PPM-MQP-1673

Designing a Constructed Wetland to Improve Water Quality in Framingham, MA

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

Sponsor: Town of Framingham

Faculty Advisor: Paul Mathisen

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Submitted by:
Cara Bereznai
Anna Franciosa
Kathryn Murphy
Jacqueline Tedesco

This report represents the work of four WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on its website without editorial or peer review. For more information about the projects program at WPI, please see http://www.wpi.edu/acdemics/projects.

Abstract

For this project, we collaborated with the Town of Framingham to reduce the impacts of urbanization and stormwater runoff on the water quality of Farm Pond and its surrounding waterbodies. We completed a field investigation and designed a Best Management Practice to address the impacts of stormwater from the Cushing Memorial Park (CMP) stream, which may contribute to Farm Pond's water quality impairments. Our recommendations included a design for a constructed wetland that would improve water quality while simultaneously providing an educational focal point for the community to enjoy.

Capstone Design Requirement

Worcester Polytechnic Institute's Civil and Environmental Engineering Department requires that all Major Qualifying Projects contain a capstone design component. This MQP met the capstone design requirement by designing a Best Management Practice (BMP) for the Cushing Memorial Park stream in Framingham, Massachusetts to improve the downstream water quality of Eames Brook and/or Farm Pond. The design approach included water quality sampling, stormwater runoff estimation, selection of the BMP, and the determination of the dimensions and components of the BMP. The design encompasses economic, environmental, sustainability, constructability, ethical, health and safety, and social and political considerations.

Economic: The proposed BMP needed to be cost-effective for the Town of Framingham. This included quantifying installation and maintenance costs.

Environmental: The overall focus of the project was to design a BMP that would improve the water quality of Eames Brook and/or Farm Pond. Improving surface water quality is important for environmental quality to be maintained in an urban watershed.

Sustainability: The selected BMP design was sustainable for the site location in terms of removal efficiency, life span, and affordability.

Constructability: The proposed BMP was designed with consideration given to the practicality of the ease of installation, operation, and any continued maintenance needed.

Ethical: Improving and maintaining the water quality around Farm Pond was important due to its location in an environmental justice community.

Health and Safety: This project has the potential to minimize human impacts from nonpoint source pollution on the surrounding environment. This would ensure that environmental degradation does not occur and that the health and safety of all people, animals, and plants continues to be maintained.

Social and Political: The Massachusetts Department of Environmental Protection has implemented programs to ensure that surface water quality is improved. Additionally, the Town of Framingham is looking for opportunities to bring more awareness about green infrastructure through the implementation of capital improvement projects involving BMPs.

Professional Licensure

Professional licensure is used to ensure that engineers are competent in their fields. Licensure is important to engineers to demonstrate that they have a minimum level of education and experience, which is an indicator of their integrity, dedication, and creativity (NSPE, 2017). Becoming a professional engineer allows the engineer to prepare, sign and seal, and submit engineering plans and drawings for public and private clients. Additionally, many states have requirements for jobs with higher level of responsibility to be filled only by licensed professional engineers (NSPE, 2017). Because public health, safety, and welfare are priorities on many projects, licensure can provide justification to the engineer and their firm's experience and capabilities.

In the Commonwealth of Massachusetts, before one can register as a Professional Engineer, he or she must have taken and passed the National Council of Examiners for Engineering and Surveying (NCEES) sanctioned Fundamentals of Engineering (FE) Exam unless the engineer had at least 20 years of prior engineering experience (Commonwealth, 2017a). Upon successful completion of the FE Exam, the licensing board will issue an Engineer-In-Training certificate to the applicant. After gaining at least 4 years of engineering experiences for applicants with an ABET-accredited Bachelor of Science degree in Engineering or 3 years of experience for applicants with a Master's Degree in Engineering, one can take the Professional Engineering exam. Registration as a Professional Engineer also upholds the engineer to standards of professional conduct to be followed while performing their duties (Commonwealth, 2017a). To maintain licensure in Massachusetts, registration must be renewed before it expires. Although not required in Massachusetts, continuing education hours may need to be completed in order to keep their licensure up-to-date. Additionally, professional engineering licenses can be obtained in multiple states if the registration requirements are met for each board.

Acknowledgements

This Major Qualifying Project would not have been possible without the support and guidance from many individuals. We would like to thank the following people:

- Our project sponsor, the Town of Framingham, for providing us with the opportunity to study the impacts on Farm Pond and gain practical field experience.
- Our Framingham contacts, James Barsanti (Assistant Director of Engineering) and Kerry Reed (Senior Stormwater & Environmental Engineer), for their continued guidance and support throughout our project.
- Our project advisor, Professor Paul Mathisen, for continually meeting with and guiding us throughout our project.
- WPI’s Civil and Environmental Engineering Laboratory Manager, Donald Pellegrino, for his assistance and knowledge of each laboratory test.

Authorship

Throughout the duration of this project, each team member took responsibility for different objectives and tasks. These are outlined below. Editing of the report was a collaborative effort amongst all group members.

- Kathryn Murphy oversaw the laboratory and sampling procedures and significantly contributed to written report sections involving Objective 1.
- Anna Franciosa oversaw modeling using HydroCAD and significantly contributed to written report sections involving Objective 1.
- Cara Bereznai oversaw work using ArcMap Geographic Information System and significantly contributed to written report sections involving Objective 2.
- Jacqueline Tedesco oversaw the BMP design specifications and significantly contributed to written report sections involving Objective 3.

Executive Summary

Background

As the largest town in Massachusetts, Framingham recognizes the importance of protecting water quality in its ponds and rivers. One of the areas that Framingham has been focusing on is the Farm Pond subbasin. Over the years, a rise in population density has resulted in a 30% increase of impervious surfaces in Farm Pond's drainage area, which increases the amount of stormwater runoff. This rapid growth has led to poor water quality issues for Farm Pond. It was listed as a Category 5 waterbody by the Massachusetts Department of Environmental Protection, which means that it is impaired for excess algal growth and high turbidity. According to Framingham's Stormwater Master Plan, stormwater runoff is one of the largest pollutant contributors to Farm Pond and its inability to meet water quality standards (S E A Consultants, 2008).

A town initiative has been established to reduce sediment and nutrient loadings into Farm Pond by using stormwater Best Management Practices (BMPs), or effective and practical improvement projects. To complete this initiative, the Town works collaboratively with other capital improvement projects occurring in the watershed area (Town of Framingham, n.d.a.). Despite these efforts, there is still a need for continued improvement of the water quality in and around Farm Pond. The goal of this project was to determine the impacts of urbanization on the water quality of Farm Pond and to evaluate and design a BMP to improve its water quality. The scope of our analyses focused on the Cushing Memorial Park (CMP) stream, a small body of water that flows from Cushing Memorial Park and potentially discharges to the western side of Farm Pond.

Methodology

We performed hydrologic and environmental analyses to estimate the flows and stormwater loadings into the CMP stream. To develop hydrologic parameters to estimate the annual runoff, we used the National Resources Conservation Service (NRCS) TR-55 Method. This involved using ArcMap Geographic Information System (GIS) to delineate the CMP stream watershed and determine the land use and soil types of the area. The CMP stream watershed was modeled with HydroCAD to estimate the watershed runoff for different storm return periods as well as the precipitation from each sampling event using the calculated time of concentrations and curve numbers.

We collected water samples from both Farm Pond and the CMP stream during dry weather events on October 11, 2016 and November 2, 2016 and during wet weather events on November 15, 2016 and November 29, 2016. The sampling locations are shown in the images on the following page. Along with collecting samples, we also gathered field data for dissolved oxygen, temperature, pH, turbidity, and depth using a Horiba U-52 Water Quality Meter. We tested samples for total phosphorus, ammonia, turbidity, dissolved oxygen, pH, total suspended solids (TSS), E. coli, and total coliforms in the laboratory. Nitrate, phosphate, bromide, fluoride, chloride, and sulfate were tested using ion chromatography. We used our laboratory results to determine the extent that stormwater runoff contributes to the water quality of Farm Pond and the CMP stream. The average pollutant concentrations were used with the watershed runoff estimations to determine the stormwater loadings. We calculated annual stormwater loadings as well as loadings for different storm return periods. Possible sources of contamination were researched after determining the pollutants of highest concern. We explored types of BMPs that are best suited for the area and ranked them based on a point scale that included factors such as cost, constructability, effectiveness of removal, aesthetics, public education, maintainability, and permitability. With input from Framingham officials, we chose the BMP with the highest overall score to design.

Sampling Locations at the Northwestern Section of Farm Pond

Sampling Location at the Southwestern Section of Farm Pond

Results & Design Recommendation

A series of laboratory procedures were performed in order to identify the current state of the CMP stream's water quality. For each field sample taken and tested in the laboratory, almost every constituent was above the limit of detection, and we found four to be above regulatory standards. These constituents were total coliforms, E. coli, TSS, and turbidity. The stormwater load estimates showed that the total coliform and E. coli concentrations were particularly high, so we determined that the BMP design would need to be able to adequately treat these concerns. The

BMP we chose was a constructed wetland, which we designed to meet the Commonwealth of Massachusetts Stormwater Specifications at the outfall of the CMP stream. A design was developed with the approximate layout and sizing of all components. Components of the constructed wetland included a sediment forebay, micropool, deep water channel, low marsh, high marsh, and semi-wet zone. The image below depicts the approximate aerial view of the proposed constructed wetland. Since the Town wants to promote green infrastructure projects and raise awareness of the amenities that Farm Pond and the surrounding area can offer to its residents, a constructed wetland complements these ideals while improving the water quality of the Farm Pond watershed.

Aerial View of Proposed Constructed Wetland

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Chapter 1: Introduction

One of the main reasons why waterbodies become impaired in urban areas is due to stormwater runoff. When it rains, water either seeps into the ground or is carried across impervious surfaces such as sidewalks or roadways. While the stormwater is being transported, it picks up many pollutants such as bacteria and sediment, which is then discharged into a nearby body of water. It is important to keep the quality of surface water high because bodies of water are often used for recreation or even drinking water purposes. One waterbody that is heavily affected by stormwater is Farm Pond. Farm Pond is located in Framingham, Massachusetts, which is about 20 miles west of Boston. A map of Framingham and Farm Pond is shown in Figure 1.

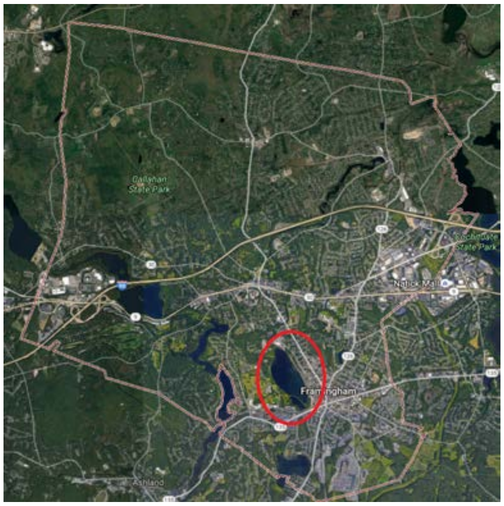


Figure 1: Aerial View of Framingham with Farm Pond Circled

The pond is used for recreational purposes and is a backup emergency water supply for Boston but is currently identified as impaired and is not meeting water quality standards for these purposes. The surrounding area is highly residential, and its population has been rapidly increasing throughout the years. Currently, Farm Pond is not an ideal candidate for a water supply because it has high turbidity and algal growth. The pond has many outfalls flowing into it that contribute unknown quantities of pollutants. In order to ensure that Farm Pond is ready for an emergency situation and complies with new Municipal Separate Storm Sewer Systems (MS4) regulations, the water quality must be improved.

As the largest town in Massachusetts, it is important that the water quality in Framingham's ponds and rivers is maintained. This is needed because the Town has transitioned from a rural to urban area. Over the years, a rise in population density has resulted in an increase of impervious surfaces by 30% in Farm Pond's drainage area, which increases the amount of stormwater runoff. According to Framingham's Stormwater Master Plan, stormwater runoff is one of the biggest pollutant contributors to Farm Pond and its inability to meet water quality standards (S E A Consultants, 2008).

Previous studies have been completed on Farm Pond and its watershed. On the eastern side of the pond, multiple infiltration basins and deep sump catch basins have been installed. The purpose of these projects was to improve stormwater management by reducing flooding, providing environmental protection in case of a spill, and improving the water quality of stormwater runoff from the watershed. An ongoing capital improvement project in Farm Pond's watershed is the removal of paved surfaces from Cushing Memorial Park, which is located on the western side of Farm Pond. Cushing Memorial Park has the potential to be used in additional conservation and water quality improvement projects (Town of Framingham, n.d.b). There is a town initiative to reduce sediment and nutrient loadings into Farm Pond by using stormwater Best Management Practices (BMPs), or effective and practical improvement projects. In doing so, the Town works collaboratively with other capital improvement projects occurring in the watershed area (Town of Framingham, n.d.a.). Despite these efforts, there is still a need for continued improvement of the water quality surrounding Farm Pond. The Town wants to promote green infrastructure projects and raise awareness of the amenities that Farm Pond and the surrounding area can offer to its residents.

The goal of our project was to identify the impacts of urbanization on the water quality of the Farm Pond watershed and to evaluate and design a BMP to improve its water quality. We focused our analyses on the Cushing Memorial Park (CMP) stream, a small body of water flowing from Cushing Memorial Park and discharging to the western side of Farm Pond. Our first step was to estimate stormwater loadings in the CMP stream. To do this, we conducted sampling in a number of locations in the CMP stream and Farm Pond, which we used to assess the significance of the interactions between the two waterbodies. We then identified potential sources of the constituents by researching past and current land uses of the area. Finally, after exploring various BMP options, we made a recommendation and designed a BMP. The results of our investigation provided the Town of Framingham with a way to help reduce the stormwater loads the CMP stream is contributing to Farm Pond. Because the CMP stream is located adjacent to both Cushing Memorial Park and Farm Pond Park, the implementation of our recommended BMP would also have the potential to educate the public about the benefits of stormwater management.

An in-depth description of this project is provided in the following five chapters: Background, Methodology, Results, Design Recommendations, and Other Recommendations and Conclusions. We discuss pertinent information about regulations, the history of Farm Pond, and its current water quality issues in Chapter 2. In Chapter 3, we explain our methodology, which includes three main objectives, to achieve our project goal of identifying water quality impairments and designing a BMP to decrease the impacts of the CMP stream. Chapter 4 discusses and analyzes the results of our study. Finally, Chapter 5 includes our design recommendations for our chosen BMP and is followed by further recommendations in Chapter 6.

Chapter 2: Background

In this chapter, we discuss important factors that encompass our project. Background information is provided about stormwater control and loadings, including point and nonpoint source pollution. In Section 2.3, Best Management Practices (BMPs) and their implementations are discussed. In the next section, we explain the history of the Town of Framingham and how it has evolved over the years as well as the history of Farm Pond and changes in the area that may contribute to the pond's current impairments. We examine the connection between the Town's growth and the water quality of the Farm Pond subbasin. Finally, Section 2.5 provides an overview of the Cushing Memorial Park (CMP) stream and its connection to Farm Pond.

2.1 Stormwater Control

Ideally, stormwater draining to a waterbody should be pure and uncontaminated. However, stormwater often carries pollutants directly into waterways - untreated. For this reason, in order to discharge stormwater, municipalities must obtain a Municipal Separate Storm Sewer Systems (MS4) permit by complying with a number of pollutant regulations. The most recent Massachusetts MS4 regulations will become effective in July of 2017. The regulations require discharges to meet water quality standards, pollutants to be reduced to the maximum extent practicable (MEP), and development of a Stormwater Management Plan (SWMP) with updated Best Management Practices (BMPs) (USEPA, 2016a). Stormwater control has become an important topic of interest in recent years, and many municipalities have had to re-evaluate their current systems and make the appropriate changes to reduce stormwater loads.

2.2 Stormwater Loads & Nonpoint Source Pollution

Stormwater loads are a measure of the amount of pollutant(s) entering a waterbody and are useful for gauging water quality. They are regulated through permits, state laws, and local ordinances with the guidance of Total Maximum Daily Loads (TMDLs). TMDLs are “the greatest amount of a pollutant that a waterbody can accept and still meet the water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation, and fishing” (MassDEP, 2016, p. 1). The Massachusetts Department of Environmental Protection (MassDEP) has a TMDL strategy that focuses on identifying and prioritizing impaired waterbodies, developing TMDLs, implementing controls to meet water quality standards, and assessing the effectiveness of the control measures (MassDEP, 2016). Waterbodies are classified in five categories to determine whether or not they are impaired. These categories are shown in Table 1.

Table 1: TMDL Category Classifications (Massachusetts Division, 2015)

TMDL Categories	Meaning
Category 1	Unimpaired and not threatened for all designated uses
Category 2	Unimpaired for some uses and not assessed for others
Category 3	Insufficient information to make assessments for any uses
Category 4a	TMDL is completed
Category 4b	Impairment controlled by alternative pollution control requirements
Category 4c	Impairment not caused by a pollutant - TMDL not required
Category 5	Impaired or threatened for one or more uses and requiring a TMDL

In order to determine a TMDL, point and nonpoint sources of pollutants must be identified. The United States Environmental Protection Agency (USEPA) identifies any point source pollutant as a source that has “any discernible, confined, and discrete conveyance…from which pollutants are or may be discharged” (USEPA, 2016b, p. 1). All other pollution sources are considered nonpoint sources. Common sources of nonpoint source pollution are any sources from land runoff, precipitation, atmospheric deposition, drainage, or seepage (USEPA, 2016b). Land runoff includes fertilizers or pesticides from residential or agricultural areas, grease and toxic chemicals from urban runoff, and sediments from improperly managed construction sites or eroding soil (MassDEP, 2014). To address nonpoint source pollution, the MassDEP has a nonpoint source pollution program. The goal of the program is to “bring the citizens and the state together to restore surface and groundwater impaired by nonpoint source pollution, to protect water quality in healthy watersheds, and to plan and address human-induced and naturally-occurring changes in the environment” (MassDEP, 2014, p. 1). This program gives guidance on common sources and how to quantify nonpoint source pollution.

It can be difficult to estimate nonpoint source pollution concentration and loads. First, water quality assessments are used to gather data to develop a baseline for the current constituents. After an initial assessment is completed, water quality monitoring should be maintained to evaluate how the nonpoint source changes over time through continued water quality sampling (MassDEP, 2014). Nonpoint source pollution is frequently measured through supplemental water quality tests including analyses for metals, sediments, and nutrients. To estimate a nonpoint source load, it is useful to have an idea of where the pollution may be originating based off of the land use in the watershed. Some typical modeling can be done to help in this endeavor. A variety of modeling software can be used to simulate the conditions in the watershed based on estimations for soil erosion, wind erosion, animal manure loading, and agricultural chemical loading potentials (He &

Croley, 2005). Some of these models are HydroCAD, Areal Nonpoint Source Watershed Environment Simulation (ANSWERS), Groundwater Loading Effects of Agricultural Management Systems (GLEAMS), and Soil and Water Assessment Tool (SWAT), among many others (He & Croley, 2005). By using these tools and estimations, one can gain an understanding of how nonpoint source pollution can affect stormwater management.

2.3 Best Management Practices (BMPs)

Best Management Practices (BMPs) are tools designed to reduce the release of toxic and hazardous compounds into waterbodies. According to the Clean Water Act, BMPs are traditionally used to control site runoff, chemical spills, waste disposal, and drainage. BMPs are practices used to prevent pollutants from reaching receiving waterbodies. They are designed to be cost effective, easily implemented, and low maintenance (USEPA, 1993). BMPs can reduce the concentration of specific contaminants. Common stormwater BMPs for land that has been previously developed include the use of porous pavement, first flush diversion systems, lawn maintenance controls, and road salt application management (USEPA, 2015). These examples show that BMPs can be either structural, such as porous pavement and first flush diversion systems, or nonstructural, such as lawn maintenance controls and road salt application management.

When selecting and designing a BMP, the land area's characteristics, such as population density, land use, soil types, and topography, should be taken into account (USEPA, 2015). Some other factors that may affect the selection of a BMP include whether the current management programs are adequate to meet water quality goals or if the system can be retro-fitted. Additionally, population growth and land development factors play a role in developing the BMP design. The MassDEP's Structural BMP Specifications included in the Massachusetts Stormwater Handbook can help assist in designing a BMP. In this document, the MassDEP provides guidance on the advantages and disadvantages of the BMP, known pollutant removal efficiencies, and the peak flow or recharge the system can support (Commonwealth, 2017b). Additionally, information on the design, construction, and maintenance is found along with schematic diagrams of the BMP. This information can be used to compare BMPs in order to select the one that best meets the project goals.

It is important to note that many different management practices and procedures can be used to achieve the same environmental goals. For example, to reduce stormwater runoff and to control nonpoint source pollutants, vegetated swales, bioretention basins, rainwater harvesting, sand filters, and riparian buffers all work to adjust the rate of infiltration and absorption of stormwater (MassDEP, 2014). Other nonpoint source pollution BMPs focus on preventing pollution, controlling erosion, protecting stream banks and streambeds, and restoring habitats. The EPA requires that any state nonpoint source pollution plan must "identify best management practices and measures to control each category and subcategory of nonpoint sources" (MassDEP, 2014, p. 12). BMPs are typically used to reduce pollutants to the MEP to protect water quality (USEPA, 2015). Placing emphasis on reducing pollutants to the MEP is important because any implemented BMP needs to have a reasonable operation and maintenance plan. For example, trying to reduce pollutant concentrations to low levels may be too expensive and therefore not effective to install the BMP based on the cost-benefit analysis. BMPs are an excellent tool to reduce the impacts of stormwater and nonpoint source pollution. One town that has previously implemented BMPs is the Town of Framingham, Massachusetts.

2.4 History of Framingham & Farm Pond

The Town of Framingham, located 20 miles west of Boston, is one of the fastest growing towns in Massachusetts, which puts a strain on its water resources. Its population is approximately

68,000 residents, with about 2,792 people per square mile. Because of this high population density and the fact that 24% of the Town's drainage area is impervious, Framingham is challenged with addressing the impacts of stormwater runoff to its water resources (Town Charts, n.d.). The Town itself has significant historic value and is considered "the hub of the MetroWest region" (Town of Framingham, n.d.a, p. 1). There are many natural, urban, rural, and suburban areas spread throughout the Town, including recreational facilities such as Farm Pond.

Farm Pond has a vast history, serving as a gathering place as well as a drinking water source. In the 1800s, it was a popular stop for the Chautauqua lecture series, an educational movement, in addition to temperance and abolition societies. Today, the pond is one of the Town's public recreation areas. The western side of Farm Pond includes a playground, bocce ball courts, and walking paths. A public boat ramp is located on the northern side of Farm Pond. On the eastern side of the pond is the CSXT Framingham train yard, which is next to downtown Framingham. As of 2016, the Town had several ongoing projects near Farm Pond, including a skate park and a downtown revitalization. The Keefe Technical Regional Vocational High School, Barbieri Elementary School, Loring Arena Ice Skating Rink, and the MBTA's Framingham Commuter Rail Station are all located within the Farm Pond subbasin (Town of Framingham, n.d.b).

The pond is located at the edge of downtown Framingham. Its location and the surrounding developments are shown in Figure 2. For a number of years, Farm Pond was the start of the Sudbury Aqueduct that extended to the Chestnut Hill Reservoir and provided water to the City of Boston. The aqueduct was later extended past Farm Pond due to concerns about the water quality. Today, the pond is still an emergency backup water source, which is one of the reasons Framingham has been focusing on improving the water quality (Town of Framingham, n.d.b). It is important to maintain the stormwater quality flowing into Farm Pond because as recently as 2010, a water main break in Boston resulted in the Massachusetts Water Resources Authority using its backup water reservoirs, including Farm Pond (WCVB, 2010).

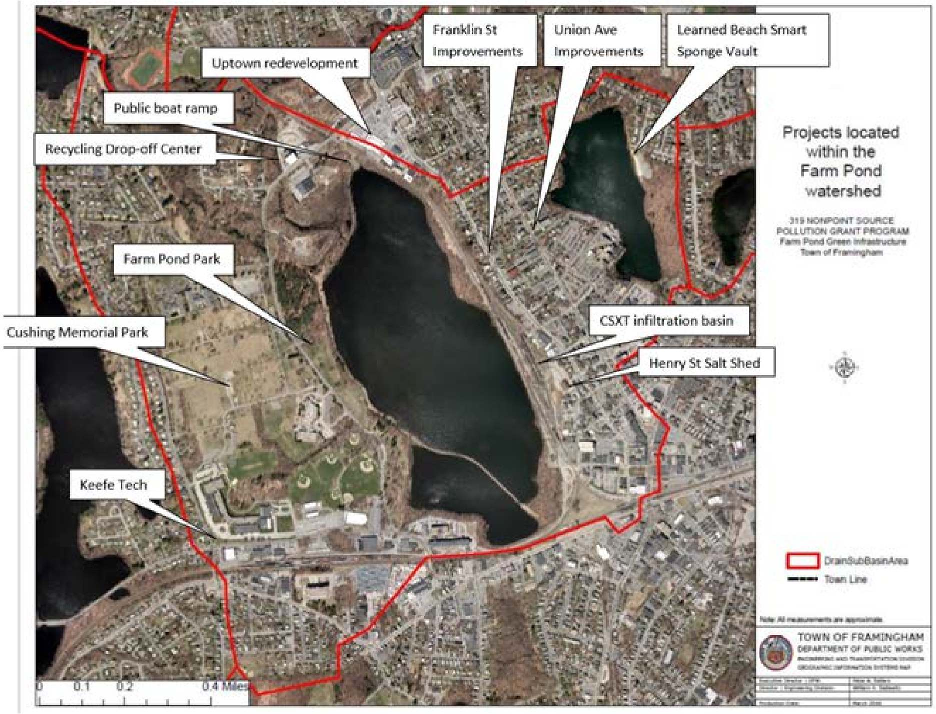


Figure 2: Map of Farm Pond

Over the past century, the area around the pond has become rapidly urbanized. This rapid growth has led to poor water quality issues including algal growth, bacteria, and turbidity. As the Town of Framingham grew, the amount of impervious surfaces also grew, creating more stormwater runoff. Framingham developed a strategy to integrate water quality improvements into all new and redevelopment projects. The Town has also enacted plans to increase public education and awareness about preserving and improving Farm Pond's natural resources. Framingham has implemented development restrictions in both resource areas and areas in need of stormwater management. Additionally, Framingham has developed a Stormwater Master Plan and an Aquatic Management Program to help combat these water issues (Town of Framingham, n.d.b).

On the EPA-approved *2014 State of Massachusetts Integrated List of Waters Final Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b) and 303(d) of the Federal Clean Water Act*, Farm Pond was listed as a Category 5 waterbody, which means that it was considered impaired and needed a TMDL completed. As previously mentioned, Farm Pond was considered impaired for excess algal growth and high turbidity. It was also noted that there were non-native aquatic plants present in addition to Eurasian Water Milfoil and Myriophyllum, but these do not require a TMDL (Massachusetts Division, 2015). The outfall of Farm Pond flows into Eames Brook, which is also a Category 5 impaired waterbody. With all of the changes in and around Farm Pond over the years, it has become increasingly difficult to identify all the sources of the stormwater loads entering Farm Pond and eventually Eames Brook (Town of Framingham, n.d.b).

2.4.1 Farm Pond Subbasin Stormwater Control

Some stormwater research has already been completed in Framingham to work toward continued MS4 permitting and the cleaning of its waterbodies, but more analysis can be done. A significant amount of stormwater pollution in Framingham can be attributed to impervious surfaces such as roads, sidewalks, parking lots, and buildings. In the area surrounding Farm Pond, development and urbanization have sparked an increase in large, connected impervious surfaces. About 30 percent of the pond's drainage area is impervious (Town of Framingham, n.d.a). The addition of the previously mentioned skate park in Farm Pond Park will soon add even more impermeable surfaces to the area (Pillar Design, n.d.). Another project that could impact the water quality of the area is the new pedestrian/bike path, which will be built directly over the Cushing Memorial Park (CMP) stream and around Farm Pond (K. Reed, personal communication, September 6, 2016). Impermeable surfaces contribute to the inability of stormwater to seep into the ground. This causes an unnatural flow along man-made surfaces and increases the likelihood of contamination and flooding.

The stormwater drainage system in Framingham was designed to handle a 2-year to 5-year storm event with mild to moderate flooding (S E A Consultants, 2008). These storms are expected to occur, on average, once every 2 years and 5 years, respectively. Framingham's Stormwater Management Plan states, "The closed drainage system that serves [the Farm Pond] sub-basin does not have the capacity to service the area during intense storms under today's built-out conditions, either in terms of hydraulic or water quality treatment capacity" (S E A Consultants, 2008, p. 1-11). This drainage infrastructure, which was built for less flow, may contribute to Farm Pond's pollutant loading.

Some progress has been made to address stormwater issues in Framingham, including the installation of Stormceptors, infiltration basins, and deep sump catch basins, all of which trap and contain sediment and pollutants (Town of Framingham, n.d.b). Although these efforts are helpful and promising, more can be done to improve the quality of Farm Pond.

2.5 Cushing Memorial Park Stream

A stream is located adjacent to Farm Pond, which we will hereafter refer to as the Cushing Memorial Park (CMP) stream. This stream flows under Cushing Memorial Park, which is across the street from Farm Pond. It flows underground because it was previously culverted in order to build a military medical facility in World War II. In 1991, the hospital was shut down after it was deemed to be a surplus medical facility. There were over 100 buildings across the 67.5-acre area, including roadways, parking lots, and the hospital. In 2001, a Master Plan was developed to turn a portion of the former hospital area into a major public park. Today, hundreds of Framingham residents use the park on a daily basis and take advantage of its features, including a promenade, open meadows, and extensive lawns (Town of Framingham, 2013).

Since Farm Pond is downstream from CMP, there could be stormwater loads entering the pond from the park. The fertilizer and pesticides used on the lawn might leach into the pond or brook through the CMP stream. This would contribute to the nutrient loads, which could be a source of the algal growth. Because of the former hospital, there is potential that medical waste was dumped on-site, which could have impacted the surrounding area. Currently, it is unclear if CMP is contributing any stormwater loads to Farm Pond (Town of Framingham, 2013). It is also possible that an upstream residential neighborhood in the watershed is a source of stormwater loads. The urbanization of the watershed area has likely had a significant impact on the surface water quality and stormwater control.

The outflow of the CMP stream is currently unknown. It is possible that there are siphons underneath the Sudbury Aqueduct connecting the stream to Farm Pond. Additionally, there is some hydrologic indication that the stream could flow into Eames Brook during a wet weather event (K. Reed, personal communication, September 6, 2016). The outfall for Farm Pond is Eames Brook. Although the outfall of the CMP stream is unknown, the close proximity of these three waterbodies could indicate that groundwater infiltration is a possible connection between them. Since both Farm Pond and Eames Brook are Category 5 impaired waterbodies, it is important to determine the possible stormwater loadings the CMP stream could contribute to them (USEPA, n.d.). In order to assess these stormwater loadings and possible improvements, we conducted a number of procedures, which are outlined in Chapter 3.

Chapter 3: Methodology

The goal of our project was to identify the impacts of urbanization on the water quality of Farm Pond and its surrounding waterbodies and to evaluate and design a Best Management Practice (BMP) to improve the water quality. For the purpose of this project, we focused our investigation on the Cushing Memorial Park (CMP) stream, which may contribute to Farm Pond's water impairments. In order to accomplish this goal, we developed the following three objectives:

1. Perform hydrologic, hydraulic, and environmental analyses to estimate the flows and stormwater loadings into the CMP stream.
2. Characterize the tributary watershed and identify and assess potential sources of constituents contributing to the CMP stream's water quality degradation.
3. Evaluate, select, identify, and design a BMP for the stream to reduce stormwater loadings and to improve the overall water quality of the pond.

In the following sections, we explain the methods we used to fulfill our objectives and achieve our goal. A proposed timeline for the project is included in Appendix A. Additionally, we kept our sponsors informed of our progress by providing weekly updates.

3.1 Perform hydrologic, hydraulic, and environmental analyses to estimate the flows and stormwater loadings into the Cushing Memorial Park (CMP) stream.

In order to estimate the hydrologic stormwater loadings, we first identified and quantified the current runoff from the watershed in the CMP stream. Next, we conducted water quality sampling to determine the concentration of the pollutants in the waterbody. Finally, we calculated the stormwater loadings. These tasks involved using the ArcMap Geographic Information System (GIS) and the HydroCAD hydrologic model to quantify the watershed's characteristics and completing fieldwork to monitor the water quality.

3.1.1 Stormwater Runoff Quantification

With the charts and equations shown in Appendix B, we used the National Resources Conservation Service (NRCS) TR-55 Method to develop our hydrologic parameters to estimate the annual runoff. The NRCS Method estimates stormwater runoff based on the amount of rainfall and the potential maximum retention after runoff begins. In order to determine the maximum retention, a curve number is estimated. This number is dependent on the watershed's hydrologic soil group, land use type, treatment, hydrologic condition, and antecedent runoff condition (ARC) (NRCS, 1986, p. 2-1). There are four hydrologic soil groups, A-D. The groups range from Group A soils, which have low runoff potential when thoroughly wet, to Group D soils, which have high runoff potential when thoroughly wet (NRCS, 2007). We used the Massachusetts Department of Environmental Protection's (MassDEP) GIS database to identify the hydrologic soil groups and land uses found in the CMP stream's watershed. The watershed was delineated on ArcMap GIS by following contours and the Town's stormwater drainage system. Both of these layers were obtained from the Town of Framingham. Once the soil groups and land uses were cut to the delineated watershed, a table showing the soil groups and land uses and their respective areas was created and exported to Excel.

The watershed was modeled as two basin nodes flowing into a river node using the HydroCAD hydrologic model. The two basins were a residential basin, including medium density, high density, and multi-family residential areas, and a parkland basin, including forest and urban public-institutional land uses. Curve numbers were calculated for each basin based off of the GIS data for soil and land uses. HydroCAD uses the NRCS TR-55 method for calculating curve numbers. A time of concentration was calculated for each basin using the Kirpich equation shown in Equation 1 from the NRCS National Engineering Handbook Part 630 Hydrology (NRCS, 2010).

