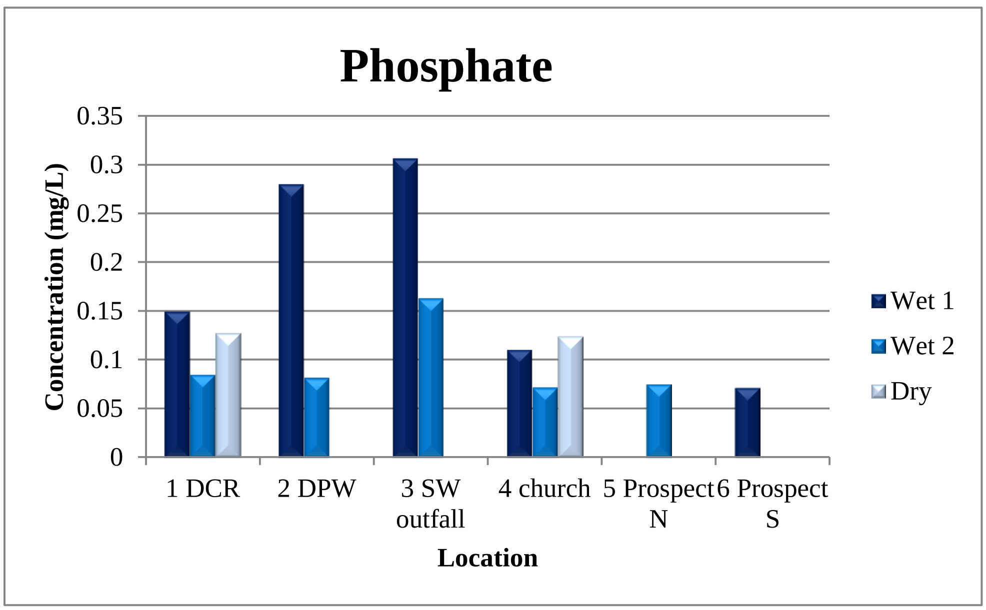


Figure 31: Phosphate Results

Dissolved Oxygen

The DO results from laboratory and Hydrolab measurements for wet samples were fairly close to each other. In addition, the dry sample results were only slightly higher than the wet samples; however, this could have been because of the colder temperatures in the brook. Aquatic life needs at least 5.0 mg/L to live. The DO values measured were well above this threshold; this could be explained by assuming a well aerated brook or stream conditions are close to equilibrium. Therefore, DO is not a stormwater concern for this brook and will not be discussed further. The full results from DO can be found in Appendix I.

Chloride and Sulfate

Both chloride and sulfate results showed that dry samples were higher than wet samples. This could mean that stormwater is not a cause for increased levels of chloride or sulfate as both had low levels at Location 3, a sampling site of only stormwater. The high chloride levels could have been from road sanding and salting from a snow storm that occurred about a week before dry sampling or groundwater inputs. Regardless of the cause, the values measured were not high enough to cause concern as the highest chloride value was under 100 mg/L and for drinking water it must be under 250 mg/L (EPA, 2011). Even though this standard does not apply to the brook, drinking water standards are stricter that any limit that could be placed on this brook. The same can be assumed for sulfate as the highest value measured was 14 mg/L which has the same secondary drinking water standard of 250 mg/L. These low values suggest that chloride and sulfate are not stormwater concerns or brook characteristics to cause concern.

Bromide, Nitrite, and Fluoride

Bromide, nitrite, and fluoride were tested for using the ion chromatography system. However, all results were at a level of 0.05 mg/L or lower for both wet and dry samples. Therefore, these anions are not a concern to the brook. The full results for these three ions can be found in Appendix I.

Summary

From the results of sampling and laboratory testing, it can be determined that some constituents pose more of a stormwater concern than others. A constituent was considered a problem if there were significant and consistent increases from dry to wet weather samples at most or all locations. A significant increase at a location means that the concentration is increasing from runoff inflow transporting pollutants from the contributing area into the brook. Therefore, if there is an increase at a location, there is likely to be a pollutant problem.

Results that had stormwater increases were found in testing for turbidity, TSS, E. coli, ammonia, total phosphorus, and phosphate. Both turbidity and TSS are measures of the particulate matter in water and both had increases from dry weather at all locations, but the largest increases were found at Locations 1 and 2. E. coli bacteria concentrations increased with during the storm as expected, but the results also showed that the high levels found throughout sampling all exceeded the suggested standard set forth by DCR. Ammonia concentrations were high compared to historical levels and were a clear result of the storm especially at Locations 1 through 3. Last total phosphorus, phosphorus in the solid and dissolved form, and phosphate, phosphorus in only the dissolved form, increased from dry to wet samples. The largest increases of phosphorus were found at Locations 1 through 3.

Alternatively, a constituent was considered not a stormwater problem if the results showed higher concentrations during dry weather samples and if the samples at Location 3 were much lower than other samples. This was observed in the results of testing for conductivity, nitrate, chloride, and sulfate. These constituents could still be water quality issues for the brook, but because of the sampling results, cannot be addressed through stormwater solutions. None of the values measured for these tests were high enough to be considered a concern.

A testing parameter was also not a stormwater concern if no noticeable change was observed in the results. This can be said for pH and DO because both had fairly consistent values and no results that would pose a general water quality concern for the brook. Still, these constituents are good measures of the overall brook condition.

The parameters determined as stormwater concerns for the brook were then used to identify areas and sites of concern as discussed in the next section.

4.4 Hydrology and Pollutant Loadings

An assessment of the subbasin hydrology and pollutant loadings was performed to better understand the existing conditions of the subbasin. A majority of the hydrological analysis and pollutant loading calculations were conducted for sample locations 5 and 6 to calibrate the Watershed Treatment Model in an efficient manner. The following results are presented in this section:

- Hydrograph of sampled storm
- Event Mean Concentrations for the sampled storm
- Flows and pollutant loadings for locations 5 and 6 using NRCS methodology
- Instantaneous pollutant loadings and flows for sample locations 1-6
- Table comparing pollutant loadings using WTM, NRCS, and Instantaneous method.

The hydrograph was created using the data from the Hydrolab probe and the USGS stage discharge relationship provided by DCR. The relationship was specific to the West Boylston Brook and cannot be applied to other tributaries; however, relationships may be available for other streams as well. The Hydrolab recorded the depths every minute and the expanded rate table was used to determine a flow by relating the height of the weir and the depth of the Hydrolab. Although various factors indicated that samples were retrieved during first-flush and peak flow conditions, this could not be confirmed since the time of concentration for the subbasin was not calculated. Nevertheless, the hydrograph in Figure 32 gave a good indication of the intensity of rainfall, along with the amount of runoff received during the storm. The first number labeling the vertical lines on the hydrograph represents either the first or second sample run; the number after the dash represents the sample location where the samples were retrieved.

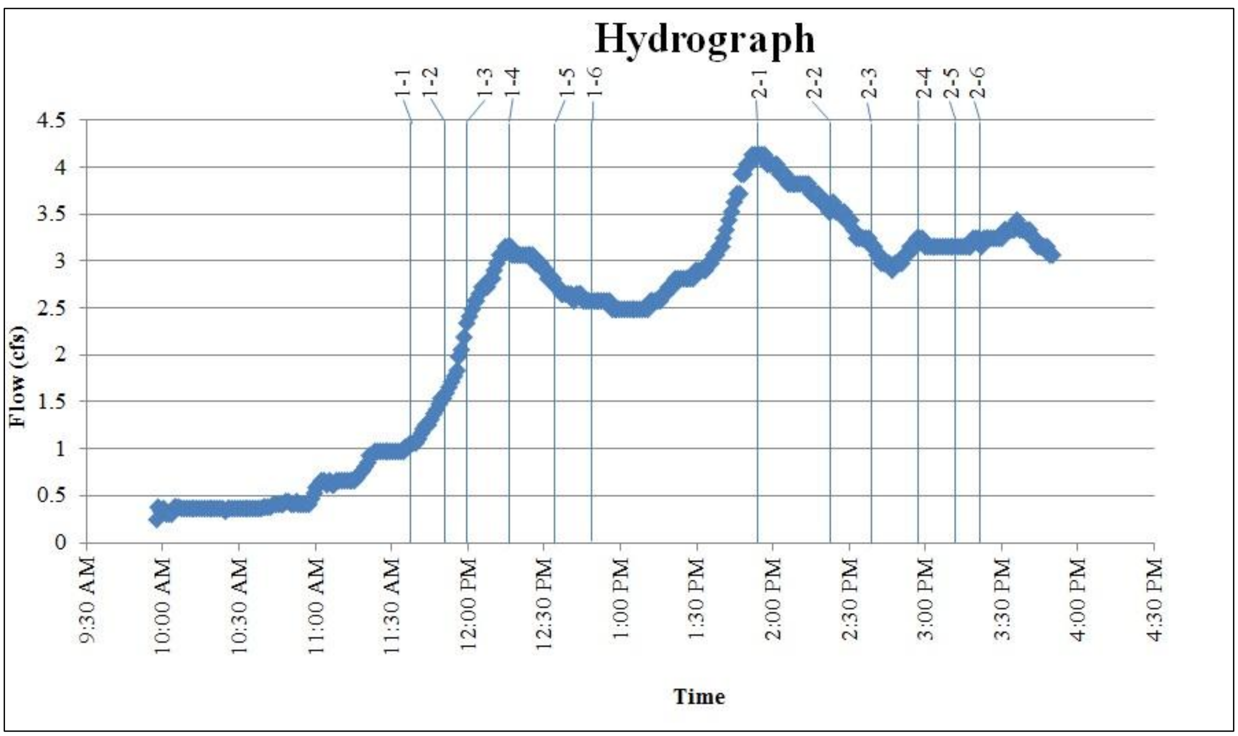


Figure 32: DCR Weir Hydrograph

A total runoff volume of 50, 850 ft^3 was determined by estimating the area under the hydrograph. This volume was then used to help determine the event mean concentrations of each pollutant at each sample location. However, it was discovered that the procedure used to calculate the concentrations was inappropriate for upstream locations as the volumes were based on flows from Location 1. An alternative approach was used to calculate the event mean concentrations using a weighted average with the instantaneous loadings using Equation 12.

$$EMC = \frac{\sum Q_i * C_i * dt}{\sum Q_i * dt} \qquad \text{(Equation 12)}$$

The results of the alternative approach were similar to those obtained in the initial mean concentration method with only slight differences. Therefore, the values obtained from the first method will still be used in this report. Full calculations for the alternative approach and a comparison between the two methods can be found in Appendix K. An example of the event mean concentrations for pollutants in sample location 6 is shown below in Table 18. The full list of event mean concentrations at each of the six sample locations can be found in Appendix J.

Table 18: Location 6 Event Mean Concentrations

LOCATION 6: PROSPECT STREET SOUTH			
Pollutant Type	1st Sample Grab Concentration (Wet 1)	2nd Sample Grab Concentration (Wet 2)	Event Mean Concentration
Total Phosphorus as P (mg/L)	0.432	0.145	0.30
Nitrate (mg/L)	0.81	0.29	0.56
Ammonia (mg/L)	0.340	0.425	0.38
Total Suspended Solids (mg/L)	20.84	37.80	28.85
E. coli (MPN/100mL)	6490	3650	5148

The concentrations above were used in conjunction with the runoff depth derived using the NRCS methodology outlined in Section 2.2. This procedure was only completed for sample locations 5 and 6 due to the added complexity of computing the loads for downstream areas under project time constraints. Nevertheless, they proved useful in the comparison of results, which is discussed at the end of this section. Table 19 and 20 summarize the results obtained using the NRCS method for the 24-hr duration of the storm that was sampled.

Table 19: Sub-Area 5 NRCS Pollutant Loadings

SUB-AREA 5: PROSPECT STREET NORTH		
CN= 72 Storage (S)= 3.80 inches 24-hr storm Precipitation (P) = 1.3 inches Runoff depth (Q)= 0.067 inches Area (A) = 59 acres		
Pollutant Type	**Event Mean Concentration**	**Loading (unit/day)**
Total Phosphorus as P	0.32 mg/L	0.287 lb
Nitrate	0.76 mg/L	0.673 lb
Ammonia	0.37 mg/L	0.330 lb
Total Suspended Solids	38.58 mg/L	34.2 lb
E. coli	2.66 MPN/100mL	3.72 billion colonies

Table 20: Sub-Area 6 NRCS Pollutant Loadings

SUB-AREA 6: PROSPECT STREET SOUTH		
CN= 77 Storage (S)= 3.03 inches 24-hr storm Precipitation (P) = 1.3 inches Runoff depth (Q)= 0.130 inches Area (A) = 79 acres		
Pollutant Type	**Event Mean Concentration**	**Loading (unit/day)**
Total Phosphorus as P	0.30 mg/L	0.69 lb/day
Nitrate	0.56 mg/L	1.31 lb/day
Ammonia	0.38 mg/L	0.880 lb/day
Total Suspended Solids	28.85 mg/L	66.8 lb/day
E.coli	5148 MPN/100mL	54.3 billion colonies

Instantaneous loadings were calculated at all of the sample locations to use as an additional comparison to the NRCS and model results. These loadings are considered to be "instantaneous" because they are simply the product of the flow, concentration at the specific time in the storm, and a conversion factor of 5.38 to have units in pounds per day (or 24-hour duration of storm). Two different loadings were computed for each pollutant at each sample location because the two concentrations obtained differed between each other since the samples were retrieved at two separate times. The E. coli loadings were omitted from the results since the units of colonies per 100 mL could not be compared to the other pollutant loadings that were computed in pounds per day. The results for the flows and instantaneous loadings at each sample location are shown in Tables 21, 22, and 23 for both wet and dry weather sets. Comprehensive tables that include concentrations for each pollutant at both sample grab times and dry weather can be seen in Appendix N.

Table 21: Wet 1 Flows and Instantaneous Pollutant Loadings

Wet 1 Sample Locations	**Flow (cfs)**	**Instantaneous Loadings (lb/day)**			
		Total Phosphorus as P	Nitrate	Ammonia	Total Suspended Solids
6	1.5	3.5	6.5	2.7	168
5	1.8	3.1	9.7	4.4	403
4	1.1	2.2	7.5	2.1	67
3	3.3	13.6	3.9	18.8	550
2	2.1	10.3	10.0	12.6	114
1	0.98	3.8	13.6	3.5	105

Table 22: Wet 2 Flows and Instantaneous Pollutant Loadings

Wet 2 Sample Locations	**Flow (cfs)**	**Instantaneous Loadings (lb/day)**			
		Total Phosphorus as P	Nitrate	Ammonia	Total Suspended Solids
6	2.5	2.0	0.7	1.1	357.2
5	2.9	5.2	1.6	0.8	76.2
4	4.0	13.9	3.1	1.8	6.3
3	1.2	2.8	0.4	0.8	109
2	2.4	4.8	2.0	0.9	105
1	3.8	6.3	3.5	1.9	95

Table 23: Dry Weather Instantaneous Pollutant Loadings

Sample Locations	Flow (cfs)	Instantaneous Loadings (lb/day)			
		Total Phosphorus as P	Nitrate	Ammonia	Total Suspended Solids
6	0.50	0.10	4.23	0.35	6.41
5	0.26	0.03	4.62	0.11	6.05
4	0.36	0.11	4.40	0.28	10.38
2	0.60	0.00	13.27	0.25	12.08
1	0.66	0.20	16.03	0.26	19.98

Most of the values themselves were not found to be very reliable since the stream velocities recorded in the field varied heavily depending on where exactly the velocity meter was placed, leaving open the possibility of human error in the use of the instrument. But if flows were assumed to be consistent for all Wet 1 samples, trends in the data showed TP, nitrate, and ammonia values generally increased for downstream areas. This reinforced the team's perception that stormwater issues were greater in the downstream sub-areas than the upstream ones. With the exception of some outliers, Wet 1 loadings were generally higher than Wet 2 loadings despite the increased flow at the duration of Wet 2. This meant that the pollutant concentrations at Wet 1 were higher than that at Wet 2, as discussed in the section on sampling results. This finding also supported the possibility that Wet 1 was the first-flush of the storm.

Dry weather pollutant loadings reveal similar trends to that seen in the sample results shown in the previous section. The relationship between the sample locations is rather consistent compared to the wet weather loadings. This was most likely due to the nearly constant flows measured between all the sample locations. With the exception of nitrate, all loadings are lower in the dry weather conditions than in wet weather because flows were greatly diminished due to the reduced amount of runoff.

Pollutant loadings for sub-areas 5 and 6 were calculated to calibrate the Watershed Treatment Model (WTM). The analysis was chosen for these up-stream areas because they were the only ones not influenced by other down-stream land. Therefore, the team concluded that with less interference of runoff from adjacent sub-areas the pollutant loading calculations for sub-areas 5 and 6 would have a higher probability of yielding accurate results.

Three different loading methods were utilized to obtain a sense of how the model results compared to the results obtained using field data. The NRCS and Instantaneous Load results used data retrieved from the field where as the WTM calculations were largely based on default data collected from a variety of published stormwater reports. The methods used to determine pollutant loadings in WTM can be found in Section 3.2. Tables 24 and 25 below show the pollutant loadings calculated for sub-areas 5 and 6 using a precipitation value of 1.3 inches for the 24-hr duration of the storm that was sampled.

Table 24: Summary of Sub-Area 5 Pollutant Loadings

SUB-AREA 5: PROSPECT STREET NORTH				
Pollutant Type	Pollutant Loadings			
	WTM	NRCS	Instantaneous	
			Wet 1	Wet 2
Total Phosphorous as P (lb/day)	0.29	0.88	3.1	5.2
Total Nitrogen* (lb/day)	5.8	1.00	14.1	13.3
TSS (lb/day)	281	34.2	403	566
Bacteria** (billion colonies/day)	222	3.72	N/A	N/A

*For NRCS and Instantaneous results, Total Nitrogen was approximated by adding the Nitrate and Ammonia loadings

**WTM measured Fecal Coliform and NRCS measured E. coli

Table 25: Summary of Sub-Area 6 Pollutant Loadings

SUB-AREA 6: PROSPECT STREET SOUTH				
Pollutant Type	Pollutant Loadings			
	WTM	NRCS	Instantaneous	
			Wet 1	Wet 2
Total Phosphorous (lb/day)	0.7	2.10	3.5	2.0
Total Nitrogen* (lb/day)	6.2	2.19	9.2	8.1
TSS (lb/day)	310	66.8	168	509
Bacteria** (billion colonies/day)	237	54.3	N/A	N/A

*For NRCS and Instantaneous results, Total Nitrogen was approximated by adding the Nitrate and Ammonia loadings

*WTM measured Fecal Coliform and NRCS measured E. coli

Similar trends were noticed when comparing the three different loads at both sub-areas. NRCS loads were generally lower in both sub-areas and instantaneous loads were generally greater than or similar to WTM loads when Wet 1 and Wet 2 loadings were averaged. Perhaps the most significant reason why the WTM loads were higher than NRCS loads was the conservative nature of the model. The authors of the WTM manual have claimed to take a very conservative approach to the judgments and assumptions made in the model. This was evident in the comparatively high pollutant concentrations compared to those obtained in the field. Also, the NRCS bacteria loadings were for E. coli, which will have a lower concentration since it is only an indicator of fecal coliform. Therefore, the large discrepancy between the WTM and NRCS bacteria loadings is reasonable.

As mentioned previously, these results were primarily to calibrate the model so particular values were not as important as the trends and comparisons between the three different approaches. Overall, the values for nutrient loadings did not significantly differ from one another, which gave the team some confidence in the accuracy of the model. The team believed that even though results differed between different methods of hydrological analysis, the percent loading reductions computed by the model would be sufficient enough to estimate the effectiveness of recommended best management practices.

4.5 Subbasin Initial Loadings

Initial yearly loadings were calculated by the WTM by adding data to the model that was necessary for operation. Table 26 summarizes the data inputted to the model and the changes that were made to any predetermined values. Appendix F details the exact inputs of the model and the sources of all data.

Table 26: WTM Inputs and Modifications

Primary Sources	Inputs and Modifications
Land Use	Total area for each land use in subbasin added
Partitioning Coefficients	No change
Watershed Data	Annual rainfall and stream length added
Soils Information	Hydrologic Soil Group percentages of subbasin added
Secondary Sources	
General Sewage Use Data	Number of dwelling unites added
Nutrient Concentration in Stream Channels	Concentration of phosphorus soil and total nitrogen soil added
On-Site Sewage Disposal Systems	Number of dwelling units with septic systems and percentage of septic system less than 100 ft. to waterway added
SSOs	No change
CSOs	No change
Illicit Connections	No change, not applicable
Urban Channel Erosion	Used Method 1 assumed with low channel erosion
Livestock	No change, not applicable
Marinas	No change, not applicable
Road Sanding	Sanding annual rate and percentage of open section roads added
Non-Stormwater Point Sources	No change
Existing Management Practices	
Turf Condition: Residential	No change
Turf Condition: Other	No change
Pet Waste Education	Activated and awareness of message assumed at 20% Calculation modified to a yearly rate
Erosion and Sediment Control	No change
Street Sweeping	Street area swept added and divided by 12 to get a yearly value because street sweeping only happens once per year, model assumes monthly
Structural Stormwater Management Practices	Wet pond and wetland used to approximate wetland and Carroll Pond effects
Riparian Buffers	No change
Catch Basin Cleanouts	Impervious area added with assumed semi-annual cleaning
Marina Pumpouts	No change

Table 27 shows the model output of initial loadings before any future management practices were applied. From the model it is estimated that most of the pollutants are coming from runoff sources. The values themselves are just estimates and may not be significant; however, they are still useful as they will be used as a base to estimate BMP reductions and the total percentages pollutant reduction.

Table 27: Initial Model Loadings

Source	Total Nitrogen lbs/year	Total Phosphorus lbs/year	Total Suspended Solids lbs/year	Fecal Coliform billion/year	Runoff Volume (acre-feet/year)
Storm	1,994	427	108,079	58,387	2,790
Non-Storm	215	22	1,548	327	Not Applicable
Total	2,209	448	109,627	58,714	2,790

4.6 Identification of Contributing Areas and Sites

Through the analysis of the existing conditions, the sub-areas contributing the most pollutants were identified by using the results of GIS mapping, field observations, and sampling analysis. Then, additional screening was done to narrow the areas down to sites which could be potential locations for BMPs.

4.6.1 Identifying Contributing Sub-Areas

Analyzing the final GIS map showed that the areas with the highest impervious areas were sub-areas 1, 2, and 3. These areas had many roads, denser housing, and catch basins that discharged directly into the brook. The team viewed these areas as being possible pollutant contributing areas since impervious areas reduce infiltration which results in more runoff and potentially higher pollutant loads.

One trend noticed by the team was the highest concentrations measured, for the pollutants of concern, were typically found at Locations 1, 2, or 3. Often the second highest measured concentrations were also at one of these locations. For example, the highest total phosphorus value was found at Location 2, but the second and third highest were at Locations 3 and 1 respectively.

Field observations verified the results of sampling and GIS mapping. From the beginning, the DPW lot had been viewed as a potential problem which is in sub-area 1. The team had observed the impervious area in sub-areas 2 and 3 as well as the numerous catch basins. The consensus was simple for the team that from the analysis of the existing conditions, sub-areas 1, 2, and 3 were the three highest contributing areas in the subbasin. Based on this finding, the additional screening of sites was focused on sub-areas 1-3 and sub-areas 4-6 were not considered further in this analysis.

4.6.2 Screening

The team went back to the subbasin to visit sub-areas 1 through 3 to find specific sites that could be contributing pollutants to storms. First, the team visited the DPW building and observed the back of the building where the town stores its road sand. The sand was mostly exposed to the elements as shown in Figure 33 with only a few small piles covered. Following the slope of the back lot, there was a visible channel where stormwater flowed into a drain pipe. The pipe then discharged into a very overgrown and eroded gully which ran a few hundred feet to join with the brook. From this site, the team believed that the sand pile was likely contributing solids to the brook

Figure 33: Sand pile at DPW

Next, the team visited Worcester Street near the First Congregational Church to find the discharge point for the stormwater piping system from the intersection of route 140 and route 12. The team found a small channelized area coming out from the bottom of a red shack next to the church and assumed this was the discharge for that intersection. This point was of interest because a large volume of stormwater comes from that busy intersection and there exists a possibility that if an incident were to occur, non-stormwater related pollutants could enter the brook.

While at the church, the team noticed that some of the roof gutters discharged directly into the parking lot where they would likely drain into a catch basin and then into the brook. The team looked along Central Street for additional houses with roof spouts that discharged into a driveway that would drain to the road. However, most of the spouts lead to the lawns or gardens. The team concluded that rooftop runoff was probably not an issue in this area.

At the library, the team observed that there was no permanent parking right next to the library except for two handicapped spots. As a result of this, many people parked their cars on the side of the road on the grass buffer in between the road and the sidewalk. Many of these buffers near the library had been reduced to dirt and looked eroded.

At the intersection of Central and Prospect Street, the team noted that the general design of the parking lots for the office buildings and bakery was to slope them down toward the road with no grass buffer between the sidewalk and road. This created a highly impervious area where all runoff would go directly into the catch basins near the intersection. The team also observed the number of parking lots in the area which were not painted with parking spaces and were very empty as shown in Figure 34. However, it is important to note that is was a Friday afternoon and the businesses may have closed or not very busy at the time. Some of the rain spouts from these buildings led to small gardens on the front of the buildings while others just drained to the parking lot.

Figure 34: Empty Parking Lot

Behind the bakery was another parking lot at a lower elevation which was also quite empty, but the team determined that this did lot did not drain into the storm-drain system, but drained into the tree line. The large amounts of impervious area at this intersection could contribute to the higher pollutant loadings.

The team then went into the forested area of sub-area 2 to look for possible pollutant sources. At numerous locations near the base of trees, the team found animal droppings. From internet research, the team later determined that the dropping were most likely from raccoons. These droppings so close to the brook could be a source of bacteria. Also in this location, the team saw downspouts from many houses along Worcester Street discharging to the steep backyards which most likely flow into the brook.

Last, the team drove along Prospect and Newton Streets looking for additional houses with roof runoff which would drain into the streets, but very few were found. Overall, most house were directing their roof runoff into gardens or into their yards.

4.6.3 Identifying Specific Sites

The team determined from sampling results that the pollutants of concern were TSS, ammonia, total phosphorus, and E. coli bacteria. Then the team investigated these pollutants for each of the three sub-areas determined. Table 28 organizes the contributing sites determined by the team, by sub-area and pollutant of concern. Some of the sites were chosen as a direct result of screening while others were chosen from previous visits or known concerns. The team considered these sites to be probably sources of pollutants which could be addressed through site specific BMPs.

Table 28: Sites of Concern

Sub-Area	Pollutants of concern	Sites of concern
1	TSS	1. DPW parking lot and rear storage lot for sand and equipment
2	Bacteria, Nutrients	1. Intersection of routes 140 and 12 2. Forested area to the between Worcester and Central Streets 3. Church parking lot
3	Nutrients	1. Intersection of Prospect and Central Streets 2. Large, unused, and sloping parking lots 3. Side of the road parking at Library

5.0 Integrated Stormwater Management Plan

This integrated stormwater management plan was designed to address the water quality issues of the West Boylston subbasin. The plan focuses on presenting BMPs selected to remove pollutants, while being cost efficient, requiring low maintenance, and having a positive social impact. In addition, the conceptual design of one BMP is presented. The plan concludes with a predicted pollutant removal and estimated cost as the result of implementing all suggested BMPs.

5.1 BMPs to Implement

In total, nine structural and seven non-structural BMPs were brainstormed. An additional idea was developed that includes a long-term redevelopment plan of the Central Street business area. The following sections detail each site and the BMPs to be implemented in it. With each BMP, the advantages, disadvantages, goal, required maintenance, and implementation considerations are discussed. The modeled pollutant removals and estimated costs are also included in the BMP descriptions. Below is a list of all BMPs brainstormed.

- **Retrofit Site 1: Department of Public Works**
  - Sediment Forebay behind DPW building
  - Tree Box Filters in DPW parking lot
- **Retrofit Site 2: Worcester Street**
  - Bioretention at Reservoir Garage
  - Bioretention on corner of Worcester and Church Streets near cemetery
- **Retrofit Site 3: Newton, Prospect, and Central Streets**
  - Bioretention at corner of Central and Prospect Streets
  - Bioretention on West side of Prospect Street
  - Bioretention bump out at Library on Newton Street
  - Bioretention bump out at Library on Central Street
  - Bioretention near Darby’s Bakery
  - Long term, low impact redevelopment options at Central Street
- **Non-structural BMPs implemented throughout subbasin**
  - Pet waste program
  - Raccoon removal
  - Street sweeping program
  - Catch basin cleanouts
  - Septic system review
  - Lawn care and municipal landscaping education program
  - Cover sand behind DPW

Figure 35 shows a map of all structural BMPs developed by the team.

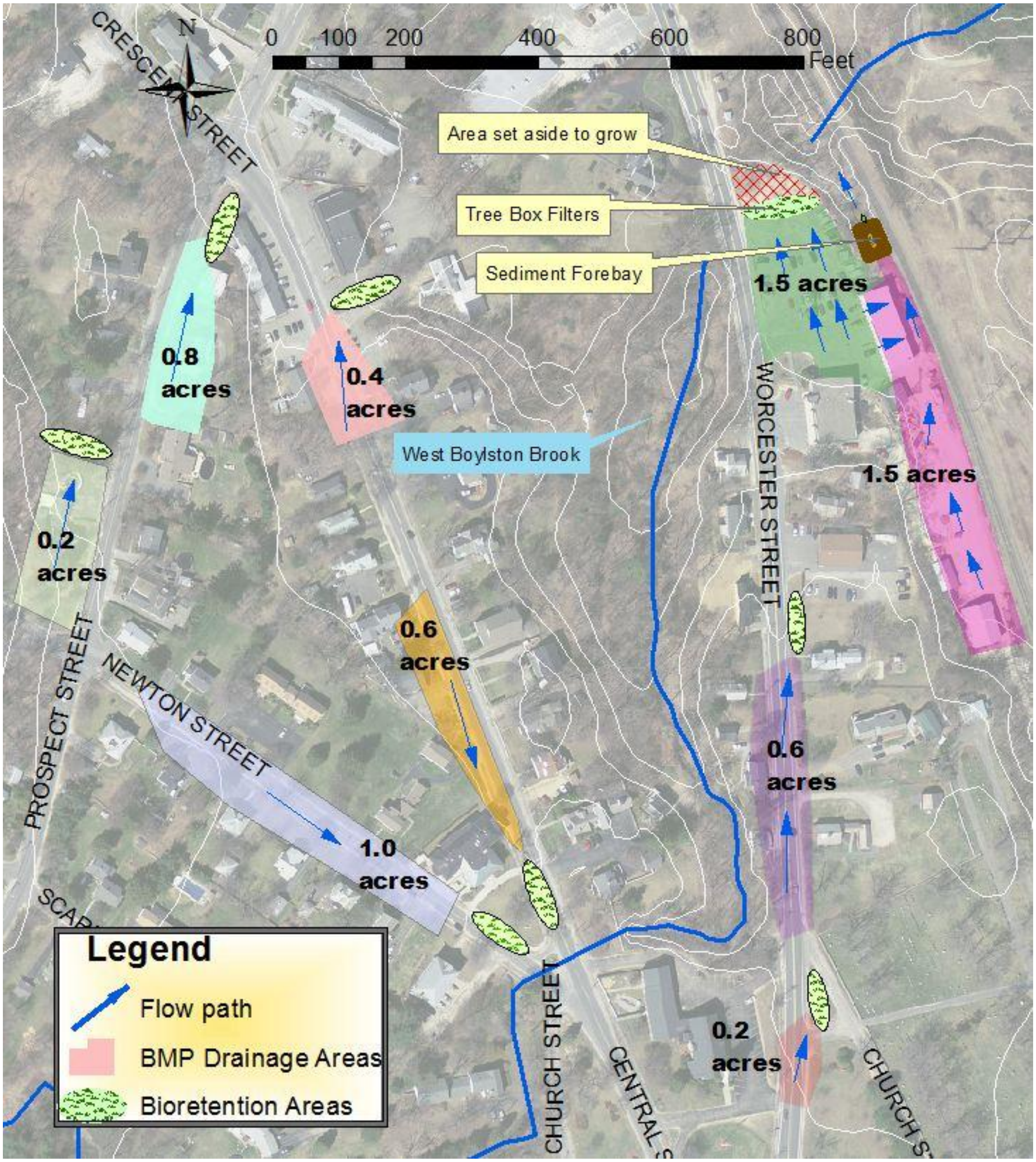


Figure 35: Structural BMPs

5.1.1 Retrofit Site 1: Department of Public Works

The first site with BMP implementation is at the Department of Public Works on Worcester Street. The site consists of two BMPs, a sediment forebay behind the DPW building and a series of tree box filters on the north side of parking lot as shown in Figure 36. Since the

DPW building is located in Area 1 where TSS is the primary concern, the main goal of both BMPs is to decrease sediment from entering the brook, but removal of other pollutants is an additional bonus.

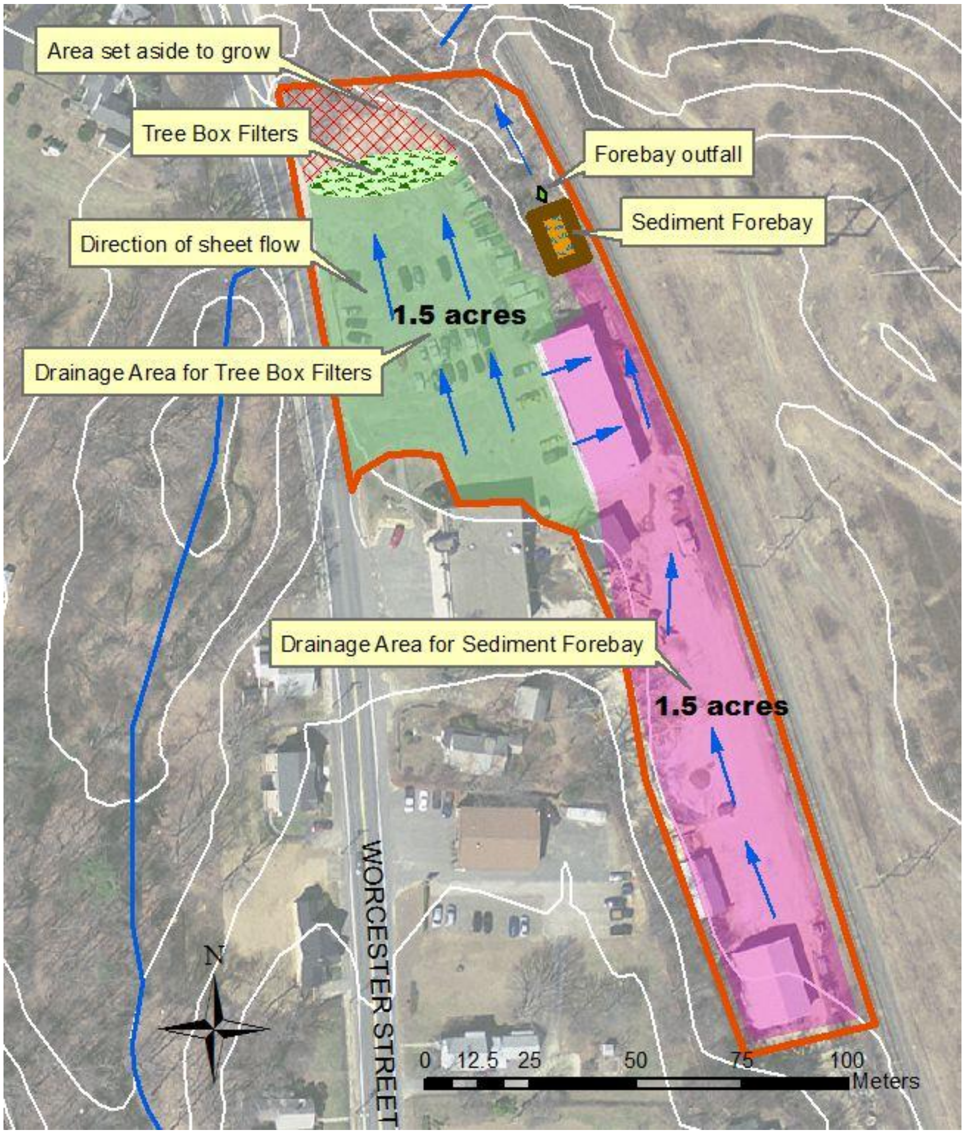


Figure 36: Retrofit Site 1

Table 29 shows the pollutants removed from the whole subbasin, total suspended solids, total phosphorus, total nitrogen, and fecal coliform as predicted by the WTM with the implementation of these BMPs. The removal is presented in pounds removed per year and the percent removed from the entire subbasin in a year. The following sections describe the BMPs and the considerations in implementing each. The section on the sediment forebay includes a conceptual design with detailed sizing and placement.

Table 29: Retrofit Site 1 Pollutant Removal

BMP	Drainage Area (acres)	TSS		TP		TN		Fecal Coliform	
		Lbs per year	% from subbasin	Lbs per year	% from subbasin	Lbs per year	% from subbasin	Billion colonies per year	% from subbasin
Tree Box Filters	1.5	1160	1.07%	4.3	1.01%	21.4	1.07%	519	0.89%
Sediment Forebay	1.5	268	0.25%	0	0%	0	0%	0	0%
Total	**3.0**	**1428**	**1.32%**	**4.3**	**1.01%**	**21.4**	**1.07%**	**519**	**0.89%**

5.1.1.1 Sediment Forebay

The back section behind the DPW has a large amount of sediment buildup due to sand storage. A sediment forebay was selected at this location to target the runoff coming from behind the DPW. The runoff currently comes from this predominantly impervious area and flows behind the DPW building on a narrow strip of pavement, then is discharged into a small amount of rocks and vegetation before it enters a pipe. To treat this runoff, the sediment forebay can be built where there is currently a small amount of rocks and vegetation before it enters the pipe. A sediment forebay works by slowing incoming stormwater runoff, therefore giving sediment enough time to settle out. The flow will travel from the impervious area then to a rip rap followed by the excavated pit. At the end of the forebay, a check dam will be above a stone berm. The water will then go over the filter berm and continue into the pipe. The forebay will also have pervious vegetation at its base to allow for dewatering between storms.

Using a sediment forebay in this location is beneficial because it has a relatively low cost compared to other BMPs, it has a long detention time and reduces the high levels of TSS coming from the site’s runoff. While sediment forebays are typically used primarily for pretreatment, this remained the best option. Infiltration BMPs were ruled out because it would be too close to sharp slopes. Larger BMPs such as constructed wetlands and detention basins were restricted due to size, and other filtration BMPs were eliminated because of high cost. The sediment forebay is small enough to fit behind the DPW building and still treat TSS. Disadvantages include its frequent maintenance and lower removal efficiency.

A conceptual design of the sediment forebay was completed using Auto CAD and included a cross sectional view and a plan view as shown in Figure 37. The dimensions were calculated first, followed by the approximate water quality volume. According to the

Massachusetts Stormwater Handbook, the volume of the sediment forebay is sized to hold 0.1 inches per impervious acre for treatment. The team also assumed the volume of runoff to be 1 inch to compensate for oversizing. To facilitate the calculations, the forebay was assumed to have bank slopes at a ratio of 1:1. This slope falls above the maximum slope of 3:1 set by MassDEP so the design would need to be refined before implementation so that it adheres to Massachusetts Stormwater Management Standards (Mass DEP, 2008). It was also assumed to be rectangular dimensions with the length equaling twice the width. The depth was assumed to be two feet, because while some other forebays are deeper, it was taken into consideration the the forebay was oversized because it was the best choice for treatment. Lastly, for the water quality volume, the design storm was set to be one half inch of runoff in accordance with Standard 7 of the Massachusetts Stormwater Management Standards. The calculations used for sizing the forebay are displayed in Appendix M.

Sediment Forebay Conceptual Design

Sediment Forebay Design Specifications	
Impervious Area Captured	1.05 acres
Area	191 ft^2
Volume	381 ft^3
Length	12 ft
Width	24 ft
Check Dam Length	9 ft
Bottom Area	160 ft
Depth	2 ft
Bank Slope	1:1
Water Quality Volume	1,933 ft

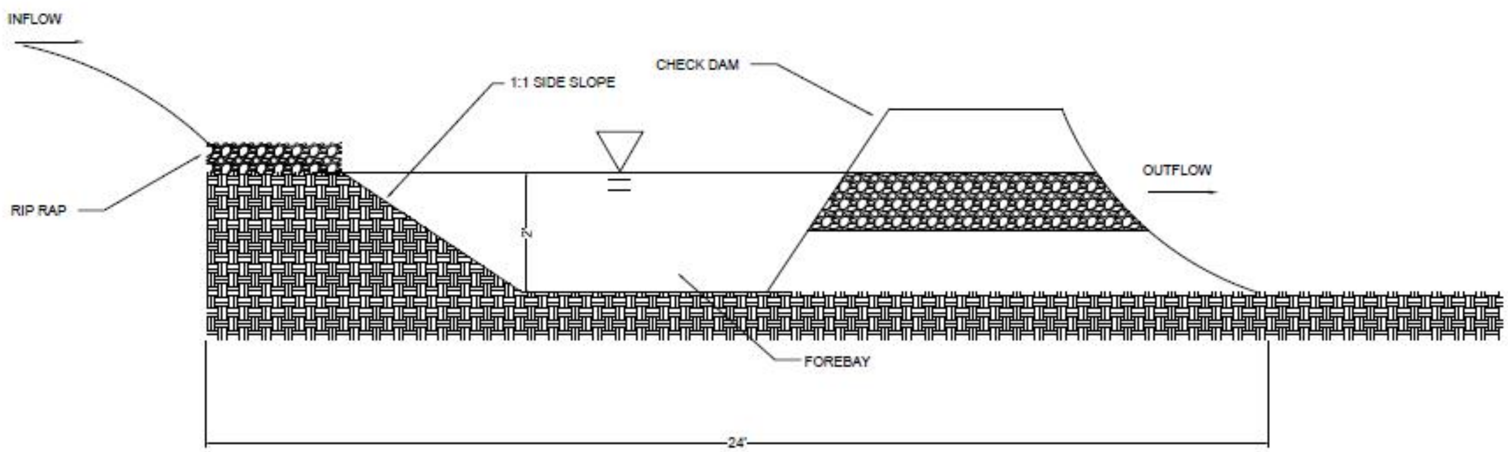


Figure 37: Sediment Forebay Conceptual Design

5.1.1.2 Tree Box Filters

For the front parking lot of the DPW, a series of tree box filters were selected to remove sediment from runoff draining towards the brook. Currently, runoff comes off of the parking lot and flows north over an unpaved, sanded area of the lot and then channelizes down into the some vegetation before it reaches the brook. The team believed that the sand part of the parking lot was contributing sediment along with any other sediment from the rest of the lot. To treat this, it is suggested that the parking lot be repaved and with this graded to drain runoff in a sheet flow manner towards the BMP. In between sections of curbing, the runoff would be channelized into three tree box filters on the north side of the lot. The tree box filters would treat the runoff with an overflow spillway into a rip rap barrier that would lead to the brook in high precipitation storms. The tree box filters would be installed with a slight grade toward the east to prevent flooding in the box filters. With these filters, sediment would be removed from the runoff along with other pollutants by having the runoff flow through the soil, therefore cleansing it, before it enters the brook.

The advantages of this BMP are that it does not require frequent or costly maintenance and it would be aesthetically pleasing compared to the current state of the lot. Upkeep would consist of bi-annual ranking of media and replacement of media and tree when the tree dies. The main disadvantage of this BMP is the cost as it is estimated the tree box filters alone could cost as much as $40,000. This cost was taken from an estimate of $13,000 per filter for materials and installation retrieved from the Charles River Watershed Association's BMP Information Sheet (CRWA, 2008). Repaving the parking lot would need to be completed to direct flow into the filters. The cost above would not include the grading and paving of the parking lot required to direct the flow into the filters. Some consideration should be included in the placement of the BMP as it may be on private property not owned by the town and therefore would require permission to implement. In addition, the DPW would have to identify an alternative snow storage location for when they plow the parking lot.

5.1.2 Retrofit Site 2: Worcester Street Bioretentions

The second site consists of two BMPs placed on Worcester Street as shown in Figure 38. Both are bioretention areas on the east side of the road; one would treat runoff before it enters the brook near the church and the other would treat runoff flowing down the street toward the DPW and channelize flow into the brook. The goal of these BMPs is to redirect runoff from directly flowing to the stream and to remove all pollutants of concern.

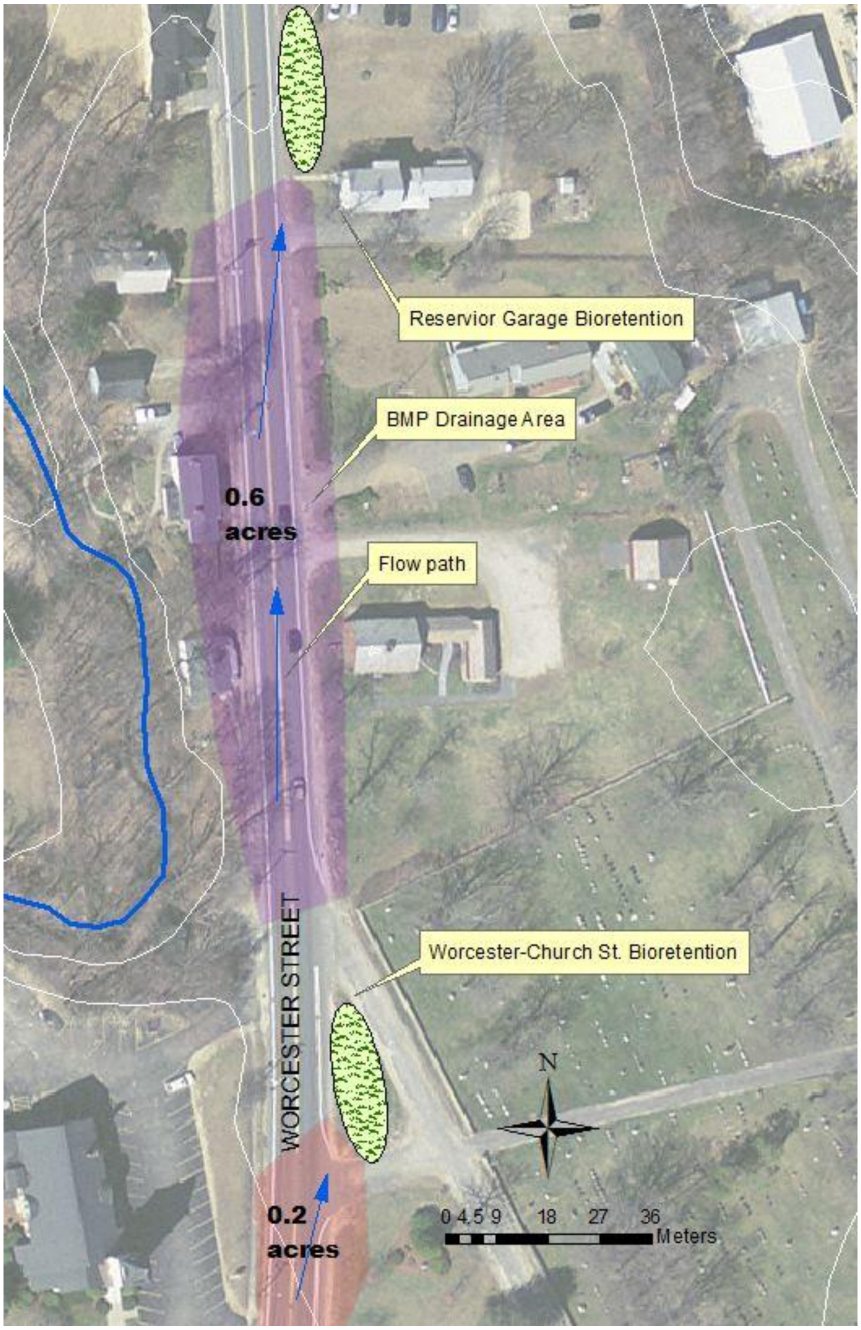


Figure 38: Retrofit Site 2

Table 30 shows the pollutant removal for Retrofit Site 2. With both BMPs being bioretention, they share a common process, advantages, and disadvantages. Both will require the flow from the street and site to be redirected into the bioretention area where it will be naturally treated by the vegetation. The advantages of both are they are relatively small, are aesthetically pleasing, and treat runoff fairly well. The problem is the area that drains to them isn't large, meaning the removal is small unless many bioretention areas are implemented. Also, bioretention requires a decent amount of maintenance throughout the year and can easily fail if not maintained properly. However, the upkeep is fairly simple and economical. The following sections describe the specifics of each BMP.

Table 30: Retrofit Site 2 Pollutant Removal

BMP	Drainage Area (acres)	TSS		TP		TN		Fecal Coliform	
		Lbs per year	% from subbasin	Lbs per year	% from subbasin	Lbs per year	% from subbasin	Billion colonies per year	% from subbasin
Bioret. near Reservior Garage	0.6	510	0.47%	2.0	0.47%	10.3	0.52%	434	0.74%
Bioret. near cemetery	0.2	212	0.20%	0.8	0.19%	4.3	0.22%	181	0.31%
Total	**0.8**	**722**	**0.67%**	**2.8**	**0.66%**	**14.6**	**0.74%**	**615**	**1.05%**

5.1.2.1 Bioretention at Reservoir Garage

The bioretention area at the Reservoir Garage should be placed to the right of the driveway in front of the rock wall. This BMP would mostly be implemented to treat runoff flowing down Worcester Street and could include some of the runoff from resident homes and lawns. The area should be slightly recessed into the ground to allow runoff to easily flow into it. The flow from the street will need to be redirected to the BMP, probably through a short grass swale. Because the BMP is on private property, permission will be needed to implement it; however, the garage may be willing to maintain it if it will make their property look nicer. Natural vegetation should be used along with fill which will allow for proper infiltration. The estimated cost of this area is 14,723 dollars calculated from Equation 13, obtained from EPA's fact sheet on bioretention BMPs (2006). This equation was used to estimate all bioretention costs.

$$Cost\ (\$) = 7.3V^{0.99} \qquad \text{(Equation 13)}$$

$$V\ (ft^3) = volume\ of\ runoff\ treated$$

The only additional consideration in the implementation of this bioretention area is the impact it could have on the business of the Reservoir Garage.

5.1.2.2 Bioretention at the Intersection of Church and Worcester Street

This island bioretention BMP is located in Area 2 where Church Street intersects with Worcester Street. This bioretention BMP would be located directly before the catch basin at the north-pointing corner of the grassed island and would effectively treat incoming runoff before entering the catch basin. The outfall for the catch basin is on the opposite site of the street and flows directly into West Boylston Brook so treating this runoff would likely reduce pollutants coming from Worcester Street or the public park.