Equation 1: Time of Concentrations Calculations

$$t_c = 0.0078 * k \left(\frac{L}{S^{0.5}}\right)^{0.77}$$

L=flow length (ft)

S = average watershed land slope (ft/ft)

K = Kirpich adjustment factor based on type of ground cover

K is equivalent to 0.4 for flow on concrete or asphalt surfaces and 1.5 for flow on natural grass channels, bare soil, or roadside ditches.

Various model runs of HydroCAD were completed by varying the rainfall for 5, 10, 25, 50, and 100 year 24-hour storm return periods. Additionally, the watershed runoff was calculated for each wet weather sampling event.

The NRCS Method has some limitations. Curve numbers relate to the average conditions over the watershed and therefore lose accuracy if the method is being used to model historical storms (NRCS, 1986). However, the NRCS Method can account for rainfall duration or intensity by using follow-up methods to generate hydrographs based on various rainfall intensities. The NRCS method is ideal for modeling runoff for urban and developing watersheds. Additionally, the method can be applied to small watersheds. Once estimates of the watershed’s runoff were calculated, we then sampled Farm Pond and the CMP stream for various constituents.

3.1.2 Sampling Procedures

We analyzed samples from both two dry and two wet weather events to determine how much the stormwater runoff contributes to the water quality issues in the pond and the CMP stream.

If we could not make it to Framingham during a wet weather event, Kerry Reed, Senior Stormwater and Environmental Engineer for Framingham, helped us by collecting the samples.

For each weather event, we sampled from multiple locations along the pond and the stream. Table 2 provides descriptions of our sampling locations and reasoning for selecting them. Point C was not sampled during dry weather events because its purpose was to determine if another possible source of stormwater had an effect on the stream. An overview of the sampling locations is shown in Figure 3; the points are labeled A through G as shown in Figures 4 and 5.

Table 2: Sampling Location Descriptions

Point	**Location**	**Reasoning**
A	Inflow to the CMP stream	First accessible stream location
B	About ¾ of the way down the CMP stream	Before the aqueduct separating the CMP stream from Farm Pond
C	Stormwater drainage south of CMP stream	May contribute during a wet weather event
D	In the pond on the other side of the aqueduct from the CMP stream	Close proximity to the stream on the Farm Pond side of the aqueduct
E	At the bottom of the hill from the composting facility	The final visible outfall of the CMP stream
F	Outfall of the pond into Eames Brook	To determine final stormwater loads of Farm Pond and potentially the CMP stream
G	In the pond, on the southwestern shore near Farm Pond Park	Other pond sampling location for comparison purposes

Figure 3: Overview of Sampling Locations

Figure 4: Sampling Locations at Northwestern Section of Farm Pond

Figure 5: Sampling Location at Southwestern Section of Pond

At each sampling location, we filled four bottles - one 1 L bottle, one 250 mL bottle, one 250 mL autoclaved bottle, and one BOD bottle. For wet weather sampling, we took samples at two different times during the storm. To provide an estimation of conditions for the first flush, we sampled at locations A, C, D, and E. All locations were sampled at a later time to estimate conditions throughout the storm. For each sampling event, we collected a duplicate sample at one location to determine analysis accuracy.

3.1.3 Sampling Conditions

The first dry weather samples, taken on October 11, 2016, mostly served as a trial run to ensure our testing processes were accurate. Total coliforms and E. coli testing were not completed for this round of sampling because we did not have the proper equipment at the time. The second set of dry weather samples was taken on November 2, 2016. The weather for both rounds of dry sampling was sunny, warm, and approximately 70°F. Location C was not tested because it was namely for wet weather sampling and there was no water at the location due to drought conditions.

The first wet weather sampling event was on November 15, 2016. During the first flush of rain, samples were taken at locations A, C, D, and E with a duplicate at C around 1:00 pm. The second set of samples were taken at 3:00 pm at all locations with no duplicates. November 29, 2016 was the date of the second wet weather event. Kerry Reed, Senior Stormwater and Environmental Engineer for the Town of Framingham, took the first set of samples at 11:00 am at locations A, C, D, and E because we were unable to get to the locations for the first flush of rain. We took the second set of samples at 2:30 pm for locations A-G with a duplicate at location C. During our sampling events, we also conducted a number of field tests in order to collect instantaneous data in the field.

3.1.4 Field Testing

To conduct field monitoring, we used a Horiba U-52 Water Quality meter. A Horiba U-52 Water Quality meter is used for fieldwork and can log multiple parameters at the same time. The meter was used to collect field data on depth, dissolved oxygen, temperature, pH, conductivity, turbidity, and total dissolved solids (TDS). The meter was calibrated on November 3, 2016. The probe was submerged into the water and the measurements were recorded once the readings had stabilized.

For the first sampling event, we measured the depth of the water, the width of the stream, and culvert dimensions with a measuring tape. During wet weather events, we estimated the velocity of the water at points A and C. We used a variety of tracers, including dye and leaves, a stopwatch, and a measuring tape to calculate the distance the tracer traveled and the amount of time it took. Using these estimates, the depth of the water from our probe data, and the width of the stream, we calculated an estimate of the flow rate.

3.1.5 Laboratory Testing

We took samples from both the pond and the CMP stream and tested them for ammonia, total phosphorus, bacteria, total suspended solids (TSS), pH, dissolved oxygen, ion chromatography, and turbidity. Nitrate, phosphate, bromide, fluoride, chloride, and sulfate were tested using ion chromatography. We performed these tests in the Environmental Engineering laboratory in Kaven Hall at Worcester Polytechnic Institute.

3.1.5.1 Determining Ammonium Using a Color Spectrophotometer

Using a color spectrophotometer we were able to determine the concentration of ammonium in our water samples. First, we turned the spectrometer on to a wavelength of 425 nm and allowed the lamp to warm up for two hours before the experiment. We prepared our samples from the stream and the pond as well as a set of standards. These standards included concentrations of ammonium that had a range that went just beyond the expected results. The standards were used to create a calibration curve.

The range for standards was estimated in order to pick suitable calibration points. Most samples fall in the range of 0.1 ppm and 1 ppm. For this project, standards were made at 0.1 ppm, 0.5 ppm, 1 ppm, and 3 ppm. Once the range was determined, we used Nitrogen Ammonium Standard Solution 100 mg/L as NH_3-N (Cat. 24065-49) to make each of the standard solutions. When determining ammonium levels in a sample, we had to first blank the spectrophotometer. A blank filled with deionized water was added to a cell up to the 25 mL mark. Then three drops of Mineral Stabilizer (Cat. 23766-26) was added to the water and the cell was capped and inverted three times. This same mixing process was repeated when three drops of Polyvinyl Alcohol Dispersing Agent (Cat. 23765-26) were added and then again when 1 mL of Nessler Reagent (Cat. 2194-49) was added. Once the solution was mixed, it then had to sit for one minute to allow all the chemical reactions to occur. After the minute, the cell was placed in the spectrophotometer and zeroed. This process was then repeated for all of our samples, but they were read instead of zeroed. In between tests, the cell was emptied and rinsed before the next sample was tested. Once all the standards were read, the values given by the spectrophotometer were then used to make the graph for the calibration curve. This curve was then used to help determine how much ammonium was in our samples by comparing where these points fell on the graph.

3.1.5.2 Determining Total Phosphorus using Sulfuric Acid-Nitric Acid Digestion and a Hach DR/3000 Color Spectrometer

To determine the total phosphorus, the samples had to be digested in order to prepare them for testing. First, we turned the spectrometer on to 400 nm two hours before testing occurred to prevent drifting absorbance readings. As for the ammonium test, a set of standards were prepared just beyond the range of the expected results. A stock solution was used to prepare the standards by using Equation 2.

Equation 2: Digestion Standards

$$X\,mL = C\frac{mg}{L} * \frac{mL}{0.1mg} * 100mL * \frac{1L}{1000mL}$$

where X = volume (mL) of stock solution needed

C mg/L represents the desired standard concentration

0.1 mg/mL is the concentration of the stock solution

100 represents the volume of standard that will be prepared

1 L/1000 mL is used to convert mL to L

Then, both the standard solutions and the unknown samples were put through the digestion process. In a clean beaker, we added 25 mL of either the standard solution, the samples, or deionized water for the blank to 5 mL of concentrated HNO_3 and 1 mL of concentrated H_2SO_4. The beaker was covered with a watch cover with enough room between the cover and the top of the beaker to provide space for the gases to evaporate. Under a hood, we gently heated the beaker on a preheated hot plate so that the sample only simmered. We continued to heat the sample until it was “down to fumes.” This means that there were visible white fumes in the beaker, and the sample had been reduced to 1 mL. The beakers were then removed from the hotplate.

Once the samples had fully cooled, we transferred the digested blank solution into a clean cell. We used deionized water to help rinse out any digested solution that may have stuck to the beaker and poured it into the cell as well. Then we added one drop of phenolphthalein indicator solution and 5N NaOH solution until it turned a faint pink. The sample got warmer as we added the 5N NaOH to the sample. When the solution turned pink, deionized water was added until the solution was at the 25 mL mark on the cell. Then 1 mL of Molybdovanadate was added to the cell. This caused a light yellow to a dark yellow tint depending on the amount of phosphorus that was present in the sample. The sample was then inverted three times and left to rest for three minutes while the reaction occurred.

To read the samples, we first placed the blank into the spectrometer after the reaction had taken place and zeroed the machine. In between reading samples, the sample cell was rinsed out. We used the same cell to reduce any variances that different cells could have had. The steps above were repeated with all the samples and were read. Once the standards had all been tested, we created a calibration curve with the results so the unknown samples could be compared to the known values. This helped to determine the concentration of phosphorus in the water samples we collected from our sample locations.

3.1.5.3 Bacteria

Coliforms are found in animal and human waste and cause bacterial issues that can lead to illness or death. Since Farm Pond is an emergency back-up water supply for the Massachusetts Water Resources Authority (MWRA), it is important to ensure coliform counts are below harmful levels. We chose to test for coliforms and E. coli.

Before we collected the samples for bacteria testing, we first had to autoclave the sampling bottles to prevent contamination. We placed the sampling bottles with loose lids and autoclave tape over the lids into the autoclaving system. One to four liters of water was added to the autoclaving system depending on the number of bottles. Once the door was securely shut, it was then set to 210^{o}C and left for about an hour. After an hour, the bottles were removed and the extra water was drained. While wearing gloves, the tape was slightly lifted while the cap was secured. Then the bottles were taken out and set aside for sampling. When sampling, we made sure not to rinse the bottles out before taking the sample. Once the samples were collected, we had 24 hours to complete the bacteria test.

To start the test, we cleaned the counter with alcohol and set up a bunsen burner for aseptic transfer. The IDEXX Quanti-Tray/2000 was turned on and given five minutes to warm up until the light turned green, indicating that the machine was ready. Using aseptic techniques, we used the Quanti-tray Sealer to determine total coliforms and E. coli. The cap of an empty bottle was removed, and the neck of the bottle was flamed. The bottle with the sample was also flamed. We transferred 100 mL of the sample into the empty bottle and added one powder packet. We shook the bottle until the powder was completely dissolved. We used one hand to hold the Quanti-Tray upright with the well side facing the palm, and the tray was squeezed to open it. Then, while avoiding touching the inside of the tray, the tab was gently pulled, and the sample and powder mixture was poured into the tray. It was gently set down on the counter with the well side facing down, and the back was gently tapped to remove any air bubbles. The tray then sat for a few minutes to allow the foam to settle. Next, the tray was placed onto the rubber insert of the Quanti-Tray Sealer with the well side facedown and inserted through the sealer. Once sealed, the trays were labeled and placed into the incubator at 36^{o}C for 24 hours.

After 24 hours, we removed the trays from the incubator and counted the number of yellow cells. Yellow cells indicated that bacteria was present in the sample. We compared the trays with a standard tray, shown in Figure 6, to determine the shade of yellow that indicated a positive result. With a UV light held at an angle over the trays in a dark room, we counted the number of glowing wells that indicated the presence of E. coli. Once the large and small wells were counted, the IDEXX Quanti-Tray/2000 MPN tables (shown in Appendix C) were used to estimate the number of bacteria and E. coli that were present per 100 mL. Lastly, we disposed of the trays.

Figure 6: Blank Comparison Quanti-Tray

3.1.5.4 Total Suspended Solids

A filtration system was used to test for total suspended solids (TSS). First, each 0.68 nm filter paper was rinsed with deionized water. The filter papers were then placed into an oven overnight to dry. The following day, the filter papers were weighed on a gram scale. For each water sample, 250 mL were filtered through the paper leaving any solids on the filter paper. The filter papers were then placed into the oven overnight to dry. Once all the water had evaporated from the filter paper, they were weighed again. The total suspended solids were then calculated using Equation 3.

Equation 3: TSS Equation

$$TSS\left(\frac{mg}{L}\right) = \frac{weight - paper\ weight\ (g)}{250mL} * \frac{1{,}000\ mL}{L} * \frac{1{,}000\ mg}{1\ g}$$

3.1.5.5 pH

The pH of the water indicates if it is too acidic or basic for aquatic life to thrive. An Orion 420A pH meter was used to measure the pH of all the samples. The meter was calibrated each day of testing. To calibrate the meter, *2nd* followed by *Mode Cal* was pressed to enter calibration mode. The electrode was immersed in the pH 4 buffer, and the meter stabilized until "4.01 ready" flashed on the screen. *Yes* was pressed, and the electrode was rinsed with deionized water. This was similarly done for the pH 7 and pH 10 buffers. Once the calibration was complete, the electrode was immersed in each of the water samples until the meter reading stabilized. The electrode was rinsed with deionized water between each sample (Plummer, 2016).

3.1.5.6 Dissolved Oxygen

When high levels of nutrients are present, algal growth occurs, depleting oxygen levels in which fish and other aquatic life need to survive. To sample for dissolved oxygen (DO), we used a DO probe. Before testing, the Biological Oxygen Demand (BOD) bottles were left on the laboratory bench so the water could rise to room temperature. The probe was taken out of the saturated BOD bottle and immersed in the sample BOD bottle. Once the reading stabilized, the probe was rinsed with deionized water and inserted back into the saturated BOD bottle. This was repeated for all samples.

3.1.5.7 Ion Chromatography

While phosphorus and nitrogen compounds are found naturally in water, excess amounts cause rapid algal growth, which leads to eutrophication. In addition to damaging water sources, food sources, and animal habitats, these algal blooms can become harmful to humans because they produce elevated toxins and bacterial growth that can cause illness (USEPA, 2016c). To estimate the concentration of nutrients, we used ion chromatography to measure chloride, fluoride, sulfate, bromide, nitrate, and phosphate. The system used was a Dionex ICS-2100, and it automatically ran the samples. In order to run the samples, the column was first heated to 30^{o}C, and the pumps were set to 1,900 psi and 2,100 psi. Next, the detectors were set to 38 mM and 30 mA while the flowrate was set to 0.25 mL/min. Once the machine was ready to test, it needed to be calibrated by running **s**tandards of 100, 200, 400, 800, 1,200, 3,000, and 5,000 ppb for each constituent tested through the machine. After the machine was calibrated, we ran our samples. The main column used was the Dionic AS15 2X250 mL, and the guard column used was the AG15 2X50 mL. The guard column collects particles that the filter did not previously remove so that they cannot enter and damage the main column. Once the samples were analyzed, they were removed from the conductivity cell, and the results were printed from the computer. The WPI Environmental Engineering laboratory manager, Donald Pellegrino, assisted us by running our samples through the Dionex ICS-2100 system and then communicated the results with us.

3.1.5.8 Turbidity

Turbidity is a measure of the amount of particles suspended or dissolved in water that cause the water to appear cloudy. It is affected by silt, clay, algae, inorganic matter, and other microscopic organisms. All of these issues can be measured through a basic lab test. The sample was placed into a clean cell, and the cell was wiped of all fingerprints. The cell was then placed into the turbidity meter after it was calibrated. The measurement was recorded, the cell was rinsed, and the procedure was repeated for additional samples.

3.1.6 Stormwater Loadings

Once we determined the constituent concentrations in the CMP stream, we then calculated the stormwater loadings during wet and dry weather events. Using the annual runoff calculated by the NRCS method, annual pollutant loads were calculated using the Simple Method, shown in Equation 4. The Simple Method uses the watershed area and pollutant concentrations and does not include loads from base flows (*The Simple Method*, n.d.).

Equation 4: Simple Method

$$L\ (annual\ load\ lbs) = 0.226 * R * C * A$$

$$where\ R = Annual\ Runoff\ (inches)$$

$$C = Pollutant\ Concentration\ \left(\frac{mg}{L}\right)$$

$$A = area\ (acres)$$

$$L\ (annual\ load\ billion\ colonies) = 1.03x10^{-3} * R * C * A$$

$$where\ C = bacteria\ concentration\ \left(\frac{\#}{100mL}\right)$$

Additionally, stormwater loads were calculated for various stormwater events by using the results from HydroCAD for the CMP watershed runoff. HydroCAD estimates the inflow to the CMP stream in acre-feet. The average wet weather pollutant concentrations for Location A, the start of the CMP stream, were calculated. Equation 5 shows the basic formula for calculating the pollutant loads from each stormwater event.

Equation 5: Stormwater Loads

$$Stormwater\ Load\ (lb) = Runoff\ (acre - ft) * \frac{1.233x10^6 L}{acre - ft} * Constituent\ Concentration\ \left(\frac{mg}{L}\right) * \frac{1lb}{453{,}592mg}$$

We used the same watershed runoff and stormwater load calculation process for the watershed contributing to our sampling location G. This location is on the southern side of the pond and is near the site for the new skate park. We used these stormwater load calculations as a baseline to understand the relative impact of the CMP stream watershed on Farm Pond.

3.2 Characterize the tributary watershed and identify and assess potential sources of constituents contributing to the CMP stream's water quality degradation.

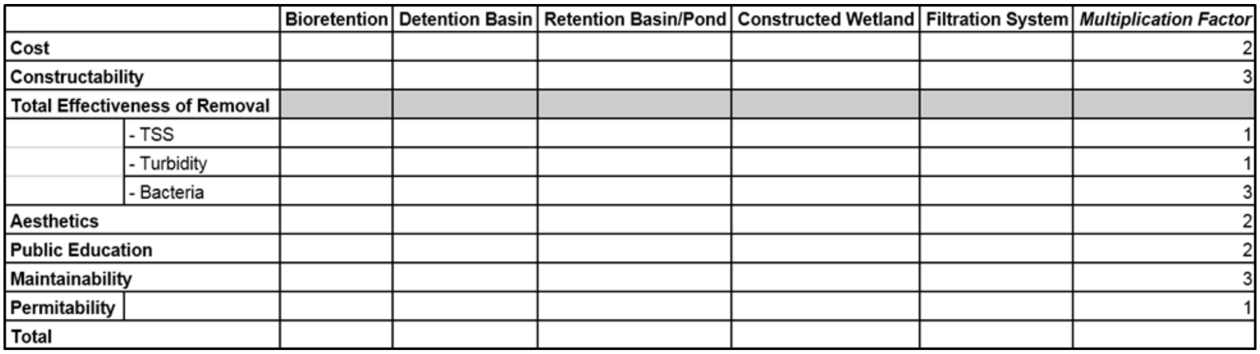
In order to reduce contamination in the CMP stream, it is helpful to know the origin of the pollutants we found to be affecting it the most. To accomplish this, we first conducted research on what has previously been known to produce the constituents we found in the CMP stream. Next, we researched historical land uses located within the watershed. We gathered this information from old maps provided by the Town of Framingham. ArcMap GIS was used to identify the current land uses within the watershed. All of this information allowed us to understand how the surrounding land was and is used as well as how these uses may impact the water quality of the stream. We compared our research about what typically produces the stream's specific constituents to the watershed to determine potential sources of contamination. Knowing these potential sources within the watershed provided us with some of the necessary criteria to develop a Best Management Practice (BMP).

3.3 Evaluate, select, identify, and design a BMP for the stream to reduce stormwater loadings and to improve the overall water quality of the pond.

The final step in our project was to design a BMP for the CMP stream to reduce stormwater loadings and to improve the overall water quality of the pond. In order to do this, we first investigated different types of BMPs that were best suited for the stream. Once we obtained the results from our water samples, we analyzed the types of constituents and the stormwater loads in order to determine the best available treatment options. We also examined and assessed other BMPs that are currently used in the Town of Framingham, the types of contaminants they address, and their effectiveness. With this information, we decided if the best option was to design a treatment system for the stream itself or at the source of the contamination. After the site of the BMP was chosen, we rated the different types of BMPs based on a point scale that we developed including factors such as cost, constructability, effectiveness of removal, aesthetics, public education, maintainability, and permitability.

The categories were chosen based on the input given by Town of Framingham officials and our research. Cost was the first category chosen because it determines the level of intricacy our BMP can have, and the Town would be less likely to approve a plan that is considerably more expensive. The second category chosen was constructability because the ability to build our BMP was a major factor, which takes into account the total space available and the resources needed. Total effectiveness of removal considers the constituents that were found to be above standards and therefore were a concern. Aesthetics was chosen because the site for the BMP is next to a main road and will be in direct view of a future bike path. It was preferable for the BMP to be aesthetically pleasing so that it will not deter citizens from visiting the area. The public education category was suggested by Framingham officials because the BMP site has potential for encouraging citizens to learn more about pollution and stormwater runoff. Aesthetics and public education go hand-in-hand because both of these factors will determine the amount of people drawn to this area. Maintainability looks to the future of the BMP design and helped decide which BMPs would be easiest to take care of and have infrequent maintenance costs. The last category was permitability to ensure that the BMP chosen would not have legalities that would prevent its construction.

Each team member gave the six categories a multiplication factor of 1-3, where a value of one was considered to be the least important and three was considered to be the most important. The factors were discussed among the members in order to decide which categories would be ranked the highest. The BMP designs were chosen after research and a meeting with the Framingham officials. They were chosen because they are common, effective, or currently being used in Framingham at other locations. Each BMP was given a ranking of 1-5, with one as the worst in each individual category. The BMPs were ranked based on research, and this ranking was multiplied by the categories' multiplication factor. The BMP with the highest overall score was chosen as our design. Figure 7 shows the shell of the BMP ranking chart that our team developed. Once the BMP was chosen, we determined the exact location and developed its design specifications, including the approximate layout and sizing of all components. The design was then presented to Framingham officials for approval. The following chapter contains the results of our objectives.



	Bioretention	Detention Basin	Retention Basin/Pond	Constructed Wetland	Filtration System	*Multiplication Factor*
Cost						2
Constructability						3
Total Effectiveness of Removal						
- TSS						1
- Turbidity						1
- Bacteria						3
Aesthetics						2
Public Education						2
Maintainability						3
Permitability						1
Total						

Figure 7: BMP Ranking Chart

Chapter 4.0 Results

This chapter contains the results of our flow quantification and modeling, field and laboratory data, stormwater load estimations, potential pollution sources, and BMP selection. These results were analyzed to determine possible solutions to improve the water quality of Farm Pond and the surrounding waterbodies.

4.1 Flow Quantification & Modeling

This section includes the results of our watershed delineation and the estimations from the watershed runoff for various precipitation events. This process involved determining the land use and soil types, a curve number, and a time of concentration for the watershed. Models were completed for each wet weather event as well as for 25, 50, and 100 year storms.

4.1.1 ArcMap GIS

Our ArcMap Geographic Information System (GIS) analysis of the contours and the Framingham stormwater drainage system allowed us to determine the Cushing Memorial Park (CMP) stream watershed delineation. Figure 8 shows the watershed location in relation to the whole Farm Pond subbasin and includes waterbodies, the stormwater drainage system, roads, and contours. Figure 9 shows most of the same characteristics but does not include contours, allowing the other features to be more visible.

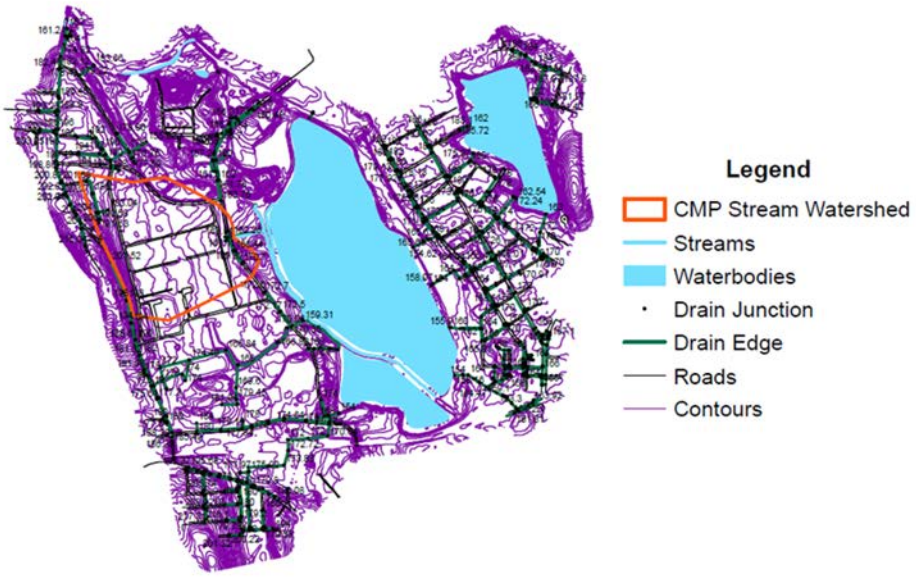


Figure 8: CMP Stream Watershed Delineation

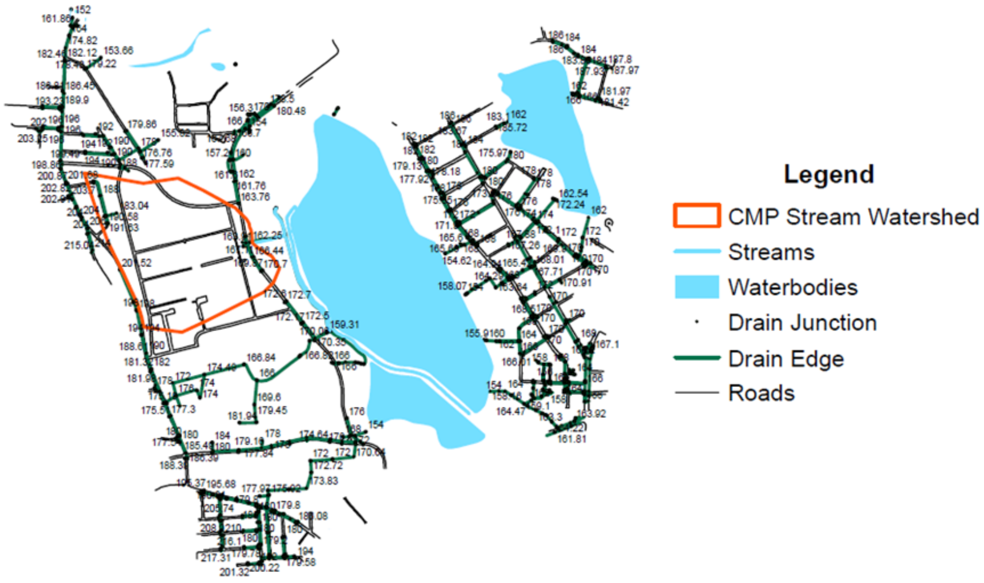


Figure 9: CMP Stream Watershed Drain System

The CMP stream watershed land use and soil types are shown in Figure 10 and Figure 11, respectively. A table in Appendix D, exported from ArcMap GIS, shows the area of each land use with each soil type. For any soil type that was listed as null on ArcMap GIS, we estimated its type based on the surrounding soil types. Table 3 shows the final areas used for each land use and soil type, including those that were estimated. These areas were later used to determine a curve number (CN) in HydroCAD.

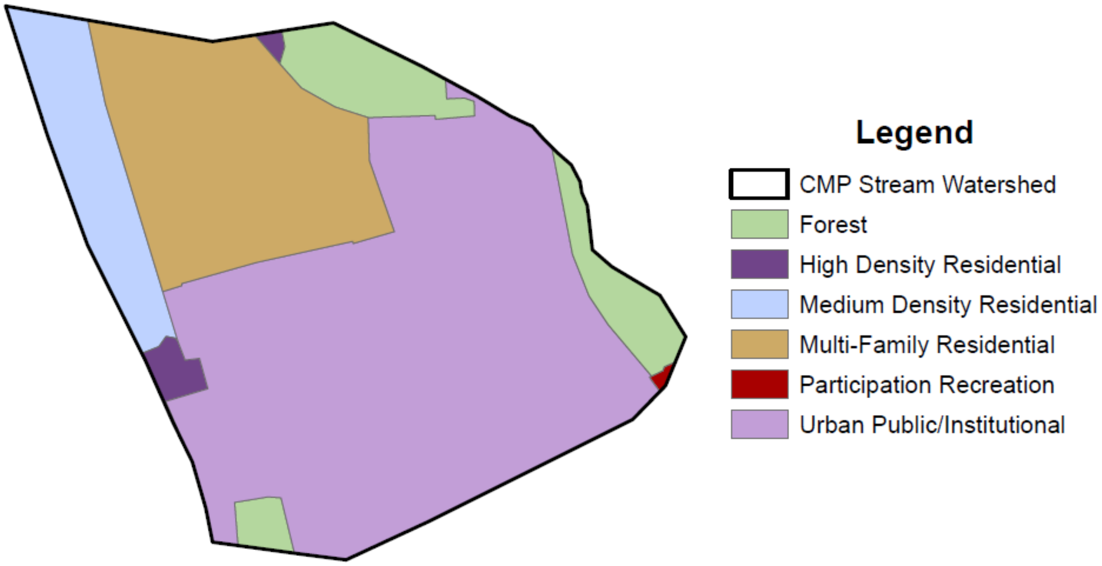


Figure 11: CMP Stream Watershed Land Use

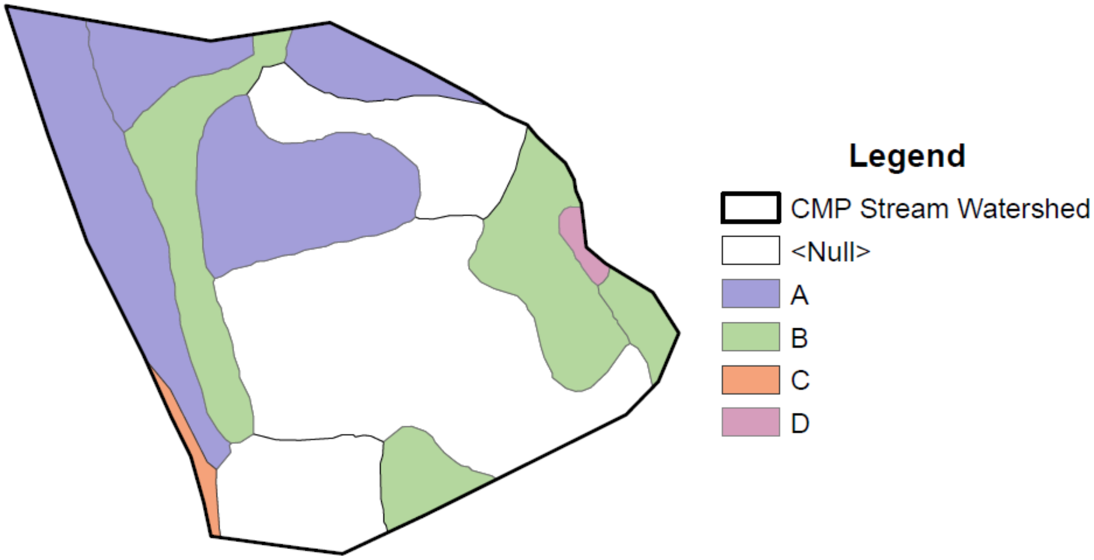


Figure 10: CMP Stream Watershed Soil Types

Table 3: Soil Groups and Land Uses With Estimated Null Values

Soil Type	**Forest**	**High Density Residential**	**Medium Density Residential**	**Multi-Family Residential**	**Urban Public - Institution**	**Participation Recreation**
A	4.63	0.68	7.11	12.27	18.47	0.00
B	2.31	0.24	0.00	5.45	26.50	0.11
C	0.00	0.10	0.01	0.00	0.67	0.00
D	0.55	0.00	0.00	0.00	0.02	0.00
Total	7.49	1.02	7.12	17.72	45.66	0.11
Modeled as:	Fair Condition	1/4 acre residential	1/2 acre residential	1/3 acre residential	open space >75%	open space >75%

4.1.2 HydroCAD

We used HydroCAD to estimate the runoff from the CMP stream watershed under different conditions. The rainfall amounts for 25, 50, and 100 year storms for Framingham, MA were found in the National Weather Service Technical Paper 40 (Hershfield, 1961). Data for 24-hour storms are shown in Table 4. We used this information to calculate inflows to the CMP stream. The total precipitation from each rainfall event during sampling was also used to estimate the stormwater runoff to the CMP stream. In approximately 10 hours, 1.17 inches of rain fell on November 15, 2016, and 0.46 inches of rain fell on November 29, 2016.

Table 4: Model 24-Hour Stormwater Events for Framingham, MA (Hershfield, 1961)

Storm Year	**Rainfall (in)**
5	4.5
10	5
25	6
50	6.5
100	7

The SCS TR-20 runoff method was used in HydroCAD, which involved finding the curve number for the watershed. To break up the watershed in HydroCAD, the system was modeled with two basins flowing into the CMP stream shown in Figure 12. The weighted curve number from all of the parkland and forest was 51. The curve number from the residential areas was 60. Additionally, the time of concentration was calculated for the watershed using the Kirpich equation. The time of concentration was 6.5 minutes for the residential areas of the CMP stream watershed and 18 minutes for all other areas including parkland (See Appendix E for calculations). These calculations take into account both overland and channel flow (LMBO Engineering, 2015).