This BMP should be designed to treat nutrient loads and bacteria from the surrounding grass areas as well as road runoff from Worcester Street. Fertilizers and pet waste from the small park just south of the grassed island could be potential contributors of the excess phosphorous, nitrogen, and E. coli observed in the sample results. Based on the drainage profile of the area, it is more likely that a majority of the runoff affecting this island area is coming from Worcester Street. This street receives the most traffic in the subbasin and could potentially be a source of harmful pollutants that were not tested in the sample analysis such oils and heavy metals.

An additional design consideration to the successful implementation of this BMP includes community disruption during construction. Since the BMP would be located within a couple of feet from the road, the implementation would require some road space to be sacrificed which could cause a disturbance to drivers passing by. The estimated cost for this bioretention area is 4,962 dollars calculated form Equation 13.

5.1.3 Retrofit Site 3: Central, Newton, and Prospect Street Bioretention

This region is within delineated Area 3 and includes five bioretention BMPs along the triangular perimeter formed by Central, Newton, and Prospect Street. Bioretention BMPs were sited in their respective locations primarily to treat nitrogen and phosphorous nutrients since the results from the existing conditions analysis concluded that the primary pollutants of concerns in Area 3 were nutrients. A map showing the proposed locations of the BMPs and the acreage treated by each is shown in Figure 39.

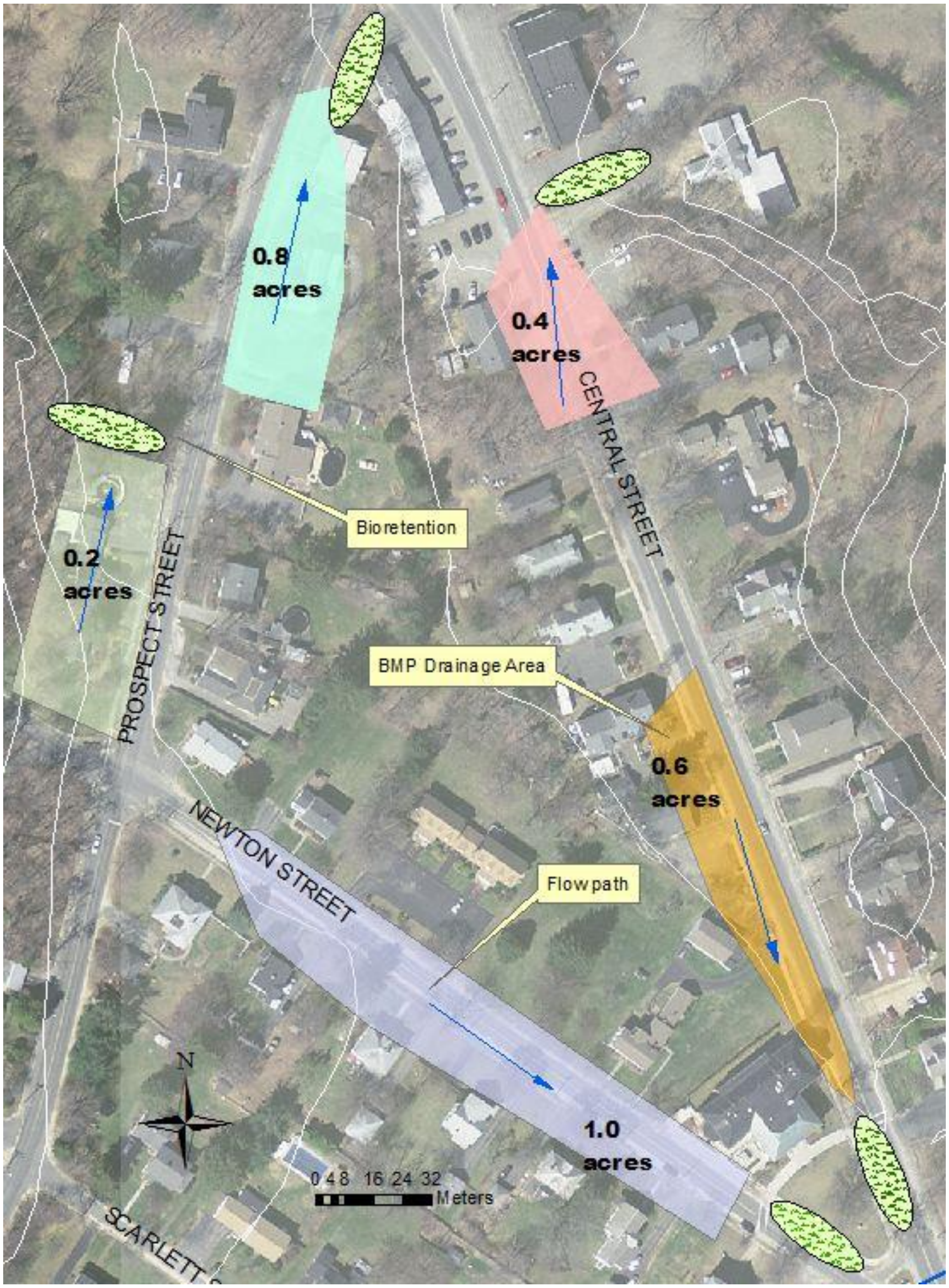


Figure 39: Retrofit Site 3

Table 31 shows the removal of total suspended solids, total phosphorus, total nitrogen, and fecal coliform from the whole subbasin as predicted by the model with the implementation of these BMPs. The removal is presented in pounds removed per year and the percent removed from the entire subbasin in a year.

Table 31: Site 2 Removal

BMP	Drainage Area	TSS		TP		TN		Fecal Coliform	
		Lbs per year	% from subbasin	Lbs per year	% from subbasin	Lbs per year	% from subbasin	Billion colonies per year	% from subbasin
Prospect-Central Bioretention	0.8	384	0.36%	1.5	0.35%	7.8	0.39%	327	0.56%
Prospect Residential Bioretention	0.2	192	0.18%	0.7	0.16%	3.9	0.20%	163	0.28%
Newton Bump-out Bioretention	1.0	699	0.65%	2.7	0.63%	14.2	0.71%	594	1.02%
Central Bump-out	0.6	487	0.45%	1.9	0.44%	9.9	0.50%	414	0.71%
Central near Darby's	0.4	324	0.30%	1.2	0.28%	6.6	0.33%	276	0.47%
Long-term Central Street	1.7	1378	1.27%	5.3	1.24%	27.9	1.40%	1172	2.01%
Total	**4.7**	**3464**	**3.21%**	**13.3**	**3.10%**	**70.3**	**3.53%**	**2951**	**5.05%**

Although all of the BMPs in this region are bioretention gardens that function similarly, each have unique requirements and considerations that are discussed in their respective sections. The sections below will summarize the functionality and constraints of each of the proposed bioretention BMPs in this retrofit region.

5.1.3.1 Prospect-Central Bioretention

This BMP would be built on the grass strip located on the east side of Prospect Street at the intersection with Central Street. The nearest catch basin on the east side of Prospect Street is approximately 450 feet away, meaning that all of the runoff from the homes after the catch basin would be flowing onto the east side of Prospect street and into the bioretention for treatment.

The primary water quality benefit that this BMP would provide is treatment of pollutants from lawn fertilizers but pollutants caused by vehicles could also be treated. This bioretention could be designed to overflow into the adjacent catch basin on Central Street when overwhelmed by large storms.

Some considerations to consider in the design and implementation of this bioretention garden are the presence of the tree on the proposed area and property ownership. The potential removal of tree in the proposed area would need to be investigated before installation. The ownership of the small grass strip may be in the public right-of-way or on the abutter's property. This would also need to be investigated prior to installation. The estimated cost of this BMP from Equation 13 was $19,574.

5.1.3.2 Prospect Residential Bioretention

This proposed bioretention is located on the west side of Prospect Street in the large grass lawn at 52 Prospect Street. The nearest catch basin is at the northwest corner of Newton Street so all runoff produced after that point would naturally drain in the direction of the BMP.
Like the previously discussed bioretention, the primary water quality benefit that this BMP could provide is treatment of pollutants from lawn fertilizers but pollutants caused by vehicles could also be treated. Since there is a sidewalk in between the road and the lawn a small drainage path would have to be built to effectively divert runoff into the BMP. A conceptual example of this BMP and the drainage path is shown in Figure 40.

Figure 40: Drainage Path Example (Image retrieved from Stormwater Management Plan for Spruce Brook Pond Subwatershed by the Charles River Watershed Association (CRWA, 2009))

Although plenty of space exists for this BMP to effectively treat the target runoff, ownership issues must be resolved first. This BMP would undoubtedly be located on private property so an agreement with the owner must be made before any designs are formalized. If an agreement is made, the additional space could be utilized to provide more runoff treatment by placing a miniature swale before the bioretention area. Further cost-analysis would need to be performed to justify the extra expense of this addition. Equation 13 was used to estimate the cost of this BMP at $4,962. This could cost could be more if the side walk diversion and swale were included.

5.1.3.3 Newton Street Library Bump-out

This bioretention BMP would be located on the east side of Newton Street adjacent to the grass space immediately south of the Beaman Memorial Library. All of the flow on the east side of Newton Street would be treated by this BMP, with the pollutants of concerns being nutrients from lawn fertilizers. This BMP was designated as a "bump-out" because it would be built on a section of Newton Street and would be placed to the side of the sidewalk closest to the road instead of being built on a grassed area on the other side of the sidewalk. The primary purpose for building in this manner was to avoid building through the existing sidewalk and to improve the aesthetics of the existing eroded grass in between the sidewalk and the road. A conceptual sketch of a bump-out BMP is shown below in Figure 41.

Figure 41: Bump-out Example (Image retrieved from Stormwater Management Plan for Spruce Brook Pond Subwatershed by the Charles River Watershed Association (CRWA, 2009))

The estimated cost of this BMP is $24,414. Adding catch basins to the bioretention itself, as shown in Figure 41, would greatly escalate the cost of the BMP and is not recommended unless absolutely necessary. Being located on the property of the library presents the opportunity to provide educational workshops on the importance of stormwater with the bioretention gardens serving as models. A BMP located on the library’s property also avoids many of the caveats of trying to implement on privately owned land. Also, side-street parking along Newton Street would be reduced as a result of this BMP but it would create official parking spots between bump-outs. In addition, there exists a designated parking lot nearby that may still suffice to meet the needs of the community.

5.1.3.4 Central Street Library Bump-out

A BMP similar to the Newton Street bump-out bioretention was proposed on the west side of Central Street on the opposite side of the grassed area in front of the library. This bump-out bioretention shared the same design concerns and constraints as the Newton Street bump-out with the added concern that the BMP would not collect as much runoff because the drainage profile of the surrounding area is not ideal for runoff collection. The section directly above this one can be referenced to learn more about the considerations of this bioretention. Using Equation 13, the cost of this BMP was estimated at $14,723.

5.1.3.5 Central Street Bioretention near Darby's

The proposed BMP would be located on the east side of Central Street on the grass strip immediately south of the commercial building containing Darby's Bakery. Due to the impervious nature of this area, the bioretention could serve to treat pollutants created by passing vehicles in addition to nutrients from residential lawns on Central Street. The bioretention would theoretically treat all of the road runoff north of the catch basin located approximately 150 feet south of it. An emergency overflow could be expelled into the vegetated area by the large trees.

This bioretention is one of the BMPs with the highest potential for pollutant removal but unfortunately poses some design and implementation challenges. There is an electric utility pole located on the sidewalk adjacent to the proposed area that may complicate construction. The proposed grassed area is slightly elevated relative to the road so some extra excavation would have to take place for runoff to successfully flow into the bioretention. A diversion trench similar to the one in the Prospect Residential Bioretention would also have to be built to divert the road runoff under the sidewalk and into the bioretention. The predicted cost for just the BMP was calculated at $9.855.

5.1.3.6 Long-term Central Street Bioretention

The business area on Central Street near the intersection with Prospect Street is one of the most impervious areas of the subbasin. During site screening, observations were made on the numerous parking lots that were underused and that many of them drained right into the road. From this, it is recommended that the impervious area slowly be changed to bioretention areas to treat the runoff from the parking lots before it enters the street and structural drainage system. This would require multiple bioretention areas on both sides of Central Street. This BMP is listed as a long-term project because of the high cost needed to implement the entire idea. There is plenty of room in some of the parking lots to add bioretention areas; the problem is removing the pavement to be able to construct bioretention. The cost would be great to treat all runoff from the business area, but it would greatly reduce the runoff volume entering the drainage system and decrease pollutant loadings of nutrients.

5.1.4 Non-structural BMPs

Seven non-structural BMPs were developed or improved upon to help prevent pollution at the source. Some of the BMPs focus on education to inform the public of better practices in pollution prevention while some focus on eliminating sources of pollution. Table 32 shows the estimated pollutant removals from the WTM model for each non-structural BMP.

Table 32: Non-structural BMP Removal

BMP	TSS		TP		TN		Fecal Coliform	
	Lbs per year	% from subbasin	Lbs per year	% from subbasin	Lbs per year	% from subbasin	Billion colonies per year	% from subbasin
Pet Waste Program	0	0%	1.0	0.23%	48.0	2.41%	2636	4.51%
Raccoon Removal	0	0%	13.0	3.04%	166	8.32%	6658	11.40%
Street Sweeping	2386	2.21%	5.0	1.17%	31.0	1.55%	0	0%
Catch Basin Cleanouts	2412	2.23%	6.0	1.41%	31.0	1.55%	0	0%
Septic System Review	16	0.01%	0	0%	2.0	0.10%	13	0.02%
Lawn Care Program	0	0%	0	0%	103	5.17%	0	0%
Cover Sand	250	0.23%	0	0%	0	0%	0	0%
Total	**5064**	**4.68%**	**25.0**	**5.85%**	**381**	**14.60%**	**9307**	**15.93%**

5.1.4.1 Pet Waste Program

Pet waste is a possible source of bacteria in the subbasin. Currently, there is a bylaw in West Boylston which fines citizens $25 for their first offensive of not removing pet waste, $50 for the second offense, and $100 for any following offenses (West Boylston, 2011). However, many towns have these bylaws which are never enforced. In addition to enforcing bylaws, public education should be implemented to educate citizens how not picking up after their dog can dramatically affect the water quality. Also, “pet waste stations” should be provided in popular dog walking areas to facilitate the removal of waste by providing waste receptacles and “dog bags” to facilitate the removal of pet waste. Brochures could also be distributed to homes to serve as a reminder to residents to pick up after their pets.

The efficiency of this program relies heavily on the continuation and public response. The main disadvantage is that people do not always choose to follow the program, but if the bylaws were enforced, people might be more likely to follow it. The advantage of this program is it is easy to implement and can be inexpensive. The total cost can range based on the extent of the program, but can still be effective at low costs. The team estimated that the program could be implemented for $1,000 to install some signs, example in Figure 42, and distribute brochures in the subbasin (EPA, 2008). Appendix L shows the calculations for all cost estimates.

Figure 42: Pet Waste Sign (Image retrieved from EPA's BMP factsheets (EPA, 2008))

5.1.4.2 Raccoon Removal

Raccoons are possibly a major problem in the West Boylston Brook subbasin because of the bacteria contamination. Surrounding the second sampling location, raccoon droppings were found during a site visit. It is possible that the raccoons waste is causing high bacteria levels in this level from runoff in the wooded area between Worcester and Central Streets. A solution for this would be to remove the raccoons from the area.

Determent of raccoons is not a viable option because the raccoons could relocate to live in homes or businesses creating additional problems. One option would be to physically relocate the raccoons by trapping them and relocate them to a larger wooded area outside of the subbasin. If this option is reasonable, consideration must be taken to determine if relocating raccoons is legal. It may not be legal to move raccoons because they could carry rabies, and the spread of rabies is not desired. Euthanization is an option which would remove the raccoons from the area and ensure they would not be a problem in the future. However, this option must be thought out as it would require killing multiple raccoons.

If this BMP were chosen, it would likely require a visit by a wildlife professional to assess the site, followed by trapping, and appropriate removal. This option would be fairly cheap as the only costs would be those for the labor of the professional. The team estimated that this would cost about $700. After the initial removal, this site and other sites close to the brook should be searched for additional droppings to ensure more raccoons do not habitat in the area.

5.1.4.3 Street Sweeping

After reviewing the annual street sweeping schedule for West Boylston, it appeared that they do not sweep frequently enough. During site visits, notable amounts of sand lined the edges of many roads, displaying the lack of sweeping. Sweeping at the right times and with greater frequently can have a major impact on the reduction of total suspended solids through the subbasin. If streets were swept immediately following winter snowmelt, before the large accumulation of sediment is washed off into the subbasin, the total load of sediments would be dramatically reduced as well. Other improvements include proper training by making sure street sweepers are not driven too fast and making sure the entire width of the road is swept. However, to further increase effectiveness, parking bands will have to be set during the more frequent sweeping schedule, which is its only disadvantage because of the annoyance to citizens. Nevertheless, this is a cheap and reasonably simple option, with a total cost (including training and more maintenance) of only $1,980 per year based on EPA cost estimates (EPA, 2008).

5.1.4.4 Catch Basin Cleanouts

Many of the catch basins in West Boylston were clogged or blocked in some way. While many communities clean their catch basins annually, it can be very beneficial to clean them more frequently. Cleaning the catch basins monthly will greatly increase the removal efficiency of nutrients and total suspended solids, while waiting until they are full will make the catch basin inefficient at removing sediments. The advantage of this, like all other non-structural options, is there is no construction process, and it is just as effective as a structural BMP. However, due to the large vacuum trucks that need to be used, many towns' hire contractors, so the cost to clean the catch basins monthly can be very expensive. For the West Boylston subbasin the cost was estimated to be around $14,400, see Appendix L.

5.1.4.5 Septic System Review

It is estimated that about 21% of the houses in the subbasin are not connected to the sewer. West Boylston recently had a large project when they connected most of their community to the sewer, however it is expensive to connect and some residents did not want to pay the cost. The downside to having a septic system is the chance of failure (can range from 1%-5%), which produces a significant pollutant load to the groundwater, and the extensive cleanup one must undergo following a leak. The best alternative for West Boylston is to increase its implementation of septic system review. The houses that have septic systems are currently inspected by the board of health every few years under Title 5 (Town of West Boylston, 2011); however, additional management programs such as regular inspection of groundwater contamination can be implemented. Advantages of this improvement include relatively low cost for increased inspection, with an estimated cost of $1,000, see Appendix L, and greater protection from high concentrations of bacteria and nutrients entering the brook. Conversely, replacing a septic system can cost up to $7,000, and with individual inspections, there can be resistance from the property owner for access.

5.1.4.6 Lawn Care Education

Nutrients are a significant source of pollution in the subbasin. One contributor of nutrient loads is fertilizer from residential lawns. Educating the public on the effects of over fertilization can greatly reduce the nutrient loads to the brook. There are currently grants available for towns that effectively educate their community on lawn care. West Boylston could provide incentives for lawn care companies that use organic or phosphorous free fertilizers and pesticides, while also providing educational programs, workshops, and brochures to the public. Workshops could include different types of landscaping that reduce fertilizer use while also reducing water usage. Major advantages of this solution include a significant removal of 5.17% total nitrogen at a maximum estimated cost of only $5,000, see Appendix L, which could all be paid off if the town were to receive a grant. Disadvantages include lack of public participation like other educational programs, because conventional lawn care techniques are usually cheaper and more effective. The goal is to convince residents that the impact on the subbasin is more important than the additional costs.

5.1.4.7 Covering Sand

The sand at the Department of Public Works (DPW) is stored behind the building on pavement, and is left uncovered as shown in Figure 43. During storm events, runoff flow down the pile and carries some sediment into the brook close to the outfall. This is not only harmful to the brook by raising the amount of sediment entering the stream, but the DPW is losing sand every time it rains. Currently, the DPW uses a 25% salt to sand ratio. Options were considered to switch the type of deicing components to less harmful compounds, but were eliminated due to the high cost. The simplest alternative is to cover the sand each day after use with a large tarp and use heavy rocks on the edge of the tarp to keep it from uncovering. This is a simple and cheap alternative, with an estimated maximum cost of $1000 for the tarp and weights. It would also benefit the DPW by reducing sand lost from runoff, thus saving them some money. The only disadvantage is the time lost to cover and uncover the sand every day it is used which should be minimal.

Figure 43: Uncovered Sand Storage at the DPW

5.2 Suggested Solution

Table 33 displays the individual and total pollutant removals for the BMPs and subbasin respectively. It also shows the estimated costs for all BMPs and the drainage areas of the structural BMPs. Table 34 shows the ranking of each BMP from highest ranked to lowest ranked. The bolded percent removals from the subbasin are the percentages which factored into the loading score for each BMP.

Table 33: Summary of Pollutant Removals

BMP	Drainage Area (acres)	Cost ($)	TSS		TP		TN		Fecal Coliform	
			Lbs per year	% from subbasin	Lbs per year	% from subbasin	Lbs per year	% from subbasin	Billion colonies per year	% from subbasin
Sediment Forebay	1.5	2,859	268	0.25%	0	0%	0	0%	0	0%
Tree Box Filters	1.5	39,000	1160	1.07%	4.3	1.01%	21.4	1.07%	519	0.89%
Bioret. Res. Garage	0.6	14,723	510	0.47%	2.0	0.47%	10.3	0.52%	434	0.74%
Bioret. Worc/Church St.	0.2	4,962	212	0.20%	0.8	0.19%	4.3	0.22%	181	0.31%
Bioret. near Darby's	0.4	9.855	324	0.30%	1.2	0.28%	6.6	0.33%	276	0.47%
Bioret. Central/Prospect	0.8	19,574	384	0.36%	1.5	0.35%	7.8	0.39%	327	0.56%
Bioret. Library Central	0.6	14,723	487	0.45%	1.9	0.44%	9.9	0.50%	414	0.71%
Bioret. Library Newton	1.0	24,414	699	0.65%	2.7	0.63%	14.2	0.71%	594	1.02%
Bioret. Prospect	0.2	4,962	192	0.18%	0.7	0.16%	3.9	0.20%	163	0.28%
Central Street Redevelopment	1.7	41,283	1378	1.27%	5.3	1.24%	27.9	1.40%	1172	2.01%
Pet Waste	N/A	1,000	0	0%	1.0	0.23%	48.0	2.41%	2636	4.51%
Street Sweeping	N/A	1,980	2386	2.21%	5.0	1.17%	31.0	1.55%	0	0%
Catch Basin Cleanouts	N/A	14,400	2412	2.23%	6.0	1.41%	31.0	1.55%	0	0%
Septic System Review	N/A	1,000	16	0.01%	0	0%	2.0	0.10%	13	0.02%
Lawn Care	N/A	5,000	0	0%	0	0%	103	5.17%	0	0%
Cover Sand	N/A	1,000	250	0.23%	0	0%	0	0%	0	0%
Raccoon Removal	N/A	700	0	0%	13.0	3.04%	166	8.32%	6658	11.40%
Total		**201,435**	**10678**	**9.88%**	**45.4**	**10.63%**	**487.3**	**24.44%**	**13387**	**22.93%**

Table 34: BMP Ranking

BMP	Cost	Maintenance	Social Impact	Pollutant removal efficiencies				Total score
	scale 0 to 10	scale 0 to 10	scale 0 to 10	% removal TSS	% removal TP	% removal TN	% removal FC	
Raccoon Removal	7	9	10	0.00%	**3.04%**	**8.32%**	**11.40%**	6.69
Cover Sand	7	10	6	**0.23%**	0.00%	0.00%	0.00%	5.76
Pet Waste	7	6	8	0.00%	**0.23%**	**2.41%**	**4.51%**	5.31
Street Sweeping	6	8	7	**2.21%**	1.17%	1.55%	0.00%	5.31
Sediment Forebay	5	4	10	**0.25%**	0.00%	0.00%	0.00%	4.76
Catch Basin Cleanouts	3	8	7	**2.23%**	**1.41%**	**1.55%**	0.00%	4.54
Bioret. near Darby's	4	4	9	0.30%	**0.28%**	**0.33%**	0.47%	4.26
Bioret. Worc/Church	4	4	9	0.20%	**0.19%**	**0.22%**	**0.31%**	4.26
Septic System Review	7	6	4	0.01%	0.00%	0.10%	**0.02%**	4.25
Lawn Care	4	7	5	0.00%	0.00%	**5.17%**	0.00%	4.13
Tree Box Filters	2	8	6	**1.07%**	1.01%	1.07%	0.89%	4.03
Bioret. Res. Garage	3	4	9	**0.47%**	0.47%	0.52%	0.74%	4.01
Bioret. Central/Prospect	3	4	9	0.36%	**0.35%**	**0.39%**	0.56%	4.01
Bioret. Library Central	3	4	8	0.45%	**0.44%**	**0.50%**	0.71%	3.76
Bioret. Prospect	4	4	7	0.18%	**0.16%**	**0.20%**	0.28%	3.75
Bioret. Library Newton	2	4	8	0.65%	**0.63%**	**0.71%**	1.02%	3.51
Central Street Redevelopment	1	4	7	1.27%	**1.24%**	**1.40%**	2.01%	3.03

The total predicted removal percentages from the brook are decent, but not as high as expected for the number of BMPs added to the model. It is thought that the reductions could be conservative because of the method the model uses. Drainage area, impervious area, and soil type are the only specifications included for each BMP. There is no way to specify the land use or location of the BMP. Therefore, the model results could be low since many of the BMPs are put in places where pollutant concentrations in runoff were thought to be fairly high. For example, the sediment forebay was put in a spot the team thought a lot of sediment would pass through because of the sand pile behind DPW. The model does not account for this in its calculation.

Because of the low total percentages, all BMPs are recommended for consideration. While some may not have high removal percentages or ranked scores, each one serves a purpose even if is just to raise public awareness, catch a small amount of runoff, or prevent a large amount of pollution from entering the brook. Further investigation into the possibility of each BMP could reveal that a few of them are not feasible at the given location or at all for this subbasin.

The BMPs should be implemented as soon as possible to begin treatment of runoff. This is especially true for nutrients as they will contribute to the eutrophication or the Wachusett Reservoir. The sooner the BMPs are implemented, the lower the pollutant loadings will be from runoff.

Economic constraints may prevent all BMPs from being implemented immediately; therefore, it is recommended that an initial phase of four BMPs, two structural and two non-structural, be implemented first:

- Raccoon removal
- Covering the sand at DPW
- Sediment forebay
- Bioretention near Darby's Bakery

These four were chosen because of their high scores from the ranking process and because the four in combination will remove TSS, TP, TN, and fecal coliform bacteria. Implementing this initial stage would cover all three sub-areas originally identified as concerns because the sediment forebay and covering the sand would treat sub-area 1, the raccoon removal program would be targeted at preventing pollution in sub-area 2, and the bioretention area would treat runoff in sub-area 3. Also in this initial stage, the other non-structural programs should be planned and prepared for implementation. The remaining BMPs can be implemented in later phases to complete the application of this plan.

Once BMPs are implemented, sampling could be used to evaluate the effectiveness of the BMPs. This could determine the pollutant reduction and be compared to the total subbasin reduction calculated by the model. If the group's assumption on the model being conservative is correct, then the BMPs should outperform their expected reductions.

Regardless of the exact reduction that would result from implementing all BMPs, it is clear that there would be some sort of reduction in all pollutant types. With this reduction, the BMPs would be reducing pollutant loads in the brook and therefore reducing its negative impact on the Wachusett Reservoir.

6.0 Conclusions and Recommendations

The goal of this project was to develop an integrated stormwater management plan for the West Boylston subbasin which was accomplished through an analysis of the existing conditions, identification of contributing sites, and the selection of best management practices. This chapter summarizes the analysis used to create the integrated plan, the suggested solution. Also modifications to our methodology will be discussed which should ease the analysis in other subbasins. Last, research and project suggestions for DCR or future MQPs will be presented.

6.1 Conclusion of Findings

From laboratory results, three sub-areas were identified as contributing pollutants which were the result of stormwater runoff. It was determined that sub-area 1 was mainly contributing sediments causing increases in total suspended solids. This was confirmed through a site visit to DPW and observing possible sources of sediment such as the sand pile. Sub-area 2 was thought to be a contributor of bacteria and nutrients. In visiting this area, raccoon droppings were found in many wooded areas close to the brook. Sub-area 3 contributed nutrients, most likely from general runoff from the impervious areas of businesses.

For these areas, specific sites were chosen with the aid of site visits to develop seventeen best management practices. Because there was limited space in the subbasin for structural BMPs, bioretention was used in all areas because of its small size, positive aesthetic qualities, and the ability to treat most pollutants. A sediment forebay and some tree box filters were also used in the subbasin to treat sediment. Many non-structural BMPs were used as they were economical and had the ability to be as effective as structural BMPs.

The BMPs were presented in the integrated plan with estimated costs, as shown in Table 33, and suggestions for implementation. In addition, a conceptual design was created for the sediment forebay. The WTM estimated the pollutant removals of all BMPs. The total reduction from the subbasin with all BMPs is shown in Table 35.

Table 35: Pollutant Reduction Summary

Parameter	Lbs. per year or billions of colonies per year	Percent removed from subbasin
TSS	10,678	9.88%
TP	45.4	10.63%
TN	487.3	24.44%
Fecal Coliform	13,387	22.93%

From this, the team determined that there would be a pollutant reduction with the implementation of BMPs. All BMPs were suggested for implementation, but an initial phase of four BMPs was suggested as a first step in the overall process.

6.2 Modifications to Approach

The team developed some modifications to the methodology for analyzing the existing conditions and for creating the integrated plan which can be applied to other subbasins to prevent the problems encountered in this project. First, recommendations on model use will be discussed as the team experienced many difficulties utilizing the Watershed Treatment Model. Then, suggestions to improve water quality sampling with be presented. Last, additions to the plan will be described to improve upon the one in this project.

6.2.1 Model Recommendations

The team recommends using WTM for the purpose of measuring the effectiveness of implementing BMPs in a given subbasin. It was found that even though the results of the model probably underestimated the actual pollutant reductions proposed in the plan, they were legitimate enough to compare the effectiveness of various solutions. WTM will not provide the user with the same accuracy that a complex model would because its main purpose is to be used as a planning tool for rapid assessments of treatment options by calculating future pollutant reductions. Although WTM was sufficient for the creation of this plan, other models exist which perform more detailed tasks but are more complicated to use.

Some difficulties were encountered with the use of WTM so it is recommended that the user be very familiar with the way the model works before arriving at conclusions. First, it is advised that the WTM be used only to calculate annual loadings because that is what the model is designed for. Trying to adjust it to produce storm loadings can be tedious as experienced in this project. As a result, many of the model inputs, such as road sanding, cannot be accounted for because they are all based on annual loadings. Second, every calculation in the model should be verified as there were major and minor errors throughout. For example, the equation calculated the pet waste program reductions in pounds per day instead of pounds per year, the desired reduction output. There was also one circular reference in the calculations which was preventing the equation from functioning correctly. The WTM manual can be of use in describing what equations are being used, but ultimately it is up to the user to determine if the model is calculating the equation correctly.

It is recommended that changes be made to the WTM pollutant concentrations if more accurate information is available. In the primary sources section of the model, the pollutant concentrations in runoff are based on previous reports researched by the creators of WTM. Although these reports are comprehensive, the pollutant concentration value used in WTM is simply the mean of those obtained from studies around the country and does not necessarily reflect local conditions. If it is possible to obtain accurate pollutant concentrations from field work then inputting these concentrations will certainly result in more accurate pollutant loadings.

6.2.2 Sampling Recommendations

The results of sampling and their analyses were very useful in the determination of areas with higher pollutant concentrations during storms. However, there are a few recommendations which could have improved the effectiveness of this task.

The main recommendation is to expand on the wet weather sampling if possible. This can be done in many ways, all of which would increase the detail obtained. The first suggestion is to sample multiple storms near their peaks. By accomplishing this, the concentrations can be compared from one storm to another to determine what the average peak concentration is from a storm. Because the team only sampled for the predicted first flush and shortly after this, it may be useful to sample the entire storm to see the trends in pollutant concentrations from beginning to end.

The team only sampled from one location that was just stormwater. This location was very useful in determining pollutant concentrations that were directly increasing from runoff in wet weather conditions. Sampling more stormwater discharge points may be of added use in other subbasins. By doing this, the base flow concentrations and pollutants in the stream from before the sampling location are eliminated and a direct stormwater impact is sampled. Additional stormwater only points would greatly help determine more specifically where pollutants were originating. The results obtained in this report were very useful, but the options described above are simply enhancements which could be made to the sampling process.

The last suggestion related to lab analysis is to use tests which determine if there are detergents or fertilizers in the water sample. These tests may be more complex or might need additional materials to complete, but the results could determine the possible source of a pollutant or at least narrow out possible sources.

6.2.3 Hydrology Recommendations

If more time and funding are available, a full hydrologic analysis would be very beneficial to provide more accurate loading rates which would result in more detailed solutions. In this project, possible BMP sites were determined without the aid of a complete analysis like the NRCS TR-55 Method because the results obtained from WTM proved to be sufficient. In addition, the outflow hydrograph that was created using depth measurements from the Hydrolab was a very useful way of creating a hydrograph using live measurements in the field. However, future projects may require the use of an in-depth analysis if a hydrograph cannot be produced using a similar method.

6.2.4 Plan Recommendations

This stormwater management plan presents a set of basic BMPs which could be implemented into the subbasin. Future plans should include further analyses to calculate the size of all BMPs so more detailed cost estimates can be determined. In addition, the ranking system can be modified so that it accurately reflects the weighting desired by DCR. Because BMPs are expensive, grant options could be explored with the plan to decrease costs.

While this plan focused strictly on creating stormwater BMPs to treat runoff, it may be valuable to design precautionary BMPs to prevent incidents like oil spills or gasoline leaks from contributing uncommon pollutants from entering the brook. An analysis of the most accident prone roads and intersections can determine which sites to focus for a preventive BMP.

6.3 Future Research Suggestions

In addition to applying this report and methodology to other subbasins, some other research and projects can be completed to expand upon the results of this report. These suggestions can be performed by the DCR or by future MQP groups.

In the West Boylston Subbasin, additional sampling could be completed to supplement the sampling of this project. The suggestions for expanding upon sampling can be found in Section 6.2.2.

If BMPs are implemented in this subbasin, a future project could evaluate the effectiveness of the BMP by sampling to determine the efficiency of the retrofit and the total removal from the subbasin. This would assist in determining if more BMPs are needed to prevent pollution in the brook.

References

Bare Hill Pond Watershed Management Committee. (2008). *Bare Hill Pond Stormwater Management Assessment Final.*

Center for Watershed Protection (CWP). (2002). *The Watershed Treatment Model.* Ellicott City, MD.

Center for Watershed Protection (CWP). (2007). *Urban Stormwater Retrofit Practices.* Ellicott City, MD.

Charles River Watershed Association (CRWA). (2008). *Stormwater Tree Pit.*

Charles River Watershed Association (CRWA). (2009a). *Low Impact Best Management Practice (BMP) Information Sheet: Gravel Wetland.* Retrieved from www.crwa.org/projects/bmpfactsheets/crwa_gravelwetland.pdf.

Charles River Watershed Association (CRWA). (2009b). *Stormwater Management Plan for Spruce Pond Brook Subwatershed.* Retrieved from http://www.crwa.org/projects/blue_franklin.html.

Clark County Regional Flood Control District (CCRFCD). (1999). *Hydrologic Criteria and Drainage Design Manual: Section 600- Storm Runoff.*

Emaruchi, B., Jin, Y., Sauchyn, D., & Fullera, G. (1997). Estimation of Runoff Index Using Landsat (TM) Data and an Artificial Nueral Network System. *Canadian Water Resources Journal, 22*(2)

Iowa State University: Institute for Transportation. (2008). *2C-1 General Information for Stormwater Hydrology, Version 2*.

Kayhanian, M., & Stenstrom, M. (2008). First-Flush Characterization for Stormwater Treatment. *Stormwater Journal,* (March-April) Retrieved from http://www.stormh2o.com/march-april-2008/pollutants-run-off.aspx.

EPA vs. MWRA on the Best Course Forward for MWRA's Drinking Water Program. (2000).

LakeSuperiorStreams. (2010). *LakeSuperiorStreams: Parking Lot Filter Strips.* Retrieved from http://www.lakesuperiorstreams.org/stormwater/toolkit/filterstrips.html

Massachusetts Department of Conservation and Recreation (DCR).*Water Quality Report: 2010 Wachusett Reservoir and Watershed.* No. 2011).

Massachusetts Department of Conservation and Recreation (DCR). (2003). *Enivronmental Quality Assessment: Reservoir District.*

Massachusetts Department of Conservation and Recreation (DCR). (2007). *Enivornmental Quality Assessment Report: Reservoir District Redux.*

Massachusetts Department of Conservation and Recreation (DCR). (2008). *2008 Watershed Protection Plan Update, Wachusett Reservoir Watershed.* No. Volume IIC.

Massachusetts Department of Conservation and Recreation (DCR) and the Ipswich River Watershed Association (IPWA). (2005). *Ipswich River Targeted Watershed Grant Fact Sheet: Three Low-Impact Development Case Studies.*

Massachusetts Department of Environmental Protection (Mass DEP). (1997). *Stormwater Management: Volume Two Stormwater Technical Handbook.*

Massachusetts Department of Environmental Protection (Mass DEP). (2008). *Massachusetts Stormwater Handbook. Volume 2, Chapters 1 and 2.*

Retrieved from http://www.mass.gov/dep/water/laws/v2c2.pdf.

Michigan Department of Enviromental Quality. (2002). *Total Suspended Solids.* Retrieved November, 20, 2011, from http://www.michigan.gov/documents/deq/wb-npdes-TotalSuspendedSolids_247238_7.pdf.

National Oceanic and Atmospheric Administration (NOAA). (2011). *Annual Climatological Summary: Worcester Regional Airport 2006-2010.* Retrieved September 16, 2011 from http://cdo.ncdc.noaa.gov/ancsum/ACS?coban=19992394746.

Natural Resources Conservation Service (NRCS). (1986). *Urban Hydrology for Small Watersheds.* No. Technical Release 55. Retrieved from http://www.hydrocad.net/pdf/TR-55%20Manual.pdf.

New Hampshire Department of Environmental Services. (2008). *New Hampshire Stormwater Manual. Chapter 8: Pollutant Loading Calculations.* Volume 1.

New Hampshire Volunteer River Assessment Program (NHVRAP). (2011). *Interpreting VRAP Water Quality Monitoring Parameters.* Concord, NH.

Pennsylvania Department of Environmental Protection. (2006). *Pennsylvania Stormwater Best Managemet Practices Manual.* Retrieved from http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305.

Standard Methods for the Examination of Water & Wastewater (2005). In Eaton A. D., Clesceri L. S., Rice E. W. and Greenberg A. E. (Eds.), (21st ed.). Washington, DC: American Public Health Association.

Town of West Boylston. *Septic Systems.* Retrieved December, 9, 2011, from http://www.westboylston.com/Pages/WBoylstonMA_Health/septic.

Town of West Boylston. (2011). *Article XIX: Dog Control.* Retrieved December, 4, 2011, from http://water.epa.gov/drink/contaminants/secondarystandards.cfm.

United States Environmental Protection Agency (EPA). (1992). *NPDES Storm Water Sampling Guidance Document.* No. 833-B-92-001).EPA.

United States Environmental Protection Agency (EPA). (1999). *Storm Water Technology Fact Sheet: Infiltration Trench.*

United States Environmental Protection Agency (EPA). (2003). *Protecting Water Quality from Urban Runoff.* Retrieved September, 15, 2011, from http://www.epa.gov/owow_keep/NPS/urban_facts.html.

United States Environmental Protection Agency (EPA). (2005). *Protecting Water Quality from Agricultural Runoff.* Retrieved September, 15, 2011, from http://www.epa.gov/owow/NPS/Ag_Runoff_Fact_Sheet.pdf.

United States Environmental Protection Agency (EPA). (2008a). *Menu of BMPs: Bioretention (Rain Gardens).* Retrieved from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=72.

United States Environmental Protection Agency (EPA). (2008b). *Stormwater Basic Information.* Retrieved December 02, 2008, from http://cfpub.epa.gov/npdes/stormwater/swbasicinfo.cfm

United States Environmental Protection Agency (EPA). (2008c). *Menu of BMPs: Parking Lot and Street Cleaning.* Retrieved December, 4, 2011, from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse.

United States Environmental Protection Agency (EPA). (2008d). *Menu of BMPs: Pet Waste Management.* Retrieved December, 4, 2011, from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse.

United States Environmental Protection Agency (EPA). (2011a). *5.4 pH.* Retrieved November, 20, 2011, from http://water.epa.gov/type/rsl/monitoring/vms54.cfm.

United States Environmental Protection Agency (EPA). (2011b). *5.7 Nitrates.* Retrieved November, 20, 2011, from http://water.epa.gov/type/rsl/monitoring/vms57.cfm.

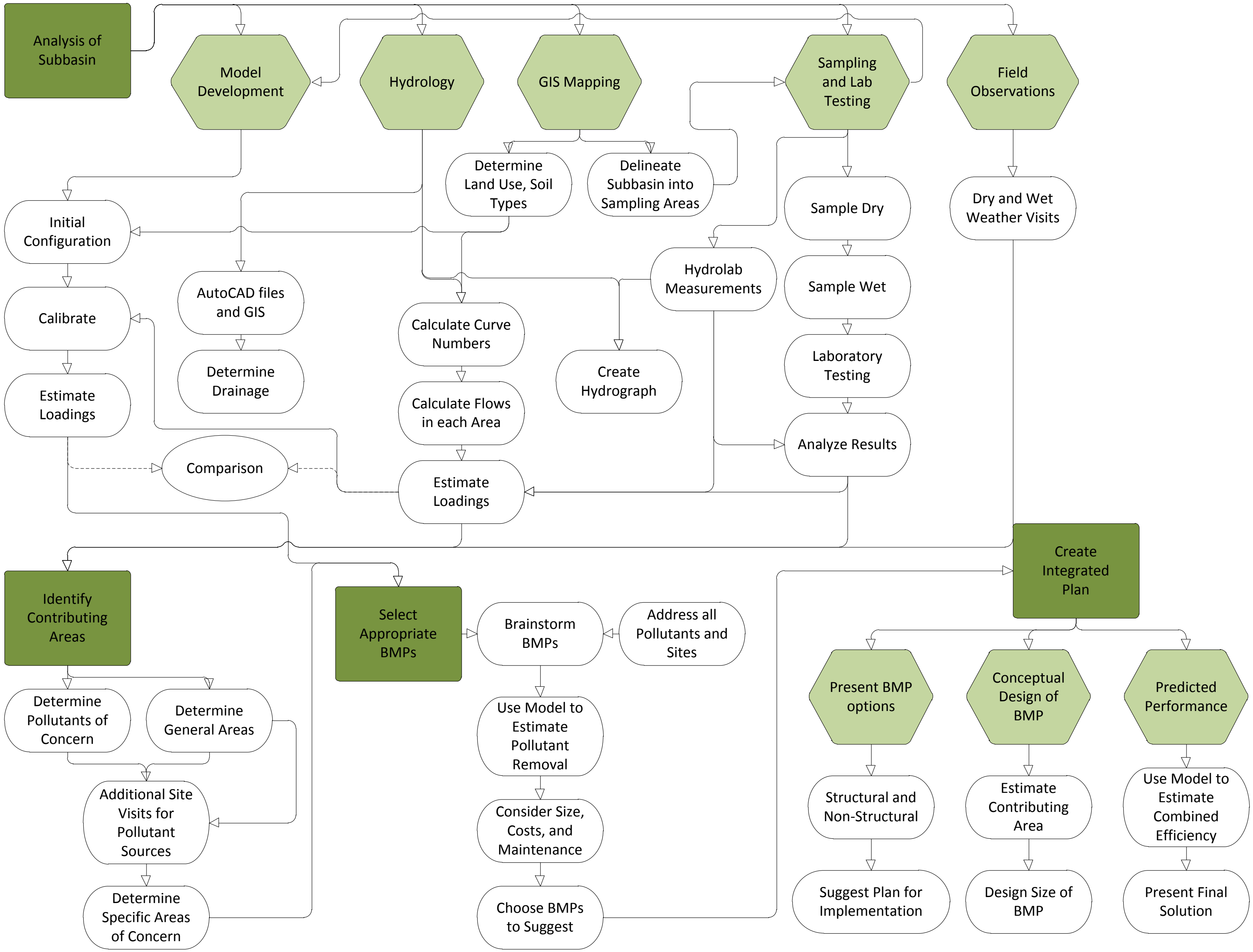
United States Environmental Protection Agency (EPA). (2011c). *Secondary Drinking Water Regulations: Guidance for Nuisance Chemicals.* Retrieved November, 20, 2011, from http://water.epa.gov/drink/contaminants/secondarystandards.cfm.

United States Environmental Protection Agency (EPA). (2011d). *SUSTAIN, System for Urban Stromwater Treatment and Analysis INtegration Model.* Retrieved October 9, 2011, from http://www.epa.gov/nrmrl/wswrd/wq/models/sustain/.

United States Geological Survey. (2001). *A Primer on Water Quality.* Retrieved September, 14, 2011, from http://pubs.usgs.gov/fs/fs-027-01/.

Virginia DCR. (2011). *VIirginia DCR Stormwater Design Specification No. 3: Grass Channels.* Retrieved from http://vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_3_GRASS_CHANNELS_Final_Draft_v1-8_04132010.htm.

Appendix A: Methodology Flow Chart



Appendix B: USGS Discharge Relationship Chart

1 U.S. DEPARTMENT OF THE INTERIOR - U.S. GEOLOGICAL SURVEY - WATER RESOURCES

STATION:01095420 WEST BOYLSTON BROOK AT WEST BOYLSTON, MA TYPE:STREAM AGENCY:USGS STATE:25 COUNTY:027
LATITUDE: 422206 LONGITUDE: 0714650 NAD27 DRAINAGE AREA: CONTRIBUTING DRAINAGE AREA: DATUM:430 NGVD29
Date Processed: 2010-11-04 12:21 By rsocolow
Rating for Discharge (cfs)
RATING ID: 7 TYPE: stage-discharge EXPANSION: logarithmic STATUS: working
Created by rsocolow on 12-15-2005 @ 10:12:39 EST, Updated by rsocolow on 01-30-2007 @ 16:03:56 EST

RATING REMARKS: BASED ON 120 DEG WEIR RATING EQUATION, PZF=0.20 ft, TOP OF WEIR=1.52 ft

OFFSET: 0.18

EXPANDED RATING TABLE

Gage height, feet	Discharge (cfs) .00	.01	.02	.03	.04	(EXPANDED PRECISION) .05	.06	.07	.08	.09	DIFF IN Q PER .1 UNITS
0.20	0.0000*	0.0010	0.0020	0.0030	0.0040	0.0050	0.0060	0.0070	0.0080	0.0090	0.0100
0.30	0.0100*	0.0132	0.0170	0.0215	0.0268	0.0330	0.0402	0.0484	0.0577	0.0682	0.0700
0.40	0.0800*	0.0897	0.100	0.111	0.123	0.136	0.149	0.163	0.178	0.194	0.130
0.50	0.210*	0.228	0.248	0.268	0.289	0.312	0.335	0.360	0.385	0.412	0.230
0.60	0.440*	0.468	0.497	0.527	0.558	0.591	0.624	0.659	0.695	0.732	0.330
0.70	0.770*	0.809	0.848	0.889	0.932	0.975	1.02	1.07	1.11	1.16	0.440
0.80	1.21*	1.26	1.31	1.37	1.42	1.48	1.54	1.59	1.66	1.72	0.570
0.90	1.78*	1.84	1.91	1.98	2.05	2.12	2.19	2.26	2.34	2.41	0.710
1.00	2.49*	2.57	2.65	2.73	2.81	2.90	2.98	3.07	3.16	3.25	0.850
1.10	3.34*	3.43	3.53	3.63	3.72	3.82	3.93	4.03	4.14	4.24	1.01
1.20	4.35*	4.46	4.57	4.68	4.80	4.91	5.03	5.15	5.27	5.40	1.17
1.30	5.52*	5.65	5.77	5.90	6.03	6.17	6.30	6.44	6.58	6.72	1.34
1.40	6.86*	7.00	7.15	7.30	7.45	7.60	7.75	7.90	8.06	8.22	1.52
1.50	8.38*	8.55	8.72*								

"*" indicates a rating descriptor point

Rating Type: Rating Type: stage-discharge

ID	Starting Date	Ending Date	A	Comments
7	11-13-2003 @ 00:00:00 EST	-----	W	

Appendix C: Event Mean Concentration Calculations

The procedure for calculating the event mean concentration was done by taking a weighted average of the two concentrations measured during the wet weather sampling for a pollutant. The following steps show how the weighting was done and include an example for Location 1 with TSS concentrations.