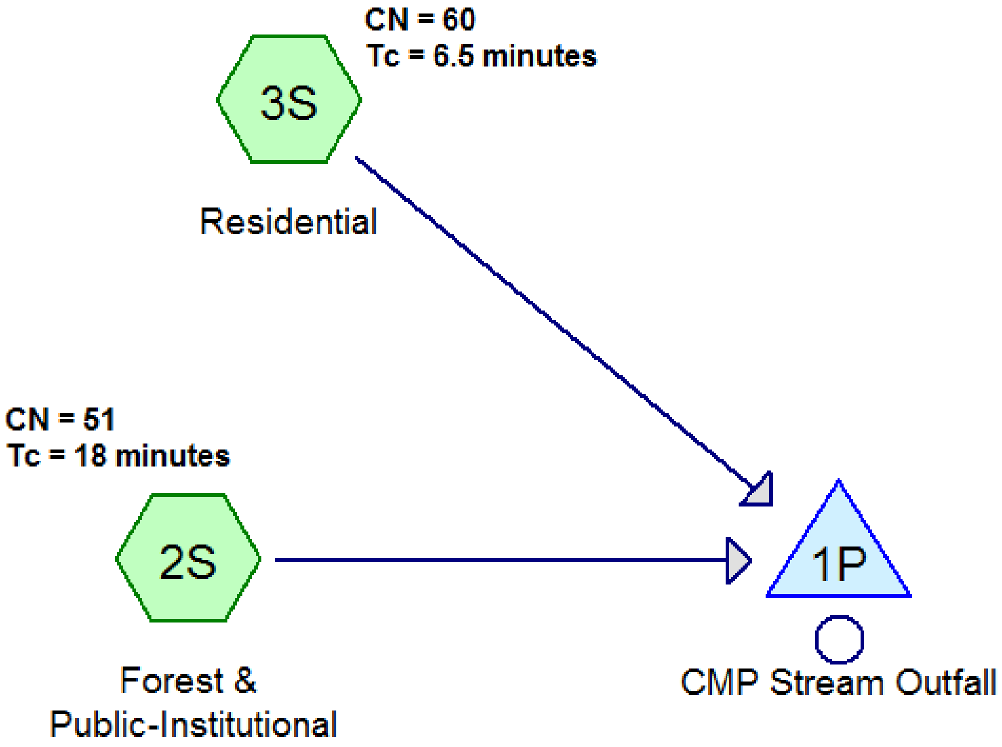


Figure 12: HydroCAD Schematic

Using the time of concentration and the weighted curve number, various HydroCAD runs were completed to estimate the runoff from the CMP stream watershed for each stormwater event. The inflows to the CMP stream are shown in Table 5.

Table 5: CMP Stream Inflow Estimates for Different Stormwater Events

Storm Year (Yr)	**Inflow (acre-feet)**
5	5.46
10	6.79
25	10.1
50	11.9
100	13.7
11/15/16 Sampling	0.615
11/29/16 Sampling	0.176

4.2 Field & Laboratory Data

In this section, we present the field data collected as well as the analyzed laboratory results. In order to test for and quantify constituents in the laboratory, we first sampled during two dry weather events and two wet weather events.

4.2.1 Field Results

During our sampling, we collected data using a Horiba U-52 water quality meter. The average results are shown in Tables 6 and 7 for dry and wet weather events. For raw data, see Appendix F. The temperature of the water was taken at each location, but as shown in Tables 6 and 7**,** there was no indication of any thermal correlation between the stream and the pond. There was also no correlation found between the pond and the CMP stream for conductivity, Total Dissolved Solids (TDS), and pH. Dissolved oxygen was higher in location G, which is outside the CMP watershed delineation, for both wet and dry sampling events. A conclusion can be drawn that the watershed of the southwestern portion of Farm Pond likely experiences low eutrophication. The depth in the table is based on the length of the Horiba U-52 water quality meter, not the actual depth of the waterbodies. The depth measurements were used to make a rough estimation of the increase in flow throughout the duration of the storm. These results are shown in Appendix G. The estimated flow rate based on the change in depth during the sampling was 7.54 ft^3/min on November 15, 2016 and 9.49ft^3/s on November 29, 2016.

Table 6: Average Dry Weather Results

Location	Temperature (˚C)	DO (mg/L)	pH	Conductivity (mS/cm)	NTU	TDS (g/L)	Specific Gravity (σt)	Depth (m)
A	18.60	13.01	5.70	0.80	6.90	0.25	0.00	0.05
B	13.99	11.28	5.67	0.85	7.00	0.55	0.00	0.15
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	17.61	11.54	6.70	1.97	4.65	1.27	0.00	0.23
E	12.87	9.58	6.02	0.79	8.20	0.51	0.00	1.05
F	12.48	15.17	6.62	1.99	110.00	1.29	0.30	0.50
G	12.63	16.85	7.26	1.73	28.50	1.16	0.20	0.15

Table 7: Average Wet Weather Results

Location	Temperature (˚C)	DO (mg/L)	pH	Conductivity (mS/cm)	NTU	TDS (g/L)	Specific Gravity (σt)	Depth (m)
A	9.82	11.63	6.45	0.30	43.90	0.20	0.00	0.04
B	9.47	10.29	6.54	0.59	18.30	0.39	0.10	0.20
C	7.37	10.24	6.53	0.46	26.30	0.42	0.15	0.10
D	8.30	12.57	6.88	1.44	12.05	0.93	0.48	0.16
E	7.90	11.53	6.49	0.84	18.38	0.58	0.23	0.44
F	9.44	14.56	7.06	1.86	71.50	1.00	0.45	0.38
G	10.89	18.40	6.89	1.84	12.02	1.20	0.50	0.28

When collecting the field data, there were several factors that may have caused variations in the data. The amount of time the water quality meter was left in the water was the most important factor. Because of external factors such as wind and any movement by the samplers, the meter never read stable numbers in all of the testing categories at once. When sampling, we collected the data once the meter's numbers varied the least in the temperature, dissolved oxygen, and pH categories. Additionally, the depth that the probe was inserted into the water may have changed between samplings. In some cases, depending on if the probe laid horizontally or vertically in the water, the depth measurement may not be as accurate. Due to the variations in our field measurements and large standard deviations, we decided our laboratory data would be more accurate. This was because we could ensure quality control of each experiment by testing duplicate samples.

4.2.2 Laboratory Results

Once the laboratory tests were completed, the results were compiled and are analyzed further in this section. We determined which constituents were of higher concern based on known standards. Graphs showing the comparison of the levels of constituents at the sampling locations to these standards are shown in Appendix I. The raw laboratory results are provided in Appendix H. Almost none of the samples had levels of constituents below the standard detection limit. Several of the constituents were determined to be below the known standards of concern, so these constituents were not seen as a major impairment to the water quality of the CMP stream and Farm Pond.

4.2.2.1 Constituents Below Standards of Concern

With the help of the Town of Framingham, we were able to eliminate chloride as an influence on the CMP stream because the chloride was only found in the pond (Figure 13), and the Town knows that it likely comes from a nearby building where salt is stored for deicing of roads in the winter (K. Reed & J. Barsanti, personal communication, January 19, 2017). Roads salted during winter storms may also contribute to excess chloride concentrations in the pond from stormwater runoff. Based on the tests conducted, we were able to conclude that nitrate, total phosphorus, bromide, sulfate, phosphate, ammonia, and fluoride were not likely significant influences affecting the CMP stream and Farm Pond. We were able to determine this because all these constituents were found to below the level of concern. However, these constituents may still contribute to the overall water quality and nutrient levels in the waterbodies in Framingham.

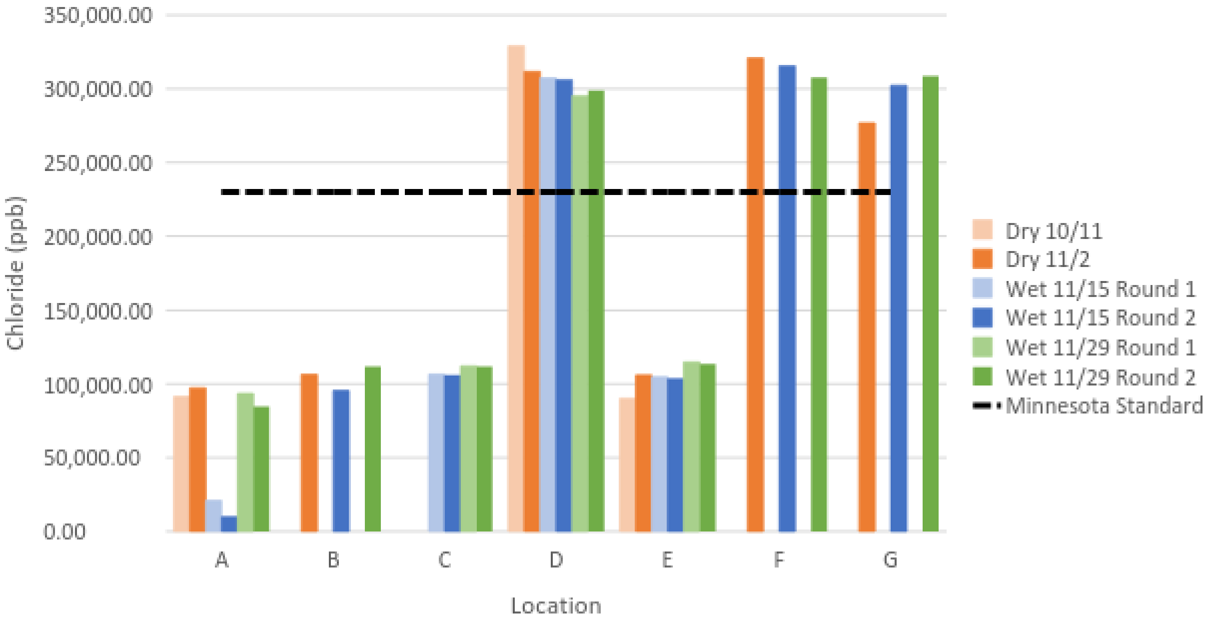


Figure 13: Chloride Concentration Comparison

4.2.2.2 Constituents of Concern

The main constituents of concern were Total Suspended Solids (TSS), total coliforms, E. coli, and turbidity. The first constituent that was found to be above standards was Total Suspended Solids (TSS). The standard of 41 mg/L was taken from the mean runoff concentration from rural highways (Soil & Water Conservation Society, 2016). As seen in Figure 14, the stormwater loads exceeded this average at locations C, D, and G (locations can be found in Figure 3). A possible conclusion for these outliers is that sediment in the pond at locations D and G was disturbed by sampler movement, causing a higher TSS result. Location C was observed to be full of leaves and other small organic matter, as shown in Figure 15. This could have also skewed the TSS results.

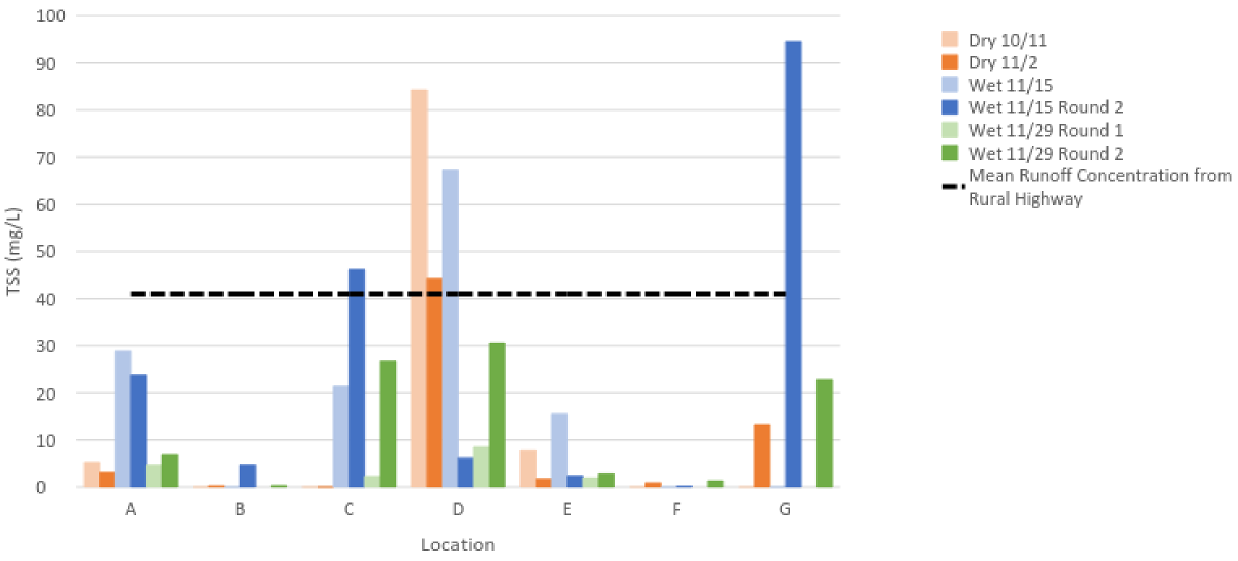


Figure 14: Total Suspended Solids Comparison

Figure 15: Location C Conditions

Another constituent of concern was the bacteria count for total coliforms and E. coli. The standard used for total coliforms was the Massachusetts Impaired Waterbody Standard, 200 Most Probable Number (MPN) per 100 mL, and all seven of the locations exceeded this amount, as shown in Figure 16. We used the E. coli standard of 406 MPN/100 mL for a lightly used waterbody from the Massachusetts Department of Environmental Protection for sample comparison

(MassDEP, 2013). As shown in Figure 17, locations A, B, and D exceeded this amount. In several locations, the number of total coliforms and E. coli detected likely exceeded the laboratory testing limit of 1,000 MPN/100mL.

The levels of total coliforms that were found in the samples collected during both dry and wet weather events were all around the same level of concern. From this observation, a possible conclusion that can be drawn is that total coliforms are most likely seeping into the CMP stream and Farm Pond through the groundwater. The levels of E. coli found in wet weather samples were significantly higher than the levels found in dry weather samples. This indicates that the E. coli is flowing into the CMP stream and the pond through stormwater runoff.

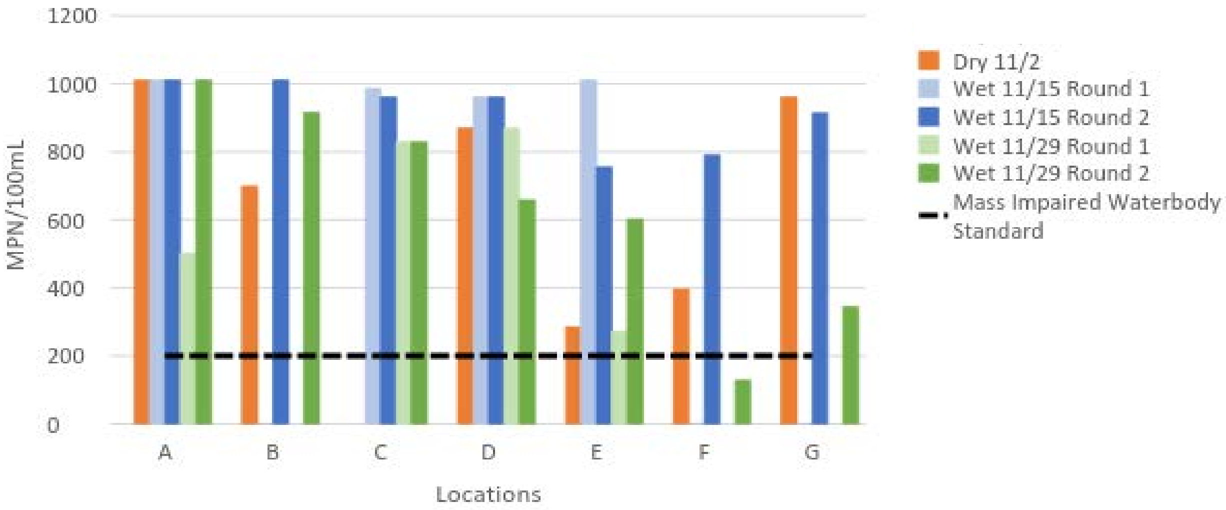


Figure 16: Total Coliforms Comparison

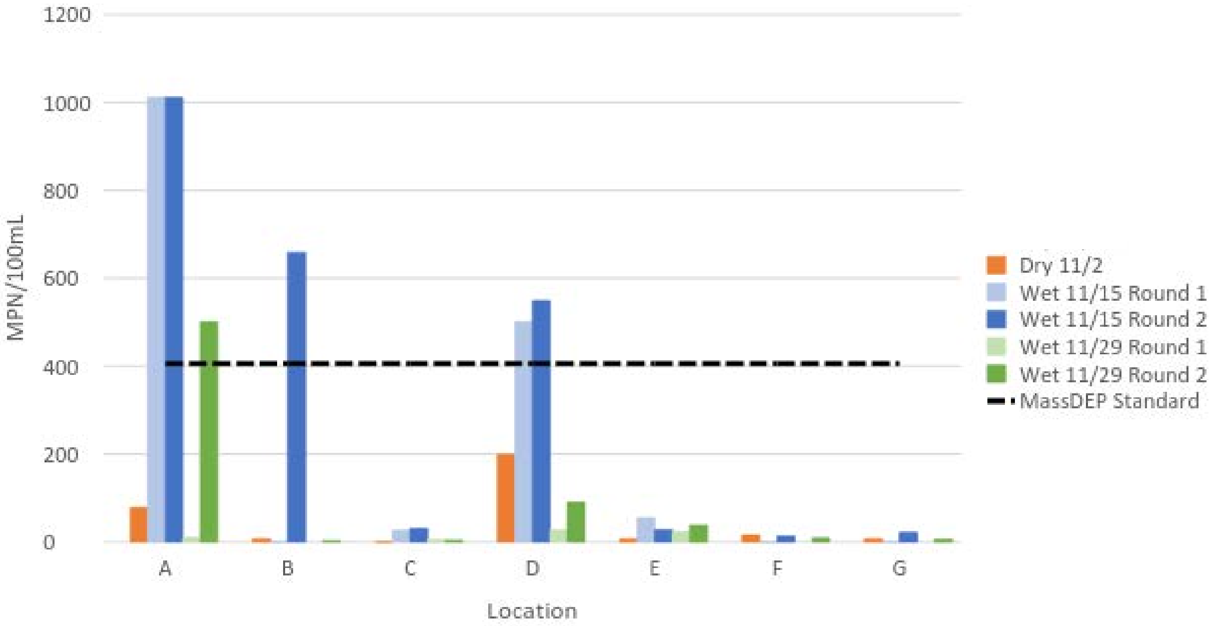


Figure 17: E.coli Comparison

Farm Pond and Eames Brook are both impaired for turbidity. However, the only standard is that it should be relatively low. Figure 18 shows that locations A, E, and G had a relatively high Normalized Turbidity Units (NTU). Similar to TSS, turbidity could have also been affected by sampler movement in the waterbody. While the levels of turbidity are low in most locations, we considered turbidity a concern due to Farm Pond’s Category 5 waterbody impairment. Once the data was analyzed, it was used to estimate the stormwater loads. Stormwater loads were calculated for all water impairments tested.

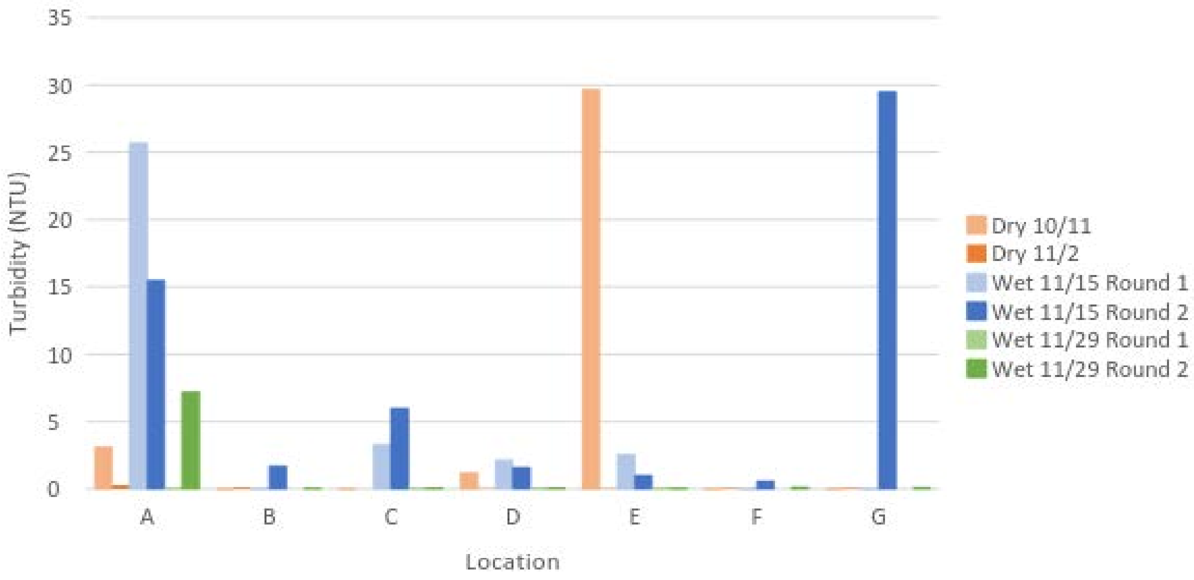


Figure 18: Turbidity Comparison

4.3 Stormwater Loads

The annual rainfall for Framingham, MA is 45.88 inches (U.S. Climate Data, 2017). Using the National Resources Conservation Service (NRCS) method, the annual runoff into the CMP stream at Point A was calculated as 49.95 inches (see Appendix J for calculations). To calculate the annual stormwater loads from precipitation, the wet weather data for each constituent from Section 4.2.2 were averaged, as shown in Table 8. This was used to approximate an average concentration that entered the stream.

Table 8: Average Constituent Concentrations at Point A for Wet Weather

Constituent	**Concentration at Entrance of Stream**
Nitrate	2.77 mg/L
Phosphate	0.081 mg/L
Bromide	0.058 mg/L
Sulfate	8.20 mg/L
Chloride	52.2 mg/L
Fluoride	0.047 mg/L
Total Phosphorus	2.83×10^{-4} mg/L
Ammonia	1.16×10^{-3} mg/L
Total Suspended Solids (TSS)	16.1 mg/L
E. coli	633 MPN/100mL
Total Coliforms	834 MPN/100mL

Using the Simple Method, described in Section 3.1.6, the annual stormwater loads for the 11 constituents studied were calculated and are shown in Table 9. Calculations are shown in Appendix J based on the yearly runoff from the NRCS result.

Table 9: Annual Stormwater Loads into CMP Stream

Constituent	**Amount**	**Units**
Nitrate	2.28×10^{3}	lbs
Phosphate	6.67×10^{1}	lbs
Bromide	4.78×10^{1}	lbs
Sulfate	6.75×10^{3}	lbs
Chloride	4.30×10^{4}	lbs
Fluoride	3.87×10^{1}	lbs
Total Phosphorus	2.33×10^{-1}	lbs
Ammonia	9.47×10^{1}	lbs
Total Suspended Solids (TSS)	1.32×10^{4}	lbs
E. coli	2.37×10^{3}	billion colonies
Total Coliforms	3.13×10^{3}	billion colonies

Additionally, stormwater loads were calculated for different stormwater events and for each sampling date. The inflows for each stormwater event, previously shown in Table 5, were multiplied by the concentrations of each constituent from Table 9 to determine the stormwater loads. The results are shown below in Table 10.

Table 10: Stormwater Loads for CMP Watershed Model Stormwater Events

Constituent	**Stormwater Loads**						
	5 yr 24hr	**10 yr 24hr**	**25 yr 24 hr**	**50 yr 24 hr**	**100 yr 24 hr**	**11/15/16 Rainfall**	**11/29/16 Rainfall**
Nitrate*	41.4	51.1	76.0	89.3	1.03x10^{2}	4.63	1.33
Phosphate*	1.20	1.49	2.22	2.61	3.03	0.135	0.039
Bromide*	0.861	1.07	1.59	1.87	2.16	0.970	0.277
Sulfate*	1.21x10^{2}	1.51x10^{2}	2.24x10^{2}	2.64x10^{2}	3.06x10^{2}	13.7	3.92
Chloride*	7.75x10^{2}	9.63x10^{2}	1.43x10^{3}	1.69x10^{3}	1.95x10^{3}	8.73x10^{2}	2.50x10^{2}
Fluoride*	0.698	0.867	1.29	1.52	1.76	7.86x10^{-2}	2.25x10^{-2}
Total Phosphorus*	4.23x10^{-3}	5.22x10^{-3}	7.76x10^{-3}	9.12x10^{-3}	1.05x10^{-2}	4.73x10^{-4}	1.35x10^{-4}
Ammonia*	1.71	2.12	3.15	3.71	4.30	0.192	2.20x10^{-2}
TSS*	2.38x10^{2}	2.96x10^{2}	4.40x10^{2}	5.17x10^{2}	5.99x10^{2}	26.8	7.68
E. coli^{+}	4.2x10^{10}	5.30x10^{10}	7.88x10^{10}	9.26x10^{10}	1.07x10^{11}	4.80x10^{9}	1.37x10^{9}
Total Coliforms^{+}	5.62x10^{10}	6.98x10^{10}	1.04x10^{11}	1.22x10^{11}	1.41x10^{11}	6.23x10^{9}	1.81x10^{9}
* Stormwater loads in lbs + Stormwater loads in MPN/100mL							

To gain a better understanding of the overall impact of the CMP Stream on Farm Pond, the stormwater loadings entering the stream were compared to estimated loads from the southern portion of the pond at Location G. Similar to the stormwater load estimations for the CMP Stream, the watershed runoff for different stormwater return periods and average pollutant concentration laboratory results were used in calculations. The results of the Location G watershed calculations, including the watershed delineation, land use and soil types, and areas, are provided in Appendix K. The estimated stormwater loads for different stormwater return periods are shown in Table 11.

Table 11: Stormwater Loads for Location G Watershed

	Return Period						
Constituent	**5 yr 24hr**	**10 yr 24hr**	**25 yr 24 hr**	**50 yr 24 hr**	**100 yr 24 hr**	**11/15/16 Rainfall**	**11/29/16 Rainfall**
Nitrate*	36.2	44.7	62.8	72.3	8.22x10^{2}	0.944	0.259
Phosphate*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bromide*	1.85x10^{2}	2.27x10^{2}	3.19x10^{2}	3.68x10^{2}	4.18x10^{2}	4.81	1.31
Sulfate*	5.28x10^{3}	6.52x10^{3}	9.15x10^{3}	1.05x10^{4}	1.19x10^{4}	1.37x10^{2}	37.6
Chloride*	1.31x10^{5}	1.62x10^{5}	2.28x10^{5}	2.62x10^{5}	2.98x10^{5}	3.42x10^{3}	9.38x10^{2}
Fluoride*	22.5	27.8	39.1	45.0	51.2	0.587	0.161
Total Phosphorus*	0.788	0.972	1.37	1.57	1.79	2.05x10^{-2}	5.62x10^{-3}
Ammonia*	1.93	2.38	3.35	3.86	4.38	5.03x10^{-2}	1.38x10^{-2}
TSS*	2.52x10^{3}	3.12x10^{3}	4.37x10^{3}	5.04x10^{3}	5.72x10^{3}	65.7	18.0
E. coli^{+}	6.00x10^{5}	7.41x10^{5}	1.04x10^{6}	1.20x10^{6}	1.36x10^{6}	1.56x10^{4}	4.28x10^{3}
Total Coliforms^{+}	2.71x10^{7}	3.34x10^{7}	4.69x10^{7}	5.40x10^{7}	6.14x10^{7}	7.04x10^{5}	1.93x10^{5}
* Stormwater loads in lbs + Stormwater loads in MPN/100mL							

The impact of the CMP stream stormwater loads were compared with the stormwater loads for location G. Graphs for each constituent for a five-year storm return period are shown in Appendix L. For the majority of constituents, the watershed around location G contributed a greater impact to Farm Pond. However, as shown in Figures 19, 20, and 21, the CMP stream watershed contributed a larger impact to Farm Pond for nitrates, total coliforms, and E. coli. Nitrates were higher at location A than G but were still below the regulatory limit. After estimating the stormwater loads flowing into the CMP stream, we researched potential sources that could be contributing to these loads.

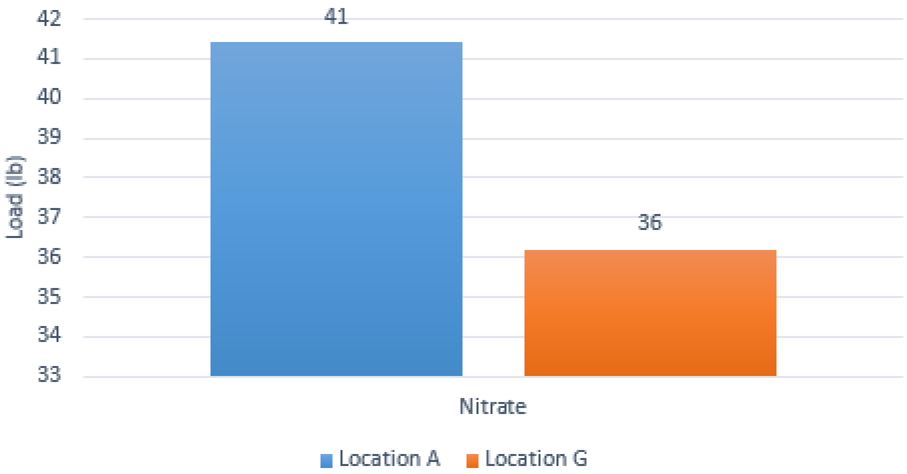


Figure 19: Nitrate Comparison at Locations A and G for Five Year Storm Return Period

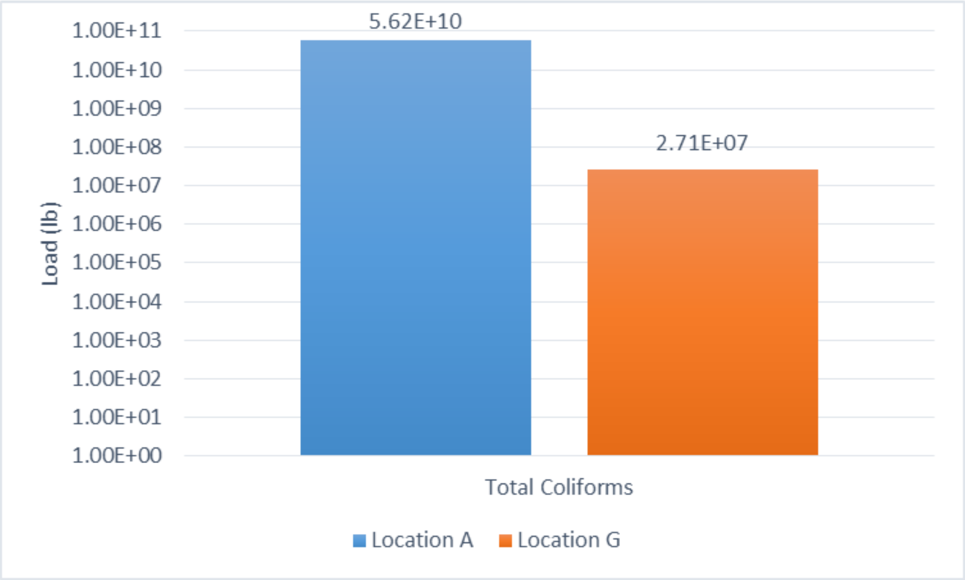


Figure 20: Total Coliforms Comparison at Locations A and G for Five Year Storm Return Period

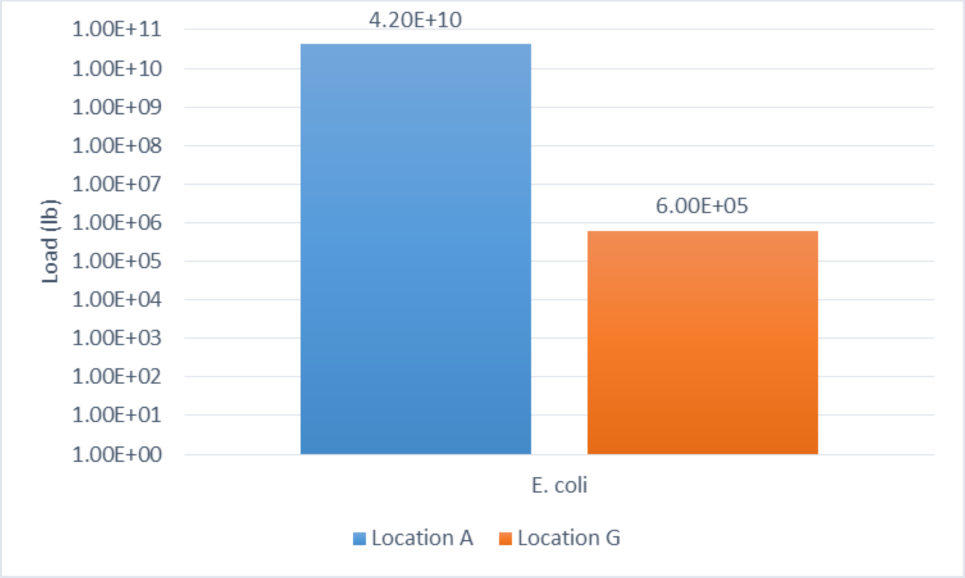


Figure 21: E. coli Comparison at Locations A and G for Five Year Storm Return Period

4.4 Potential Pollution Sources Based on Constituents of Concern

Some of the constituents of specific concern were total coliforms and E. coli. These constituents of concern could be flowing into Framingham waterbodies through the groundwater along with other constituents. Total coliforms and E. coli are indicators that a potential threat may exist. Total coliforms can be found in both the environment and animal intestines. E. coli, on the other hand, is more present in animal feces than total coliforms. The presence of both E. coli and total coliforms in water indicates that sewage may be a contributing factor (Minnesota Department of Health, 2015).