1. Plot the hydrograph with the two sampling times noted on the graph.

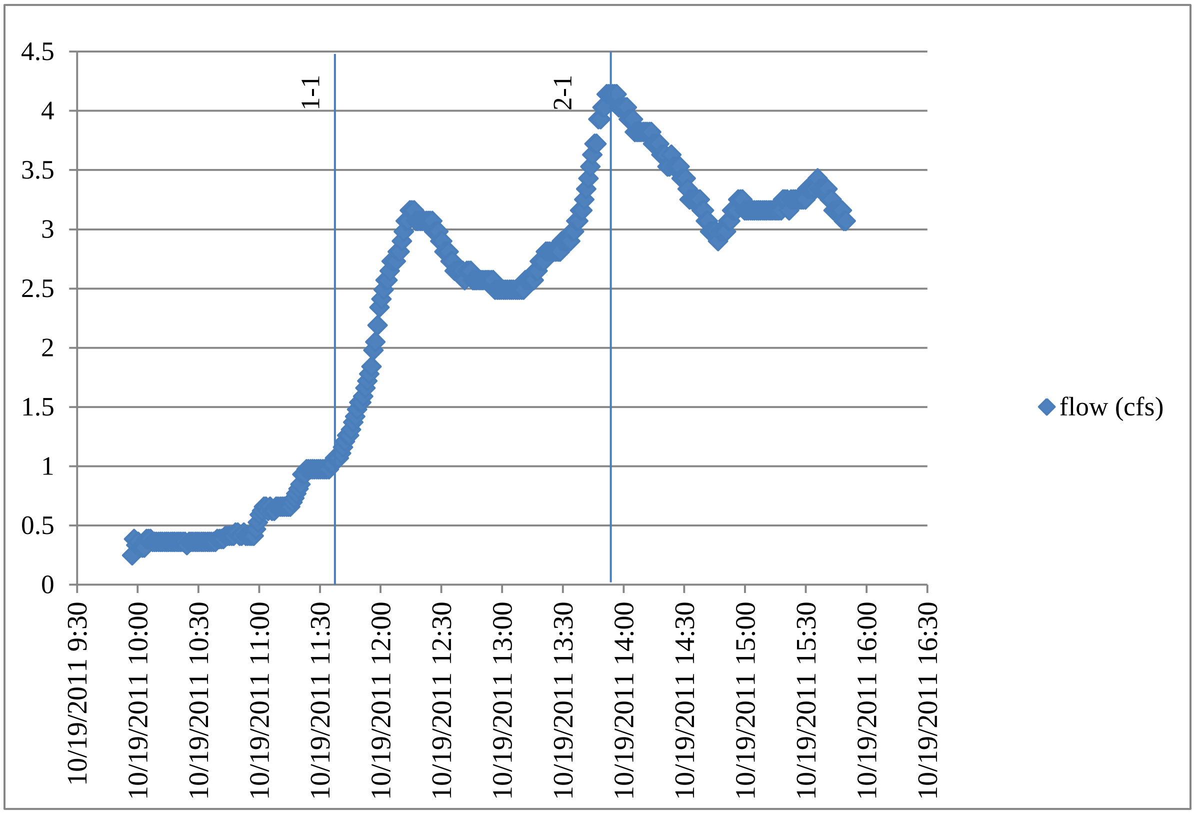


Figure 44: Hydrograph with Wet 1 and Wet 2 times

2. Split the hydrograph in two by finding the time midpoint of the two sampling times.

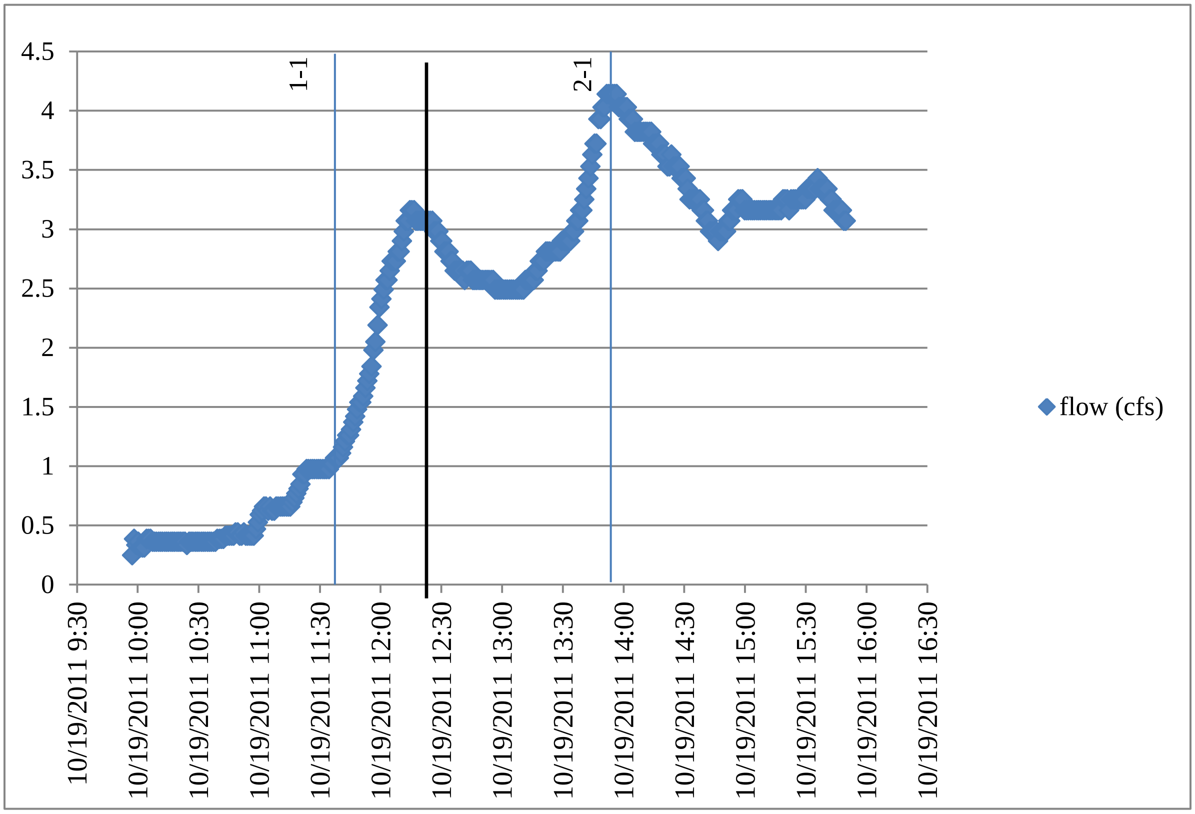


Figure 45: Hydrograph with time split

3. Find the area to each side of the split under the hydrograph curve to obtain the volume of each side. This can be done using geometric shapes, trapezoids, to approximate the volume.

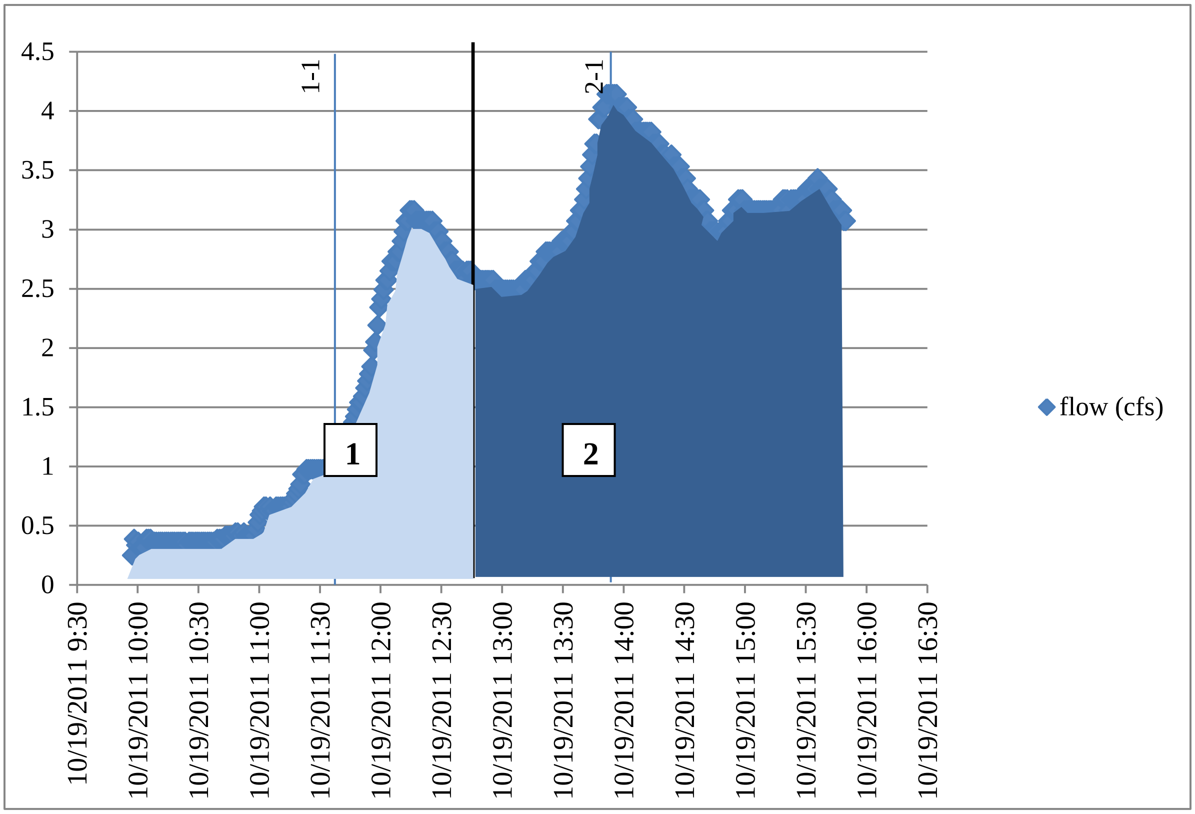


Figure 46: Hydrograph with Estimated Volumes

For TSS at Location 1:

Volume 1 = 16,020

Volume 2 = 34,830

4. The event mean concentration was then calculated by multiplying the concentration of the first wet sampling run by volume 1 and multiplying the concentration of the second sampling run by volume 2, adding the two results and dividing by the total volume as shown in the equation below.

$$Event\ mean\ concentration = \frac{(C_1 * V_1 + C_2 * V_2)}{total\ V}$$

Table 36: Event Mean Concentration for TSS at Location 1

Sample	Concentration (mg/L)	Volume (cfs)	C*V (mg*cfs/mL)
1	20.02	16,020	320,720
2	93.50	34,830	3,256,605
Total		50,850	3,577325
EMC	**70.35 mg/L**		

Appendix D: Laboratory Procedures

Lab Procedure: Ammonia
Method: Color Spectrophotometer at 425 nm

Apparatus:

- Spectrophotometer (Hach DR/3000 Color Spectrophotometer)
- 25 mL Spectrophotometer sample cell
- 1 mL Automatic Pipette
- Volumetric Flasks

Solutions:

- DI water (E-pure)
- Nitrogen, Ammonia Standard Solution at 100 mg/L as (NH_3-N)
- Mineral Stabilizer
- Polyvinyl Alcohol Dispersing Agent
- Nessler Reagent

Procedure:

1. Turn the color spectrophotometer on two hours before testing to allow the lamp to warm up and stabilize the absorbance readings. Set the wavelength to 425 nm.

2. Prepare at least two standards of known ammonia concentrations in volumetric flasks using the nitrogen, ammonia standard solution. Prepare concentrations that will encompass the expected range of results.

3. Create a blank by filling a clean sample cell with DI water. To this add the following three reagents making sure to cap and invert the cell several times between each:

    a. Three drops of Mineral Stabilizer

    b. Three drops of Polyvinyl Dispersing Agent

    c. 1 mL of Nessler Reagent using the automatic pipette

4. After adding the Nessler Reagent, allow for a three minute reaction time. During this time, wipe down the outside of the cell to ensure there is no dirt or smudges which could interfere with the reading.

5. After the three minutes, press **Manual Program** on the spectrophotometer.

6. Insert the cell into the instrument and close to door.

7. Press **Zero Abs.** to zero the instrument. The display should read 0.000 Abs.

8. Empty the sample cell and rinse with DI. This cell must be used for each reading to prevent discrepancies between sample cells.

9. Obtain absorbance readings on all standards and unknowns by repeating steps three and four. Instead of filling the cell with DI, fill it with the standard or unknown. Make sure to mix the sample before filling the cell. It is not necessary to select **Manual Program**. After the reaction period, place the cell in the spectrophotometer and press **Abs.** to get an absorbance reading.

10. Determine the concentration of ammonia in each unknown by making a standard curve from the absorbance readings of the blank and all standard solutions. Interpolate within the calibration curve to obtain the unknown concentrations.

Lab Procedure: Total Phosphorus
Method: Sulfuric Acid-Nitric Acid Digestion with Color Spectrophotometer at 400 nm

Apparatus:

- Spectrophotometer (Hach DR/3000 Color Spectrophotometer)
- 25 mL Spectrophotometer sample cell
- 5 mL and 1 mL Automatic Pipettes
- Volumetric Flasks
- Hot plate
- Small beakers
- Watch covers
- Hood

Solutions:

- DI water (E-pure)
- Phosphorus Standard Solution at 100 mg/L
- Concentrated Nitric Acid
- Concentrated Sulfuric Acid
- Phenolphthalein indicator
- 5N NaOH solution
- Molybdovanadate

Procedure:

1. Turn the color spectrophotometer on two hours before testing to allow the lamp to warm up and stabilize the absorbance readings. Set the wavelength to 400 nm.

2. Prepare at least two standards of known ammonia concentrations in volumetric flasks using the phosphorus standard solution. Prepare concentrations that will encompass the expected range of results.

3. Digest all samples, standards, and a blank by following the steps below:

    a. Pour 25 mL of sample, standard, or blank into a beaker.

    b. Add 5 mL of concentrated nitric acid using an automatic pipette.

    c. Add 1 mL of concentrated sulfuric acid using an automatic pipette.

    d. Cover with a watch cover and heat gently under a hood on a hot plate. The sample should not boil. Heat until the sample until it is down to visible fumes so that the remaining volume is about 1 mL.

    e. Remove beaker from hot plate and allow it to cool.

4. Transfer the digested blank into a sample cell. Add 1 drop of phenolphthalein indicator.

5. Add as much 5N NaOH to the cell as needed to produce a constant pink color using a dropper.

6. Add DI water up to the 25 mL mark on the cell.

7. Add 1 mL of Molybdovanadate using an automatic pipette.

8. Allow for a three minute reaction time. During this time, wipe down the outside of the cell to ensure there is no dirt or smudges which could interfere with the reading.

9. After the three minutes, press **Manual Program** on the spectrophotometer.

10. Insert the cell into the instrument and close to door.

11. Press **Zero Abs.** to zero the instrument. The display should read 0.000 Abs.

12. Empty the sample cell and rinse with DI. This cell must be used for each reading to prevent discrepancies between sample cells.

13. Obtain absorbance readings on all standards and unknowns by repeating steps four through eight. Instead of filling the cell with DI, fill it with the standard or unknown. It is not necessary to select **Manual Program**. After the reaction period, place the cell in the spectrophotometer and press **Abs.** to get an absorbance reading.

14. Determine the concentration of phosphorus in each unknown by making a standard curve from the absorbance readings of the blank and all standard solutions. Interpolate within the calibration curve to obtain the unknown concentrations.

Lab Procedure: Total Suspended Solids
Method: Dried at 103-105° C

Apparatus:

- Vacuum filter apparatus
- Filter
- Graduated cylinder
- Porcelain weighing dish
- Forceps
- Oven
- Balance
- Desiccator

Solutions:

- DI water (E-pure)

Procedure:

1. Turn on the oven and set it to 104° C to allow it to warm up.
2. Rinse filter three times with DI water and place on weighing dish. Only use forceps to handle the filter.
3. Place in oven for one hour. Once complete, put in desiccator to cool.
4. Weigh the dish and filter together. Use as precise an instrument as possible.
5. Assemble the vacuum filter apparatus with the dried filter. Wet the filter using DI water.
6. Draw a measured, mixed volume of sample through the filter using the vacuum suction.
7. Wash the filter three times with DI water allowing the filter to completely drain each time.
8. There should be visible solid on the filter. If there is not, measure more sample and suction it through the filter.
9. Remove the filter and place it on the weighing dish.
10. Heat in the oven for one hour. Once complete, allow to cool in the desiccator.
11. Weigh the dish and filter together.
12. Calculate the concentration of total suspended solids by subtracting the initial weight (mg) from the final weight (mg) and dividing the result by the volume filtered (L).

$$TSS\left({}^{mg}/_{L}\right) = (W_f - W_i(mg))/V(L)$$

Lab Procedure: Anions, fluoride, bromide, sulfate, phosphate, nitrate, chloride, nitrite
Method: Ion Chromatography

Apparatus:

- Ion Chromatograph
- Ion Chromatograph cells
- Disposable syringe and filter

Procedure:

1. Draw up mixed sample and filter it through an attachable filter into the chromatograph cell.
2. Repeat until cell is filled to line.
3. Seal the cell using a cap with the pointed end facing up.
4. Repeat for all samples and a blank with DI water.
5. Place all cells in the ion chromatograph and operate instrument for fluoride, bromide, sulfate, phosphate, nitrate, chloride, and nitrite anions
6. Place in oven for one hour. Once complete, put in desiccator to cool.

Lab Procedure: pH
Method: pH meter

Apparatus:

- pH meter

Solutions:

- DI water (E-pure)
- pH buffer solutions of pH 4, 7, 10 (only needed to calibrate pH meter if necessary)

Procedure:

1. Calibrate pH meter if needed.
2. Mix sample thoroughly.
3. Place pH meter into the sample.
4. Wait for the meter to stabilize; then read result off the instrument.
5. Repeat with all samples. Rinse probe between samples.

Lab Procedure: Specific Conductance
Method: conductivity meter

Apparatus:

- conductivity meter

Solutions:

- DI water (E-pure)

Procedure:

1. Mix sample thoroughly.
2. Place conductivity meter into the sample.
3. Wait for the meter to stabilize; then read result off the instrument.
4. Repeat with all samples. Rinse probe between samples.

Lab Procedure: Dissolved Oxygen
Method: DO meter

Apparatus:

- DO meter
- 300 mL DO glass bottle

Solutions:

- DI water (E-pure)

Procedure:

1. Calibrate DO meter if needed by placing probe in a DO bottle with some water and allow the air to become saturated. Once saturated, press **Calibrate** on the DO meter
2. Mix sample thoroughly by inverting DO bottle several times.
3. Place DO meter into the sample on the stir plate making sure that the magnet on the DO meter is spinning.
4. Wait for the meter to stabilize; then read result off the instrument.
5. Repeat with all samples.

Lab Procedure: Turbidity
Method: Turbidimeter

Apparatus:

- Turbidimeter (Hach 2100N)
- Turbidimeter vial

Solutions:

- DI water (E-pure)

Procedure:

1. Thoroughly mix sample.
2. Fill turbidimeter vial with mixed sample.
3. Invert vial several times, wipe down the sides of the vial, and place into turbidimeter.
4. Read turbidity off of the unit.

Rinse out the vial and repeat with all other samples using the same vial.

Appendix E: WTM Land Use Assumptions

List of MassGIS Land Uses

Cemetery, Commercial, Cropland, Forest, Forested Wetland, Golf Course, Industrial, Low Density Residential, Medium Density Residential, Multi-Family Residential, Non-Forested Wetland, Open Land, Pasture, Powerline/Utility, Transportation, Urban Public/Institutional, Very Low Density Residential, and Water

Table 37: Relationship Between WTM and MassGIS Land Use

WTM Land Uses	Similar Mass GIS Land Uses	Reason(s)
Low Density Residential	Low Density Residential Very Low Density Residential	Matches <1 acre designation set by WTM
Medium Density Residential	Medium Density Residential Cemetery Golf Course	Similar Curve Numbers
High Density Residential	N/A	N/A
Multifamily Residential	Multi-Family Residential	Same Land Use
Commercial	Commercial Urban Public/Institutional	Same or very similar land use
Roadway	N/A. Was retrieved from EOT Roads Data layer	N/A
Industrial	Industrial Transportation	Old rail tracks in transportation layer were exposed to chemicals in the past
Forest	Forest	Same Land Use
Rural	Cropland Open Land Pasture Powerline/Utility	Similar Curve Numbers
Open Water	Water Non-Forested Wetland Forested Wetland	Similar Curve Numbers

Appendix F: WTM Input

Table 38: WTM Inputs and Modifications

Primary Sources	Inputs and Modifications	Source
Land Use	1. Area for each Land Use (acres) LDR = 56.67 MDR= 45.7 Multifamily= 4.92 Commercial= 13.61 Roadway= 20.94 Industrial= 2.23 Forest= 83.48 Rural= 30.34 Open Water= 17.19	1. Mass GIS
Partitioning Coefficients	No change	
Watershed Data	1. Annual Rainfall= 51 inches 2. Stream Length= 1.88524 miles	1. Worcester Regional Airport Data obtained from NOAA 2. Mass GIS
Soils Information	1. Percent Hydrologic Soil Group A= 21% B= 8% C=68% D= 3%	1. Mass GIS
Secondary Sources		
General Sewage Use Data	1. Dwelling Units= 165	1. Mass GIS
Nutrient Concentration in Stream Channels	1. Concentration of P and TN in soil Soil P= 0.150% Soil TN= 0.150 %	1. WTM Manual
On-Site Sewage Disposal Systems	1. Unsewered Dwelling Units= 21% 2. Septic Systems <100’ to stream= 2% 3. System type= 100% conventional	1. DCR, 2007 2. Assumption 3. Assumption
SSOs	No change	
CSOs	No change	
Illicit Connections	No change, not applicable	
Urban Channel Erosion	1. Used Method 1	1. Assumption
Livestock	No change, not applicable	
Marinas	No change, not applicable	
Road Sanding	1. Sand Application= 2824 lbs/year 2. Open Section Roads= 72%	1. DPW Director 2. Mass GIS
Non-Stormwater Point Sources	No change	
Existing Management Practices		

Turf Condition: Residential	No change	
Turf Condition: Other	No change	
Pet Waste Education	1. Activated Program 2. Awareness of Message= 20%	1. Town of West Boylston 2. Assumption
Erosion and Sediment Control	No change	
Street Sweeping	1. Street Swept Area Residential =0.76 Other streets =0.46 2. Frequency= monthly The team wanted yearly values so the areas are a twelfth of the original areas	1. Mass GIS 2. Assumption to get yearly
Structural Stormwater Management Practices	1. Wetland Drainage Area= 33.23 acres 2. Impervious Area= 0.7 acres	1. Mass GIS 2. Mass GIS
Riparian Buffers	No change	
Catch Basin Cleanouts	1. Impervious Area for capture areas (Semi-Annual Cleaning) =19.98 acres	1. Mass GIS
Marina Pumpouts	No change	

Appendix G: BMP Ranking Calculations

Table 39: BMP Rankings

	Cost	Maintenance	Social Impact	Pollutant removal efficiencies				Total score
BMP	scale 0 to 10	scale 0 to 10	scale 0 to 10	% removal TSS	% removal TP	% removal TN	% removal FC	
NS Raccoon removal	7	9	10	0.00%	**3.04%**	**8.32%**	**11.40%**	6.69
Cover Sand DPW	7	10	6	**0.23%**	0.00%	0.00%	0.00%	5.76
NS Pet waste program	7	6	8	0.00%	**0.23%**	**2.41%**	**4.51%**	5.31
NS Street sweeping	6	8	7	**2.21%**	1.17%	1.55%	0.00%	5.31
Sediment Forebay behind DPW	5	4	10	**0.25%**	0.00%	0.00%	0.00%	4.76
NS Catch basin cleanouts	3	8	7	**2.23%**	**1.41%**	**1.55%**	0.00%	4.54
Bioretention next to dance studio driveway	4	4	9	0.30%	**0.28%**	**0.33%**	0.47%	4.26
Bioretention on Worcester Street near cemetery	4	4	9	0.20%	**0.19%**	**0.22%**	**0.31%**	4.26
NS Septic system review	7	6	4	0.01%	0.00%	0.10%	**0.02%**	4.25
Tree Box filter DPW lot	2	8	6	**1.07%**	1.01%	1.07%	0.89%	4.03
Bioretention on Worcester Street near garage	3	4	9	**0.47%**	0.47%	0.52%	0.74%	4.01
Bioretention at Central and Prospect	3	4	9	0.36%	**0.35%**	**0.39%**	0.56%	4.01
NS Lawn care and municipal landscaping educ. Program	4	6	5	0.00%	0.00%	**5.17%**	0.00%	3.88
Bioretention Bump out Central St	3	4	8	0.45%	**0.44%**	**0.50%**	0.71%	3.76
Bioretention Prospect St.	4	4	7	0.18%	**0.16%**	**0.20%**	0.28%	3.75
Bioretetnion Bump out Newton St	2	4	8	0.65%	**0.63%**	**0.71%**	1.02%	3.52
Long term redevlopment of Central Street Businesses	1	4	7	1.27%	**1.24%**	**1.40%**	2.01%	3.03
Total				9.88%	10.63%	24.44%	22.93%	

Table 40: Cost Scoring

Cost ($)	Score
0-100	10
100-300	9
300-700	8
700-1000	7
1,000-2,000	6
2,000-4,000	5
4,000-10,000	4
10,000-20,000	3
20,000-40,000	2
40,000+	1

All Maintenance and Social Impact scores were mutually agreed upon by the group. Maintenance scores were influenced by research especially from Massachusetts Stormwater Handbook (Mass DEP, 2008).

Calculation for Score:

$$Score = \left(\frac{Cost + Maint. + Soc. Imp.}{3}\right) * (0.75) + \left(\frac{\sum relevant\ removal\ percentages * 10}{Number\ of\ percentages\ used}\right) * (0.25)$$

Example: Sediment Forebay

$$Score = \frac{(5 + 4 + 10)}{3} * (0.75) + \left(\frac{0.25 * 10}{1}\right) * (0.25) = 4.76$$

Appendix H: Field Observations Notes

September 7th, 2011 Site Visit

Conditions: Rain

Purpose: Gain general understanding of brook and existing conditions. See as much of brook as possible.

The team first traveled to the DCR's sampling location for the brook which is close to the discharge point into the reservoir. Between the sampling point and the discharge point, there are no official roads, only access roads for the DCR. At the sampling point, the brook flows out of a culvert and then over a metal v-notch weir. There is also USGS water level gage a few feet upstream of the weir. The area was covered with fairly dense vegetation. The brook had a decent flow to it and there was some visible turbidity making it look cloudy.

Next, the team went upstream to the DPW parking lot. The runoff from the lot ran into vegetation which would then drain down to the brook. The parking lot was fairly large and the low point of the lot was not well paved and contained a lot of sediment. According to one of the DCR staff, DPW sometimes stores sand for road sanding in this lot. It was clear from the DCR staff that they viewed this location as a potential contributor to the stormwater concerns of the brook.

Across the street from the DPW lot, the brook continued upstream where it was joined by stormwater discharge which exited from a culvert and then had eroded away some of the land to form a channel which is flowed down and into the brook. Some of the discharge did not follow the channel, turning some of the area into a wetland. The area consisted mostly of trees and some medium to dense vegetation on the ground. The turbidity of the brook or the runoff was not observed. The DCR staff tried to approximate where the runoff was coming from and suggested we consult GIS maps to see where the runoff was originating.