With this information, we began analyzing the CMP stream watershed to determine possible sources of contamination. Sewers, septic systems, feedlots, and animal yards are common sources of bacteria (Minnesota Department of Health, 2015). The CMP stream watershed land uses, previously shown in Figure 10, are primarily residential and park land. Human waste could enter the stormwater drainage system from old, broken sewer pipes or direct cross-connections (Framingham, n.d.). The residential areas of the CMP stream watershed discharge to public sewer systems, so these are both potential constituent sources if they are leaking. Although feedlots and animal yards are not present within the watershed, animals may still be a significant constituent contributor. Cushing Memorial Park is highly visited, and dog owners may not always clean up their dogs' waste. Additionally, waterfowl are prevalent within the proximity of Farm Pond. All of this indicates that the presence of feces in the CMP stream would not be a surprising discovery.

We also analyzed historical land uses from old maps provided by the Town of Framingham for the years of 1894, 1943, and 1951. Appendix F shows the area surrounding Farm Pond on each of these maps. From 1894 to 1943, we noticed that development expanded and roads were added. In 1943, the land across Dudley Rd. from Farm Pond, which is now Cushing Memorial Park, included wetlands. By 1951, however, Cushing Hospital had been built, and the wetlands no longer existed. This rapid development of land and elimination of natural land features throughout the years could impact the CMP stream water quality today. The numerous manmade surfaces could easily carry constituents, such as animal and human waste, to waterbodies. To address these water quality issues, we needed to select a BMP that could reduce bacteria while taking into account the characteristics of the watershed.

4.5 Best Management Practice (BMP) Selection

After reviewing the Commonwealth of Massachusetts' Stormwater Handbook and meeting with Framingham officials, we chose five BMPs to evaluate because they are common, effective, and some are currently being used in the area. The five BMPs selected were a bioretention basin, detention basin, retention basin, constructed wetland, and filtration system. Each BMP was ranked on a scale from 1-5 for each previously chosen category: cost, constructability, total effectiveness of removal, aesthetics, public education, maintainability, and permitability. We evaluated the total effectiveness of removal for Total Suspended Solids (TSS), turbidity, total coliforms, and E. coli because these constituents were areas of concern.

4.5.1 BMP Descriptions

This section describes each BMP we considered, including bioretention ponds, detention basins, retention basins, constructed wetlands, and filtration systems. A bioretention basin, which is also known as a rain garden, is a landscaped depression used to slow the flow and treat stormwater runoff. The stormwater is directed to flow into the basin. Once in the basin, the water is treated by a number of chemical, physical, and biological processes. The water is then allowed to infiltrate into the soil, nearby stormwater drains, or waterbodies. Bioretention basins require weekly maintenance at first and once established would only be reduced to monthly upkeep. They remove up to 90% of TSS, but no data could be found on constituent removal for turbidity and bacteria (Commonwealth, 2017b). Bioretention basins are aesthetically pleasing and provide opportunities for public education about the operation of the BMP.

Detention basins temporarily hold stormwater runoff and release it at a controlled rate. They are most useful for reducing flows and are not efficient removers of constituents. Detention basins require a significant amount of space, and efficiency depends partly on the type of soil present. They are low cost and require maintenance only a handful of times a year. Vegetative buffers could make detention basins more aesthetically appealing. Additionally, educational opportunities could exist with such a large, visible area. The basins would not be difficult to permit if they were designed within the guidelines and regulations regarding wetland areas, soils, and other environmental factors (Commonwealth, 2017).

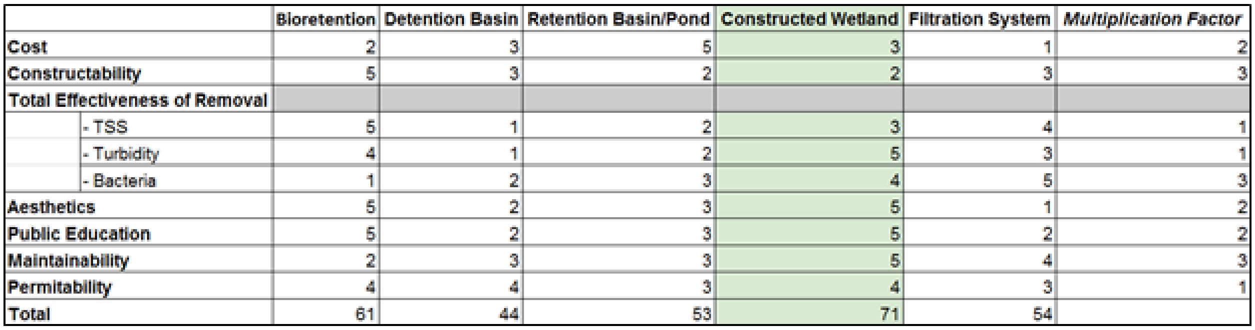
Retention basins differ from detention basins in that they permanently hold water. Because water stays in the basin for a longer period of time, pollutants are better able to settle out. Retention basins are good at removing TSS, and bacteria removal ranges from 40%-90%. Retention basins are less expensive than detention basins (Weiss, Gulliver, & Erickson, 2005). Like detention basins, retention basins require a lot of space and depend on the soil type. Maintenance is only required a handful of times a year. Since they look like ponds, retention basins are aesthetically pleasing and would be educational and permitable (Commonwealth, 2017b).

A constructed wetland consists of shallow pools that maximize pollutant uptake by temporarily storing stormwater runoff. These areas are built in such a way that supports the growth of vegetative wetland plants. The initial setup of a constructed wetland can be difficult due to the excavation and high costs depending on the topography of the area. The process is rather straightforward, but it requires a lot of area. Constructed wetlands have a high upfront cost and a low maintenance cost because only minimal maintenance is required at regular intervals. A constructed wetland can remove up to 80% of TSS, up to 75% of bacteria, and is efficient at removing soluble and insoluble particles. Some of the advantages to a constructed wetland are that they are aesthetically pleasing, support new habitats for wildlife, and provide recreational benefits. This in turn creates an opportunity for public education because citizens would be more inclined to want to learn about an aesthetically pleasing area. They could learn about stormwater runoff, invasive species, and wildlife. Lastly, acquiring a permit to build a constructed wetland would not be too difficult if it would be restoring land to its previous historic use (Commonwealth, 2017).

A filtration system is a BMP that uses media filters to remove constituents from stormwater runoff. Media filters are “typically proprietary two-chambered underground concrete vaults that reduce both TSS and other pollutants” (Commonwealth, 2017b, p. 54). One of the most important considerations of this BMP is that it can be designed to remove a number of pollutants effectively depending on the type of filter media chosen. A filtration system is relatively easy to maintain, only needing inspection twice a year for any trash and debris clogging the filter media. Filtration systems tend to be more expensive than other BMPs. The construction involves building a pretreatment chamber, a filtering bed, and a by-pass device for large stormwater flows. Along with treating stormwater, there is potential for a large scope of audience for public education because many may not know about the technology (Commonwealth, 2017).

4.5.2 BMP Selection

Based on these results from our research, we used our ranking system to complete our BMP ranking sheet, as shown in Figure 22. The highest ranked BMP was a constructed wetland with a ranking of 71 out of a possible 90. The next highest ranking BMP was a bioretention basin with a score of 61, which proves that a constructed wetland was the best option. The only category a constructed wetland did not perform well in was constructability, however this was outweighed by high performances in all other categories. Additionally, Framingham town officials concurred that a constructed wetland would be ideal for the CMP stream since the area is already set up for its implementation (K. Reed & J. Barsanti, personal communication, January 19, 2017).



	Bioretention	Detention Basin	Retention Basin/Pond	Constructed Wetland	Filtration System	*Multiplication Factor*
Cost	2	3	5	3	1	2
Constructability	5	3	2	2	3	3
Total Effectiveness of Removal						
- TSS	5	1	2	3	4	1
- Turbidity	4	1	2	5	3	1
- Bacteria	1	2	3	4	5	3
Aesthetics	5	2	3	5	1	2
Public Education	5	2	3	5	2	2
Maintainability	2	3	3	5	4	3
Permitability	4	4	3	4	3	1
Total	61	44	53	71	54	

Figure 22: BMP Ranking

Based on our results, we developed a number of recommendations, including a constructed wetland BMP design, for the Town of Framingham. Our design recommendations are provided in the next chapter.

Chapter 5: Design Recommendations

This chapter presents our design recommendations for building a constructed wetland to reduce bacteria and improve the overall water quality of the Cushing Memorial Park stream. It includes information on the design specifications, costs, construction sequence, and maintenance. Additionally, the plants required for the constructed wetland, the education, and permitability of the wetland are discussed.

5.1 Design Specifications

The majority of the information used to design our constructed wetland was developed using guidelines from the Massachusetts Department of Environmental Protection (MassDEP) Stormwater handbook. The type of wetland we chose to design was a shallow marsh because it provided extra contact time to treat for bacteria and did not require a large flow. Sampling locations A and B (see Table 2 and Figure 4) were chosen as the site of our Best Management Practice (BMP) because it is right before the town boundary line, and there is already a land bridge that would provide easy access for maintenance as well as a viewing area for the public. The distance from the inlet to outlet was measured using ArcMap Geographic Information System (ArcMap GIS) and was approximately 360 feet. According to the MassDEP guidelines, the length to width ratio of the wetland had to be 2:1, so we chose our width to be 180 feet. The watershed surface area was a known value, so we calculated our wetland surface area to be 64,800 ft^2. The ratio between these values was within the accepted limits. Based on communications with Framingham officials, the BMP was designed for one inch of rain. The total volume for a one-inch storm over 24 hours was estimated using the hydrologic modeling software, HydroCAD, and used for the % Water Quality Volume (WQv), which was 21,475 ft^2. The total area of each attribute was divided by the necessary percentage amount to determine the minimum depth required. Each depth was below the required depths, so the minimum value was used for all attributes. The next step was to calculate the area of each aspect of the wetland and create the layout. All of these values can be seen in Table 12 (Commonwealth, 2017b).

The deep water zone consists of the sediment forebay, deep water channel, and micropool. All three of these zones support little vegetative life but can have floating vegetation. The sediment forebay is located at the beginning of the BMP because its primary purpose is to allow sediments to settle before the flow enters the other portions of the wetland; as such, the forebay is essentially considered a settling basin. The deep water channel directs the flow throughout the BMP. The micropool is located at the downstream end of the BMP to allow for additional sedimentation to prevent any further particles from clogging the outfall. The high and low marsh regions are used to support emergent wetland plants at different depths. The high marsh allows for more species and a higher density of plants than the low marsh. The semi-wet zone lies above the normal pool elevation and allows for a smooth transition into the surrounding grass and shrubbery. It also supports a variety of wetland plants (Commonwealth, 2017).

Table 12: Constructed Wetland Design in Comparison to MassDEP Standards

Design Criteria	**MassDEP Handbook**	**Our Design**
Minimum Drainage Area (acres)	>= 25	72.9 acres ~ 3,175,524 ft^2
Constructed Wetland Surface Area/Watershed Area Ratio	>= 0.02	64,800 ft^2 / 3,175,524 ft^2 ~0.02
Length to Width Ratio (Minimum)	>= 2:1	360 feet:180 feet ~ 2:1
Outlet Configuration	Reverse slope pipe or hooded broad crested weir	Weir
	% Surface Area (ft^2)	
Sediment Forebay	5%	3,240 ft^2
Micropool	5%	3,240 ft^2
Deep Water Channel	5%	3,240 ft^2
Low Marsh	40%	25,920 ft^2
High Marsh	40%	25,920 ft^2
Semi-Wet Zone	5%	3,240 ft^2
	% WQv Volume	
Sediment Forebay	10%	>10% ~ (12,960 ft^3)
Micropool	10%	>10% ~ (12,960 ft^3)
Deep Water Channel	10%	>10% ~ (4,860 ft^3)
Low Marsh	45%	>45% ~ (25,920 ft^3)
High Marsh	25%	>25% ~ (12,960 ft^3)
Semi-Wet Zone	0%	0
	Depth (ft)	
Sediment Forebay	4-6 feet	4 feet
Micropool	4-6 feet	4 feet
Deep Water Channel	1.5-4 feet	1.5 feet
Low Marsh	0.5-1.5 feet	1 foot
High Marsh	Up to 6 inches	0.5 feet
Semi-Wet Zone	0	0

Several different layouts were evaluated, and the selected layout is pictured in Figure 23 with the schematic in Figure 24. The approximate placement of the wetland in relation to Farm Pond and Dudley Road is shown in Figure 25. Each individual attribute, including the sediment forebay, micropool, deep water channel, low marsh, high marsh, and semi-wet zone, has individual schematics and drawings that are located in Appendix N. An emergency spillway will be directly connected to the wetland that will empty into Farm Pond. A potential location is shown in Figure 25, although the final placement of the spillway will be up to the discretion of the Town of Framingham after a thorough survey of the area can be done to assess elevations and best placement. Because the emergency spillway will enter either Eames Brook or Farm Pond, the town property line will be crossed, so permission will need to be granted by the Commonwealth of Massachusetts. A broad crested weir will be located between the sediment forebay and the deep water channel to direct the flow. Another broad crested weir will be located immediately upstream of the micropool. The weirs should be proportional to the rest of the wetland and should be located one foot below the normal water level. No further specifications regarding the weir were provided in the MassDEP Stormwater Handbook (Commonwealth, 2017). Safety benches will be placed in 10-foot intervals near the deep water channel, sediment forebay, and micropool. Since an access road already exists for Farm Pond off of Dudley Road, an extension from the road to the constructed wetland will need to be constructed. For maintenance of the weirs near the sediment forebay and the outfall, pathways will be needed. A pathway to the weir near the sediment forebay can be extended from the bike path to provide access. This pathway can also be used as a viewing platform for the public. A side view of the wetland is shown in Figure 26.

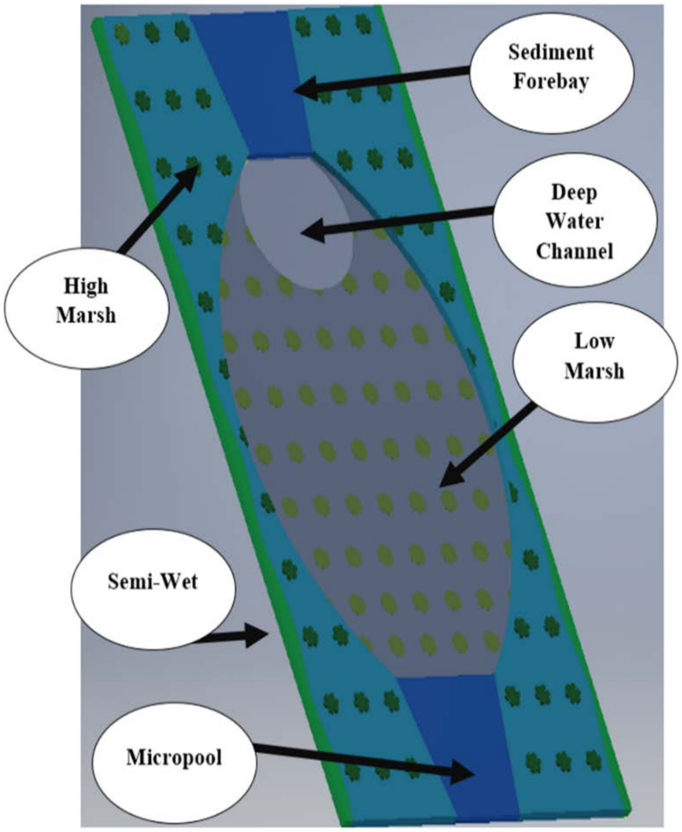


Figure 23: Shallow Marsh Constructed Wetland

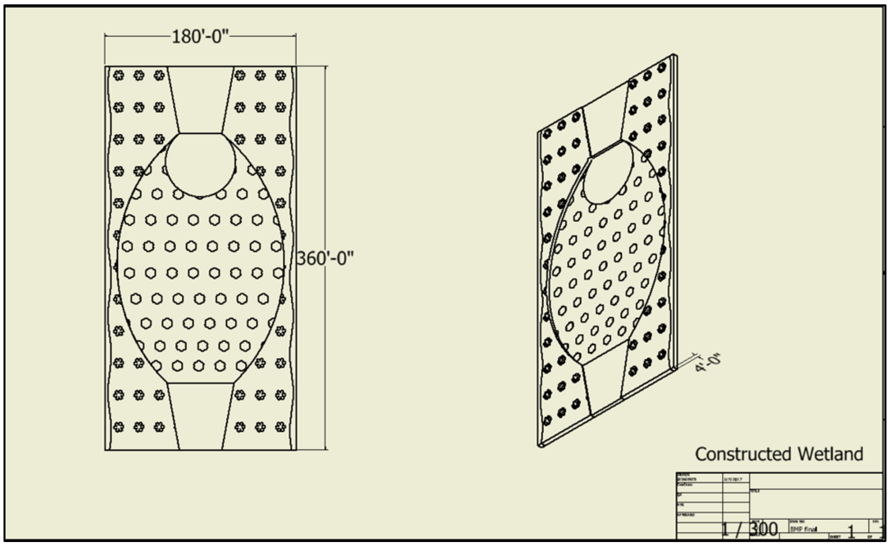


Figure 24: Schematic of the Constructed Wetland

Figure 25: Aerial View of Constructed Wetland over CMP Stream with Emergency Spillway

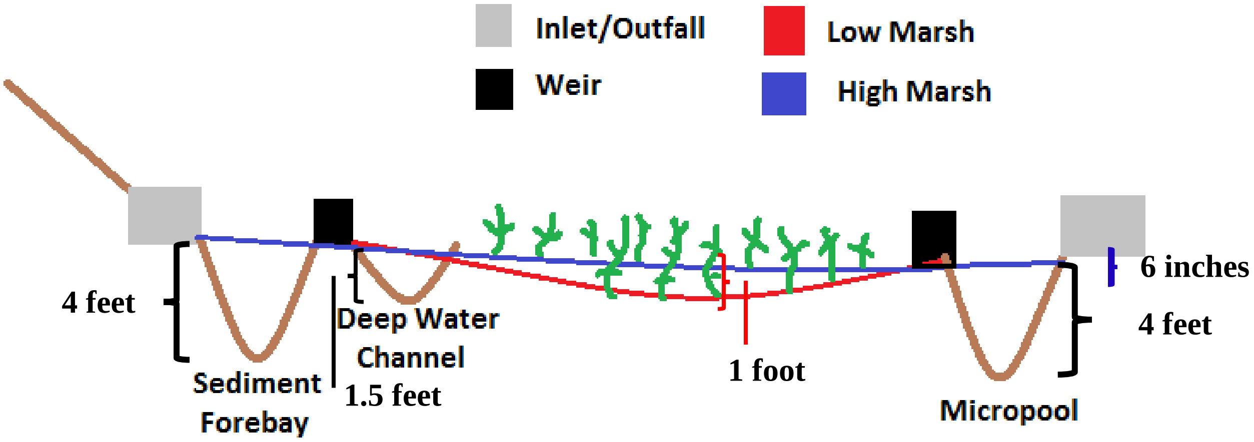


Figure 26: Side View of BMP

The design presented is not the only possible layout of the constructed wetland. The areas and depths of each attribute would need to stay relatively the same in order to fully treat the water. The sediment forebay needs to stay at the inlet of the stream and the micropool needs to stay at the outfall. Semi-wet regions must remain on the outskirts of the wetland, adjacent to the high marsh with the low marsh in the center. However, each attribute can be arranged in different shapes to accommodate any unforeseen problems and better match the contours of the land. A rectangle is not the only possible shape for the constructed wetland, and the deep water channel does not need to remain sinuous. A complete site survey of the land would need to be done along with soil samples to determine the best possible shape of the wetland.

5.2 Vegetation

To determine what plans to include in the CMP stream constructed wetland, we researched the plants that were used in the Alewife Reservation Constructed Wetland in Cambridge, Massachusetts. We focused our research on this because these plants are already effectively used in Massachusetts, and we were able to determine a number of plants that could be used in the CMP stream constructed wetland. We divided the plants into four separate locations in the wetland based on the depths in which they best grow. Deep water channel plants grow in one foot to three feet of water, low marsh plants grow in six inches to one foot of water, high marsh plants grow in six inches of water, and semi-wet plants grow along the outskirts of the wetland (The Friends of Alewife Reservation, n.d.). All of the chosen plants are native species to the Northeast United States and should thrive in the weather and soil conditions in Framingham. Stormwater wetlands should have a diversity of plants for aesthetic, invasive species and pest resistant, and disturbance recovery purposes (EPA, n.d.). A summary of the types of plants, including their sun and soil needs, are provided in Table 13.

Table 13: Wetland Plants

Plant	Wetland Location	Sun Needs	Soil/Water Needs	Citation
Wool Grass	High Marsh	Full sun to part shade	Moist to wet soils or shallow water	(Missouri Botanical Garden, n.d.d)
Tussock Sedge	High Marsh	Full sun to part shade	Moist to wet soils or standing water	(Missouri Botanical Garden, n.d.b)
Marsh Marigold	High Marsh	Full sun to part shade	Wet, boggy soils or shallow water	(Missouri Botanical Garden, n.d.a)
Riverbank Wildrye	High Marsh	Part shade	Medium to wet soils	(Roundstone Native Seed, 2015)
Canada Rush	High Marsh	Part shade	Medium water use and wet soils	(Lady Bird, 2012a)
Marsh Hibiscus	High Marsh	Sun to part shade	Moist to wet soils	(Lady Bird, 2015a)
Arrow Arum	Low Marsh	Full to medium sun, average shade	High soil moisture	(Grow Native, n.d.)
Spike Rush	Low Marsh	Part shade	Moist to wet soils	(Lady Bird, 2012b)
Lesser Bur-reed	Low Marsh	Part shade	Wet soils	(Lady Bird, 2015b)
Green Bulrush	Low Marsh	Sun	Wet soils	(Lady Bird, 2009)
Blue Flag Iris	Low Marsh	Full sun to part shade	Medium to wet soils	(Missouri Botanical Garden, n.d.c)
Soft Stem Bulrush	Low Marsh	Sun	Wet soil to standing water	(Lady Bird, 2016b)
Hard Stem Bulrush	Deep Water Channel	Sun	Wet soils	(King County, 2013)
White Water Lily	Deep Water Channel	Sun, part shade, shade	Wet soils, shallow water	(Lady Bird, 2016c)
Pickerelweed	Deep Water Channel	Sun, part shade	Moist, wet soils	(Lady Bird, 2016a)
Silky Dogwood	Semi-Wet	Full sun, partial sun/shade, full shade	Moist, well-drained, wet soils	(The Morton Arboretum, 2017)
Pussy Willow	Semi-Wet	Full sun, partial shade	Moist, well-drained soils	(Arbor Day Foundation, 2016)
Black Chokeberry	Semi-Wet	Full sun, partial shade	Poorly-drained to well-drained and moist to wet soils	(The University of Minnesota, 2017)
Sweet Pepperbush	Semi-Wet	Shade to sun	Wet to moist soils	(eNature.com, 2007)
Meadowsweet	Semi-Wet	Sun, partial shade	Moist soils	(Softschools.com, 2017)
Highbush Blueberry	Semi-Wet	Semi-shade or no shade	Well-drained, moist soils	(Plants for a Future, 2012)

5.3 Costs

The general cost of a constructed wetland is between $30,000 and $65,000 per acre (USEPA Wetlands Fact Sheet, 1999). This only includes construction and pre-construction costs. Average pre-construction costs are minimally around $5,565, which includes preparing the site for construction and soil testing such as geotechnical soil investigations. The soil permeability needs to be tested in the proposed constructed wetland site to make sure that excessive infiltration will not cause the wetland to dry out. To help prevent this, the site should have highly compacted subsoil or an impermeable liner to minimize infiltration. If the site has soil types C and D, they are suitable without modification and would lower construction cost. If the site has soil types A and B, the site may require a clay or synthetic liner. The soil types around the CMP stream are generally types B and D. Another added cost would be if the site requires organic soil. Organic soils are used in constructed wetlands because they can serve as a sink for pollutants and have a high water holding capacity. It will also facilitate plant growth while possibly hindering invasion of undesirable species (Pennsylvania DEP, 2006). Other additional work that may not be included in this cost is the annual upkeep for the site. These costs can average $370 for both the annual maintenance and the intermittent maintenance. The price could increase depending on the number of severe storms in a year or the amount of damage done to the site. These numbers were found from the Maryland Department of the Environment spreadsheet for BMP design costs (2011).

5.4 Construction

When starting the process of constructing a wetland, the first step is to separate the wetland area from the contributing drainage area. This means that all channels and pipes have to be rerouted away while the wetland is constructed and until it is stable enough to handle the flows. The next step is to excavate the area of all vegetation. In our design, it would mostly require removal of trees and roots. All the stump holes and crevices will need to be backfilled. From there, the bottom of the constructed wetland would be excavated to the desired elevations. The fourth step would be to install surrounding embankments and inlet and outlet control structures. Once this has been completed, the subsoil has to be graded and compacted. The next step is to apply the grade planting soil. Aquatic plants can be sensitive to depth, so matching the design grades is crucial. Once completed, the geotextiles should be applied as well as other erosion-control measures. The second to last step is to implement the planting plan, which includes applying seeds, plants, and mulch. Lastly, to keep the constructed wetland in good condition for optimal constituent removal, a maintenance and monitoring plan is required (Pennsylvania DEP, 2006).

5.5 Maintenance

In order for a shallow marsh constructed wetland to be successful, it has to be maintained. During the first year of operation, there is more maintenance required than subsequent years. Vegetation should be inspected every two to three weeks during the first growing season to ensure the plants are healthy. The BMP should also be inspected at least four times a year and after any major storms within the first two years of operation. A major storm is defined as precipitation that is greater than two inches in twenty-four hours (Pennsylvania DEP, 2006). When completing an assessment for the constructed wetland, the vegetation, erosion, flow channelization, bank stability, inlet/outlet conditions, and sediment/debris accumulation should be inspected (Pennsylvania DEP, 2006). It is common within the first three years to need to complete basic gardening tasks on the wetland and buffer vegetation, such as weeding, mulching, and replanting. If a clay liner is incorporated into the design depending on the results of the soil investigation, it would only need to be inspected biannually to ensure proper function.

To improve the constituent removal of the BMP in the summer, annual vegetation can be harvested while being careful to minimize sediment disturbance on the bottom of the wetland. This allows time for the plants to grow before winter. Additionally, sediments should be occasionally monitored in the forebay. Once the sediments reach 50% of the forebay capacity, they should be removed; this occurs usually once every 3 to 7 years (Pennsylvania DEP, 2006).

5.6 Education

A key component of the constructed wetland design is to incorporate a public education plan. A constructed wetland provides more than just stormwater management. It provides an opportunity to educate an environmental justice area as well as future generations of students who will visit the site. The site provides a field trip location for schools to educate students about the ecosystems that naturally remove constituents from the environment. The constructed wetland also provides an opportunity to teach students about stormwater management and the environmental impacts of their everyday decisions. There is also a potential to learn about physics and engineering since the constructed wetland incorporates weirs which affect the velocity of the water flow through the system. In order to educate the general public, there should be signage along the bike path explaining the broader impacts of the constructed wetland. This signage should include information on the different plants used in the wetland, the new biodiversity of the land, and the stormwater management improvements. The frequent users of Cushing Memorial Park and the bike path will also appreciate and enjoy the natural aesthetics of the wetland.

5.7 Permitting

Before construction can proceed, several permits need to be obtained. We recommend the completion of a survey on the land to determine the exact location of the land boundary between the Commonwealth of Massachusetts' land and the Town's property. Additionally, the historical society should be consulted or at the very least be made aware of the construction plans. Because a constructed wetland would return the CMP stream area to its original land use, we do not anticipate any issues to get the historical society’s approval for the project to proceed. This construction would preserve the land and prevent any future construction over natural areas. The design team should communicate with the Town and State to make sure the BMP meets all relevant and applicable requirements. Additionally, we recommend that the design team makes a presentation at a town hall meeting to communicate the benefits of installing a constructed wetland and allow opportunities for citizens to voice their concerns.

Overall, we believe our shallow marsh constructed wetland is the best BMP design for Farm Pond. It is effective at treating for bacteria as well as other constituents that may impact the CMP stream and Farm Pond (Commonwealth, 2017b). It takes up the minimal required space in order to preserve the surrounding area while adding an aesthetic appeal and additional wildlife habitat. In addition to this recommended design, we address several other areas for improvement in the following chapter.

Chapter 6: Additional Recommendations & Conclusion

This short-term study on the impacts of the Cushing Memorial Park (CMP) stream on Farm Pond and its watershed can be expanded with further research. In this chapter, we discuss improvements and recommendations for future work on Farm Pond. These suggestions include updating a sampling plan, field data collection techniques, and map layers on the ArcMap Geographic Information System (GIS). We then conclude with a brief summary of our accomplishments.

6.1 Additional Recommendations

There are many benefits to creating a regular sampling plan to gather water quality data for each of the outfalls to Farm Pond. This work would include characterizing the runoff from the skate park as well as the CMP stream, which could be used as an educational tool to promote the Town's stormwater management efforts. This study would also involve a more in-depth investigation on the influence of groundwater as a potential transport mechanism for pollutants. Understanding where these pollutants may enter the groundwater would be an important factor to study. This investigation could also address the possibility of the groundwater flowing beneath the aqueduct into Farm Pond. Additionally, while some of the outfalls may not be currently accessible, Framingham can work toward identifying ways to safely access all of the outfalls. This may be difficult for some of the outfalls on the eastern side of Farm Pond because they are located next to a railroad station. Framingham officials could try to negotiate with private property owners to gain sampling access with the intent of improving Farm Pond's water quality. By adding locations to the sampling plan, more information can be gathered in order to identify which outfalls have the highest stormwater loadings contributing to the pond and how they change through every season. Additionally, a regular sampling plan would provide baseline data for any new construction projects that are built in the area. For example, once the bike path and skate park are built near the pond and the CMP stream, new sampling measurements should be taken to ensure the projects' stormwater management systems are working properly. If a constructed wetland Best Management Practice (BMP) is built at the outfall of the CMP stream, the sampling procedures and locations we used throughout this project would provide adequate data to see any changes between pre- and post-construction.

While sampling, we encountered some challenges, especially during wet weather events. We have determined some recommendations so that future samplers can avoid the same problems. Samplers should try to use a wheeled cooler to make it easier to transport all of the samples. We recommend this because the samples became heavy by the end of sampling. Another way to address this issue is to start with the farthest location and work your way back to the location closest to your vehicle. Alternatively, you can take smaller bags of bottles to the site and leave the cooler near the car. During wet weather events, consider having an extra person available whose only job is to take notes on the field data. This person should bring an umbrella or an E-Z Up canopy tent so that the notebook for recording field data and notes will stay dry. He or she should also bring back-up pens or sharpies in case one stops working. When collecting the turbidity samples, make sure large debris such as big pieces of leaves or twigs are not collected in the sampling containers. Large pieces of debris can skew the laboratory results and cause outliers in the data. It is important to keep in mind that the coliform tests are the most time sensitive because they have to be completed within 24 hours of collecting the samples. We recommend either preparing and placing the samples in the incubator when you get back from sampling or immediately the following morning. We also recommend preparing two dilutions of each sample along with a normal sample. This will help to identify a more accurate estimation for samples above 1,000 MPN/100mL.

During our project, determining the flow of the stream was one of our difficulties. One way to improve upon our flow measurement techniques would be to use a Hydrolab HL4 Multiparameter Water Quality Sonde. Samplers would take it out to the sampling site and leave it in the water for the duration of the storm event. One concern about using this method is that it would be left out in a public area where it is susceptible to theft. In this way, it is possible to monitor any change in flow even when you are not physically at the site. Another way to obtain more accurate flow measurements would be to improve the depth measurement techniques by measuring from the same reference point locations.

In order to estimate a more accurate depiction of the curve numbers for the watershed, it would be helpful to update the GIS soils layer. This would be valuable information to have, but it may be difficult to accomplish. As was shown in Figure 11, there were large data gaps of area not classified as one of the four soil types. For the CMP stream watershed, 45% of the area was classified as null values. The Location G watershed did not have soil classifications for 76% of the land. Because we estimated the null areas’ soil types based on the next closest classified area, this could have skewed the curve number values from their actual values. While this may not lead to significant impacts on the watershed runoff estimations, improving the quality of the GIS soil layer would be more accurate for detailed modeling. It is important to note that the Massachusetts state GIS soil layer was used in our modeling, which provides a general overview of the area but was not detailed enough for our purposes. We suggest that Framingham use the state GIS soil layer as a baseline for making their own town soil layer. This would be helpful because Framingham's GIS land use and contour layers were much more detailed than the state GIS layers.

While our project focused on the specific CMP stream watershed area, these additional recommendations can be used to characterize the nature of Farm Pond's surrounding area and other outfalls into the pond. The results from these recommendations can be used to expand the scope of future investigations on Farm Pond and its water quality.

6.2 Conclusion

Throughout this project, we worked to identify the impacts of urbanization on the water quality of Farm Pond and its surrounding waterbodies and to evaluate and design a Best Management Practice (BMP) to reduce the water quality impacts of the CMP stream. The CMP stream watershed was used to estimate the watershed runoff for different storm return periods as well as the precipitation from each sampling event. Based on the laboratory results as well as the research conducted, we determined that total suspended solids (TSS), turbidity, total coliforms, and E. coli were the constituents contributing the most to the poor water quality of Farm Pond and the CMP stream. Out of all the BMPs that were ranked, we determined that a constructed wetland would be the best option to treat the pollutants of concern. Once possible sources of the pollutants were researched, we used the information to determine possible locations for the constructed wetland. We designed a constructed wetland that would improve the quality of the CMP stream and Farm Pond while providing an educational focal point for the community to enjoy. Since the Town wants to promote green infrastructure projects and raise awareness of the amenities that Farm Pond and the surrounding area can offer to its residents, a constructed wetland complements these ideals while improving the water quality of the Farm Pond watershed.