Further down the road(further upstream), the brook came out of a culvert right near a church. There was a steep embankment from the church down to the brook. There was a partial curb along the parking lot of the church, but it was broken or missing at certain sections allowing runoff to flow down the embankment into the brook.

The team and the DCR staff drove along Central St. looking for catch basins which could discharge into the runoff across the street from the DPW. Then, they drove further upstream to where the brook splits into two sections. Between the church and the two sections is a wetland where the join occurs. The team did not visit this area because it is hard to access and the wet conditions would make trekking the area difficult.

The team only visited one of the splits of the brook which was downstream of Carroll's Pond. The flow appeared to be a lot lower at this section than the main sections the team had previously seen. The DCR staff did not view these upstream areas being major pollutant contributors to the brook.

The other section of the brook was not visited because the DCR staff said it would look very similar to the section the team visited and because of time constraints.

The subbasin consisted mostly of medium to low density residential in a forested system. As the brook flowed downstream the density of streets and houses increased.

September 25th, 2011 Site Visit

Conditions: Partly Cloudy, Dry

Purpose: Visit some specific areas to see some of the neighborhoods that were not previously seen and further investigate some previously visited locations.

The team first went back to the DPW lot to observe the area since the team was viewing it as a possible source of pollutants. The team noticed that there was a waste oil area on the east side of the parking lot. There appeared to be some kind of small collection basin where waste oil could be poured. Where the oil goes is unknown. From CAD drawings, there is a drain on the east side of the lot. It could not be found, but it probably drained out to the vegetation behind the DPW buildings.

In the southwest section of the subbasin is a one road neighborhood, Lost Oak Rd. This road was not included in any CAD drawings, but it has many catch basins shown in GIS drainage layers. The team wanted to see where the runoff from this neighborhood drains. The neighborhood had very large yards and lots of land in-between homes. Many of the catch basins were clogged from a recent storm, but it seemed like at least some of the runoff drains down Prospect Street to one of the sections of the brook. It is also possible that some of the runoff drains into a detention basin north of the neighborhood and then drains upstream of Carroll Pond as noted a DCR staff member.

Very close to Lost Oak Rd. is a golf course which is partially in the subbasin. There wasn't much we could observe from the parking lot besides that most of the runoff would probably not go into the subbasin; although, some definitely could.

The team visited two neighborhoods, Scarlett St. and Newton St, but not much could be observed besides that they were medium residential areas with no curbs and few catch basins.

Last, the team went to the intersection of Prospect and Central Streets where a large amount of runoff should be joining to then discharge somewhere to the East. The team scouted the area and could only determine that the pipe must be underground and does not discharge until the culvert on the opposite side of the DPW.

Appendix I: Sampling Results

Table 41: Full Sampling Results

WET 1	DO	pH	Conduc-tivity	Turb-idity	TSS	E. coli	Ammon-ia	TP as Phosphate	TP as P	IC				
Location:	mg/L		micro-Siemens	ntu	mg/L	MPN/ 100 mL	mg/L	mg/L	mg/L	Nitrate	Phos-phate	Chlor-ide	Flour-ide	Sulf-ate
1 DCR	8.47	6.73	508	16.2	20.02	1480	0.659	2.218	0.724	2.59	0.46	61.29	0.05	8.57
2 DPW	7.91	6.73	189	27.1	10.04	14,100	1.111	2.780	0.907	0.88	0.86	12.46	ND	3.72
3 SW outfall	8.12	6.72	48	20.3	31.33	2760	1.071	2.377	0.776	0.22	0.94	1.630	ND	0.92
4 church	8.90	6.96	392	10.1	11.24	2010	0.347	1.108	0.361	1.26	0.34	35.04	0.04	6.11
5 Prospect N	10.91	6.81	412	17.6	41.17	557	0.452	0.963	0.314	0.99	0	37.83	0.04	7.34
6 Prospect S	8.33	6.89	276	13.7	20.84	6490	0.340	1.324	0.432	0.81	0.22	28.99	0.04	5.00
WET 2														
1 DCR	9.24	7.06	346	39.8	93.50	1780	0.488	0.934	0.073	0.92	0.26	45.38	0.03	3.59
2 DPW	9.20	6.79	249	17.8	31.48	1670	0.367	1.122	0.086	0.81	0.25	24.28	0.03	3.70
3 SW outfall	8.92	6.81	34	8.2	5.44	2990	0.662	1.367	0.103	0.31	0.50	1.18	ND	0.75
4 church	9.67	6.87	259	18.8	27.24	3080	0.459	1.973	0.664	0.78	0.22	24.71	0.04	4.21
5-Prospect N	8.29	6.86	357	9.2	36.24	1250	0.301	1.021	0.333	0.55	0.23	34.21	0.05	6.27
6 Prospect S	8.99	6.56	203	7.19	37.80	3650	0.425	0.444	0.145	0.29	0	16.88	0.04	4.16
DRY														
1 DCR	10.43	6.88	730	1.45	5.631579	10	0.072	0.170	0.056	4.52	0.39	95.29	0.05	14.03
1 DCR-DUP	10.3	7.04	725	1.35	8.04	31	0.069	0.257	0.084	4.59	ND	95.39	0.046	14.15
2 DPW	9.48	6.97	590	1.45	3.76	<10	0.079	0.000	0.000	4.13	ND	69.92	0.046	12.64
4 church	10.11	7.16	476	1.35	5.42	20	0.145	0.170	0.056	2.3	0.38	52.19	0.047	10.74
5 Prospect N	9.35	6.96	508	1.15	4.4	<10	0.082	0.069	0.023	3.36	ND	56.68	0.049	11.58
6 Prospect S	10.48	6.94	577	0.81	2.38	<10	0.132	0.112	0.037	1.57	ND	49.17	0.05	10.19

Notes on table:

- ND = No detection by Ion chromatography
- Ion Chromatography did not detect nitrite and bromide in any samples
- Phosphate concentrations were converted to mg/L as phosphorus for comparison

Appendix J: Event Mean Concentration Results

Event mean concentrations for all areas calculated with procedure in Appendix C

Table 42: Area 1 EMC

Area 1: DCR			
Volume 1		Volume 2	
16,020		34,830	
Pollutant Type	1st Sample Grab Concentration (Wet 1)	2nd Sample Grab Concentration (Wet 2)	Event Mean Concentration
Total Phosphorus as P (mg/L)	0.724	0.305	0.437
Nitrate (mg/L)	2.59	0.92	1.45
Ammonia (mg/L)	0.659	0.488	0.542
Total Suspended Solids (mg/L)	20.02	93.50	70.35
E. coli (MPN/100mL)	1480	1780	1685

Table 43: Area 2 EMC

Area 2: DPW			
Volume 1		Volume 2	
18,382		32,468	
Pollutant Type	1st Sample Grab Concentration (Wet 1)	2nd Sample Grab Concentration (Wet 2)	Event Mean Concentration
Total Phosphorus as P (mg/L)	0.937	0.366	0.437
Nitrate (mg/L)	0.88	0.81	0.84
Ammonia (mg/L)	1.11	0.367	0.636
Total Suspended Solids (mg/L)	10.04	31.48	23.73
E. coli (MPN/100mL)	14,100	1,670	6,163

Table 44: Area 3 EMC

Area 3: Stormwater Outfall			
Volume 1		Volume 2	
18,382		32,468	
Pollutant Type	1st Sample Grab Concentration (Wet 1)	2nd Sample Grab Concentration (Wet 2)	Event Mean Concentration
Total Phosphorus as P (mg/L)	0.776	0.446	0.565
Nitrate (mg/L)	0.22	0.31	0.28
Ammonia (mg/L)	1.071	0.662	0.810
Total Suspended Solids (mg/L)	31.33	5.44	14.80
E. coli (MPN/100mL)	2,760	2,990	2,907

Table 45: Area 4 EMC

Area 4: Church			
Volume 1		Volume 2	
20,858		29,992	
Pollutant Type	1st Sample Grab Concentration (Wet 1)	2nd Sample Grab Concentration (Wet 2)	Event Mean Concentration
Total Phosphorus as P (mg/L)	0.362	0.644	0.528
Nitrate (mg/L)	1.26	0.78	0.98
Ammonia (mg/L)	0.347	0.459	0.413
Total Suspended Solids (mg/L)	11.24	27.24	20.68
E. coli (MPN/100mL)	2010	3080	2641

Table 46: Area 5 EMC

Area 5: Prospect St. North			
Volume 1		Volume 2	
24,120		26,730	
Pollutant Type	1st Sample Grab Concentration (Wet 1)	2nd Sample Grab Concentration (Wet 2)	Event Mean Concentration
Total Phosphorus as P (mg/L)	0.314	0.333	0.324
Nitrate (mg/L)	0.99	0.55	0.76
Ammonia (mg/L)	0.452	0.301	0.373
Total Suspended Solids (mg/L)	41.17	36.24	38.58
E. coli (MPN/100mL)	557	1250	921

Table 47: Area 6 EMC

Area 6: Prospect St. South			
Volume 1		Volume 2	
26,820		24,030	
Pollutant Type	1st Sample Grab Concentration (Wet 1)	2nd Sample Grab Concentration (Wet 2)	Event Mean Concentration
Total Phosphorus as P (mg/L)	0.432	0.145	0.296
Nitrate (mg/L)	0.81	0.29	0.56
Ammonia (mg/L)	0.340	0.425	0.380
Total Suspended Solids (mg/L)	20.84	37.8	28.85
E. coli (MPN/100mL)	6490	3650	5148

Appendix K: EMC Alternative Method and Calculations

Using the following equation:

$$EMC = \frac{\sum Q_i * C_i * dt}{\sum Q_i * dt}$$

Because only two sample were taken, the dt is removed from each summation to get the following equation.

$$EMC = \frac{\sum Q_i * C_i}{\sum Q_i}$$

The concentrations are the same as the ones presented in Appendix J. The instantaneous flows used are shown in Table 48. An example calculation for nitrate concentration at Location 1 follows the table.

Table 48: Instantaneous Flows

Location	Wet 1 Flow (cfs)	Wet 2 Flow (cfs)
1	0.98	3.8
2	2.1	2.4
3	3.3	1.2
4	1.1	4.0
5	1.8	2.9
6	1.5	2.5

$$EMC = \frac{\sum Q_i * C_i}{\sum Q_i} = \frac{(0.98 * 0.724) + (3.8 * 0.305)}{(0.98 + 3.8)} = 0.39\frac{mg}{L}$$

Table 49 shows the EMCs for all locations and pollutants using the alternative method. These can be compared to the results of Appendix J.

Table 49: Event Mean Concentrations using Alternative Method

Location	Nitrate (mg/L)	Ammonia (mg/L)	TP as P (mg/L)	TSS (mg/L)	Bacteria (MPN/100ML)
1	1.26	0.523	0.390	78.60	1720
2	0.84	0.714	0.618	21.50	7463
3	0.24	0.965	0.690	24.59	2821
4	0.88	0.435	0.583	23.80	2851
5	0.72	0.359	0.326	38.16	983
6	0.49	0.393	0.253	31.46	4717

.

Appendix L: Cost Estimates

Table 50: Cost Estimates

Bioretention	Area Captured (acre)	Volume captured (ft^3) for 1in storm = area*1*3630	Estimated[1] Cost c=7.3v^.99
Bioret. at Central and Prospect	0.8	2904	19574
Bioret. on Central St.	0.4	1452	9855
Bioret. Prospect St.	0.2	726	4962
Bioret. Bump out Newton St	1	3630	24414
Bioret. Bump out Central St	0.6	2178	14723
Bioret. on Worcester Street near garage	0.6	2178	14723
Bioret. on Worcester Street near cemetery	0.2	726	4962
Long term re-devlopment of Central Street Businesses	1.7	6171	41283

Sediment Forebay	Area Captured (acre)	impervious %	Vcaptured for 1in storm = Area*imperv %*3630	Volume of Forebay =Volume* (0.1)	top area for 2 ft depth (ft^2) = volume/ 2ft	Estimated[2] Cost at $15/ft^2
Sediment Forebay	1.5	70	3812 ft^3	381.2 ft^3	191 ft^2	2859

Tree Box Filter	Trees	Cost at $13,000 per tree[3]
Tree Box Filter	3	39000

Estimate Cost[4] for various Non-structural BMPs	Estimated Cost
Cover Sand DPW	1000
Pet Waste Program	1000
Raccoon Removal	700
Lawn Care	5000

Septic System Review	Cost per inspection[5]	Inspections	Cost/year

Septic System Review	$125		8	1000
Street Sweeping	**Cost per curbmile[6]**	**Curbmiles**	**done monthly (12 times/year)**	**Cost/year**
Street Sweeping	$30	5.5	12	1980
Catch Basin Cleanouts	**Hourly Rate[7]**	**Time (hours)**	**done monthly (12 times/year)**	**Cost/year**
Catch Basin Cleanouts	150	8	12	14400

Sources:

1. EPA, 2006
2. BHPWMC, 2008
3. CRWA, 2008
4. Approximations from EPA, 2006 BMP menu. If no approximation was given, then the cost was guessed by the group.
5. EPA, 2006
6. EPA, 2006

Appendix M: Sediment Forebay Calculations

$$Volume = {}^{0.1''}/_{imperv.acre} * 1.05\ imperv.acres * 1'' * 3630\ (conversion) = 381\ ft^3$$

$$Area = \frac{volume}{depth}; Area = 381\frac{ft^3}{2ft} = 190.5\ ft^2 \sim (191\ ft^2)$$

$$Area = Length * Width;\ 191\ ft^2 = 2w^2;\ (L = 2w);\ w = 9.8\ ft$$

$$L = 2 * w = 19.6\ ft.$$

$$Check\ dam\ Length\ (ft) = 6 * drainage\ area(acre) = 6 * 1.5\ acres = 9\ ft.$$

$$WQV = 0.5'' * Impervious\ Area;\ WQV = 0.5'' * 1.05\ acres = 0.525\ ac - in$$
$$= 1905.75\ ft^3$$

Notes:

The Dimensions were all increased because we wanted to oversize the forebay. The width was increased to 12 ft. and the length was increased to 24 ft.

The above area is the average area of the basin. Because of the 1: 1 slope and 2 ft depth, the bottom dimensions are 2 ft. less in both directions. Therefore, the bottom area was calculated to be 160 ft^2. The top area will be 255 ft^2

The WTM had a calculated value of 1,933 ft^3 for the water quality volume.

Appendix N: Instantaneous Loadings

Table 51: Instantaneous Wet 1 Loadings

Wet 1		Concentrations				Loadings			
Location	Flow cfs	Nitrate mg/l	Ammonia mg/l	TP as P mg/l	TSS mg/l	Nitrate lb/day	Ammonia lb/day	TP as P lb/day	TSS lb/day
1	0.98	2.59	0.66	0.724	20.02	13.59	3.46	11.64	105.09
2	2.11	0.88	1.11	0.907	10.04	9.99	12.62	31.57	114.03
3	3.26	0.22	1.07	0.776	31.33	3.86	18.79	41.71	549.83
4	1.1	1.26	0.35	0.362	11.24	7.46	2.05	6.56	66.55
5	1.82	0.99	0.45	0.314	41.17	9.70	4.43	9.43	403.36
6	1.5	0.81	0.34	0.432	20.84	6.54	2.75	10.69	168.26

Table 52: Instantaneous Wet 2 Loadings

Wet 2		Concentrations				Loadings			
Location	Flow cfs	Nitrate mg/l	Ammonia mg/l	TP as P mg/l	TSS mg/l	Nitrate lb/day	Ammonia lb/day	TP as P lb/day	TSS lb/day
1	3.82	0.92	0.49	0.303	93.50	18.92	10.03	19.20	1922.55
2	2.42	0.81	0.37	0.365	31.48	10.55	4.78	14.62	410.06
3	1.15	0.31	0.66	0.447	5.44	1.92	4.10	8.46	33.67
4	4	0.78	0.46	0.643	27.24	16.79	9.88	42.48	586.50
5	2.9	0.55	0.30	0.333	36.24	8.59	4.70	15.94	565.70
6	2.5	0.29	0.43	0.144	37.80	3.90	5.72	5.97	508.67

Table 53: Instantaneous Dry Loadings

		Concentrations				Loadings			
Location	Flow cfs	Nitrate mg/l	Ammonia mg/l	TP as P mg/l	TSS mg/l	Nitrate lb/day	Ammonia lb/day	TP as Phosphate lb/day	TSS lb/day
1	0.66	4.52	0.072	0.055	5.63	16.03	0.26	0.60	19.98
2	0.60	4.13	0.079	0.000	3.76	13.27	0.25	0.00	12.08
4	0.36	2.3	0.145	0.055	5.42	4.40	0.28	0.33	10.38
5	0.26	3.36	0.082	0.023	4.40	4.62	0.11	0.09	6.05
6	0.50	1.57	0.132	0.037	2.38	4.23	0.35	0.30	6.41

Appendix O: WTM Default Values

Table 54: WTM Total Suspended Solids Pollutant Concentrations

Land Use	Concentration (mg/L)
Residential	100
Commercial	75
Roadway	150
Industrial	120

Table 55: WTM Total Nitrogen Pollutant Concentrations

Land Use	Concentration (mg/L)
Residential	2.2
Commercial	2.0
Roadway	3.0
Industrial	2.5

Table 56: WTM Total Phosphorous Pollutant Concentrations

Land Use	Concentration (mg/L)
Residential	0.4
Commercial	0.2
Roadway	0.5
Industrial	0.4

Table 57: WTM Bacteria Pollutant Concentrations

Land Use	Concentration (MPN/100mL)
Residential	20,000
Commercial	20,000
Roadway	20,000
Industrial	20,000

Table 58: WTM Unit Loads for Forest and Rural Land Use

Land Use by Pollutant							
Forest				Rural			
TSS (lbs/acre/year)	TP (lbs/acre/year)	TN (lbs/acre/year)	Bacteria (billion/ acre/year)	TSS (lbs/acre/year)	TP (lbs/acre/year)	TN (lbs/acre/year)	Bacteria (billion/ acre/year)
100	0.2	2.0	12	100	0.75	5.0	39

Appendix P: Curve Number Calculations

Table 59: Curve Numbers and Additional Land Use Information

Land Use	CN*				Additional Info
	A	B	C	D	
Cemetery	49	69	79	84	Open Space: Fair condition (grass cover 50% to 75%)
Commercial	89	92	94	95	85% Impervious
Cropland	39	61	74	80	Open Space: Good condition (grass cover > 75%)
Forest	30	55	70	77	Woods: Good condition
Forested Wetland	98	98	98	98	According to Emaruchi et. al, 1997 Assuming fully saturated conditions
Golf Course	49	69	79	84	Open Space Fair condition (same as cemetery)
Industrial	81	88	91	93	
Very LD Res	46	65	77	82	2acre
LD Res	51	68	79	84	1acre
MD Res	57	72	81	86	1/3
Multi-fam Res	61	75	83	87	¼ acre
Non-forested wetland	98	98	98	98	According to Emaruchi et. al, 1997 Assuming fully saturated conditions
Open land	49	69	79	84	Open Space: Fair condition (grass cover 50% to 75%) same as cemetery and golf course
Pasture	49	69	79	84	Pasture: fair condition
Powerline/ Utility	68	79	86	89	Open Space: Poor condition (grass cover<50%)
Transportation	76	85	89	91	Imp areas: streets and roads: gravel
Urban Public/Institutional	89	92	94	95	Urban districts: Commercial and business
Water	98	98	98	98	

* CN obtained from NRCS TR-55 report

Table 60: Area 5 CN

Land Use	Area of A soils (acres)	Area of B soils (acres)	Area of C soils (acres)	Total	A CN	B CN	C CN	D CN	Sum CNs
Cropland	0.24	0	11.28	11.52	39	61	74	80	843.9
Forest	2.66	0.85	17.99	21.50	30	55	70	77	1385.9
Low Density Residential	0.85	0.29	15.89	17.04	51	68	79	84	1318.9
Medium Density Residential	0	0	0.11	0.11	57	72	81	86	8.8
Non-Forested Wetland	0	0	1.26	1.26	98	98	98	98	123.1
Pasture	0	0	2.24	2.24	49	69	79	84	176.7
Very Low Density Residential	0	0.02	4.56	4.57	46	65	77	82	352.0
Water	0	0	0.35	0.35	98	98	98	98	34.1
Total	3.75	1.16	53.67	58.58					
% soil	6.4%	2.0%	91.6%	100.0%			**Area 5 CN=**		**72.4**

Table 61: Area 6 CN

Row Labels	Area of C soils (acres)	Area of D soils (acres)	Total	A CN	B CN	C CN	D CN	Sum CNs
Commercial	0.52	0	0.52	89	92	94	95	49.0
Cropland	2.66	0.35	3.01	39	61	74	80	224.8
Forest	34.29	2.82	37.11	30	55	70	77	2617.3
Forested Wetland	4.49	2.54	7.03	98	98	98	98	689.0
Golf Course	11.99	0	11.99	49	69	79	84	947.0
Low Density Residential	2.28	0	2.28	51	68	79	84	180.4
Non-Forested Wetland	0.27	1.52	1.80	98	98	98	98	176.1
Open Land	0.83	0	0.83	49	69	79	84	65.3
Pasture	1.48	0	1.48	49	69	79	84	116.7
Very Low Density Residential	14.43	0	14.43	46	65	77	82	1111.4
Total	73.24	7.23	80.48					
% Soil	91%	9%	100.0%			**Area 6 CN=**		**76.8**

West Boylston Subbasin Stormwater Management

Proposal

10/13/2011

Worcester Polytechnic Institute
Lucas Smith-Horn
Chris Stanton
David Warfel

1.0 Introduction

Although traditional stormwater conveyance systems provide an efficient means of preventing flooding and transporting runoff away from developed sites, they often disrupt the hydrologic cycle and pose long-term threats to managing stormwater. Conveying stormwater solely through underground conduits inhibits groundwater recharge while increasing runoff velocities, volumes, and discharge rates. These combined factors may lead to various adverse impacts such as erosion, flooding, and degradation of water quality (EPA, 2000). The result of such consequences creates risk to ecosystems, public health, and economic costs.

Low Impact Development (LID) principles, applied in conjunction with stormwater Best Management Practices (BMP's), have proven to be sustainable alternatives to conventional stormwater systems. The use of LID principles with BMPs helps to control stormwater at the source, along with a goal of maintaining or replicating pre-development hydrologic site conditions. LID principles also offer economic benefits in the form of cost savings for initial construction and long-term maintenance (EPA, 2000). Structural BMPs designed with LID principles, such as rain gardens, green roofs, and porous pavement, help recycle water and filtered pollutants before they enter surface water bodies and public water supplies.

One major goal of stormwater BMP's is to improve water quality of large water resources for a population. The Quabbin and Wachusett reservoirs supply water for more than two million people in the metropolitan Boston area and are thus some of the most significant water resources in New England (DCR, 2008). The Department of Conservation and Recreation (DCR) and the Massachusetts Water Resource Authority (MWRA) regularly monitor the water quality in the reservoir watersheds and implement solutions to combat threats to water quality. Unfortunately, stormwater runoff from residential and commercial sites throughout the Wachusett watershed continues to flow untreated into the streams and rivers that lead into the reservoir. One area of particular concern is the West Boylston subbasin and the brook that flows through it. The water quality of the West Boylston Brook is one of the poorest in the watershed with pollutants such as bacteria and excess nutrients being the greatest concerns. This subbasin also has one of the highest percentages of impervious area in the watershed and possesses an aged stormwater infrastructure that poses potential threats to the brook unless improvements can be implemented.

As stormwater regulations increase and the drainage systems of the towns neighboring the reservoir begin to age, the importance of sustainable stormwater management will become an indisputable necessity in order for the Wachusett Reservoir to maintain acceptable water quality standards. While many subbasins are too small to have a noticeable impact on the quality of the reservoir, it is important to implement stormwater solutions in subbasins that do have water quality concerns, so the number of problems in the watershed does not increase.

The goal of this project is to develop an integrated stormwater management plan which can be implemented within the West Boylston subbasin by the DCR to improve the overall quality of stormwater discharge in West Boylston Brook. First, research will be conducted on the Wachusett Reservoir, West Boylston Brook, and other relevant topics such as BMPs, stormwater quality, and past case studies. By combining research, field observations, GIS software, sampling and analyses, and computer modeling, areas of concern will be determined which should be addressed by the implementation of BMPs. Next, stormwater BMPs which are suitable to the site(s) will be designed to decrease pollutant loading, and use a computer model to predict the effectiveness of the BMPs.

The results of this project will be presented to the DCR with intent that the new stormwater management plan will be implemented in the West Boylston Brook Subbasin. The project will not be continued beyond the planning and design stages by the team, but the designs and recommendations will hopefully be successful as predicted by the report and projected by the computer model. While this new plan will only improve the West Boylston Brook; a small subbasin compared to the much large watershed it is contained in, DCR hopes the methodology of this project can be replicated for use with other subbasins in the Wachusett Reservoir watershed. Through this, the project can indirectly extend to improving the water quality of the whole watershed in future research, projects, and designs.

1.1 Capstone Design Statement

In order to meet the capstone requirement of this project, an integrated stormwater management plan will be designed for the West Boylston subbasin. The development of this design will include site assessments, development of a sampling plan, followed by sampling at different locations, and development of a model for existing and future conditions. The design may include various structural BMP’s at different locations, along with programs and controls which can be used to educate the residents and stop pollution at the source. The model will be used to help estimate the effectiveness of different BMP’s at various locations by quantifying important data.

This project takes realistic constraints into consideration by addressing economic, environmental, sustainability, manufacturability, health, and safety issues. For instance, a BMP design will have to be economically feasible; while there are many effective large scale BMP’s, some are very expensive. As a result, cost-benefit ratios will be an important consideration. Also, a stormwater plan is meant to help the environment and be sustainable by improving water quality, which will also improve the overall health and safety of the Wachusett reservoir, while not adversely affecting any species or their habitats. Therefore, any water quality improvement that has a negative impact on species will not be considered. A structural BMP design will also take manufacturing constraints into consideration by having a design with a minimal amount of materials and maintenance.

2.0 Background

The purpose of this background chapter is to achieve a greater understanding of the key topics of this project and to highlight the research that was done in order to develop the methodology. First, the water quality concerns of stormwater will be discussed followed by an examination of the characteristics and significance of both the Wachusett Reservoir and the West Boylston subbasin. The background chapter will conclude with an assessment the considerations necessary when selecting and designing BMPs, followed by a review of water quality models. The process of investigating these topics and summarizing them in the chapter will be crucial in enhancing the project team's understanding of how to continue the progression of the project.

2.1 Stormwater Quality Concerns

Water quality is a generalized term for the overall measurement of water's characteristics. Quality is a comparable attribute which can be determined by meeting pre-set standards. Because water has physical, chemical, and biological properties, the quality of a water sample cannot be determined through one method. For example, drinking water cannot be determined clean just because it has a clear appearance. There could be pathogens in the water which are not apparent by simply looking at the water. Therefore, water is tested through various methods and then compared to standards to determine the quality of the water (USGS, 2001).

Natural and human processes cause substances to be released into water and impair quality. Through natural processes, water flows in soil, over rocks, and through other vegetation on the ground. Nutrients, sand, and other debris can flow with the water affecting its overall quality. These natural substances will not normally be harmful to animal and human health, but too much of certain nutrients can have negative impacts. Human activity causes many pollutants to affect the quality of surface and ground waters (USGS, 2001).

2.1.1 Point vs. Non-point Sources

Pollutants can reach water through point and non-point sources. A point source is a direct discharge from an industry or wastewater plant which directly inputs its waste into the water system. Point sources are regulated by permits and have specific discharge limits by flow and concentration. Non-point sources (NPS) differ in they are the runoff from rainfall or snowmelt as it flows over developed areas and discharges into surface and ground waters at any point instead of one specific location. Stormwater is an NPS which can pick up many different types of pollutants (EPA, 2003).

2.1.2 Agricultural Quality Concerns

Agriculture is considered to be the largest NPS contributor of pollution to lakes and rivers. Loose soil is picked up by rain runoff and deposits sediment into the natural water system causing an increase in turbidity. Fertilizers that are over applied or applied right before a storm are washed away causing increase nutrient loads of nitrogen, phosphorus, and potassium. High nutrient loads support the growth of algae blooms and can have negative health impacts at high concentrations. In addition, livestock waste can enter runoff and carry bacteria and viruses into surface and ground waters. Finally, pesticides that are applied to plants are also picked up by stormwater and can contaminate wildlife. All these sources of pollution are commonly used in agricultural practices and can severely affect the water quality of stormwater runoff (EPA, 2005).

2.1.3 Residential and Commercial Quality Concerns

Residential and commercial areas also contribute to low stormwater quality. These urbanized areas have more impervious surface which causes rainwater to not flow into the ground, but instead flow over these nonporous surfaces until it enters a stormwater sewer system or enters a porous surface. As the water flows over the impervious area, the stormwater can pick up any of the following pollutants: sediments, oils, pesticides, bacteria, nutrients, and heavy metals. Most stormwater sewers will eventually discharge into a natural environment where the water will flow into surface waters or infiltrate into ground water (EPA, 2010).

The quality of stormwater does not have to be nearly as high as the quality of drinking water, but stormwater runs into streams, rivers, lakes, and groundwater. This water will most likely end up flowing into a body of water which will be used for recreation or even as a drinking water source. Therefore, the quality of stormwater should be good enough so that it does not negatively impact wildlife, natural vegetation, or human health.

2.2 Wachusett Reservoir and the West Boylston Subbasin

The area of particular concern for this project is the West Boylston subbasin, which is located in the Wachusett Reservoir basin. The purpose of this background chapter is to provide the reader with an understanding of the characteristics and significance of both the Wachusett Reservoir and the West Boylston subbasin. The first section describes the reservoir's role as a component of metropolitan Boston's water supply and reveals the various land uses within its area. The next and final section of the background is on the water quality concerns and land use characteristics of the West Boylston subbasin.

2.2.1 Wachusett Reservoir

As shown in Figure 1, the Wachusett Reservoir is the last in a series of reservoirs that provides drinking water for the city of Boston and its surrounding metropolitan communities. Water from the Quabbin Reservoir, the Ware River Watershed, and connecting tributaries is fed into the Wachusett Reservoir where it is piped to Boston for treatment and distribution (DCR, 2008).

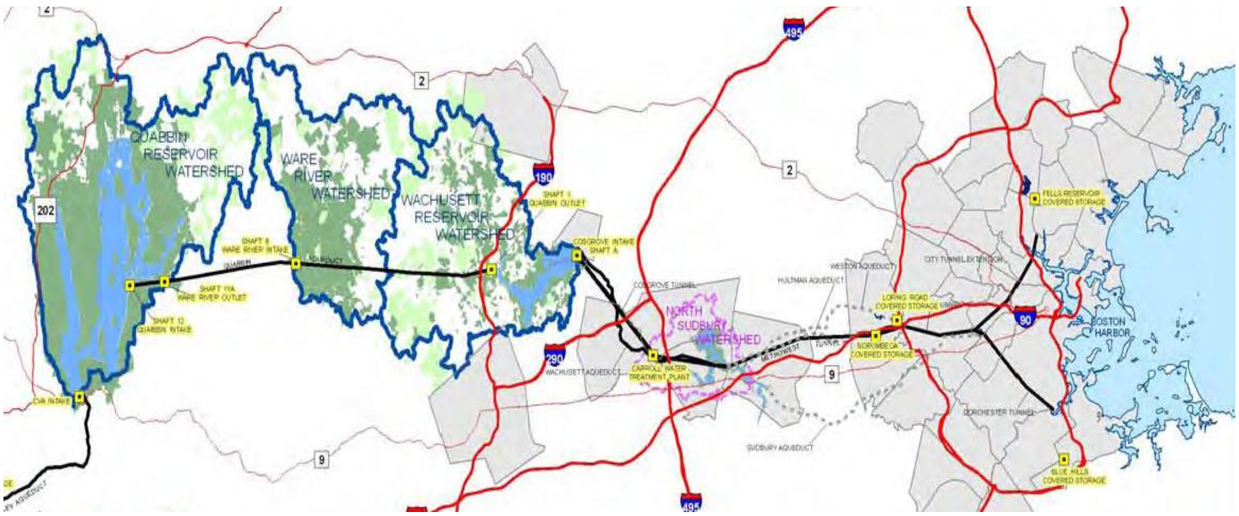


Figure 47: Map of Boston's Water Supply

Protection of the watershed is a priority because the first line of defense in delivering clean water is maintaining clean water at the source. Most drinking water treatment systems are required to filter and disinfect their water. However, Boston does not have to filter its water because of a lawsuit in 2000 in which a judge declared that the protection and treatment of water was sufficient to satisfy the Safe Water Drinking Act. In the case, the judge noted that the high water quality at the source and strict protection plan were more than enough to overcome the need for filtration (MWRA, 2000). Therefore, it is important for the Wachusett Reservoir to maintain its excellent water quality.

The watershed covers over 74,000 acres of land with just over 4,000 of that containing the reservoir itself. Table 1 shows the land use data from 1999; this is the most recent summary available for the whole reservoir. However, in the past twelve years, it is estimated that data for commercial/industrial and agricultural land has stayed the same or decreased. The largest change in land use is estimated to increase in residential use, because populations in the watershed communities have increased overall (DCR, 2008). DCR has protected development as much as possible by buying unused land and promoting undeveloped land through tax breaks. Combining that land with land controlled by other conservation groups, accounts for 44.5% of protected watershed land (DCR, 2008).

Table 62: Percent Land Use 1999 (DCR, 2008; DCR 2007)

	Forest and Open	Residential	Agricultural	Commercial/ Industrial	Wetland and Open Water
Watershed	75.1	13.4	5.2	0.7	3.3
West Boylston Brook	35.0	44.0	11.0	5.0	7.0

Figure 2 shows a map of the Wachusett watershed boundary and the surrounding towns.

Figure 48: Wachusett Reservoir Watershed

2.2.2 West Boylston Brook

Within the Wachusett Watershed, 57 subbasins encompass areas over eleven towns (DCR, 2008). The West Boylston Brook subbasin is located on the southwest side of the reservoir and is focused around the brook, which the basin is named after. The main difference between this subbasin and the watershed overall is the land use. As shown in Table 1, there is significantly more residential, agricultural, and commercial land by percent. This subbasin has more residential land than any other subbasin in the Reservoir Sanitary District. The data suggests that there is a lot of agriculture; however, DCR has noted that of the six sites that contributed to this data in 1999, only one remains in operation and it does not house any livestock or animals (DCR, 2007). A map of the subbasin is shown in Figure 3.

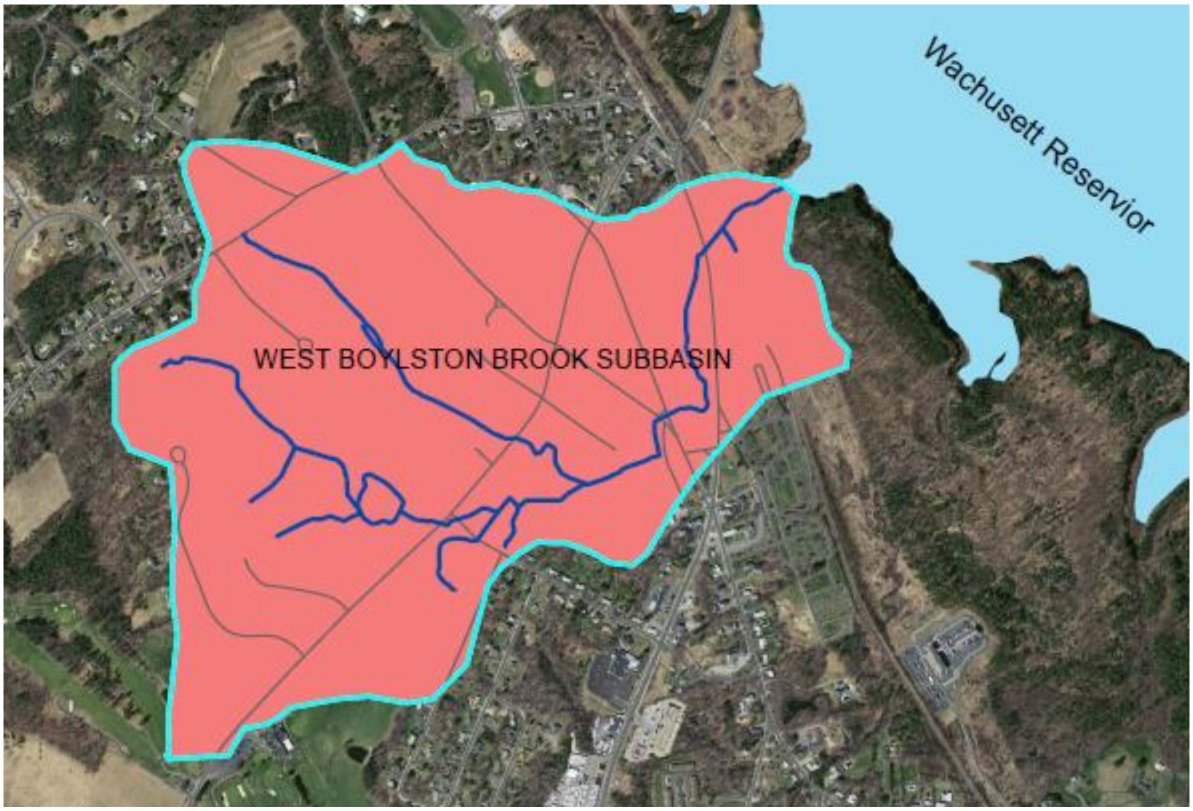


Figure 49: Map of West Boylston subbasin

Historically, West Boylston Brook has had the worst water quality in the district and at one point had the worst fecal bacteria samples in the watershed. From 1991 to 1996, the brook exceeded the fecal coliform limit of 20 colonies per 100mL for more than 80% of all samples taken. Levels began to decrease leading up to 2003; which coincided with the installation of a public sewer system. It was thought that this would reduce the coliform levels as less septic systems would be used. Despite these improvements, this did not help, as coliform levels have continued to rise since then. In 2006, the median sample was 70 colonies per 100mL with 74% of samples exceeding the limit set by the Surface Water Quality Standard. Nutrient levels for nitrate-nitrogen have also been high with phosphorous levels being fairly low compared to the rest of the district (DCR, 2007).

Starting in 2008, measurements assessments for bacteria were accomplished by measuring for E. Coli coliform instead of fecal bacteria. This was done to follow the new standards for the Surface Water Treatment Rule. Under this change the E. Coli coliform geometric mean should not exceed 126 colonies per 100mL. Also, the count should not occasionally exceed 235 colonies per 100mL; if it does, then the tributary is put on a watch list (DCR, 2008). Table 2 shows the E. Coli means from 2008 to 2010 and the percentage of samples over 235 colonies per 100mL. The brook does not cross the geometric mean of 126, but it does occasionally have sample greater than 235 colonies per 100mL. Therefore, West Boylston Brook still has poor bacteria water quality which should be addressed.

Table 63: West Boylston Brook E. Coli Samples from 2008 to 2010

Year	Geometric Mean Colonies per 100mL	Percent > 235 Colonies per 100mL
2008	73	27
2009	50	19
2010	107	24

The impact of stormwater is considered a major concern for West Boylston Brook. This can be shown by the 300% increase in turbidity during wet weather versus dry weather in 2006. The subbasin had 20.9% impervious land in 1999 compared to the overall 8.9% in the watershed (DCR, 2007). The high amount of impervious surface could link to the increase in turbidity pollution. Previous studies have recommended practices which would attempt to address the stormwater pollution. One idea was the suggestion of a wet pond be installed to allow pollutants to settle out; however, the project never succeeded because there was insufficient land on which to construct it (DCR, 2007). In the 2008 Watershed Protection Plan Update the report states, "Stormwater management is likely the most important program for the immediate future in the Wachusett Reservoir watershed" (DCR, 2008). This statement applies to the whole watershed, but it also has a direct relation to the West Boylston Brook.

There is low potential for growth in the subbasin because most areas that could be developed already have been. From 1997 to 2007, there were only two applications made with the DCR for the construction of new buildings, both single family homes. Under the Watershed Protection Act, any new construction or alteration must be approved by the DCR to prevent building too close to the reservoir or its tributaries. Even without a concern of growth, DCR is still watching this brook. The DCR wants to determine where contamination is occurring and treat the problem. They also want to determine if the municipal sewers are having any effect on improving the water quality. Finally, they need a solution to improve the water quality before it flows into the reservoir (DCR, 2007).

2.3 Selecting and Designing BMPs

The BMP selection process is important to determine if the BMP chosen meets stormwater standards, is the most effective in pollutant removal, and is the most cost effective. All parts of the BMP must be considered when selecting a BMP, including site suitability, design specifications, construction methods, and maintenance requirements (MassDEP, 2008).

According to the Massachusetts Stormwater Handbook, structural BMP's should be implemented after site planning, pollution prevention, and source control measure have been implemented. As a first step to the BMP selection process the following questions should be asked by the engineer (MassDEP, 2008):

How can the stormwater management system be designed to meet the standards for stormwater quantity and quality most effectively?
What are the opportunities to meet the stormwater quality standards and the stormwater recharge and peak discharge standards simultaneously?
What opportunities exist to use comprehensive site planning to minimize the need for structural controls?
Are there Critical Areas on or adjacent to the project site?
Does the project involve stormwater discharges from land uses with higher potential pollutant loads?
What are the physical site constraints?
Given the site conditions, which BMP types are most suitable?
What pollutants does this land use typically generate?
Is there an opportunity to receive the LID Site Design credits by incorporating environmentally sensitive design or low impact development techniques?
Is the future maintenance reasonable and acceptable for this type of BMP?
Has adequate access been provided for maintenance?
Is the BMP option cost-effective?
Does the stormwater discharge near or to an impaired surface water?
Are BMPs available to remove the pollutant of concern?

The next step is to determine whether a system of many BMP's or a single BMP is more feasible. This step is facilitated if site planning is done prior to BMP selection and sizing. Therefore, a BMP can be selected due to the historical data of the major pollutants that need to be treated. The planning for a site's pre- development hydrology, along with its post-development hydrology, is needed to determine the site's stormwater quantity management. The volume of stormwater based on post development conditions and percent of impervious area are a few key concepts to address when designing BMPs for stormwater management.

The site and BMP suitability are also important design criteria to determine. These criteria can eliminate many BMP's in the selection process due to physical constraints such as watershed size, depth to the water table, slopes or soil conditions. For example, if the proposed site has low permeable soils, many infiltration BMP's would be eliminated. Other important constraints may include proximity to animal habitats. Many BMP's can be dangerous to small animals, and if this is the case, LID techniques may be more useful to protect animals. Also, public acceptance can be a major constraint, because more and more BMP's are being placed on private property. As a result, many BMP's should be aesthetically pleasing to not discourage others, and education on BMP's could be beneficial. (MassDEP, 2008)

Land use is extremely important in selecting a BMP. Highly urbanized areas have higher pollutant loadings and thus must meet additional requirements. The BMP choices are also very limited because of space. This constraint eliminates many large BMP's such as extended dry detention basins. Another constraint in an urban area is the presence of underground utilities, such as water mains and sewer pipes; because they can limit the ability to properly excavate land for the BMP (MassDEP, 2008).

Maintenance requirements must be considered during the selection process. Keeping this into perspective can also narrow down certain BMP's. For example, BMP's above ground are easier and cheaper to maintain than those below ground and BMP's that utilize natural cover are cheaper than manmade alternatives. While each BMP needs its own maintenance plan, they should be designed to have the least maintenance possible while not violating the stormwater standards.

2.4 Computer Modeling

Because of the complexity of subwatershed systems through continuously varying factors, the approximation of pollutant loadings and determination of treatments and solutions can be difficult to complete. To further complicate the situation, economic feasibility must also be accounted for, since retrofit solutions are more costly than new stormwater practices (Urban Stormwater, 2007). Therefore, the solution must have proof of success before being implemented. Computer models can simplify the process by taking GIS and other data and forming a simplified characterization of the subbasin. The models then make assumptions for retrofit solutions and combine the input data with the selected BMPs to approximate the effectiveness of the solution.

There are many computer programs available for use in subbasin modeling including the STEPL model, the BASINS model, the HSP-F, the WTM, the SUSTAIN model and the SWMM5. The main differences between them are in the complexity, the governing program, the purpose and the input requirements of the model. The following sections will focus on two models of specific interest to this report: the Watershed Treatment Model (WTM) and the System for Urban Stormwater Treatment and Analysis INtegration Model (SUSTAIN).

2.4.1 Watershed Treatment Model

The WTM is a very simple computer model used in Microsoft Excel which uses generalizations to approximate pollutant loadings of fecal coliform, total phosphorus, total nitrogen, and total suspended solids from primary and secondary sources before and after implementation of BMPs. The primary pollution sources assume loadings based on the type of land use. There are a variety of secondary sources including septic systems, active construction, channel erosion, and road sanding. The model allows for multiple BMPs to be implemented in a combination. If desired, future loads can be factored into the calculations before a final loading is calculated based on the implementation of the BMPs (WTM 2002).

Because of the simplicity of the WTM model, there are some limitations to the program. The program does not account for seasonal effects or agricultural treatment processes. Also, many of the calculations are generalized to the point that there may be uncertainty in the results (WTM 2002). While the WTM may not be the most accurate of the models, it does provide a good starting point for analysis of a subbasin. Also, the assumed values in the calculations can be changed by the operator if more appropriate values are found or determined.

2.4.2 System for Urban Stormwater Treatment and Analysis INtegration Model

The SUSTAIN Model is a much more complicated model than the WTM. Using GIS as a platform, it goes beyond pollutant loadings to include BMP siting and cost analysis tools to determine the most effective and cost-efficient results. The SUSTAIN requires many GIS layer inputs but, because of the large amounts of input, the model has the capability of providing a comprehensive plan and solution to stormwater management from a single subbasin up to a whole watershed (EPA, 2011).

The main advantage of the SUSTAIN is its ability to model any area and fit cost-effective solutions into it. There is also much flexibility in how the user tailors the model to the watershed. When used properly, SUSTAIN can be a valuable asset. The complexity of the SUSTAIN is the weakness of this program. A large amount of data input is required for operations meaning the user must spend lots of time finding specific files and layers. It is also recommended that a skilled user of watershed modeling use the SUSTAIN as many of its algorithms and features have be replicated from previous models.

3.0 Methodology

The overarching goal of this project is to develop an integrated stormwater management plan that includes a set of preliminary designs for structural and non-structural stormwater Best Management Practices (BMPs). The following methods will be used to achieve this goal:

1. Refine the project scope and conduct background research on the Wachusett Reservoir, West Boylston Brook, and other relevant topics such as BMPs, stormwater quality, and past case studies.
2. Determine the areas contributing the greatest pollutant loads to the subbasin through the analysis and consideration of the following objectives. These objectives will accomplish more than just determining areas of concern as described in their respective sections
    a. Field observations of the subbasin
    b. GIS mapping of various data
    c. Sampling and testing of the brook's water quality
    d. Computer modeling of pollutant loadings.
3. Select and design a set of stormwater BMPs to improve water quality through an integrated stormwater management plan.
4. Utilize the computer model to predict the effectiveness of the management plan.

The group hopes the methodology of this project can be replicated for use with other subbasins in the Wachusett Reservoir watershed. Through this, the project can indirectly extend to improving the water quality of the whole watershed in future research, projects, and designs.

3.1 Project Scope & Background Research

Before data can be collected, the team will research and gather information on the subbasin and surrounding watershed. Through the DCR reports and data files, conferences with the DCR staff, meetings with academic advisors, and additional research, the team will develop a sound scope and understanding of the problems to be addressed. Reviewing past and current data on the brook will provide the team with a basic concept of the water quality issues. DCR's *Water Quality Report* from 2010 will greatly help the team as it outlines definitive concerns for the Wachusett Watershed and West Boylston Brook through quantitative and qualitative data. Meetings with the DCR staff will aid the team in developing specific concerns which may not be expressed in the water quality reports and provide insight into possible areas that could have high contributions of pollutant loadings. Additional research will help in the team's understanding of topics relating specifically to this report.

The team has already begun to research and conference with the DCR. The Background chapter of this proposal presents some of the initial findings, but additional research will be continued throughout the progress of the project. The tasks listed above will give the team a strong background and outline the scope of the project to support and guide the next steps of the methodology.

3.2 Identifying Areas of Concern

Locating areas of higher pollutant loading will be important to the implementation of the integrated management plan. Several tasks will be completed which when analyzed together by the team, will help determine areas of concern. First, GIS mapping software will be used to combine data layers from various sources which will provide a detailed, mapped overview of the subbasin. Next, multiple site visits will be conducted to observe the existing conditions of the brook and subbasin. Data from GIS layers and other sources will be loaded into a computer model to estimate the current pollutant loadings from the subbasin. Last, a sampling plan will be implemented to measure the water quality at various locations along the brook.

3.2.1 GIS Mapping

Using GIS software is an ideal way of storing and organizing geographic data (CWP, 2007). GIS will also allow the team to evaluate many types of data simultaneously by utilizing multiple data layers. Table 3 below lists some of the GIS data layers that will be used throughout the project as well as the significance of each in the preliminary assessment of the subbasin.

Table 64: GIS Mapping Layers

Layers	Purpose(s)	Source
Land Use	Delineate subbasin by land use	MassGIS
Topography	Topographical lines approximate the drainage profile of subbasin	USGS
Streams	West Boylston brook and its tributary are the water resources of concern	DCR
Wetlands	Important hydrologic feature	DCR
Watershed/Subbasin boundaries	Essential geographic data	DCR
Parcels	Determine land ownership and property sizes	DCR
Orthophotographs	Provides comprehensive view of area.	MassGIS

	Aerial images help quickly identify land uses	
Storm drain network	Locations of culverts, catch basins, and manholes, help determine feasible locations for retrofits	DCR
Roadways	(From Parcels) Shows streets which can be combined with land use to produce impervious area	DCR
Soils	Shows soil types throughout subbasin. Useful in determining how quickly water seeps through ground	MassGIS
Impervious Area	Photo layer showing impervious area	MassGIS

3.2.2 Field Observations

To develop an overall understanding of the subbasin, the team will perform field observations on the West Boylston Brook and the surrounding neighborhoods and roads. These observations will help accomplish the following tasks:

- Determine existing qualitative conditions of brook
- Observe stormwater drainage during storms
- Connect facts and data from reports and GIS mapping to actual subbasin

The research performed by the team will provide a good concept of the conditions of the brook. However, the reports referenced are based on past conditions. The team will visit the subbasin multiple times throughout the project to gain a visual perspective of the problem. Initially, the team will be accompanied by the DCR staff so someone experienced with the area can show the team some sites that are easily accessible to the brook. Visits after that may or may not include DCR staff. At all times, the team will be careful to avoid crossing into private property.