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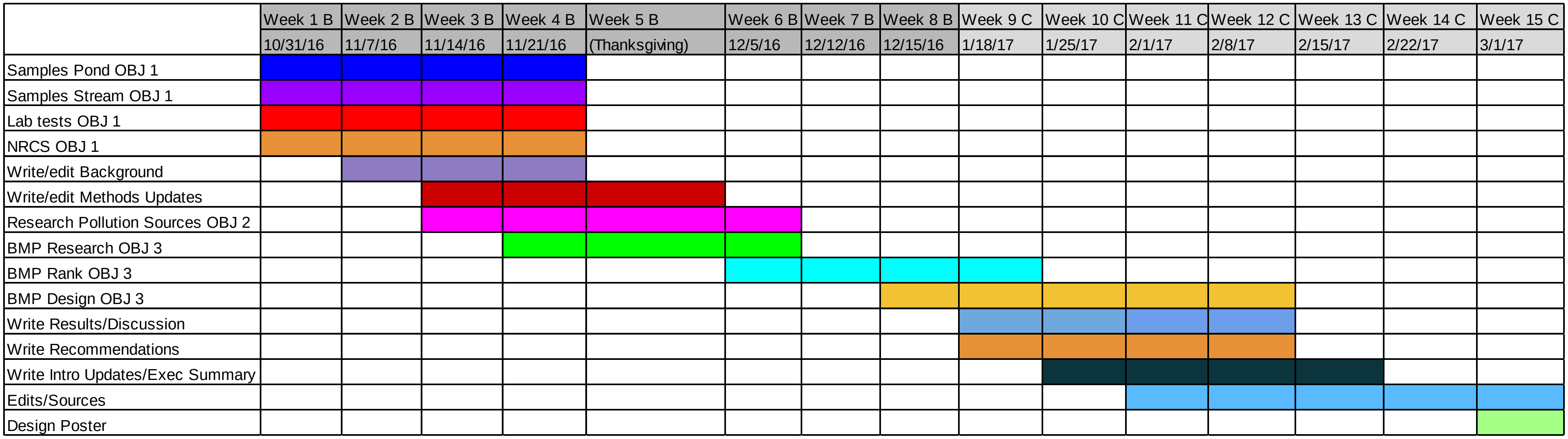
Appendix A: Gantt Chart



	Week 1 B	Week 2 B	Week 3 B	Week 4 B	Week 5 B	Week 6 B	Week 7 B	Week 8 B	Week 9 C	Week 10 C	Week 11 C	Week 12 C	Week 13 C	Week 14 C	Week 15 C
	10/31/16	11/7/16	11/14/16	11/21/16	(Thanksgiving)	12/5/16	12/12/16	12/15/16	1/18/17	1/25/17	2/1/17	2/8/17	2/15/17	2/22/17	3/1/17
Samples Pond OBJ 1	🟦	🟦	🟦	🟦											
Samples Stream OBJ 1	🟪	🟪	🟪	🟪											
Lab tests OBJ 1	🟥	🟥	🟥	🟥											
NRCS OBJ 1	🟧	🟧	🟧	🟧											
Write/edit Background		🟪	🟪	🟪											
Write/edit Methods Updates			🟥	🟥	🟥										
Research Pollution Sources OBJ 2			🟪	🟪	🟪	🟪									
BMP Research OBJ 3				🟩	🟩	🟩									
BMP Rank OBJ 3						🟦	🟦	🟦	🟦						
BMP Design OBJ 3								🟨	🟨	🟨	🟨	🟨			
Write Results/Discussion									🟦	🟦	🟦	🟦			
Write Recommendations									🟧	🟧	🟧	🟧			
Write Intro Updates/Exec Summary										⬛	⬛	⬛	⬛		
Edits/Sources											🟦	🟦	🟦	🟦	🟦
Design Poster															🟩

Appendix B: NRCS Calculations

$$Q = \frac{(P-0.2S)^2}{(P-0.8S)} \text{ where:}$$

Q = runoff (in)

P = rainfall (in)

S = potential maximum retention after runoff begins (in)

$$S = \frac{1,000}{CN} - 10$$

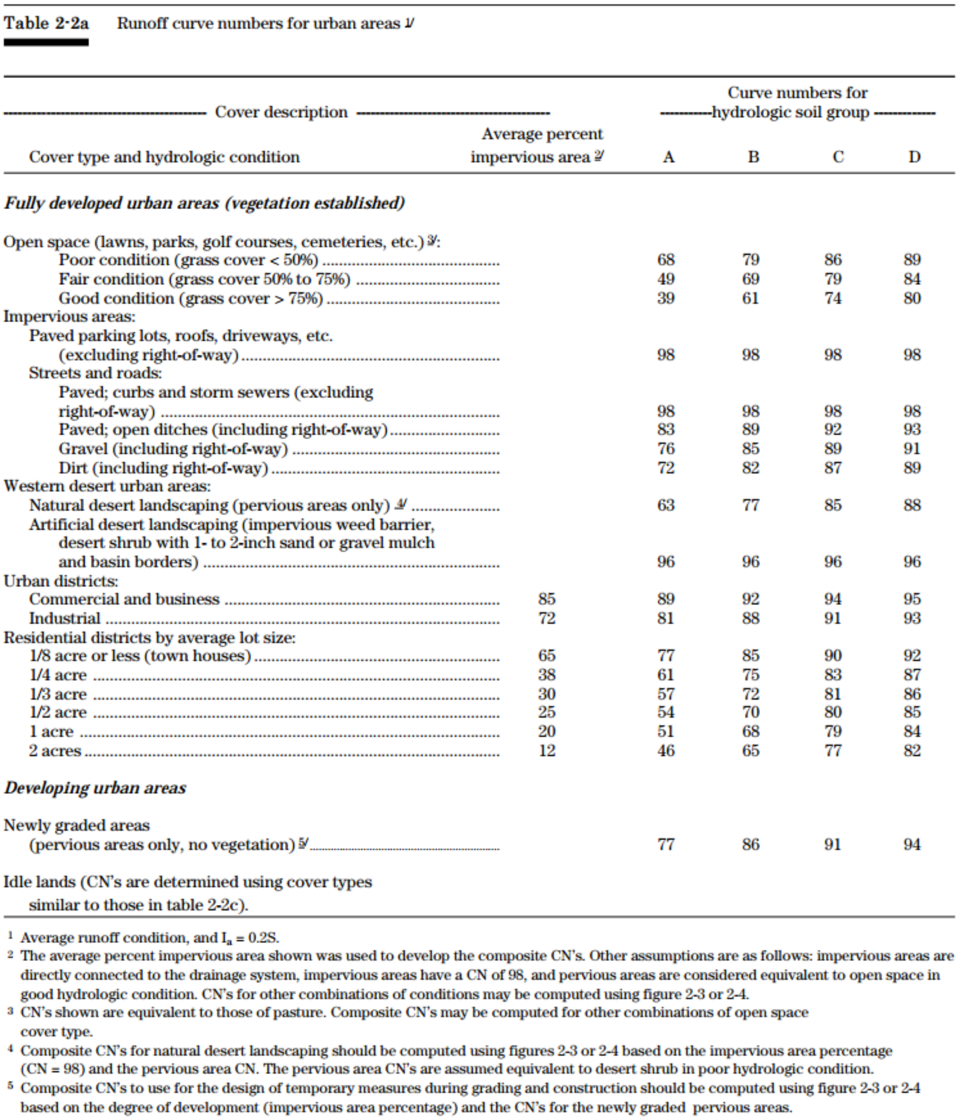


Table 2-2a Runoff curve numbers for urban areas [1]

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1] Average runoff condition, and $I_a = 0.2S$.

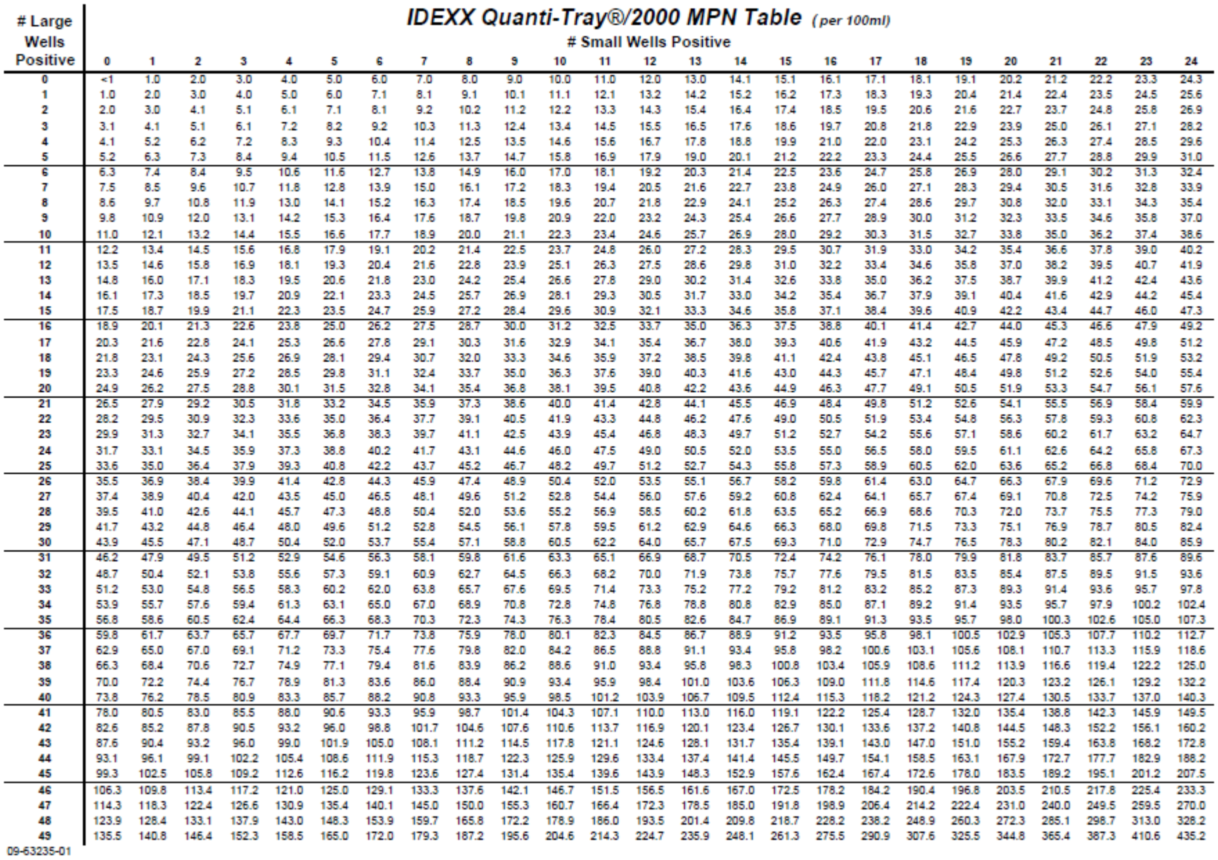
[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Appendix C: MPN Table for Bacteria Test



IDEXX Quanti-Tray®/2000 MPN Table *(per 100ml)*

# Large Wells Positive	# Small Wells Positive																								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	<1	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.1	15.1	16.1	17.1	18.1	19.1	20.2	21.2	22.2	23.3	24.3
1	1.0	2.0	3.0	4.0	5.0	6.0	7.1	8.1	9.1	10.1	11.1	12.1	13.2	14.2	15.2	16.2	17.3	18.3	19.3	20.4	21.4	22.4	23.5	24.5	25.6
2	2.0	3.0	4.1	5.1	6.1	7.1	8.1	9.2	10.2	11.2	12.2	13.3	14.3	15.4	16.4	17.4	18.5	19.5	20.6	21.6	22.7	23.7	24.8	25.8	26.9
3	3.1	4.1	5.1	6.1	7.2	8.2	9.2	10.3	11.3	12.4	13.4	14.5	15.5	16.5	17.6	18.6	19.7	20.8	21.8	22.9	23.9	25.0	26.1	27.1	28.2
4	4.1	5.2	6.2	7.2	8.3	9.3	10.4	11.4	12.5	13.5	14.6	15.6	16.7	17.8	18.8	19.9	21.0	22.0	23.1	24.2	25.3	26.3	27.4	28.5	29.6
5	5.2	6.3	7.3	8.4	9.4	10.5	11.5	12.6	13.7	14.7	15.8	16.9	17.9	19.0	20.1	21.2	22.2	23.3	24.4	25.5	26.6	27.7	28.8	29.9	31.0
6	6.3	7.4	8.4	9.5	10.6	11.6	12.7	13.8	14.9	16.0	17.0	18.1	19.2	20.3	21.4	22.5	23.6	24.7	25.8	26.9	28.0	29.1	30.2	31.3	32.4
7	7.5	8.5	9.6	10.7	11.8	12.8	13.9	15.0	16.1	17.2	18.3	19.4	20.5	21.6	22.7	23.8	24.9	26.0	27.1	28.3	29.4	30.5	31.6	32.8	33.9
8	8.6	9.7	10.8	11.9	13.0	14.1	15.2	16.3	17.4	18.5	19.6	20.7	21.8	22.9	24.1	25.2	26.3	27.4	28.6	29.7	30.8	32.0	33.1	34.3	35.4
9	9.8	10.9	12.0	13.1	14.2	15.3	16.4	17.6	18.7	19.8	20.9	22.0	23.2	24.3	25.4	26.6	27.7	28.9	30.0	31.2	32.3	33.5	34.6	35.8	37.0
10	11.0	12.1	13.2	14.4	15.5	16.6	17.7	18.9	20.0	21.1	22.3	23.4	24.6	25.7	26.9	28.0	29.2	30.3	31.5	32.7	33.8	35.0	36.2	37.4	38.6
11	12.2	13.4	14.5	15.6	16.8	17.9	19.1	20.2	21.4	22.5	23.7	24.8	26.0	27.2	28.3	29.5	30.7	31.9	33.0	34.2	35.4	36.6	37.8	39.0	40.2
12	13.5	14.6	15.8	16.9	18.1	19.3	20.4	21.6	22.8	23.9	25.1	26.3	27.5	28.6	29.8	31.0	32.2	33.4	34.6	35.8	37.0	38.2	39.5	40.7	41.9
13	14.8	16.0	17.1	18.3	19.5	20.6	21.8	23.0	24.2	25.4	26.6	27.8	29.0	30.2	31.4	32.6	33.8	35.0	36.2	37.5	38.7	39.9	41.2	42.4	43.6
14	16.1	17.3	18.5	19.7	20.9	22.1	23.3	24.5	25.7	26.9	28.1	29.3	30.5	31.7	33.0	34.2	35.4	36.7	37.9	39.1	40.4	41.6	42.9	44.2	45.4
15	17.5	18.7	19.9	21.1	22.3	23.5	24.7	25.9	27.2	28.4	29.6	30.9	32.1	33.3	34.6	35.8	37.1	38.4	39.6	40.9	42.2	43.4	44.7	46.0	47.3
16	18.9	20.1	21.3	22.6	23.8	25.0	26.2	27.5	28.7	30.0	31.2	32.5	33.7	35.0	36.3	37.5	38.8	40.1	41.4	42.7	44.0	45.3	46.6	47.9	49.2
17	20.3	21.6	22.8	24.1	25.3	26.6	27.8	29.1	30.3	31.6	32.9	34.1	35.4	36.7	38.0	39.3	40.6	41.9	43.2	44.5	45.9	47.2	48.5	49.8	51.2
18	21.8	23.1	24.3	25.6	26.9	28.1	29.4	30.7	32.0	33.3	34.6	35.9	37.2	38.5	39.8	41.1	42.4	43.8	45.1	46.5	47.8	49.2	50.5	51.9	53.2
19	23.3	24.6	25.9	27.2	28.5	29.8	31.1	32.4	33.7	35.0	36.3	37.6	39.0	40.3	41.6	43.0	44.3	45.7	47.1	48.4	49.8	51.2	52.6	54.0	55.4
20	24.9	26.2	27.5	28.8	30.1	31.5	32.8	34.1	35.4	36.8	38.1	39.5	40.8	42.2	43.6	44.9	46.3	47.7	49.1	50.5	51.9	53.3	54.7	56.1	57.6
21	26.5	27.9	29.2	30.5	31.8	33.2	34.5	35.9	37.3	38.6	40.0	41.4	42.8	44.1	45.5	46.9	48.4	49.8	51.2	52.6	54.1	55.5	56.9	58.4	59.9
22	28.2	29.5	30.9	32.3	33.6	35.0	36.4	37.7	39.1	40.5	41.9	43.3	44.8	46.2	47.6	49.0	50.5	51.9	53.4	54.8	56.3	57.8	59.3	60.8	62.3
23	29.9	31.3	32.7	34.1	35.5	36.8	38.3	39.7	41.1	42.5	43.9	45.4	46.8	48.3	49.7	51.2	52.7	54.2	55.6	57.1	58.6	60.2	61.7	63.2	64.7
24	31.7	33.1	34.5	35.9	37.3	38.8	40.2	41.7	43.1	44.6	46.0	47.5	49.0	50.5	52.0	53.5	55.0	56.5	58.0	59.5	61.1	62.6	64.2	65.8	67.3
25	33.6	35.0	36.4	37.9	39.3	40.8	42.2	43.7	45.2	46.7	48.2	49.7	51.2	52.7	54.3	55.8	57.3	58.9	60.5	62.0	63.6	65.2	66.8	68.4	70.0
26	35.5	36.9	38.4	39.9	41.4	42.8	44.3	45.9	47.4	48.9	50.4	52.0	53.5	55.1	56.7	58.2	59.8	61.4	63.0	64.7	66.3	67.9	69.6	71.2	72.9
27	37.4	38.9	40.4	42.0	43.5	45.0	46.5	48.1	49.6	51.2	52.8	54.4	56.0	57.6	59.2	60.8	62.4	64.1	65.7	67.4	69.1	70.8	72.5	74.2	75.9
28	39.5	41.0	42.6	44.1	45.7	47.3	48.8	50.4	52.0	53.6	55.2	56.9	58.5	60.2	61.8	63.5	65.2	66.9	68.6	70.3	72.0	73.7	75.5	77.3	79.0
29	41.7	43.2	44.8	46.4	48.0	49.6	51.2	52.8	54.5	56.1	57.8	59.5	61.2	62.9	64.6	66.3	68.0	69.8	71.5	73.3	75.1	76.9	78.7	80.5	82.4
30	43.9	45.5	47.1	48.7	50.4	52.0	53.7	55.4	57.1	58.8	60.5	62.2	64.0	65.7	67.5	69.3	71.0	72.9	74.7	76.5	78.3	80.2	82.1	84.0	85.9
31	46.2	47.9	49.5	51.2	52.9	54.6	56.3	58.1	59.8	61.6	63.3	65.1	66.9	68.7	70.5	72.4	74.2	76.1	78.0	79.9	81.8	83.7	85.7	87.6	89.6
32	48.7	50.4	52.1	53.8	55.6	57.3	59.1	60.9	62.7	64.5	66.3	68.2	70.0	71.9	73.8	75.7	77.6	79.5	81.5	83.5	85.4	87.5	89.5	91.5	93.6
33	51.2	53.0	54.8	56.5	58.3	60.2	62.0	63.8	65.7	67.6	69.5	71.4	73.3	75.2	77.2	79.2	81.2	83.2	85.2	87.3	89.3	91.4	93.6	95.7	97.8
34	53.9	55.7	57.6	59.4	61.3	63.1	65.0	67.0	68.9	70.8	72.8	74.8	76.8	78.8	80.8	82.9	85.0	87.1	89.2	91.4	93.5	95.7	97.9	100.2	102.4
35	56.8	58.6	60.5	62.4	64.4	66.3	68.3	70.3	72.3	74.3	76.3	78.4	80.5	82.6	84.7	86.9	89.1	91.3	93.5	95.7	98.0	100.3	102.6	105.0	107.3
36	59.8	61.7	63.7	65.7	67.7	69.7	71.7	73.8	75.9	78.0	80.1	82.3	84.5	86.7	88.9	91.2	93.5	95.8	98.1	100.5	102.9	105.3	107.7	110.2	112.7
37	62.9	65.0	67.0	69.1	71.2	73.3	75.4	77.6	79.8	82.0	84.2	86.5	88.8	91.1	93.4	95.8	98.2	100.6	103.1	105.6	108.1	110.7	113.3	115.9	118.6
38	66.3	68.4	70.6	72.7	74.9	77.1	79.4	81.6	83.9	86.2	88.6	91.0	93.4	95.8	98.3	100.8	103.4	105.9	108.6	111.2	113.9	116.6	119.4	122.2	125.0
39	70.0	72.2	74.4	76.7	78.9	81.3	83.6	86.0	88.4	90.9	93.4	95.9	98.4	101.0	103.6	106.3	109.0	111.8	114.6	117.4	120.3	123.2	126.1	129.2	132.2
40	73.8	76.2	78.5	80.9	83.3	85.7	88.2	90.8	93.3	95.9	98.5	101.2	103.9	106.7	109.5	112.4	115.3	118.2	121.2	124.3	127.4	130.5	133.7	137.0	140.3
41	78.0	80.5	83.0	85.5	88.0	90.6	93.3	95.9	98.7	101.4	104.3	107.1	110.0	113.0	116.0	119.1	122.2	125.4	128.7	132.0	135.4	138.8	142.3	145.9	149.5
42	82.6	85.2	87.8	90.5	93.2	96.0	98.8	101.7	104.6	107.6	110.6	113.7	116.9	120.1	123.4	126.7	130.1	133.6	137.2	140.8	144.5	148.3	152.2	156.1	160.2
43	87.6	90.4	93.2	96.0	99.0	101.9	105.0	108.1	111.2	114.5	117.8	121.1	124.6	128.1	131.7	135.4	139.1	143.0	147.0	151.0	155.2	159.4	163.8	168.2	172.8
44	93.1	96.1	99.1	102.2	105.4	108.6	111.9	115.3	118.7	122.3	125.9	129.6	133.4	137.4	141.4	145.5	149.7	154.1	158.5	163.1	167.9	172.7	177.7	182.9	188.2
45	99.3	102.5	105.8	109.2	112.6	116.2	119.8	123.6	127.4	131.4	135.4	139.6	143.9	148.3	152.9	157.6	162.4	167.4	172.6	178.0	183.5	189.2	195.1	201.2	207.5
46	106.3	109.8	113.4	117.2	121.0	125.0	129.1	133.3	137.6	142.1	146.7	151.5	156.5	161.6	167.0	172.5	178.2	184.2	190.4	196.8	203.5	210.5	217.8	225.4	233.3
47	114.3	118.3	122.4	126.6	130.9	135.4	140.1	145.0	150.0	155.3	160.7	166.4	172.3	178.5	185.0	191.8	198.9	206.4	214.2	222.4	231.0	240.0	249.5	259.5	270.0
48	123.9	128.4	133.1	137.9	143.0	148.3	153.9	159.7	165.8	172.2	178.9	186.0	193.5	201.4	209.8	218.7	228.2	238.2	248.9	260.3	272.3	285.1	298.7	313.0	328.2
49	135.5	140.8	146.4	152.3	158.5	165.0	172.0	179.3	187.2	195.6	204.6	214.3	224.7	235.9	248.1	261.3	275.5	290.9	307.6	325.5	344.8	365.4	387.3	410.6	435.2

09-63235-01

IDEXX Quanti-Tray®/2000 MPN Table *(per 100ml)*

# Large Wells Positive	# Small Wells Positive																							
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0	25.3	26.4	27.4	28.4	29.5	30.5	31.5	32.6	33.6	34.7	35.7	36.8	37.8	38.9	40.0	41.0	42.1	43.1	44.2	45.3	46.3	47.4	48.5	49.5
1	26.6	27.7	28.7	29.8	30.8	31.9	32.9	34.0	35.0	36.1	37.2	38.2	39.3	40.4	41.4	42.5	43.6	44.7	45.7	46.8	47.9	49.0	50.1	51.2
2	27.9	29.0	30.0	31.1	32.2	33.2	34.3	35.4	36.5	37.5	38.6	39.7	40.8	41.9	43.0	44.0	45.1	46.2	47.3	48.4	49.5	50.6	51.7	52.8
3	29.3	30.4	31.4	32.5	33.6	34.7	35.8	36.8	37.9	39.0	40.1	41.2	42.3	43.4	44.5	45.6	46.7	47.8	48.9	50.0	51.2	52.3	53.4	54.5
4	30.7	31.8	32.8	33.9	35.0	36.1	37.2	38.3	39.4	40.5	41.6	42.8	43.9	45.0	46.1	47.2	48.3	49.5	50.6	51.7	52.9	54.0	55.1	56.3
5	32.1	33.2	34.3	35.4	36.5	37.6	38.7	39.9	41.0	42.1	43.2	44.4	45.5	46.6	47.7	48.9	50.0	51.2	52.3	53.5	54.6	55.8	56.9	58.1
6	33.5	34.7	35.8	36.9	38.0	39.2	40.3	41.4	42.6	43.7	44.8	46.0	47.1	48.3	49.4	50.6	51.7	52.9	54.1	55.2	56.4	57.6	58.7	59.9
7	35.0	36.2	37.3	38.4	39.6	40.7	41.9	43.0	44.2	45.3	46.5	47.7	48.8	50.0	51.2	52.3	53.5	54.7	55.9	57.1	58.3	59.4	60.6	61.8
8	36.6	37.7	38.9	40.0	41.2	42.3	43.5	44.7	45.9	47.0	48.2	49.4	50.6	51.8	53.0	54.1	55.3	56.5	57.7	59.0	60.2	61.4	62.6	63.8
9	38.1	39.3	40.5	41.6	42.8	44.0	45.2	46.4	47.6	48.8	50.0	51.2	52.4	53.6	54.8	56.0	57.2	58.4	59.7	60.9	62.1	63.4	64.6	65.8
10	39.7	40.9	42.1	43.3	44.5	45.7	46.9	48.1	49.3	50.6	51.8	53.0	54.2	55.5	56.7	57.9	59.2	60.4	61.7	62.9	64.2	65.4	66.7	67.9
11	41.4	42.6	43.8	45.0	46.3	47.5	48.7	49.9	51.2	52.4	53.7	54.9	56.1	57.4	58.6	59.9	61.2	62.4	63.7	65.0	66.3	67.5	68.8	70.1
12	43.1	44.3	45.6	46.8	48.1	49.3	50.6	51.8	53.1	54.3	55.6	56.8	58.1	59.4	60.7	62.0	63.2	64.5	65.8	67.1	68.4	69.7	71.0	72.4
13	44.9	46.1	47.4	48.6	49.9	51.2	52.5	53.7	55.0	56.3	57.6	58.9	60.2	61.5	62.8	64.1	65.4	66.7	68.0	69.3	70.7	72.0	73.3	74.7
14	46.7	48.0	49.3	50.5	51.8	53.1	54.4	55.7	57.0	58.3	59.6	60.9	62.3	63.6	64.9	66.3	67.6	68.9	70.3	71.6	73.0	74.4	75.7	77.1
15	48.6	49.9	51.2	52.5	53.8	55.1	56.4	57.8	59.1	60.4	61.8	63.1	64.5	65.8	67.2	68.5	69.9	71.3	72.6	74.0	75.4	76.8	78.2	79.6
16	50.5	51.8	53.2	54.5	55.8	57.2	58.5	59.9	61.2	62.6	64.0	65.3	66.7	68.1	69.5	70.9	72.3	73.7	75.1	76.5	77.9	79.3	80.8	82.2
17	52.5	53.9	55.2	56.6	58.0	59.3	60.7	62.1	63.5	64.9	66.3	67.7	69.1	70.5	71.9	73.3	74.8	76.2	77.6	79.1	80.5	82.0	83.5	84.9
18	54.6	56.0	57.4	58.8	60.2	61.6	63.0	64.4	65.8	67.2	68.6	70.1	71.5	73.0	74.4	75.9	77.3	78.8	80.3	81.8	83.3	84.8	86.3	87.8
19	56.8	58.2	59.6	61.0	62.4	63.9	65.3	66.8	68.2	69.7	71.1	72.6	74.1	75.5	77.0	78.5	80.0	81.5	83.1	84.6	86.1	87.6	89.2	90.7
20	59.0	60.4	61.9	63.3	64.8	66.3	67.7	69.2	70.7	72.2	73.7	75.2	76.7	78.2	79.8	81.3	82.8	84.4	85.9	87.5	89.1	90.7	92.2	93.8
21	61.3	62.8	64.3	65.8	67.3	68.8	70.3	71.8	73.3	74.9	76.4	77.9	79.5	81.1	82.6	84.2	85.8	87.4	89.0	90.6	92.2	93.8	95.4	97.1
22	63.8	65.3	66.8	68.3	69.8	71.4	72.9	74.5	76.1	77.6	79.2	80.8	82.4	84.0	85.6	87.2	88.9	90.5	92.1	93.8	95.5	97.1	98.8	100.5
23	66.3	67.8	69.4	71.0	72.5	74.1	75.7	77.3	78.9	80.5	82.2	83.8	85.4	87.1	88.7	90.4	92.1	93.8	95.5	97.2	98.9	100.6	102.4	104.1
24	68.9	70.5	72.1	73.7	75.3	77.0	78.6	80.3	81.9	83.6	85.2	86.9	88.6	90.3	92.0	93.8	95.5	97.2	99.0	100.7	102.5	104.3	106.1	107.9
25	71.7	73.3	75.0	76.6	78.3	80.0	81.7	83.3	85.1	86.8	88.5	90.2	92.0	93.7	95.5	97.3	99.1	100.9	102.7	104.5	106.3	108.2	110.0	111.9
26	74.6	76.3	78.0	79.7	81.4	83.1	84.8	86.6	88.4	90.1	91.9	93.7	95.5	97.3	99.2	101.0	102.9	104.7	106.6	108.5	110.4	112.3	114.2	116.2
27	77.6	79.4	81.1	82.9	84.6	86.4	88.2	90.0	91.9	93.7	95.5	97.4	99.3	101.2	103.1	105.0	106.9	108.8	110.8	112.7	114.7	116.7	118.7	120.7
28	80.8	82.6	84.4	86.3	88.1	89.9	91.8	93.7	95.6	97.5	99.4	101.3	103.3	105.2	107.2	109.2	111.2	113.2	115.2	117.3	119.3	121.4	123.5	125.6
29	84.2	86.1	87.9	89.8	91.7	93.7	95.6	97.5	99.5	101.5	103.5	105.5	107.5	109.5	111.6	113.7	115.7	117.8	120.0	122.1	124.2	126.4	128.6	130.8
30	87.8	89.7	91.7	93.6	95.6	97.6	99.6	101.6	103.7	105.7	107.8	109.9	112.0	114.2	116.3	118.5	120.6	122.8	125.1	127.3	129.5	131.8	134.1	136.4
31	91.6	93.6	95.6	97.7	99.7	101.8	103.9	106.0	108.2	110.3	112.5	114.7	116.9	119.1	121.4	123.6	125.9	128.2	130.5	132.9	135.3	137.7	140.1	142.5
32	95.7	97.8	99.9	102.0	104.2	106.3	108.5	110.7	113.0	115.2	117.5	119.8	122.1	124.5	126.8	129.2	131.6	134.0	136.5	139.0	141.5	144.0	146.6	149.1
33	100.0	102.2	104.4	106.6	108.9	111.2	113.5	115.8	118.2	120.5	122.9	125.4	127.8	130.3	132.8	135.3	137.8	140.4	143.0	145.6	148.3	150.9	153.7	156.4
34	104.7	107.0	109.3	111.7	114.0	116.4	118.9	121.3	123.8	126.3	128.8	131.4	134.0	136.6	139.2	141.9	144.6	147.4	150.1	152.9	155.7	158.6	161.5	164.4
35	109.7	112.2	114.6	117.1	119.6	122.2	124.7	127.3	129.9	132.6	135.3	138.0	140.8	143.6	146.4	149.2	152.1	155.0	158.0	161.0	164.0	167.1	170.2	173.3
36	115.2	117.8	120.4	123.0	125.7	128.4	131.1	133.9	136.7	139.5	142.4	145.3	148.3	151.3	154.3	157.3	160.5	163.6	166.8	170.0	173.3	176.6	179.9	183.3
37	121.3	124.0	126.8	129.6	132.4	135.3	138.2	141.2	144.2	147.3	150.3	153.5	156.7	159.9	163.1	166.5	169.8	173.2	176.7	180.2	183.7	187.3	191.0	194.7
38	127.9	130.8	133.8	136.8	139.9	143.0	146.2	149.4	152.6	155.9	159.2	162.6	166.1	169.6	173.2	176.8	180.4	184.2	188.0	191.8	195.7	199.7	203.7	207.7
39	135.3	138.5	141.7	145.0	148.3	151.7	155.1	158.6	162.1	165.7	169.4	173.1	176.9	180.7	184.7	188.7	192.7	196.8	201.0	205.3	209.6	214.0	218.5	223.0
40	143.7	147.1	150.6	154.2	157.8	161.5	165.3	169.1	173.0	177.0	181.1	185.2	189.4	193.7	198.1	202.5	207.1	211.7	216.4	221.1	226.0	231.0	236.0	241.1
41	153.2	157.0	160.9	164.8	168.9	173.0	177.2	181.5	185.8	190.3	194.8	199.5	204.2	209.1	214.0	219.1	224.2	229.4	234.8	240.2	245.8	251.5	257.2	263.1
42	164.3	168.6	172.9	177.3	181.9	186.5	191.3	196.1	201.1	206.2	211.4	216.7	222.2	227.7	233.4	239.2	245.2	251.3	257.5	263.8	270.3	276.9	283.6	290.5
43	177.5	182.3	187.3	192.4	197.6	202.9	208.4	214.0	219.8	225.8	231.8	238.1	244.5	251.0	257.7	264.6	271.7	278.9	286.3	293.8	301.5	309.4	317.4	325.7
44	193.6	199.3	205.1	211.0	217.2	223.5	230.0	236.7	243.6	250.8	258.1	265.6	273.3	281.2	289.4	297.8	306.3	315.1	324.1	333.3	342.8	352.4	362.3	372.4
45	214.1	220.9	227.9	235.2	242.7	250.4	258.4	266.7	275.3	284.1	293.3	302.6	312.3	322.3	332.5	343.0	353.8	364.9	376.2	387.9	399.8	412.0	424.5	437.4
46	241.5	250.0	258.9	268.2	277.8	287.8	298.1	308.8	319.9	331.4	343.3	355.5	368.1	381.1	394.5	408.3	422.5	437.1	452.0	467.4	483.3	499.6	516.3	533.5
47	280.9	292.4	304.4	316.9	330.0	343.6	357.8	372.5	387.7	403.4	419.8	436.6	454.1	472.1	490.7	509.9	529.8	550.4	571.7	593.8	616.7	640.5	665.3	691.0
48	344.1	360.9	378.4	396.8	416.0	436.0	456.9	478.6	501.2	524.7	549.3	574.8	601.5	629.4	658.6	689.3	721.5	755.6	791.5	829.7	870.4	913.9	960.6	1011.2
49	461.1	488.4	517.2	547.5	579.4	613.1	648.8	686.7	727.0	770.1	816.4	866.4	920.8	980.4	1046.2	1119.9	1203.3	1299.7	1413.6	1553.1	1732.9	1986.3	2419.6	>2419.6

09-63235-01

Appendix D: CMP Stream Water Land Use & Soil Type Areas

CMP Stream Watershed Soils & Land Use

Land Use	Soil Type	Total Area
Forest		
	<null>	
		382.007432
		3581.766011
		3799.413571
	A	
		10979.364002
	B	
		3316.812899
		5648.805629
		382.017995
	D	
		2240.718147
High Density Residential		
	A	
		2732.022011
	B	
		694.546981
		322.86638
	C	
		403.876769
Medium Density Residential		
	A	
		28598.901833
		192.506794
	C	
		31.097021
Multi-Family Residential		
	<null>	
		0.035871
		7290.269489
	A	
		3589.775863
		12759.14222
		30901.817686
	B	
		17247.468056

Land Use	Soil Type	Total Area
Participation Recreation		
	<null>	
		83.823652
	B	
		343.157307
Urban Public/Institutional		
	<null>	
		92951.712574
		20880.931635
		16389.606589
	A	
		3774.24384
		566.314564
		5305.354675
	B	
		9349.463404
		23318.608377
		0.743561
		9456.842161
	C	
		2698.748743
	D	
		67.765359

Appendix E: Time of Concentration Calculations

$$t_c = 0.0078 * k \left(\frac{L}{S^{0.5}}\right)^{0.77}$$

L=flow length (ft)

S = average watershed land slope (ft/ft)

K = Kirpich adjustment factor based on type of ground cover

K is equivalent to 0.4 for flow on concrete or asphalt surfaces and 1.5 for flow on natural grass channels, bare soil, or roadside ditches (LMBO, 2015).

$$t_{c,residential} = 0.0078 * 0.4 \left(\frac{2{,}484\ ft}{0.0144^{0.5}}\right)^{0.77} = 6.5\ minutes$$

$$t_{c,parkland} = 0.0078 * 1.5 \left(\frac{1{,}609\ ft}{0.0124^{0.5}}\right)^{0.77} = 18\ minutes$$

Appendix F: Raw Field Data

Date	Temperature (˚C)	DO (mg/L)	pH	pHmV	ORPmV	Conductivity (mS/cm)	NTU	TDS (g/L)	ppt	σt	Depth (m)
10/11/2016	19.55	15.01	5.5	25	278	0.804	9	0.513	0.4	0	0.2
11/3/2016	17.64	11.01	5.9	-2	214	0.789	4.8	0.505	0.4	0	0.1
11/15/2016	11.96	9.76	6.23	-20	226	0.208	87.2	0.141	0.1	0	0
11/15/2016	11.02	14.02	6.39	-30	246	0.093	67.7	0.062	0	0	0.05
11/29/2016	5.2	15.12	6.62	2	253	0.47	0	0.305	0.2	0	0
11/29/2016	11.09	7.63	6.55	6	237	0.446	20.7	0.28	0.2	0	0.1
Avg (Dry)	**18.60**	**13.01**	**5.70**	**11.50**	**246.00**	**0.80**	**6.90**	**0.51**	**0.40**	**0.00**	**0.15**
Std	1.35	2.83	0.28	19.09	45.25	0.01	2.97	0.01	0.00	0.00	0.07
Avg (Wet)	**9.82**	**11.63**	**6.45**	**-10.50**	**240.50**	**0.30**	**43.90**	**0.20**	**0.13**	**0.00**	**0.04**
Std	3.11	3.53	0.17	17.31	11.68	0.18	40.44	0.12	0.10	0.00	0.05

Date	Temperature (˚C)	DO (mg/L)	pH	pHmV	ORPmV	Conductivity (mS/cm)	NTU	TDS (g/L)	ppt	σt	Depth (m)
11/3/2016	13.99	11.28	5.67	11	207	0.85	7	0.546	0.4	0	0.15
11/15/2016	11.58	13.54	6.34	-27	238	0.641	34.7	0.431	0.3	0	0.1
11/29/2016	7.36	7.03	6.73	-4	228	0.532	1.9	0.34	0.3	0.2	0.3
Avg (Wet)	**9.47**	**10.29**	**6.54**	**-15.50**	**233.00**	**0.59**	**18.30**	**0.39**	**0.30**	**0.10**	**0.20**
Std	**2.98**	**4.60**	**0.28**	**16.26**	**7.07**	**0.08**	**23.19**	**0.06**	**0.00**	**0.14**	**0.14**

Date	Temperature (˚C)	DO (mg/L)	pH	pHmV	ORPmV	Conductivity (mS/cm)	NTU	TDS (g/L)	ppt	σt	Depth (m)
11/15/2016	9.7	11.97	6.28	-24	120	0.011	45.4	0.478	0.3	0	0
11/15/2016	8.24	10.44	6.23	-22	205	0.832	41.1	0.548	0.4	0.2	0.1
11/29/2016	5.76	11.52	6.86	-12	306	0.47	16.8	0.308	0.2	0.2	0
11/29/2016	5.76	7.03	6.73	-4	228	0.532	1.9	0.34	0.3	0.2	0.3
Avg (Wet)	**7.37**	**10.24**	**6.53**	**-15.50**	**214.75**	**0.46**	**26.30**	**0.42**	**0.30**	**0.15**	**0.10**
Std	**1.95**	**2.23**	**0.32**	**9.29**	**76.54**	**0.34**	**20.57**	**0.11**	**0.08**	**0.10**	**0.14**

Date	Temperature (˚C)	DO (mg/L)	pH	pHmV	ORPmV	Conductivity (mS/cm)	NTU	TDS (g/L)	ppt	σt	Depth (m)
10/11/2016	20.94	9.7	6.84	-56	241	2.08	3.2	1.33	1.1	0	0.35
11/3/2016	14.28	13.38	6.55	-39	234	1.85	6.1	1.21	0.9	0	0.1
11/15/2016	10.3	10.12	6.58	-41	163	1.96	11.8	1.26	1	0.5	0
11/15/2016	9.63	18.68	6.42	-32	154	1.57	26.9	1.06	0.8	0.5	0.15
11/29/2016	6.93	9.99	7.19	-30	281	1.1	5.7	0.704	0.5	0.4	0
11/29/2016	6.35	11.47	7.34	-208	98	1.11	3.8	0.712	0.5	0.5	0.5
Avg (Dry)	**17.61**	**11.54**	**6.70**	**-47.50**	**237.50**	**1.97**	**4.65**	**1.27**	**1.00**	**0.00**	**0.23**
Std	4.71	2.60	0.21	12.02	4.95	0.16	2.05	0.08	0.14	0.00	0.18
Avg (Wet)	**8.30**	**12.57**	**6.88**	**-77.75**	**174.00**	**1.44**	**12.05**	**0.93**	**0.70**	**0.48**	**0.16**
Std	1.95	4.13	0.45	86.97	76.91	0.41	10.47	0.27	0.24	0.05	0.24

Date	Temperature (˚C)	DO (mg/L)	pH	pHmV	ORPmV	Conductivity (mS/cm)	NTU	TDS (g/L)	ppt	σt	Depth (m)
10/11/2016	14.04	10.77	6.23	-20	250	0.789	7.3	0.503	0.4	0	1.15
11/3/2016	11.69	8.38	5.8	3	128	0.792	9.1	0.507	0.4	0	0.95
11/15/2016	11.66	14.42	5.91	-3	23	0.8	11.2	0.564	0.4	0	0.6
11/15/2016	9.63	18.68	6.42	-32	154	1.57	26.9	1.06	0.8	0.5	0.15
11/29/2016	4.54	5.49	6.83	-10	28	0.477	10.8	0.371	0.2	0.2	0.1
11/29/2016	5.77	7.53	6.8	-21	109	0.529	24.6	0.338	0.2	0.2	0.9
Avg (Dry)	**12.865**	**9.575**	**6.015**	**-8.5**	**189**	**0.7905**	**8.2**	**0.505**	**0.4**	**0**	**1.05**
Std	1.661700936	1.689985	0.304056	16.26346	86.26703	0.00212132	1.272792	0.002828	0	0	0.141421
Avg (Wet)	**7.90**	**11.53**	**6.49**	**-16.50**	**78.50**	**0.84**	**18.38**	**0.58**	**0.40**	**0.23**	**0.44**
Std	3.31	6.11	0.43	12.71	63.93	0.50	8.57	0.33	0.28	0.21	0.38

Date	Temperature (˚C)	DO (mg/L)	pH	pHmV	ORPmV	Conductivity (mS/cm)	NTU	TDS (g/L)	ppt	σt	Depth (m)
11/3/2016	12.48	15.17	6.62	-43	207	1.99	110	1.29	1	0.3	0.5
11/15/2016	9.89	17.76	6.67	-46	215	2.03	112	1.3	1	0.6	0.35
11/29/2016	8.99	11.35	7.45	-45	215	1.688	31	0.692	0.5	0.3	0.4
Avg (Wet)	**9.44**	**14.56**	**7.06**	**-45.50**	**215.00**	**1.86**	**71.50**	**1.00**	**0.75**	**0.45**	**0.38**
Std	**0.64**	**4.53**	**0.55**	**0.71**	**0.00**	**0.24**	**57.28**	**0.43**	**0.35**	**0.21**	**0.04**

Date	Temperature (˚C)	DO (mg/L)	pH	pHmV	ORPmV	Conductivity (mS/cm)	NTU	TDS (g/L)	ppt	σt	Depth (m)
11/3/2016	12.63	16.85	7.26	-79	215	1.73	28.5	1.16	0.9	0.2	0.15
11/15/2016	9.14	19.94	6.51	-37	233	1.94	22.3	1.24	1	0.7	0.05
11/29/2016	12.63	16.85	7.26	-79	215	1.73	1.73	1.16	1	0.3	0.5
Avg (Wet)	**10.89**	**18.40**	**6.89**	**-58.00**	**224.00**	**1.84**	**12.02**	**1.20**	**1.00**	**0.50**	**0.28**
Std	**2.47**	**2.18**	**0.53**	**29.70**	**12.73**	**0.15**	**14.55**	**0.06**	**0.00**	**0.28**	**0.32**

Averaged Field Data Results

Location	Temperature (˚C)	DO (mg/L)	pH	pHmV	ORPmV	Conductivity (mS/cm)	NTU	TDS (g/L)	ppt	Specific Gravity (σt)	Depth (m)
A	9.82	11.63	6.45	-10.50	240.50	0.30	43.90	0.20	0.13	0.00	0.04
B	9.47	10.29	6.54	-15.50	233.00	0.59	18.30	0.39	0.30	0.10	0.20
C	7.37	10.24	6.53	-15.50	214.75	0.46	26.30	0.42	0.30	0.15	0.10
D	8.30	12.57	6.88	-77.75	174.00	1.44	12.05	0.93	0.70	0.48	0.16
E	7.90	11.53	6.49	-16.50	78.50	0.84	18.38	0.58	0.40	0.23	0.44
F	9.44	14.56	7.06	-45.50	215.00	1.86	71.50	1.00	0.75	0.45	0.38
G	10.89	18.40	6.89	-58.00	224.00	1.84	12.02	1.20	1.00	0.50	0.28

Location	**Temperature (˚C)**	**DO (mg/L)**	**pH**	**pHmV**	**ORPmV**	**Conductivity (mS/cm)**	**NTU**	**TDS (g/L)**	**ppt**	**Specific Gravity (σt)**	**Depth (m)**
A	18.60	13.01	5.70	11.50	246.00	0.80	6.90	0.25	0.20	0.00	0.05
B	13.99	11.28	5.67	11.00	207.00	0.85	7.00	0.55	0.40	0.00	0.15
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	17.61	11.54	6.70	-47.50	237.50	1.97	4.65	1.27	1.00	0.00	0.23
E	12.87	9.58	6.02	-8.50	189.00	0.79	8.20	0.51	0.40	0.00	1.05
F	12.48	15.17	6.62	-43.00	207.00	1.99	110.00	1.29	1.00	0.30	0.50
G	12.63	16.85	7.26	-79.00	215.00	1.73	28.50	1.16	0.90	0.20	0.15

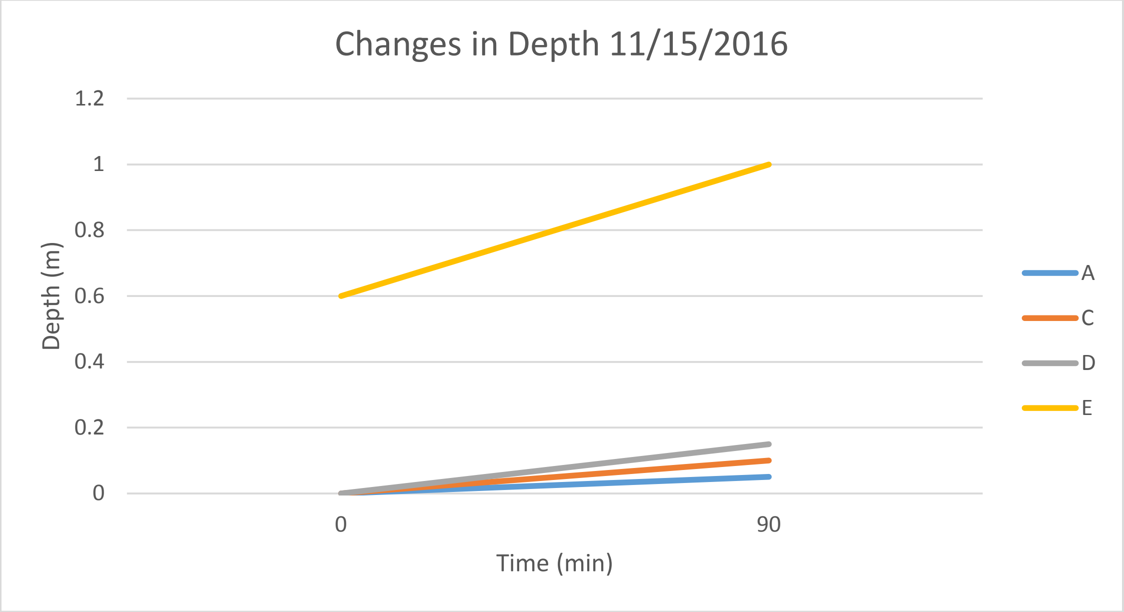
Appendix G: Estimation of Volumetric Flow Rate from Field Data

Section of Stream	**Length**	**Unit**	**Length**	**Unit**
Length A-C	455	ft	139	m
Length C-E	399	ft	121	m
Length E-F	627	ft	191	m
Width	20	ft	6	m
Surface Area (A-C)	9100	ft^2	834	m^2
Surface Area (C-E)	7980	ft^2	726	m^2

11/15/16 Sampling Data

Location	**First Sampling (m)**	**Second Sampling (m)**	**Change in Depth* (m)**
A (culvert)	0	0.05	0.05
C (stormwater drainage)	0	0.1	0.1
D (pond)	0	0.15	0.15
E (by dump)	0.6	1	0.4
*Change in depth while at site			

Event	Time
Start time first sampling	1:15 pm
Start time second sampling	2:45 pm
End time	4:30 pm
Net time	195 minutes

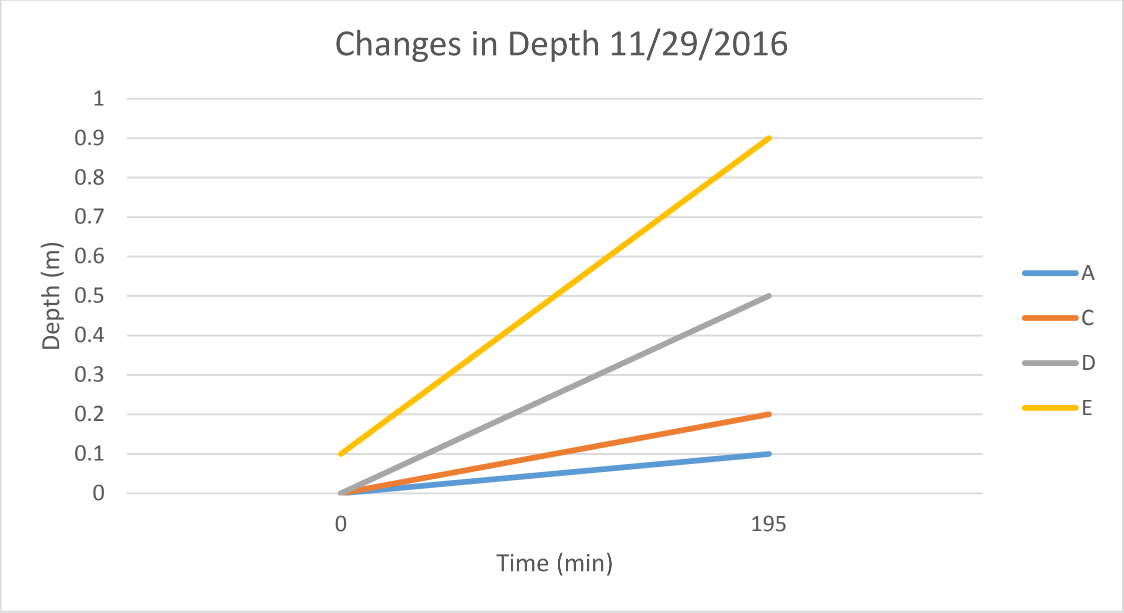


11/29/16 Sampling Data

Location	First Sampling (m)	Second Sampling (m)	Change in Depth* (m)
A (culvert)	0	0.1	0.1
C (stormwater drainage)	0	0.2	0.2
D (pond)	0	0.5	0.5
E (by dump)	0.1	0.9	0.8
*Change in depth while at site			

Event	**Time**
Start time first sampling	11:00 am
Start time second sampling	2:15 pm
End time	3:30 pm
Net time	270 minutes

Location	**Flow (m^3/min)**	
	11/15/2016	**11/29/2016**
A	0.214	0.269
C	0.428	0.538
D	0.642	1.34
E	1.71	2.15



Appendix H: Raw Laboratory Results

10/11/16

TSS					
ID Number	**Weight of Filter Paper**	**Weight of Paper & Solid**	**Weight of Solids**	**Amount Sample Filtered**	**mg/L**
110216SA1	0.099	0.100	0.001	250mL	5.28
110216SA2	0.097	0.099	0.002	250mL	7.84
110216SB	0.099	0.103	0.004	250mL	15.4
110216SC	0.099	0.138	0.038	250mL	153

Total Phosphate		
ID Number	**Phosphate Abs.**	**Phosphate (ppm)**
110216SA1	0.172	0.056
110216SA2	0.091	0.035
110216SB	0.807	0.209
110216SC	0.880	0.035

Ammonia		
ID Number	**Ammonia Abs.**	**Ammonia (ppm)**
110216SA1	0.029	0.290
110216SA2	0.059	0.045
110216SB	0.036	0.033
110216SC	0.026	0.027

ID Number	Turbidity (NTU)
110216SA1	3.12
110216SA2	29.7
110216SB	0.77
110216SC	1.65

ID Number	pH
110216SA1	6.61
110216SA2	6.76
110216SB	7.40
110216SC	7.44

ID Number	DO (mg/L)
110216SA1	8.37
110216SA2	5.14
110216SB	8.93
110216SC	10.39

11/3/16

TSS					
ID Number	**Weight of Filter Paper**	**Weight of Paper & Solid**	**Weight of Solids**	**Amount Sample Filtered**	**mg/L**
110216SA1	0.096	0.097	1.10E-03	250mL	4.4
110216SA2	0.099	0.099	4.60E-04	250mL	1.84
110216SB	0.098	0.098	6.00E-05	250mL	0.24
110216SC	-	-	-	-	
110216PD	0.098	0.109	1.11E-02	250mL	44.2
110216SE	0.101	0.101	4.30E-04	250mL	1.72
110216SF	0.100	0.101	2.20E-04	250mL	0.88
110216PG	0.100	0.103	3.30E-03	250mL	13.2

Ammonia		
ID Number	**Ammonia Abs.**	**Ammonia (ppm)**
110216SA1	0.081	0.0561
110216SA2	0.067	0.0488
110216SB	0.076	0.0535
110216SC	-	-
110216PD	0.058	0.0441
110216SE	0.058	0.0441
110216SF	0.059	0.0446

Total Phosphate		
ID Number	**Phosphate Abs.**	**Phosphate (ppm)**
110216SA1	0.290	0.1115
110216SA2	1.085	0.3139
110216SB	0.059	0.0527
110216SC		
110216PD	0.135	0.0721
110216SE	0.024	0.0438
110216SF	0.173	0.0817
110216PG	0.000	0.0377

ID Number	Turbidity (NTU)
110216SA1	0.274
110216SA2	0.273
110216SB	0.095
110216SC	-
110216PD	0.042
110216SE	0.047
110216SF	0.053
110216PG	0.051

ID Number	DO (mg/L)
110216SA1	7.26
110216SA2	4.18
110216SB	3.65
110216SC	
110216PD	6.65
110216SE	2.92
110216SF	8.24
110216PG	6.61

ID Number	pH
110216SA1	6.54
110216SA2	6.41
110216SB	6.50
110216SC	-
110216PD	6.97
110216SE	6.69
110216SF	7.25
110216PG	7.21

Total Coliforms			
ID Number	**Large**	**Small**	**MNP/100mL**
110216SA1	48	48	1,011
110216SA2	48	48	1,011
110216SB	48	40	689
110216SC			
110216PD	48	45	870
110216SE	48	21	285
110216SF	48	28	397
110216PG	48	47	961

E. coli			
ID Number	**Large**	**Small**	**MNP/100mL**
110216SA1	34	10	72.8
110216SA2	37	10	84.2
110216SB	7	0	7.5
110216SC			
110216PD	47	16	198.9
110216SE	5	2	7.3
110216SF	14	0	16.1
110216PG	6	1	7.4

11/15/16

TSS					
ID Number	**Weight of Filter Paper**	**Weight of Paper & Solid**	**Weight of Solids**	**Amount Sample Filtered**	**mg/L**
111516A*	0.097	0.105	0.0072	250mL	28.84
111516C1*	0.098	0.106	0.0082	250mL	32.92
111516C2*	0.099	0.102	0.0025	250mL	10.04
111516D*	0.110	0.126	0.0168	250mL	67.24
111516E*	0.110	0.114	0.0039	250mL	15.56
111516A	0.097	0.103	0.0060	250mL	23.8
111516B	0.095	0.096	0.0012	250mL	4.72
111516C	0.096	0.108	0.0116	250mL	46.2
111516D	0.099	0.100	0.0016	250mL	6.2
111516E	0.098	0.098	0.0006	250mL	2.36
111516F	0.099	0.099	0.0000	250mL	0.16
111516G	0.097	0.121	0.0236	250mL	94.52

Ammonia		
ID Number	**Ammonia Abs.**	**Ammonia (ppm)**
111516A*	0.017	0.0227
111516C1*	0.139	0.0865
111516C2*	0.071	0.0509
111516D*	0.090	0.0609
111516E*	0.060	0.0452
111516A	0.181	0.1084
111516B	0.047	0.0384
111516C	0.060	0.0452
111516D	0.023	0.0258
111516E	0.034	0.0316
111516F	0.029	0.0290
111516G	0.077	0.0541

Total Phosphate		
ID Number	**Phosphate Abs.**	**Phosphate (ppm)**
111516A*	0.067	0.0548
111516C1*	0.022	0.0433
111516C2*	0.026	0.0443
111516D*	0.03	0.0453
111516E*	0.044	0.0489
111516A	0.056	0.0520
111516B	0.028	0.0448
111516C	0	0.0377
111516D	0.022	0.0433
111516E	0.021	0.0430
111516F	0.006	0.0392
111516G	0.015	0.0415

ID Number	Turbidity (NTU)
111516A*	25.7
111516C1*	4.18
111516C2*	2.46
111516D*	2.16
111516E*	2.53
111516A	15.5
111516B	1.70
111516C	5.99
111516D	1.60
111516E	1.02
111516F	0.558
111516G	29.5

ID Number	DO (mg/L)
111516A*	7.29
111516C1*	2.98
111516C2*	N/A
111516D*	7.10
111516E*	2.52
111516A	6.55
111516B	7.36
111516C	3.30
111516D	7.16
111516E	2.16
111516F	8.02
111516G	7.20

ID Number	pH
111516A*	6.78
111516C1*	6.74
111516C2*	6.77
111516D*	7.17
111516E*	6.80
111516A	6.54
111516B	6.66
111516C	6.86
111516D	7.39
111516E	6.72
111516F	7.35
111516G	7.24

Total Coliforms			
ID Number	Large	Small	MNP/100mL
111516A*	48	48	>1011.2
111516C1*	48	47	960.6
111516C2*	48	48	>1011.2
111516D*	48	47	960.6
111516E*	48	48	>1011.2
111516A	48	48	>1011.2
111516B	48	48	>1011.2
111516C	48	47	960.6
111516D	48	47	960.6
111516E	48	42	755.6
111516F	48	43	791.5
111516G	48	46	913.9

E. coli			
ID Number	Large	Small	MNP/100mL
111516A*	48	48	>1011.2
111516C1*	22	2	30.9
111516C2*	16	2	21.3
111516D*	48	33	>501.2
111516E*	31	5	54.6
111516A	48	48	>1011.2
111516B	48	39	>658.6
111516C	21	3	30.5
111516D	48	35	>549.3
111516E	20	2	27.5
111516F	11	1	13.4
111516G	17	1	21.6

11/29/16

TSS					
ID Number	**Weight of Filter Paper**	**Weight of Paper & Solid**	**Weight of Solids**	**Amount Sample Filtered**	**mg/L**
112916A*	0.097	0.111	0.0012	250mL	4.68
112916C*	0.098	0.110	0.0006	250mL	2.28
112916D*	0.099	0.112	0.0022	250mL	8.60
112916E*	0.110	0.109	0.0005	250mL	1.96
112916A	0.110	0.112	0.0017	250mL	6.88
112916B	0.097	0.110	0.0001	250mL	0.44
112916B2	0.095	0.109	0.0000	250mL	0.16
112916C	0.096	0.117	0.0067	250mL	26.8
112916D	0.099	0.116	0.0076	250mL	30.6
112916E	0.098	0.111	0.0007	250mL	2.84
112916F	0.099	0.109	0.0003	250mL	1.32
112916G	0.097	0.115	0.0057	250mL	22.8

Ammonia		
ID Number	**Ammonia Abs.**	**Ammonia (ppm)**
112916A*	0.013	0.0206
112916C*	0.050	0.0399
112916D*	0.035	0.0321
112916E*	0.059	0.0446
112916A	0.126	0.0796
112916B	0.020	0.0242
112916B2	0.022	0.0253
112916C	0.055	0.0425
112916D	0.037	0.0331
112916E	0.041	0.0352
112916F	0.051	0.0404
112916G	0.042	0.0357

Total Phosphate		
ID Number	**Phosphate Abs.**	**Phosphate (ppm)**
112916A*	0.007	0.0151
112916C*	0.016	0.0173
112916D*	0.025	0.0195
112916E*	2.803	0.6923
112916A	0.000	0.0134
112916B	0.007	0.0151
112916B2	0.001	0.0136
112916C	0.070	0.0304
112916D	0.007	0.0151
112916E	0.000	0.0134
112916F	0.000	0.0134
112916G	0.034	0.0216

ID Number	Turbidity (NTU)
112916A*	0.026
112916C*	0.044
112916D*	0.050
112916E*	0.052
112916A	7.218
112916B	0.043
112916B2	0.037
112916C	0.059
112916D	0.064
112916E	0.043
112916F	0.123
112916G	0.092

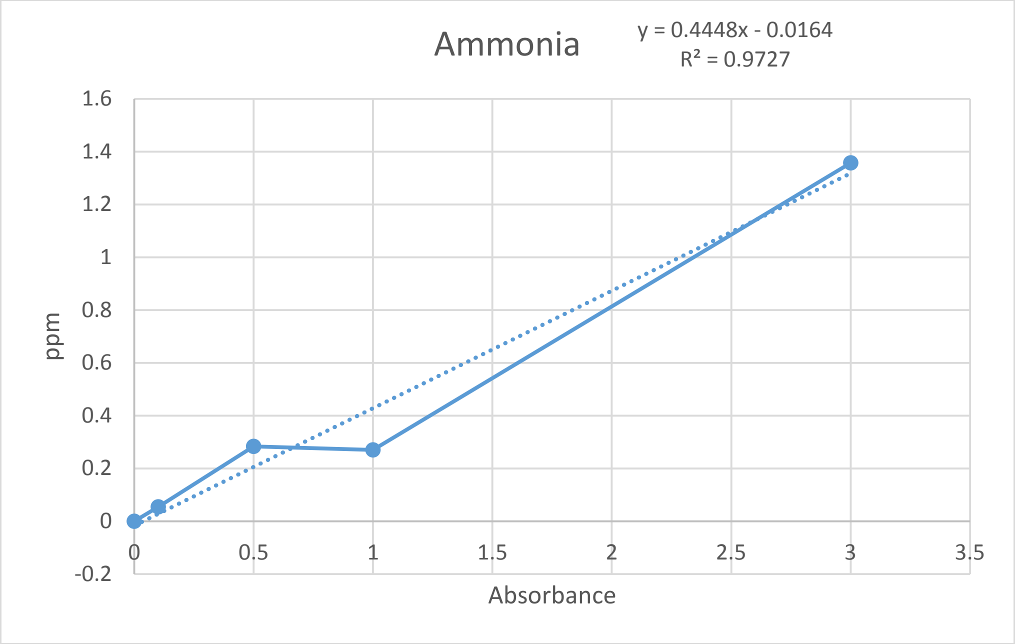
ID Number	DO (mg/L)
112916A*	12.0
112916C*	7.25
112916D*	11.4
112916E*	7.14
112916A	6.35
112916B	11.4
112916B2	6.14
112916C	6.56
112916D	10.4
112916E	7.81
112916F	11.4
112916G	11.6

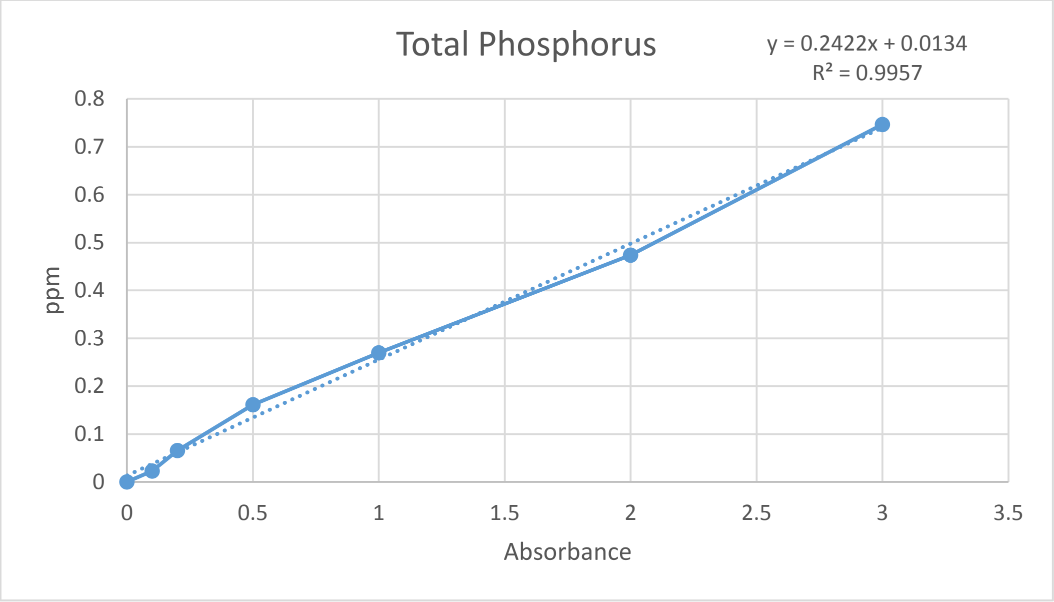
ID Number	pH
112916A*	6.74
112916C*	6.75
112916D*	7.09
112916E*	6.76
112916A	6.56
112916B	6.65
112916B2	6.66
112916C	6.63
112916D	6.98
112916E	6.74
112916F	7.26
112916G	7.23

Total Coliforms			
ID Number	**Large**	**Small**	**MNP/100mL**
112916A*	48	33	501.2
112916C*	48	44	829.7
112916D*	48	45	870.4
112916E*	48	20	272.3
112916A	48	48	>1011.2
112916B	48	45	870.4
112916B2	48	47	960.6
112916C	48	44	829.7
112916D	48	39	658.6
112916E	48	37	601.5
112916F	43	13	128.1
112916G	48	25	344.1

E. coli			
ID Number	**Large**	**Small**	**MNP/100mL**
112916A*	8	1	9.7
112916C*	5	0	5.2
112916D*	19	3	27.2
112916E*	17	2	22.8
112916A	48	33	501.2
112916B	5	0	5.2
112916B2	1	0	1
112916C	3	1	4.1
112916D	41	5	90.6
112916E	25	3	37.9
112916F	8	0	8.6
112916G	5	1	6.3