The group will visit as many sections of the brook as possible to get a full understanding of how the brook flows through the subbasin especially during wet weather conditions to see the flow of stormwater runoff. Site visits will also be performed during dry weather to see the difference in brook conditions as well as complete a preliminary scouting of possible BMP locations. In the brook, the team will observe the qualitative water quality, noticeable stormwater culverts which feed into the brook, and general conditions of the terrain around the brook. In the whole subbasin, the team will examine neighborhood trends, locations of catch basins, and road conditions.

3.2.3 Initial Model Run

To represent the stormwater activity of the subbasin, a computer model will be set-up and utilized under initial conditions with no BMPs implemented. Either the WTM or the SUSTAIN model will be chosen to complete this. An appropriate model will be chosen so the team can accomplish the following tasks:

- Locate areas or sites with higher pollutant contributions
- Estimate total pollutant loadings
- Provide a base for comparison with BMP implementation

The model will be chosen once more research and testing can be done on the two models being considered. The SUSTAIN Model is the more powerful and versatile of the two, but also requires a large amount of data input. This model will be evaluated to determine if it can be used for this project without extending beyond the time constraints of the project.

The group will acquire as much data as feasibly possible to run the model and to represent the conditions of the brook. The model will then use pre-determined calculations and assumptions to produce a statistical output on various aspects of the subbasin. Some of the calculation coefficients may be modified by the group if they feel they can produce a more accurate model by doing so. The output of the model may include different types of pollutant loadings, contributions based on land use, septic system contributions, etc. These outputs will be clearly defined once the model has been chosen.

With the statistical output of the pollutant loadings, it may be possible to compare this to the actual loadings calculated in previous reports from the DCR. This would provide a test for the validity of the model. However, the accuracy specific load estimates provided by the model is not considered to be critical for the purposes of this project. Rather, the relative estimates for loads from different areas within the watershed and the predicted changes resulting from the implementation of BMPs are important. Further uses of modeling will be described in later sections of the methodology.

3.2.4 Sampling Plan

Water quality data is currently only obtained by the DCR from the outfall of the West Boylston Brook near the reservoir. This data is very useful for generalizing the whole subbasin, but does not provide sufficient information to determine sources of pollutant loading. The completion of this sampling plan will accomplish the following tasks:

- Locate areas or sites with higher pollutant contributions
- Determine flows from brook throughout storm duration
- Compare water quality of dry and wet weather conditions

Three sets of six samples will be taken from the brook; one set will be during dry weather and the other two will be collected during a storm. The dry weather samples will be taken to practice the sampling technique in non-storm conditions and to have a comparison for wet weather samples. The first wet weather sample set will be taken during the first flush of the storm, within the first hour, to measure the pollutant concentrations close to their peak. The second wet weather set will be taken some undetermined time after the first set to capture data during the storm or runoff directly after the storm. A relative change in pollutants over the course of the storm will be observed from the second wet sample. The time in between samples will be determined based on the duration and intensity of the storm.

3.2.4.1 Storm Qualifications

EPA's *NPDES Storm Water Sampling Guidance Document* states that a storm must meet the following conditions for it to be considered acceptable for sampling (1992):

- The storm must accumulate at least 0.1 inches of rainwater
- The storm must be preceded by at least three full days of dry weather
- The depth of rain and the duration of the storm should not vary by more than 50% from the past year's average depth and duration based on the closest data collection station.

Because this brook does not is not required to comply with a NPDES permit and because we are only sampling twice during the storm, the third condition will not be considered in the team's selection of a storm. Instead, the team will look for a steady storm which will be predicted to produce close to or more than the average storm depth. For the month of October, the range where the team will sample, the average storm depth from the past five years is 0.77 in. Considering project time constraints, the team will attempt to sample any storm which appears to be acceptable as they would like to complete sampling and testing as soon as possible.

3.2.4.2 Sampling Locations

The team will collect samples from the following six locations as shown in Figure 4.

Location 7. DCR's Sampling Location
This location is east of Route 12/140 and northeast of the DPW parking lot. Downstream of this point contains no stormwater discharges and drains directly into the reservoir. Directly upstream is the drainage from the DPW yard.

Location 8. Culvert Entrance opposite of DPW
On the west side of Route 12/140 is a culvert running under the road toward Location 1. From here samples will be collected. Upstream, the brook turns south, while to the west is a stormwater discharge that forms a channel into the brook.

Location 9. Stormwater Discharge Culvert
Runoff from sections of Newton, Prospect, and Central streets collects into a culvert which discharges just west of Location 2. This culvert opening is Location 3 and will be the only site not to have in-brook samples. Therefore, this location will not be sampled in dry weather conditions.

Location 10. First Congregational Church
Just north of the church is a sharp downhill wooded area where the brook runs between Central Street and Route 12/140. Samples will be collected at the outfall of the culvert which runs upstream under Central Street.

Location 11. Prospect Street #1 (North)
A wetland area lies in the center of the subbasin where the brook splits into two directions, both heading west. This location will be on the west side of Prospect Street before the brook runs under the road. Upstream of this location, the brook runs northwest toward Goodale Street.

Location 12. Prospect Street #2 (South)
Right down the road from Location 5 is Location 6, the other split from the wetland. This location will also be on the west side of Prospect Street before the brook flows under the road. Upstream are Carroll's Pond and the continuation of the brook to the west.

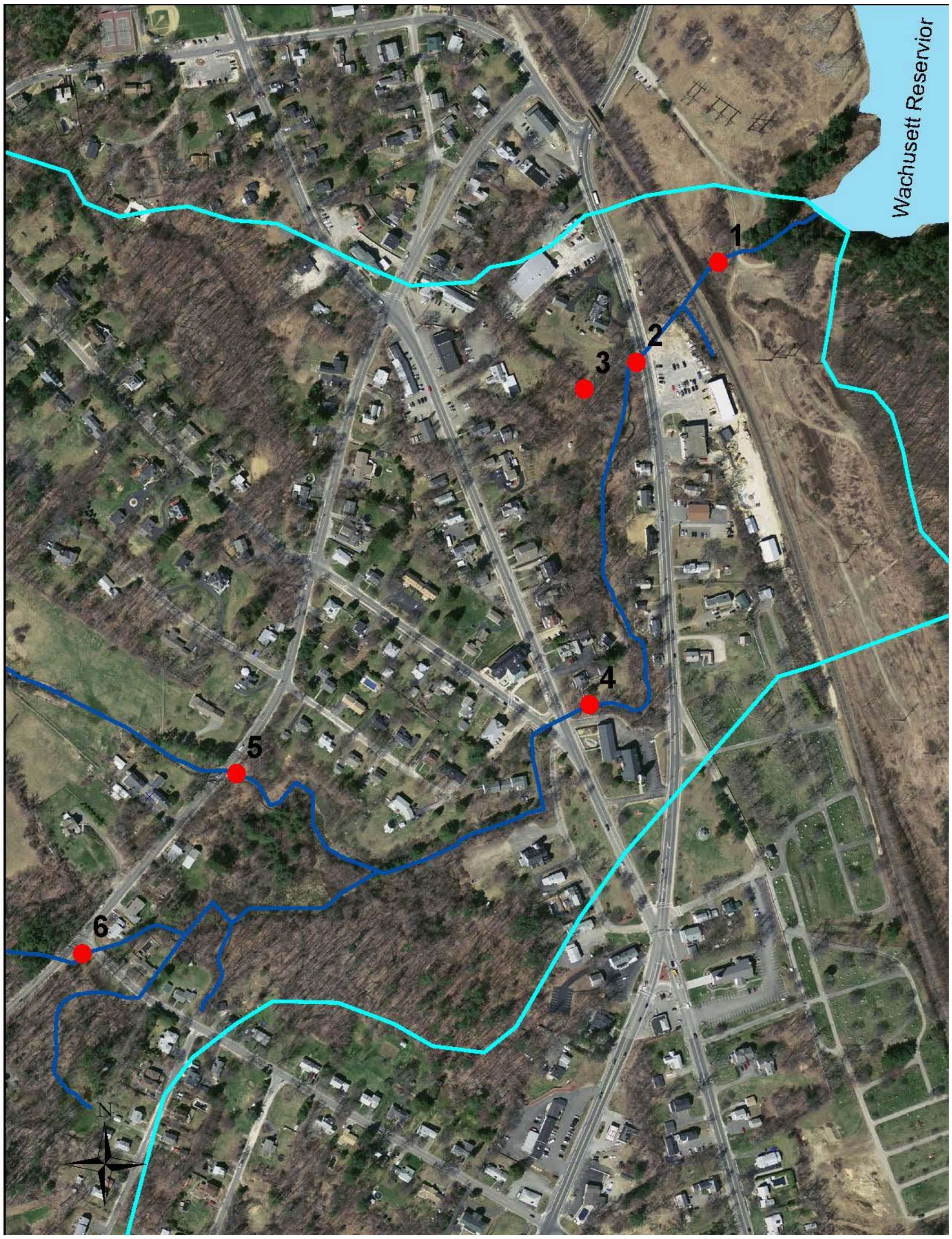


Figure 50: Sampling Locations

3.2.4.3 Sampling Procedure

The team will have all collection materials prepared ahead of time to be ready for storm sample collection. Because all sampling locations are very close to one another, the samples will be taken to replicate a snapshot of the brook concentrations during the storm. Therefore, the order of samples is not as important as obtaining them in an efficient matter.

At each location, the sample will be manually collected into plastic bottles which will be sanitized prior to sampling in the laboratory. Care will be taken not to take samples too close to the bottom of the brook or to contaminate samples once collected. The volume needed for each constituent is shown in Table 4. Additionally, the velocity of the brook will be measured using a flow meter. The flow will be calculated by using a scale on the flow meter to measure the depth and width of the brook. Samples will immediately be stored in an iced cooler to preserve the samples through transportation to the laboratory. *Standard Methods for Examination of Water and Wastewater* states the minimum holding time for some of the test the team plans to perform is 24 hours (2005). Therefore, samples will be analyzed as soon as possible following collection.

Table 65: Sample Volume Required (Standard Methods, 2005)

Constituent	Volume Required (mL)*
Coliform Bacteria	500
Anions	30
Total Suspended Solids	1000
Specific Conductance/pH	250
Turbidity	125
Total Phosphorus	60
Ammonia	60
DO	500 (glass)

*Values may vary based on testing procedure requirements

In addition to the above sampling, WPI's Hydrolab will be used at Location 1 to create a hydrograph for the storm during wet weather conditions. The Hydrolab will measure the depth at a specified time increment for the entire duration of the storm. Turbidity, pH, DO, and specific conductance will also be measured by the Hydrolab.

3.2.4.4 Testing Procedures

The team will test its samples for E. Coli coliform bacteria, nutrients, total suspended solids, specific conductance, turbidity, and Dissolved Oxygen. For the dry weather and first set of wet weather samples, all procedures will be performed. The second set of wet weather samples will not be fully analyzed to save time. For comparison, these samples will be tested for nutrients, specific conductance, and turbidity. All procedures will be performed in WPI's Environmental Engineering Laboratory unless otherwise specified. The following sections describe each procedure in detail.

Coliform Bacteria

Bacteria procedures test for coliform as they are a high indicator for the presence of bacteria. The coliform bacteria will be measured because the brook has a history of high fecal and E. Coli coliform concentrations. Sampling for coliform may reveal the source or the sources or these high concentrations. *Standard Methods* suggests using procedure 9221, Multiple Tube Fermentation, or 9222 Membrane Filtration Technique. Both require a holding time of less than six hours and overnight incubation. Because of these specifications, the DCR will send samples for coliform testing to MWRA's EPA certified lab.

Nutrients

Test(s) for nutrients will be conducted because the DCR has expressed concern in the nutrient levels of the brook. *Standard Methods* procedure 4110 for Ion Chromatography will be used to measure nutrient concentrations in the samples. The results desired from this procedure will yield concentrations of Phosphate, Nitrate, and Nitrite. The chromatography system will also yield concentrations of chloride, bromide, fluoride, and sulfate. Procedures for ammonia and total phosphorous may also be performed if time permits.

Total Suspended Solids

As a measure of the sediment loadings in the water and the overall water quality, a test for total suspended solids will be conducted. Procedure 2540D dried at 103 to 105 °C will be performed to determine total suspended solids. In this procedure, a volume of the sample is pipetted into a vacuum filter. The filter is washed with laboratory Epure water three times. Then the filter is transferred to a plate and dried in an oven for one hour. The sample is then measured for mass and the heating process is repeated until the mass does not change by more than four percent. A simple calculation is used to calculate the concentration of suspended solids. The procedure recommends repeating the process with multiple samples to ensure an accurate sample.

Turbidity, Conductance, and Dissolved Oxygen

All three of these constituents will be measured as determinants for overall water quality in all samples. A conductivity meter will be used to measure specific conductance and the output will be adjusted for the cell constant and to 25 °C as needed. Turbidity will be measured using the Hach 2100N Turbidimeter in the laboratory and dissolved oxygen (DO) will be measured using a probe in the laboratory.

3.3 Selecting Appropriate On-site BMPs

After identifying feasible non-structural improvements for prioritized areas of concern, the following criteria will be used to determine the type of structural BMP(s) best suited for the respective location: physical size, approximate cost, community impact, and pollutant removal.

3.3.1 Physical Size

The physical constraints of a site may help eliminate BMPs that are known to be incompatible with low space availability. GIS will be used to conduct a rapid assessment of physical space for the target sites. Some of the layers that will be used are the orthographic photos, roadways, topography, and storm drain network. Topographic lines will assist in determining the drainage of the site, which provides an indication for where BMPs should be implemented .It may also be necessary to conduct site visits to collect detailed information, such as the location and function of curbs, sidewalks, and other minor features that cannot be seen using the orthographic photos. Sources such as the Massachusetts Stormwater Handbook will be utilized to determine the required physical specifications of BMPs.

3.3.2 Approximate Cost

Knowing the approximate costs of preliminary solutions will help refine the selection process. Quite often, the approximate cost of implementing structural BMPs is directly correlated to physical size. One way to quickly determine the value of a BMP is to calculate the cost per cubic feet of stormwater treated. These figures are readily available in stormwater reports, such as the *Urban Subwatershed Restoration Manual Series* written by the Center for Watershed Protection in 2007. More detailed cost analysis, such as cost-benefit ratios, will be performed after this initial cost screening.

It is already apparent to the project team that space and cost are crucial factors in sizing and designing solutions for West Boylston Brook. For instance, DCR has made it clear that large and expensive BMPs will not be feasible to implement given budget constraints and apparent space limitations. Therefore, the two criteria will be reviewed early on in the selection process.

3.3.3 Community Impact

Assessing the impacts of stormwater retrofits on the surrounding community is essential to the long-term success of any proposed solutions. Some of the common concerns that arise when retrofits are proposed are mosquitoes, construction issues, BMP appearance, and maintenance (Urban Stormwater, 2007). The DCR will also prove to be very helpful in assessing community impact since they have a lot of experience dealing with such issues. GIS can also be used with this criterion. Assessing the sites surrounding the proposed on-site BMP will help determine what effect it may have on neighboring residents and businesses.

3.3.4 Pollutant Removal

The last criterion, pollutant removal, is important in the selection process because understanding the treatment benefits of particular BMPs aligns directly with the project goal of improving the stormwater runoff quality entering West Boylston Brook. The Watershed Treatment Model (WTM) will assist in the selection process by providing a rapid quantitative assessment of the treatment effectiveness of BMPs that are physically suited for the site. There exists a plentiful amount of reports on the proven effectiveness of BMPs in particular situations. Further research of such reports will be helpful in expediting the BMP selection process. The team plans to use *Manual 3: Urban Stormwater Retrofit Practices*, which is one of many insightful manuals in the Urban Subwatershed Restoration Manual Series written by the Center for Watershed Protection in 2007. Table 5 summarizes what will be used to analyze the different criteria.

Table 66: BMP Selection Criteria

BMP Selection Criteria	GIS	WTM	Background Research	Site Visits
Physical Size	X		X	X
Approximate Cost			X	
Community Impact	X		X	
Pollutant Removal		X	X	

A weighting system is currently being considered as a method of determining the value of each criterion. A possible method of weighing criteria is to arbitrarily assign points to each based on relative importance. The relative importance of each criteria may differ depending on the audience so in addition to the project team, DCR will also be asked to assign their own weight values to respective criteria impact.

3.4 Model BMP Performance

With the BMPs selected and designed, the performance will be modeled using the same computer model from the initial run. The model will produce a combined result of the overall impact from implementing the entire plan. The model will once again use predetermined calculations to determine the change in pollutant loadings as a result of implementing the integrated plan. The accuracy of the reduction is unknown since the model is making many assumptions; but with a noticeable decreases output from the model, the team expects that a noticeable change can also be observed in the field. The team hopes the BMPs will improve water quality overall by decreasing nutrient, bacteria, and sediment loadings from stormwater runoff and therefore provide a tributary of cleaner water flowing into the Wachusett Reservoir.

Unfortunately, this project will not permit time for construction and testing of BMP performance. The model will serve as the only measure of prediction in this report. The team hopes that the BMPs designed will be successfully implemented and produce a noticeable change in the water quality of the West Boylston Brook

3.5 Project Timeline

Figure 5 displays the timeline for various tasks to be performed throughout the next nine weeks. The collection of water samples spans about a week for both dry and wet weather, but this is simply a time range for collection based on the weather. Lab testing will occur the day after any sample is collected. Writing will occur throughout, starting with revisions and additions being made to the Introduction, Background, and Methodology chapters. As results are produced, sections will be written in those topics. All data collection and writing of the Results chapter should be completed by Thanksgiving break. This will allow the focus of after break to be on revisions and the writing of the Conclusions and Recommendations Chapter. The goal is to have all final deliverables completed by December 12th; this includes the written report, project poster, and presentation for the DCR.

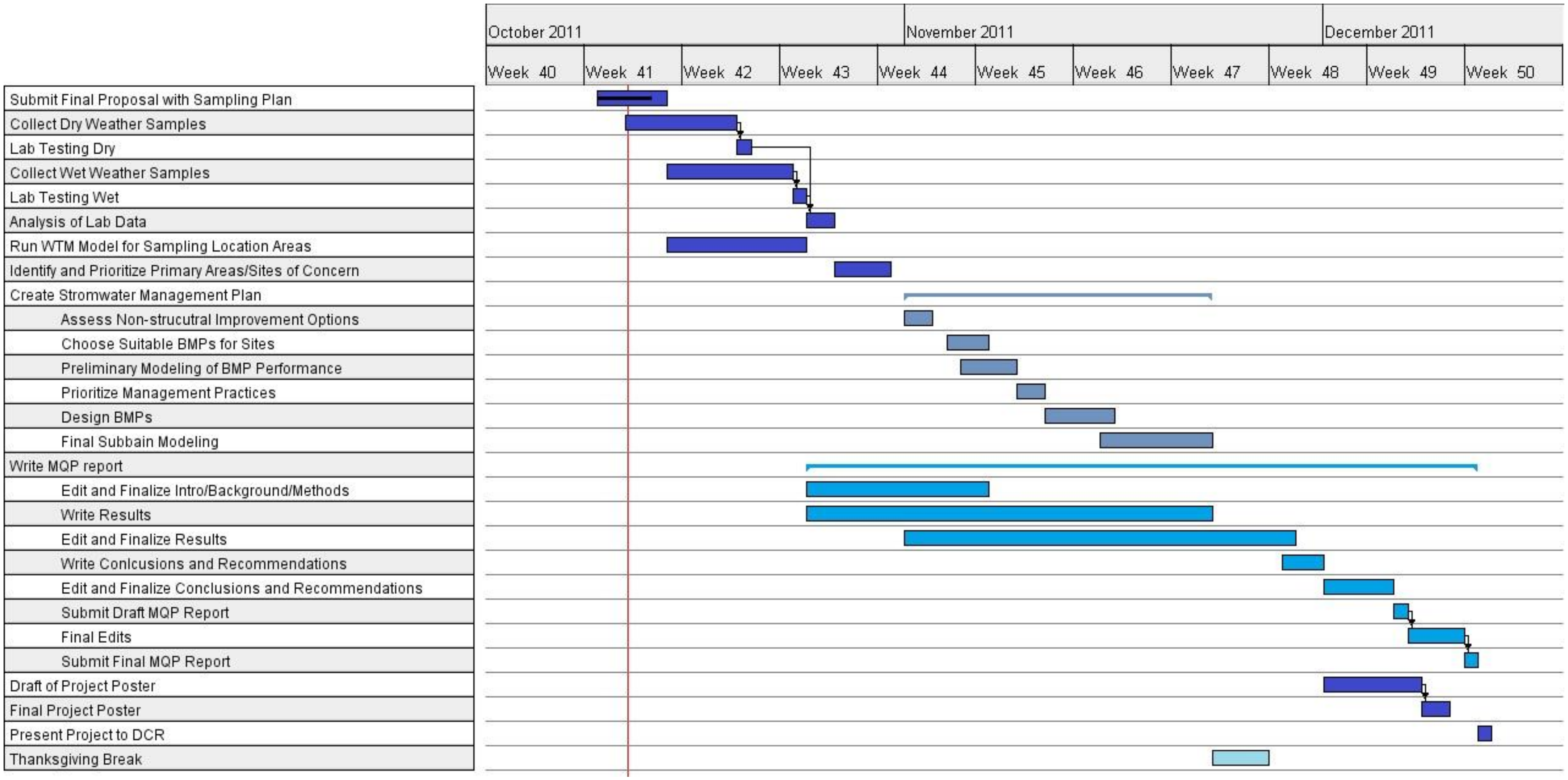


Figure 51: Gantt Chart of Project Timeline

References

Center for Watershed Protection. (2002). *The Watershed Treatment Model.* Ellicott City, MD.

Center for Watershed Protection. (2007). *Urban Stormwater Retrofit Practices.* Ellicott City, MD.

Charles River Watershed Association (CRWA).*Low Impact Best Management Practice (BMP) Information Sheet: Gravel Wetland.*

EPA vs. MWRA on the Best Course Forward for MWRA's Drinking Water Program, 2000.

LakeSuperiorStreams. (2010). *LakeSuperiorStreams: Parking Lot Filter Strips* . Retrieved September, 19, 2011, from http://www.lakesuperiorstreams.org/stormwater/toolkit/filterstrips.html

Massachusetts Department of Conservaction and Recreation (DCR). (2011) *Water Quality Report: 2010 Wachusett Reservoir and Watershed.*

Massachusetts Department of Conservaction and Recreation (DCR). (2003). *Enivronmental Quality Assessment: Reservoir District.*

Massachusetts Department of Conservaction and Recreation (DCR). (2007). *Enivornmental Quality Assessment Report: Reservoir District Redux.*

Massachusetts Department of Conservaction and Recreation (DCR). (2008). *2008 Watershed Protection Plan Update, Wachusett Reservoir Watershed.* Volume IIC.

Massachusetts Department of Conservation and Recreation (DCR) and the Ipswich River Watershed Association (IPWA). (2005). *Ipswich River Targeted Watershed Grant Fact Sheet: Three Low-Impact Development Case Studies*

Massachusetts Department of Environmental Protection (MassDEP). (1997). *Stormwater Management: Volume Two Stormwater Technical Handbook.*

Massachusetts Department of Environmental Protection (MassDEP). (2008). *Volume 2 Chapter 2: Structural BMP Specifications for the Massachussetts Stormwater Handbook.* Retrieved from http://www.mass.gov/dep/water/laws/v2c2.pdf.

Standard Methods for the Examination of Water & Wastewater (2005). In Eaton A. D., Clesceri L. S., Rice E. W. and Greenberg A. E. (Eds.), (21st ed.). Washington, DC: American Public Health Association.

United States Environmental Protection Agency (EPA). (1992). *NPDES Storm Water Sampling Guidance Document.* No. 833-B-92-001).EPA.

United States Environmental Protection Agency (EPA). (1999). *Storm Water Technology Fact Sheet: Infiltration Trench.*

United States Environmental Protection Agency (EPA). (2003). *Protecting Water Quality from Urban Runoff.* Retrieved September, 15, 2011, from http://www.epa.gov/owow_keep/NPS/urban_facts.html.

United States Environmental Protection Agency (EPA). (2005). *Protecting Water Quality from Agricultural Runoff.* Retrieved September, 15, 2011, from http://www.epa.gov/owow/NPS/Ag_Runoff_Fact_Sheet.pdf .

United States Environmental Protection Agency (EPA). (2006). *Menu of BMPs: Bioretention (Rain Gardens).* Retrieved from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=72.

United States Environmental Protection Agency (EPA). (2008). Retrieved December, 02, 2008, from http://cfpub.epa.gov/npdes/stormwater/swbasicinfo.cfm.

United States Environmental Protection Agency (EPA). (2011). *SUSTAIN, System for Urban Stromwater Treatment and Analysis INtegration Model.* Retrieved October, 9, 2011, from http://www.epa.gov/nrmrl/wswrd/wq/models/sustain/.

United States Geological Survey. (2001). *A Primer on Water Quality.* Retrieved September, 14, 2011, from http://pubs.usgs.gov/fs/fs-027-01/.

Virginia DCR. (2011). *Virginia DCR Stormwater Design Specification No. 3: Grass Channels.* Retrieved from http://vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_3_GRASS_CHANNELS_Final_Draft_v1-8_04132010.htm.