Standard Graphs for Ammonia





Chromatography Results

Fluoride (ppb)				
Location	**Dry 10/11/16**	**Dry 11/2/16**	**Wet 11/15/16**	**Wet 11/15/16**
A	60.1	None Detected	43.0	31.0
B		None Detected		61.9
C			62.6	61.9
D	48.9	57.8	54.8	52.2
E	65.5	None Detected	62.5	62.4
F		64.0		53.0
G		60.0		51.8

Chloride (ppb)				
Location	**Dry 10/11/16**	**Dry 11/2/16**	**Wet 11/15/16**	**Wet 11/15/16**
A	91,443	97,404	20,875	9,830
B		106,460		95,493
C			106,505	105,624
D	329,082	311,698	307,339	306,085
E	90,334	105,976	104,799	103,414
F		320,840		315,530
G		276,828		302,338

Sulfate (ppb)				
Location	**Dry 10/11/16**	**Dry 11/2/16**	**Wet 11/15/16**	**Wet 11/15/16**
A	15,142	13,962	3,340	1,643
B		15,020		13,712
C			14,984	14,912
D	12,796	12,636	12,560	12,348
E	15,448	14,843	14,833	14,564
F		12,964		12,610
G		11,012		11,931

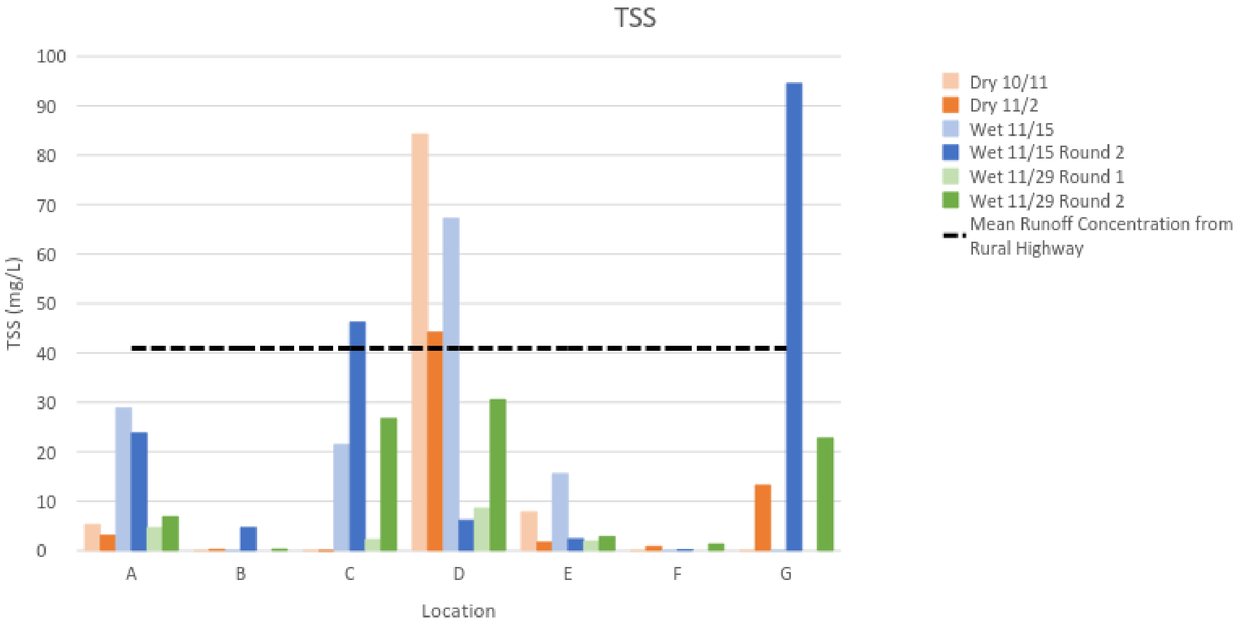
Bromide				
Location	**Dry 10/11/16**	**Dry 11/2/16**	**Wet 11/15/16**	**Wet 11/15/16**
A	117.4	95.6	10.0	None Detected
B		112.0		99.3
C			41.1	41.2
D	698.1	556.5	746.7	610.7
E	96.8	141.2	121.8	39.8
F		365.6		321.8
G		311.5		572.0

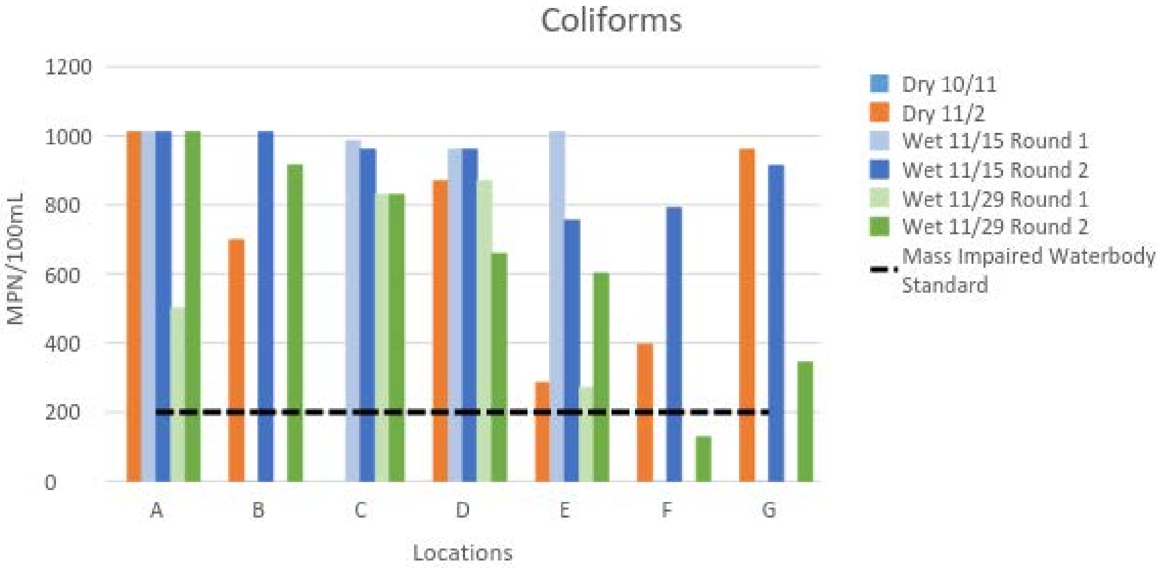
Nitrate (ppb)				
Location	**Dry 10/11/16**	**Dry 11/2/16**	**Wet 11/15/16**	**Wet 11/15/16**
A	5549.4	4260.7	None Detected	943.0
B		2366.7		None Detected
C			None Detected	2272.3
D	None Detected	22.4	4.0	24.1
E	2181.1	1608.8	1552.7	1488.1
F		309.4		269.8
G		239.2		23.5

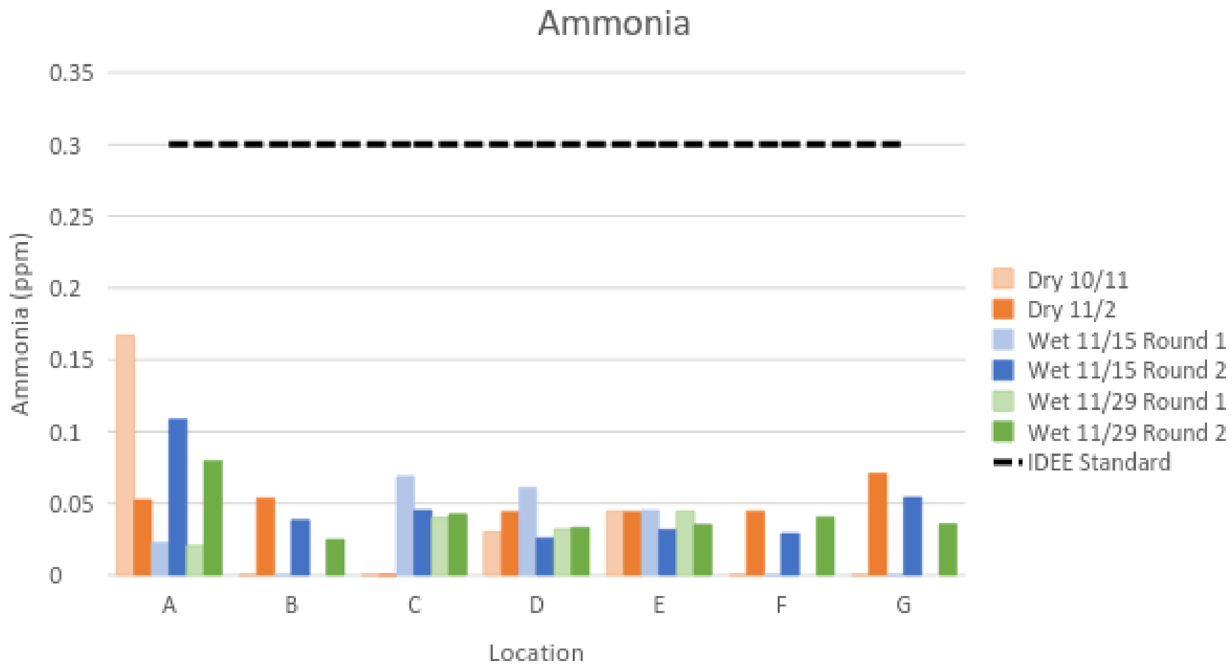
Phosphate (ppb)				
Location	**Dry 10/11/16**	**Dry 11/2/16**	**Wet 11/15/16**	**Wet 11/15/16**
A	107.4	None Detected	82.00	81
B		None Detected		None Detected
C			22.8	None Detected
D	None Detected	None Detected	None Detected	None Detected
E	None Detected	120.1	None Detected	None Detected
F		None Detected		None Detected
G		None Detected		None Detected

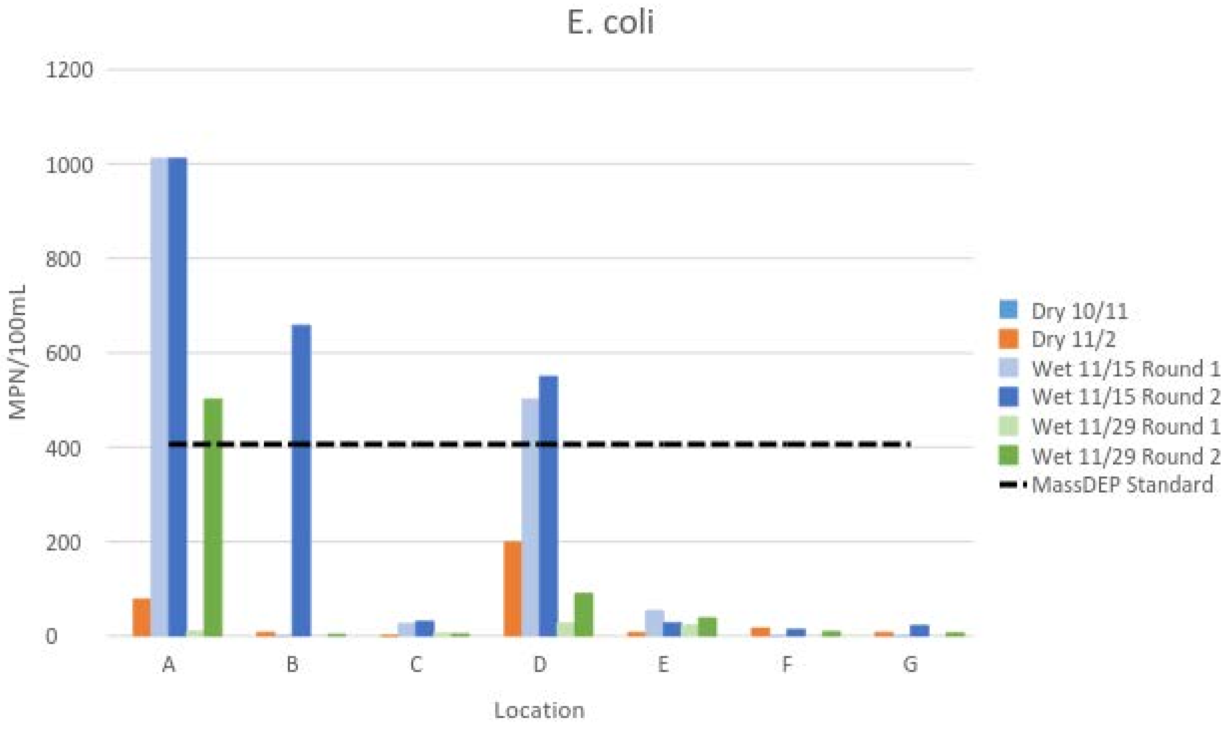
Nitrite (ppb)				
Location	**Dry 10/11/16**	**Dry 11/2/16**	**Wet 11/15/16**	**Wet 11/15/16**
A	None Detected	None Detected	200.4	113.1
B		None Detected		None Detected
C			None Detected	None Detected
D	None Detected	None Detected	None Detected	None Detected
E	584.2	None Detected	None Detected	None Detected
F		None Detected		None Detected
G		None Detected		None Detected

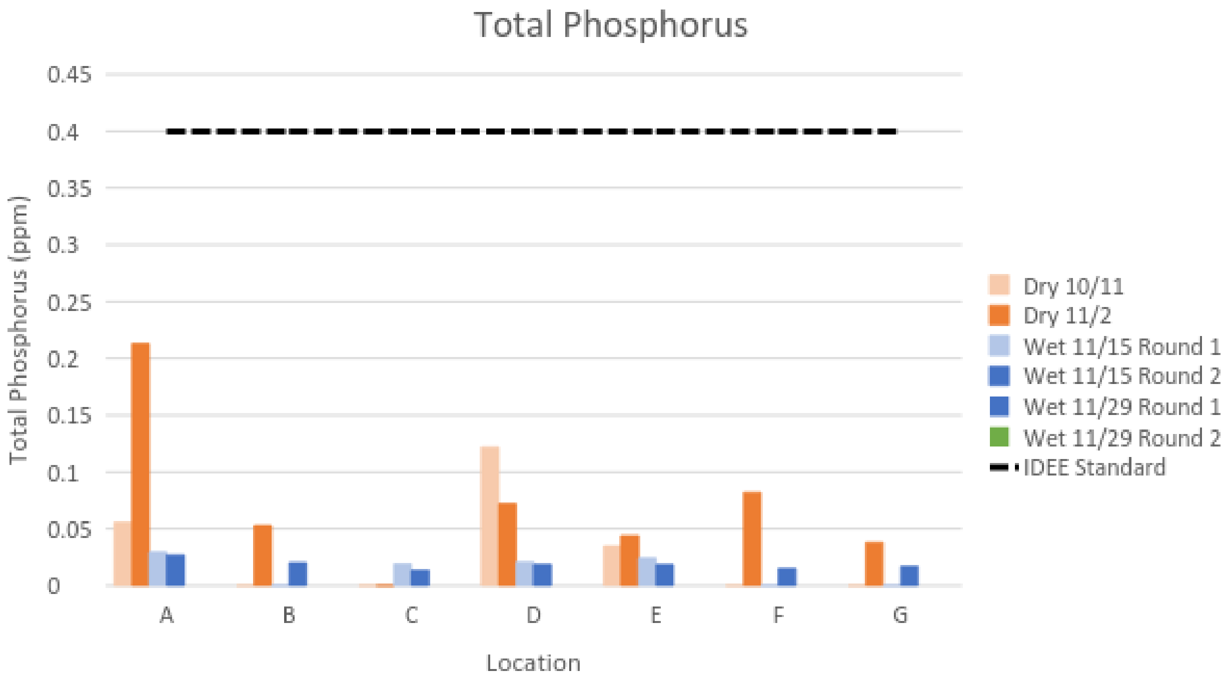
Appendix I: Comparative Data

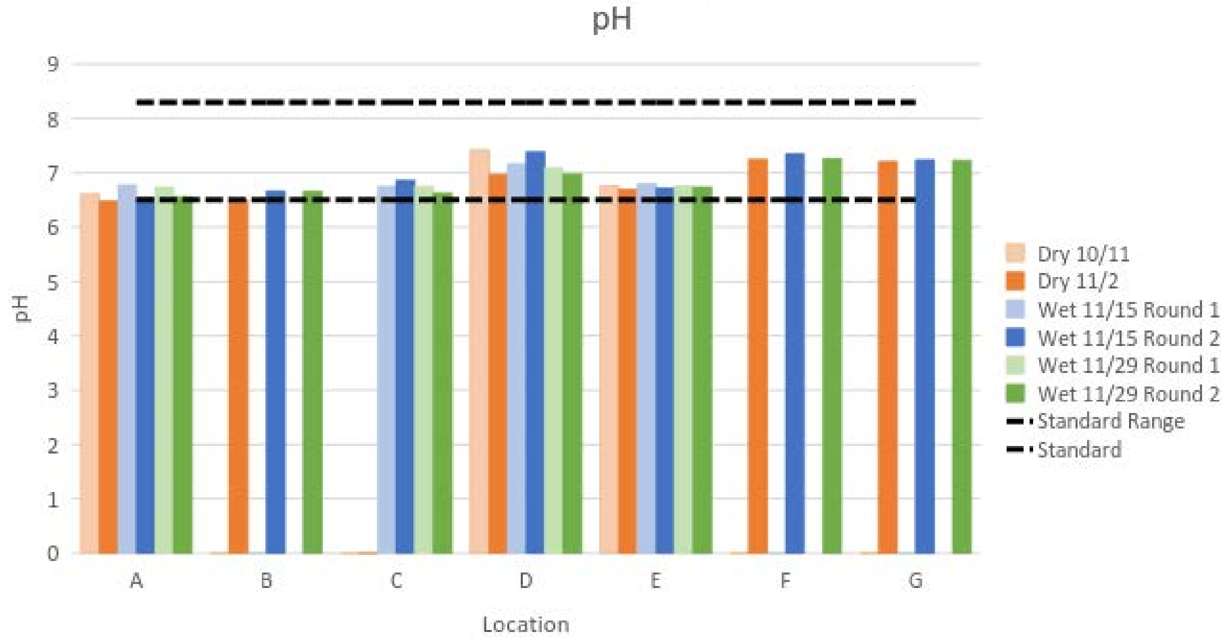


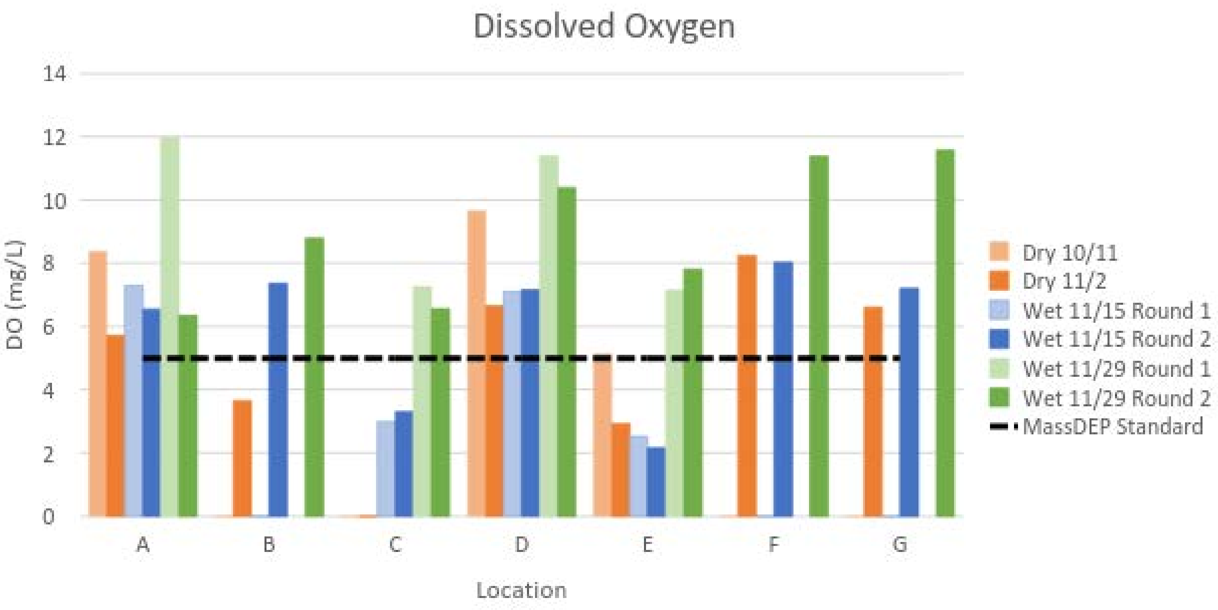


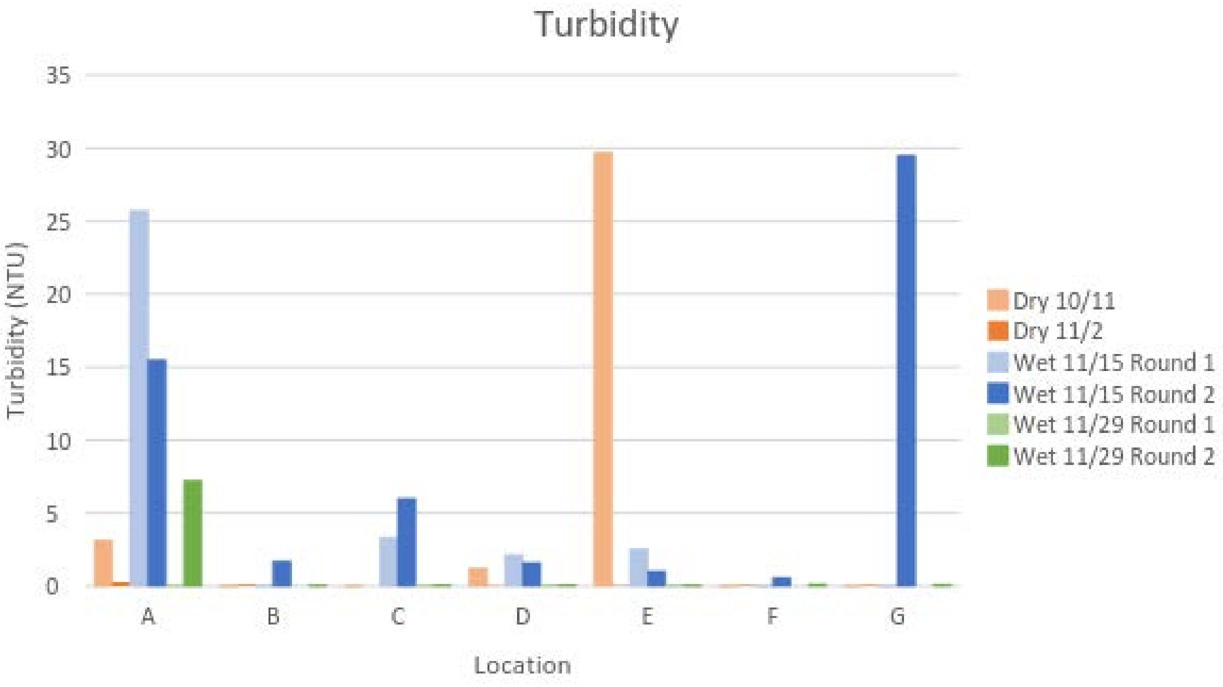

Ammonia
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Ammonia (ppm)
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2
IDEE Standard

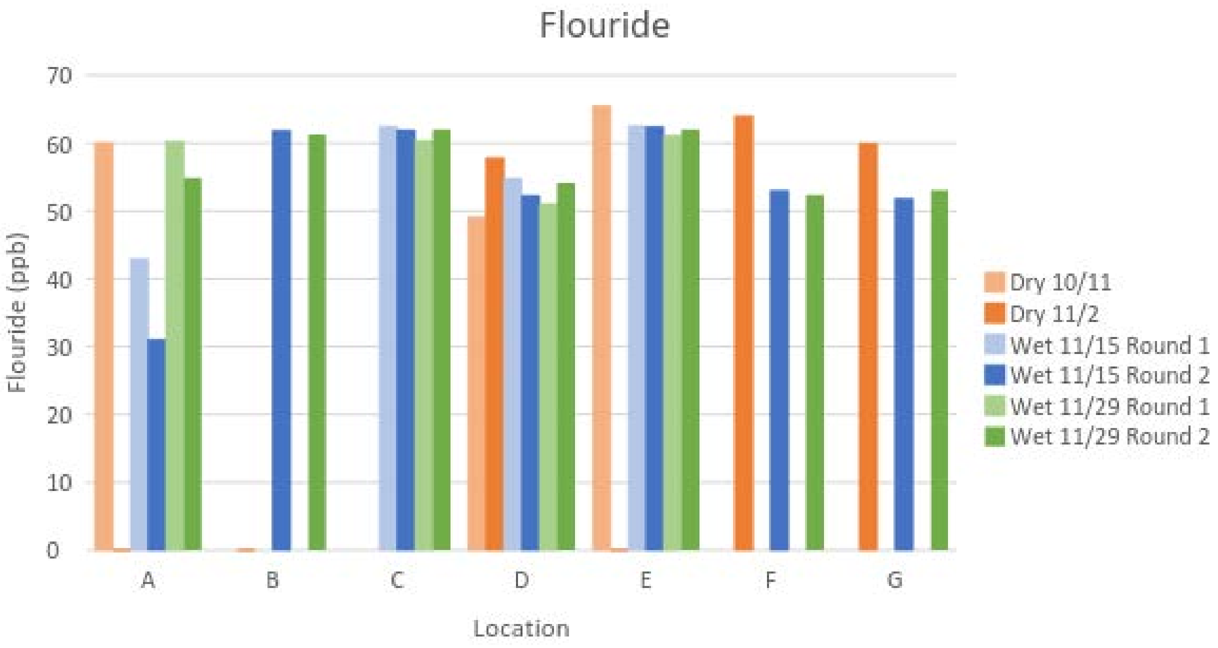

E. coli
1200
1000
800
600
400
200
0
MPN/100mL
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2
MassDEP Standard

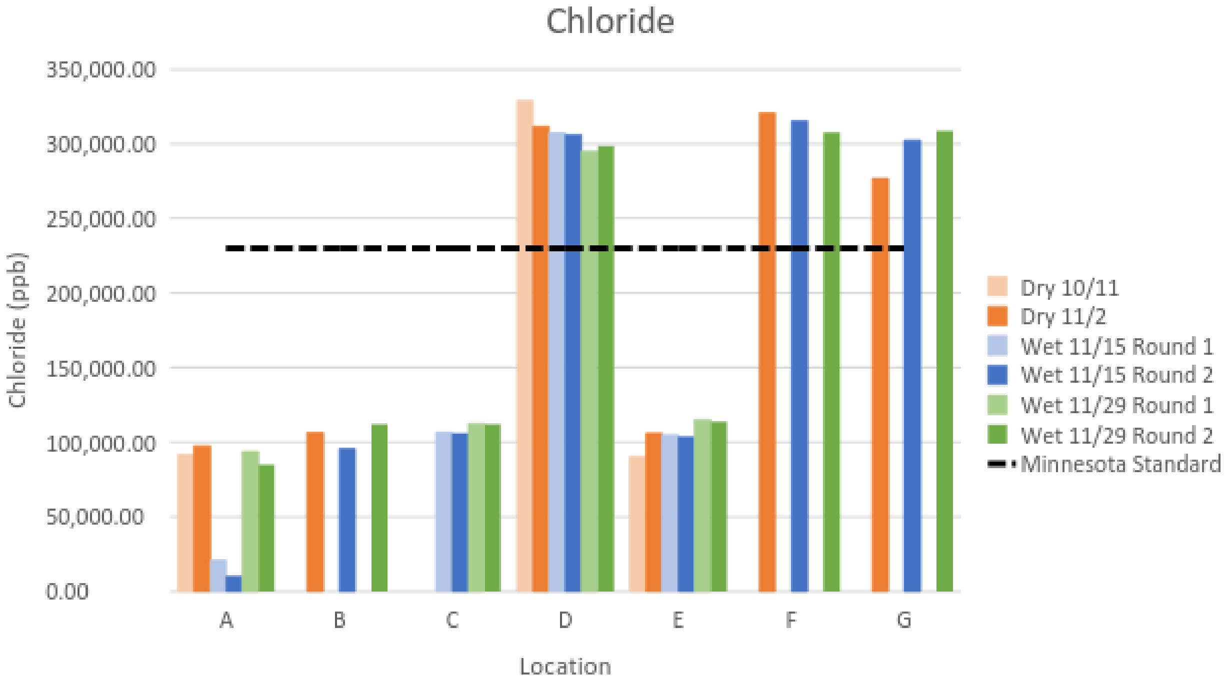

Total Phosphorus
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Total Phosphorus (ppm)
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2
IDEE Standard

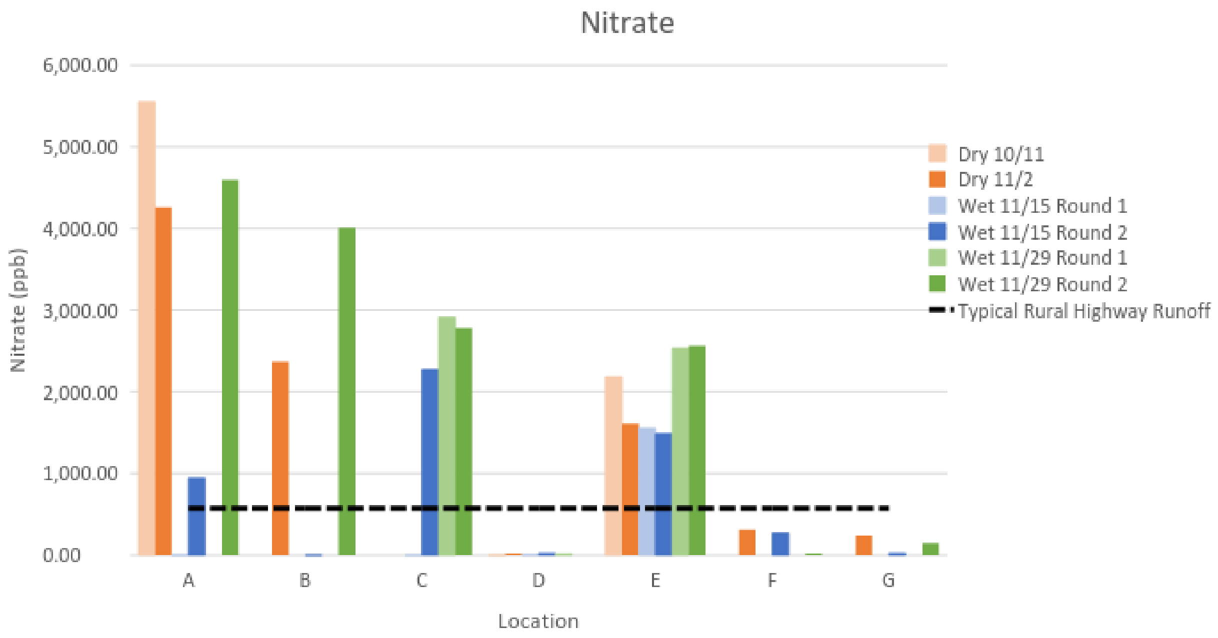

pH
9
8
7
6
5
4
3
2
1
0
pH
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2
Standard Range
Standard

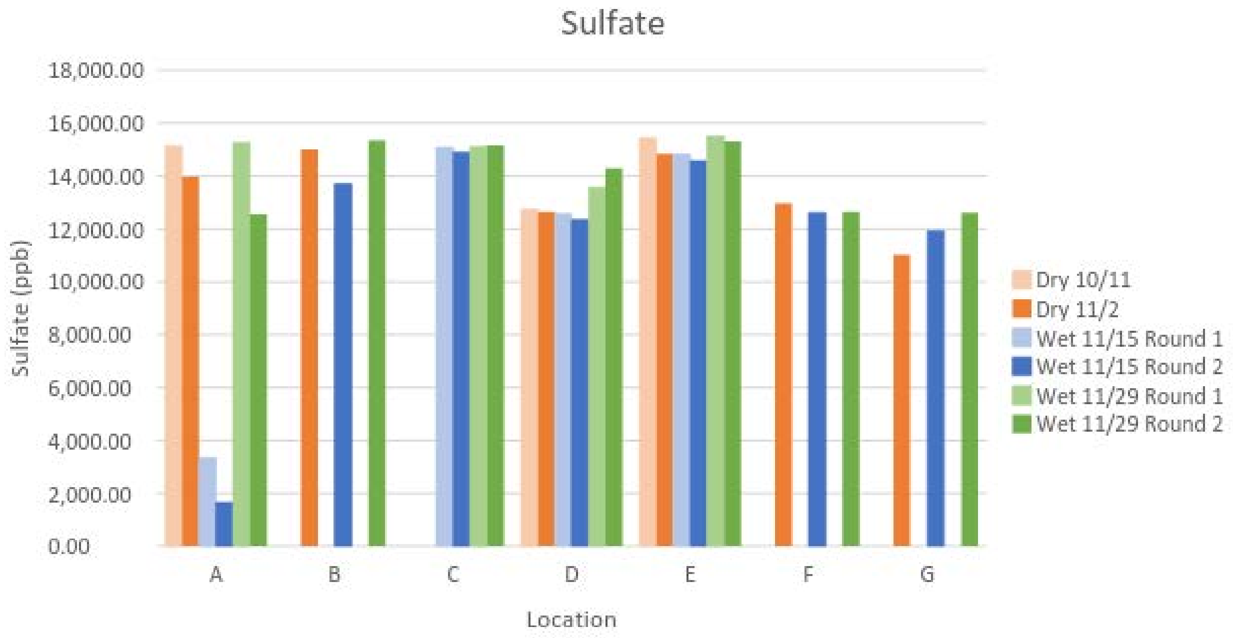

Dissolved Oxygen
DO (mg/L)
14
12
10
8
6
4
2
0
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2
MassDEP Standard

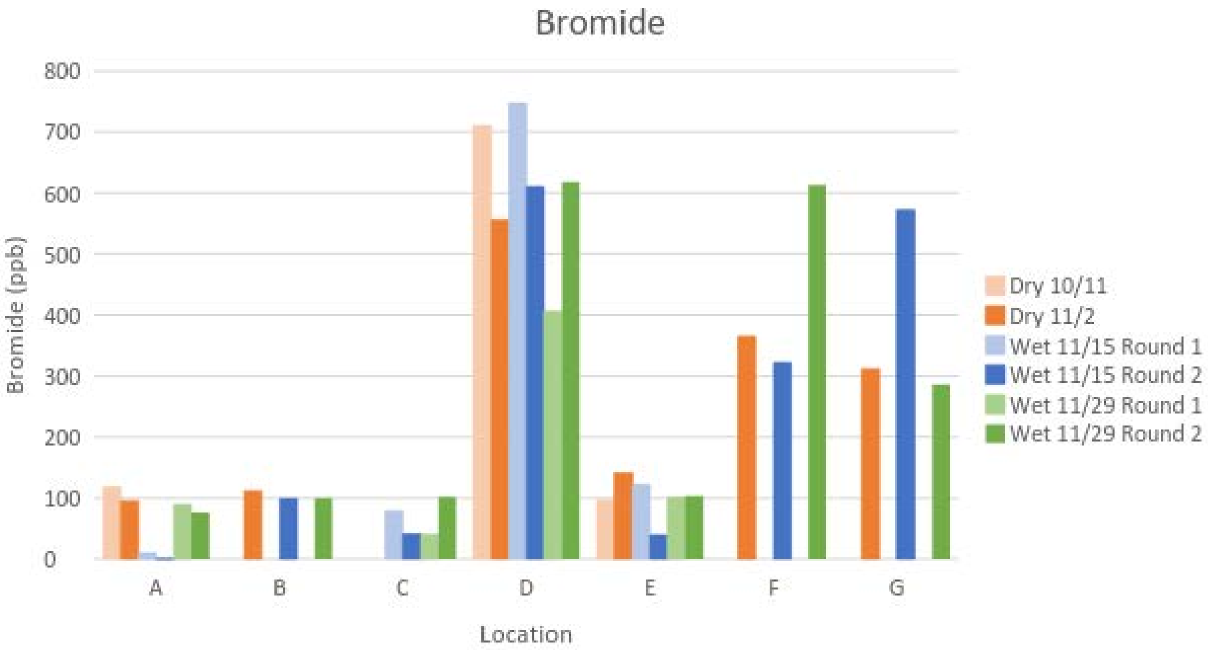

Turbidity
Turbidity (NTU)
35
30
25
20
15
10
5
0
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2

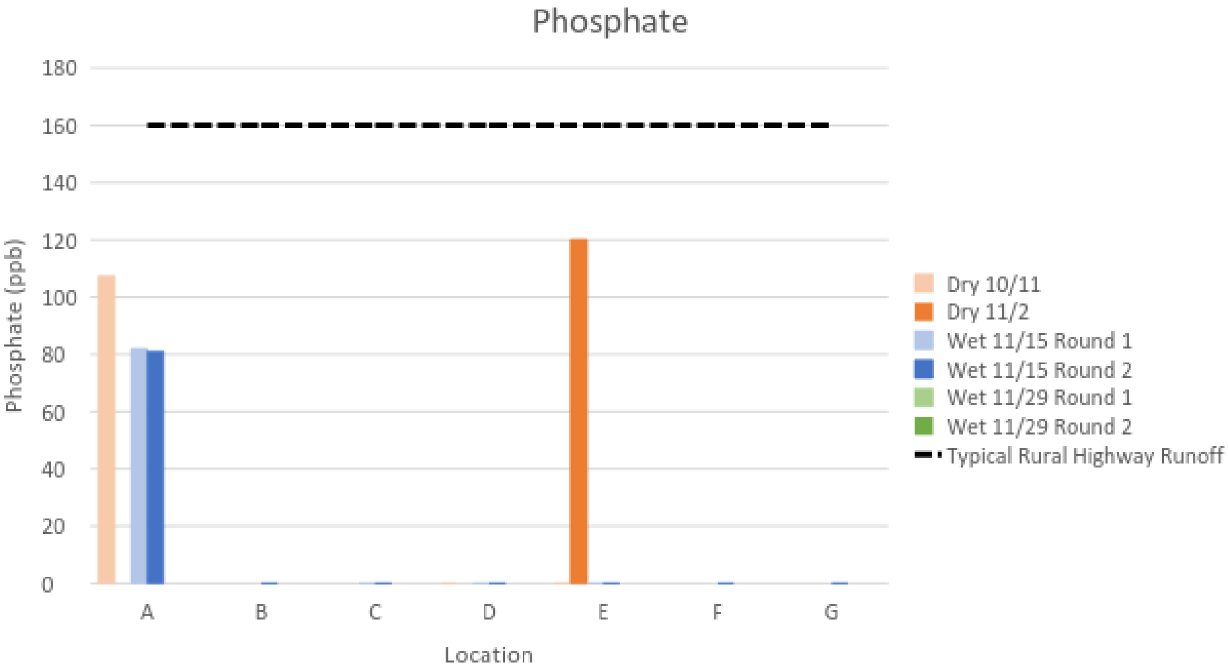

Flouride
70
60
50
40
30
20
10
0
Flouride (ppb)
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2


Chloride
350,000.00
300,000.00
250,000.00
200,000.00
150,000.00
100,000.00
50,000.00
0.00
Chloride (ppb)
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2
Minnesota Standard


Nitrate
6,000.00
5,000.00
4,000.00
3,000.00
2,000.00
1,000.00
0.00
Nitrate (ppb)
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2
Typical Rural Highway Runoff


Sulfate
18,000.00
16,000.00
14,000.00
12,000.00
10,000.00
8,000.00
6,000.00
4,000.00
2,000.00
0.00
Sulfate (ppb)
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2


Bromide
800
700
600
500
400
300
200
100
0
Bromide (ppb)
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2


Phosphate
180
160
140
120
100
80
60
40
20
0
Phosphate (ppb)
A
B
C
D
E
F
G
Location
Dry 10/11
Dry 11/2
Wet 11/15 Round 1
Wet 11/15 Round 2
Wet 11/29 Round 1
Wet 11/29 Round 2
Typical Rural Highway Runoff

Appendix J: Calculations for Annual Pollutant Loads

Part 1: Estimating Annual Runoff (NRCS Method)

$Q = \frac{(P-0.2S)^2}{(P-0.8S)}$ where:

Q = runoff (in)

P = rainfall (in) = 45.88 inches

S = potential maximum retention after runoff begins (in)

$$S = \frac{1{,}000}{CN} - 10$$

$$S = \frac{1{,}000}{54} - 10 = 8.52$$

$$Q = \frac{(45.88 - 0.2 * 8.52)^2}{(45.88 - 0.8 * 8.52)} = 49.96\ in$$

Part 2: Estimating Stormwater Loads (Simple Method)

$$L\ (annual\ load\ lbs) = 0.226 * R * C * A$$

$$R\ (annual\ runoff\ in) = 49.96\ inches$$

$$A\ (area\ acres) = 533\ acres$$

$$C = pollutant\ concentration\ \left(\frac{mg}{L}\right)$$

$$L_{nitrate} = 0.226 * 49.96\ inches * \frac{2.77mg}{L} * 295{,}271\ acres = 9{,}234{,}166\ lb$$

$$L_{phosphate} = 0.226 * 49.96\ inches * \frac{0.081mg}{L} * 295{,}271\ acres = 270{,}024\ lb$$

$$L_{bromide} = 0.226 * 49.96\ inches * \frac{0.058mg}{L} * 295{,}271\ acres = 193\ 350\ lb$$

$$L_{sulfate} = 0.226 * 49.96\ inches * \frac{8.20mg}{L} * 295{,}271\ acres = 27{,}3351800\ lb$$

$$L_{chloride} = \ 0.226 * 49.96\ inches * \frac{52.24mg}{L} * 295{,}271\ acres = 174{,}149{,}053\ lb$$

$$L_{fluoride} = \ 0.226 * 49.96\ inches * \frac{0.047mg}{L} * 295{,}271\ acres = 156{,}680\ lb$$

$$L_{total\ phosphate} = \ 0.226 * 49.96\ inches * \frac{2.83x10^{-4}mg}{L} * 295{,}271\ acres = 943\ lb$$

$$L_{ammonia} = \ 0.226 * 49.96\ inches * \frac{1.16x10^{-3}mg}{L} * 295{,}271\ acres = 3{,}867\ lb$$

$$L_{TSS} = \ 0.226 * 49.96\ inches * \frac{16.05mg}{L} * 295{,}271\ acres = 53{,}504{,}829\ lb$$

$$L\ (annual\ load\ billion\ colonies) = 1.03x10^{-3} * R * C * A$$

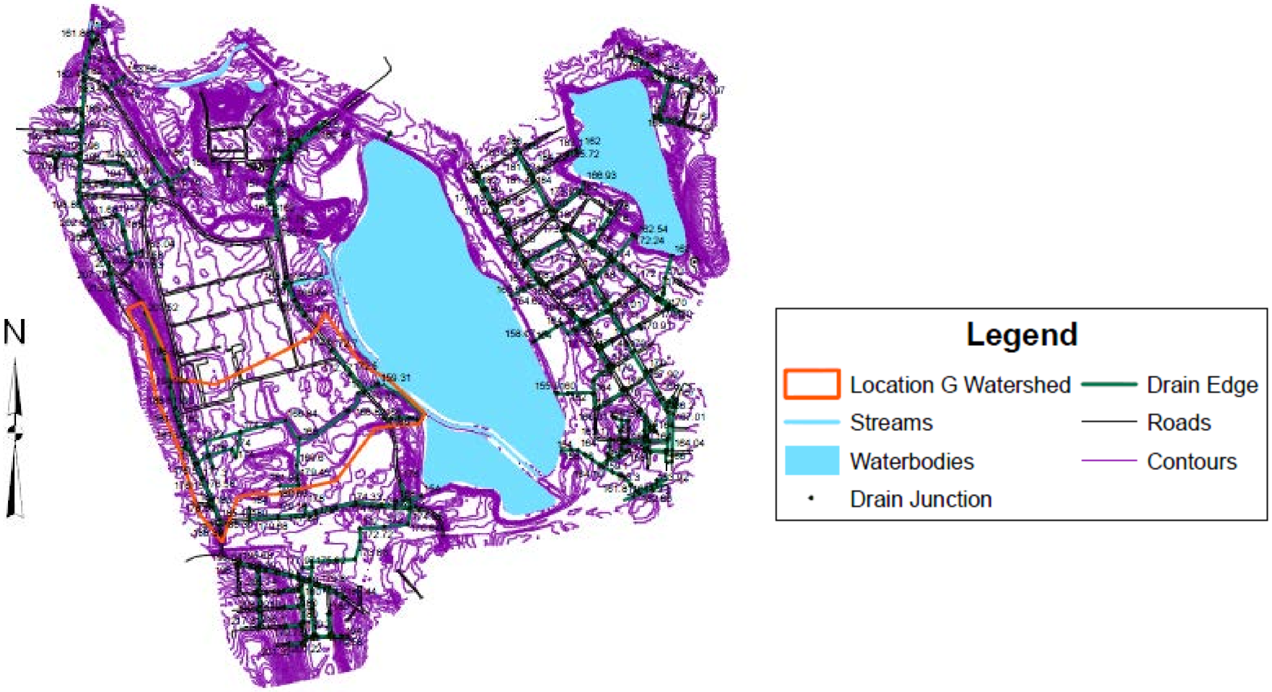
$$C = bacteria\ concentration\ \left(\frac{\#}{100mL}\right)$$

$$L = 1.03x10^{-3} * 49.96\ inches * 633\frac{MPN}{100mL} * 295{,}271\ acres = 9{,}617{,}239\ billion\ colonies$$

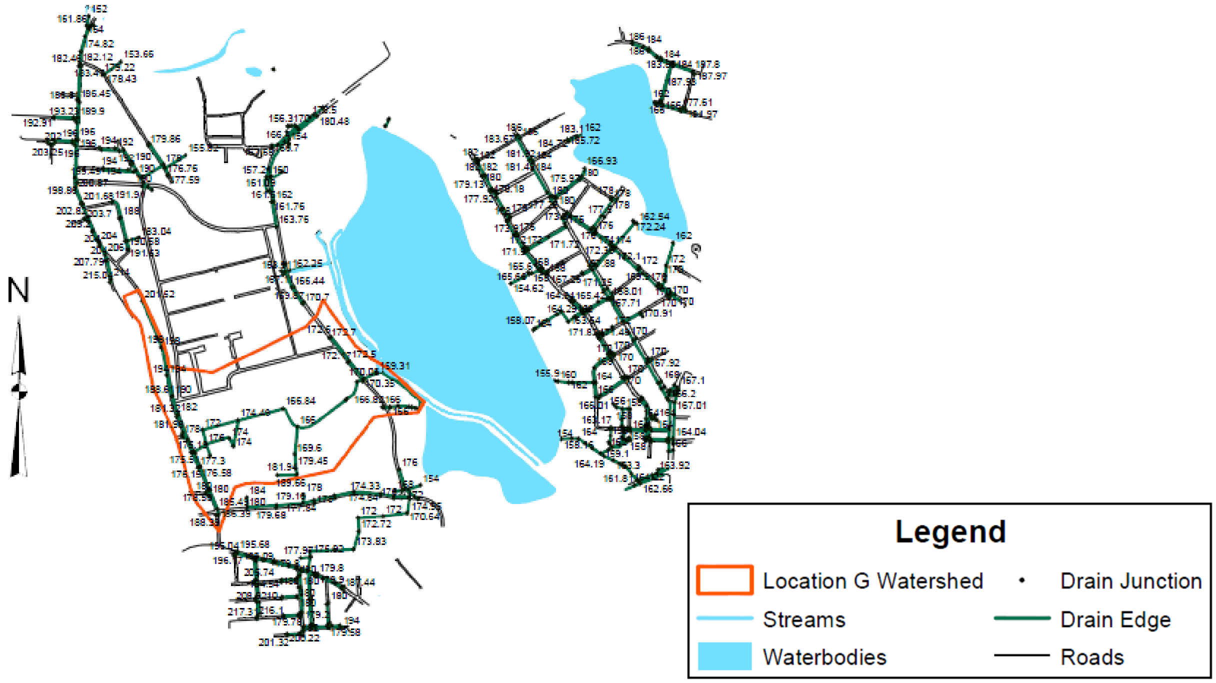
$$L = 1.03x10^{-3} * 49.96\ inches * 834\frac{MPN}{100mL} * 295{,}271\ acres = 12{,}671{,}055\ bilion\ colonies$$

Appendix K: Location G Watershed Results

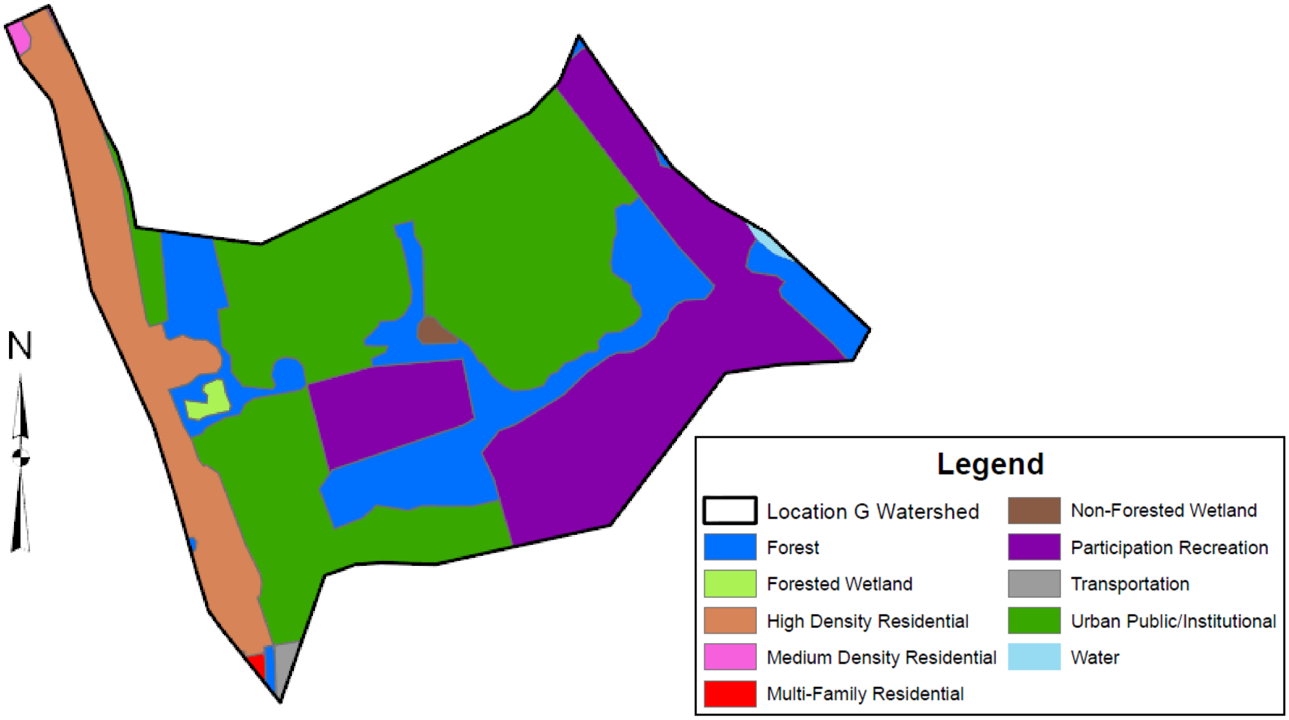
Location G Watershed:



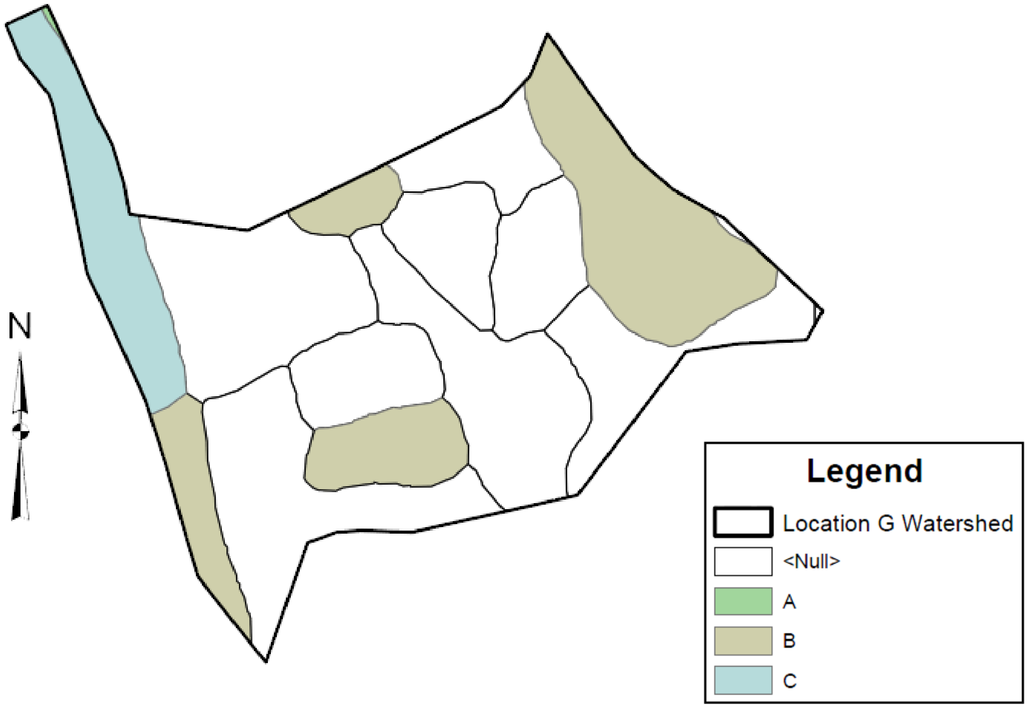
Location G Watershed:



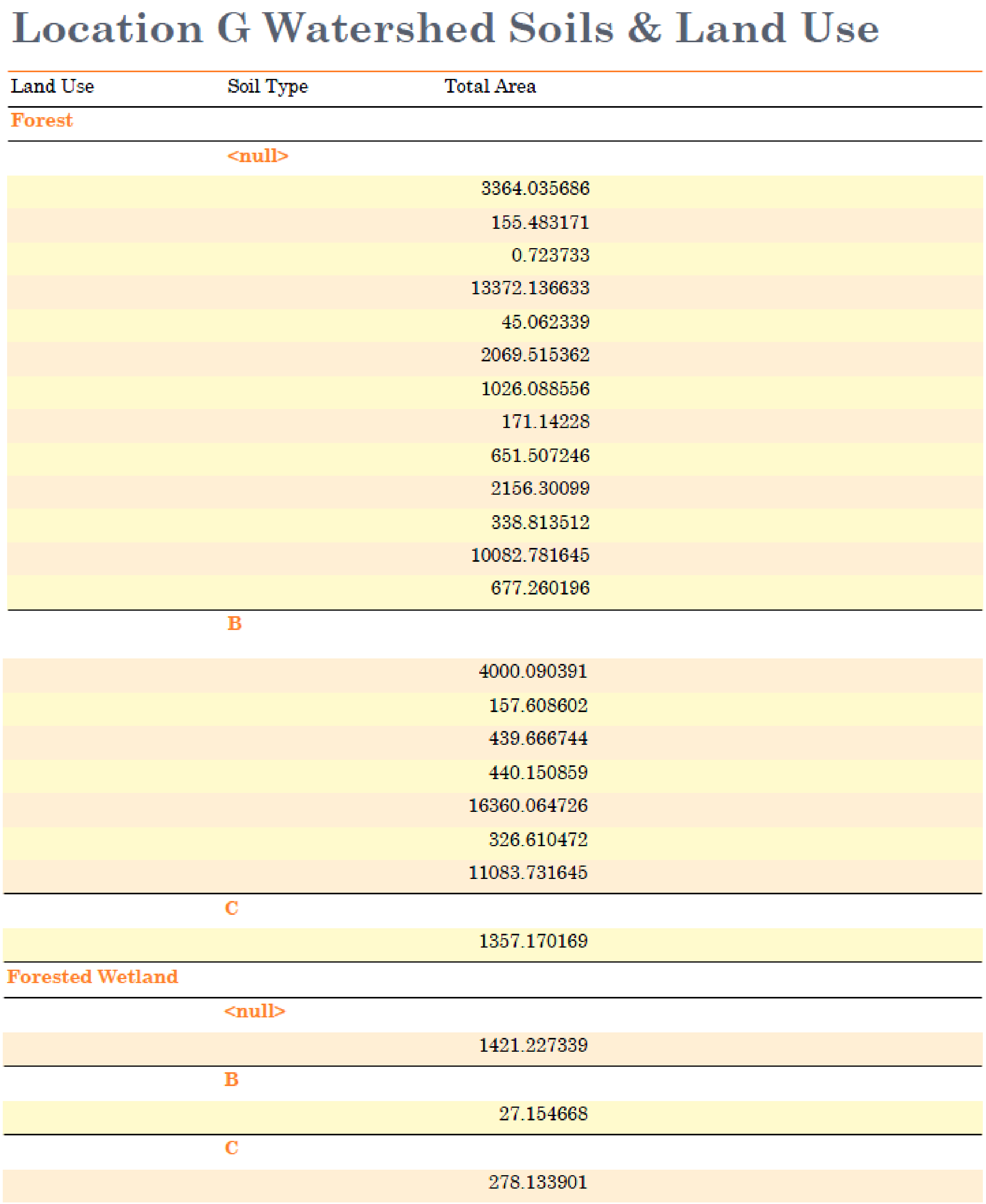
Location B Land Use:



Location G Soil Types:



Location G Watershed Land Use and Soil Types Area:



Location G Watershed Soils & Land Use

Land Use	Soil Type	Total Area
Forest		
	<null>	
		3364.035686
		155.483171
		0.723733
		13372.136633
		45.062339
		2069.515362
		1026.088556
		171.14228
		651.507246
		2156.30099
		338.813512
		10082.781645
		677.260196
	B	
		4000.090391
		157.608602
		439.666744
		440.150859
		16360.064726
		326.610472
		11083.731645
	C	
		1357.170169
Forested Wetland		
	<null>	
		1421.227339
	B	
		27.154668
	C	
		278.133901

Land Use	Soil Type	Total Area
High Density Residential		
	<null>	
		1906.96395
		3806.194623
	A	
		153.514218
	B	
		13343.830982
	C	
		30739.125889
Medium Density Residential		
	A	
		228.093433
	C	
		918.182508
Multi-Family Residential		
	<null>	
		51.979777
	B	
		519.174852
Non-Forested Wetland		
	<null>	
		7.049818
		1153.584315
Participation Recreation		
	<null>	
		17430.347408
		102.509759
		428.655792
		22545.028206
		790.36391
		23707.983336
	B	
		1736.802391
		223.867737
		34141.032215

Land Use	Soil Type	Total Area
Transportation		
	<null>	
		1391.899663
Urban Public/Institutional		
	<null>	
		315.374931
		729.929802
		43623.627677
		1328.48078
		18453.295083
		32476.386925
		20158.653615
		19035.709604
		1715.840242
		10467.587464
	B	
		1113.020922
		1368.382374
		7988.966503
		5308.294334
	C	
		3760.699681
Water		
	<null>	
		494.798134
	B	
		246.260332

Estimates of Land Use with Null Values Estimations (acres)

Soil Type	Forest	Forested Wetland	High Density Residential	Medium Density Residential	Multi-Family Residential	Non-forested Wetland	Recreation	Transportation	Urban-Public Institutional
A	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
B	12.28	0.12	4.00	0.00	0.14	0.29	24.99	0.08	44.60
C	4.17	0.30	8.30	0.23	0.00	0.00	0.00	0.00	41.63
D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	16.45	0.42	12.30	0.28	0.14	0.29	24.99	0.08	86.22

Time of Concentration

$$t_c = 0.0078 * k \left(\frac{L}{S^{0.5}}\right)^{0.77}$$

L=flow length (ft)

S = average watershed land slope (ft/ft)

K = Kirpich adjustment factor based on type of ground cover

K is equivalent to 0.4 for flow on concrete or asphalt surfaces and 1.5 for flow on natural grass channels, bare soil, or roadside ditches (LMBO, 2015).

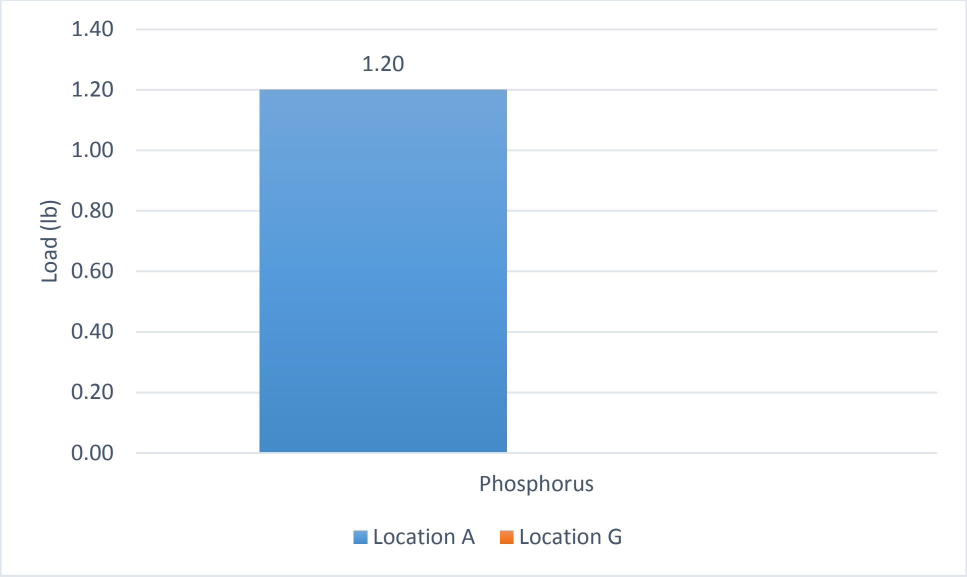
$$t_{c,Location\ G} = 0.0078 * 1.5 \left(\frac{3{,}668\ ft}{0.01898^{0.5}}\right)^{0.77} = 30\ minutes$$

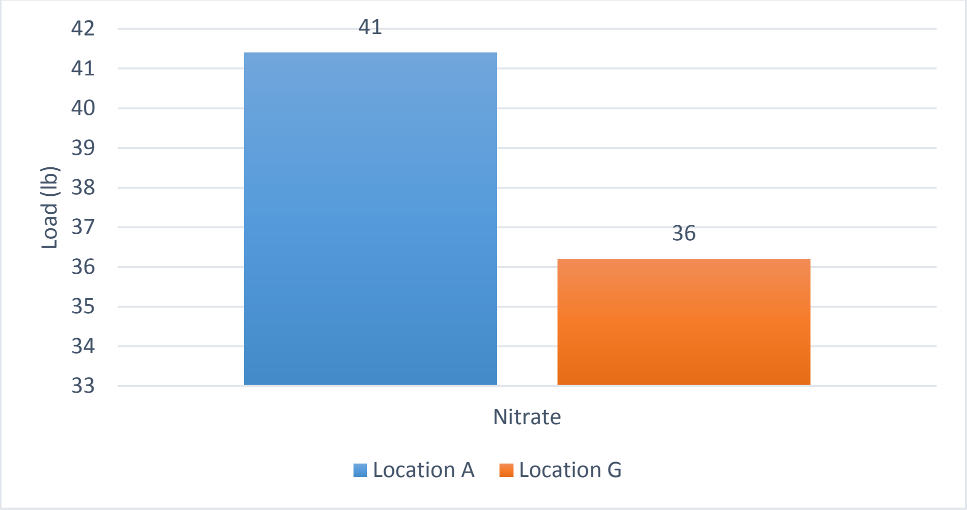
Year	**Rainfall (in)**	**Runoff (L)**
5	4.5	$1.95\text{x}10^7$
10	5	$2.41\text{x}10^7$
25	6	$3.38\text{x}10^7$
50	6.5	$3.90\text{x}10^7$
100	7	$4.43\text{x}10^7$
11/15/16 Storm	1.2	$5.08\text{x}10^5$
11/29/16 Storm	0.46	$1.39\text{x}10^5$

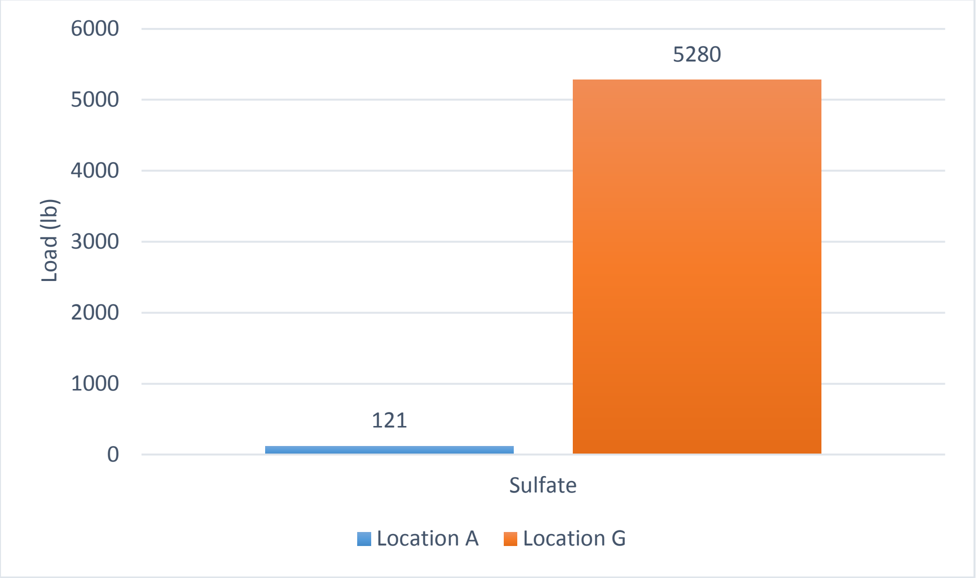
Constituent	Concentration	Units
Nitrate	0.84271	mg/L
Phosphorus	0.00	mg/L
Bromide	4.290176	mg/L
Sulfate	122.7091	mg/L
Chloride	3054.462	mg/L
Fluoride	0.524375	mg/L
Total Phosphate	1.83E-02	mg/L
Ammonia	4.49E-02	mg/L
Total Suspended Solids (TSS)	58.66	mg/L
E. coli	13.95	MPN/100mL
Total Coliforms	629	MPN/100mL

Constituent	**Return Period**						
	5 yr 24hr	**10 yr 24hr**	**25 yr 24 hr**	**50 yr 24 hr**	**100 yr 24 hr**	**11/15/16 Rainfall**	**11/29/16 Rainfall**
Nitrate*	3.62x10^{1}	4.47x10^{1}	6.28x10^{1}	7.23x10^{1}	8.22x10^{2}	9.44x10^{-1}	2.59x10^{-1}
Phosphate*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bromide*	1.85x10^{2}	2.27x10^{2}	3.19x10^{2}	3.68x10^{2}	4.18x10^{2}	4.81	1.31
Sulfate*	5.28x10^{3}	6.52x10^{3}	9.15x10^{3}	1.05x10^{4}	1.19x10^{4}	1.37x10^{2}	3.76x10^{1}
Chloride*	1.31x10^{5}	1.62x10^{5}	2.28x10^{5}	2.62x10^{5}	2.98x10^{5}	3.42x10^{3}	9.38x10^{2}
Fluoride*	2.25x10^{1}	2.78x10^{1}	3.91x10^{1}	4.50x10^{1}	5.12x10^{1}	5.87x10^{-1}	1.61x10^{-1}
Total Phosphorus*	7.88x10^{-1}	9.72x10^{-1}	1.37	1.57	1.79	2.05x10^{-2}	5.62x10^{-3}
Ammonia*	1.93	2.38	3.35	3.86	4.38	5.03x10^{-2}	1.38x10^{-2}
TSS*	2.52x10^{3}	3.12x10^{3}	4.37x10^{3}	5.04x10^{3}	5.72x10^{3}	6.57x10^{1}	1.80x10^{1}
E. coli^{+}	6.00x10^{5}	7.41x10^{5}	1.04x10^{6}	1.20x10^{6}	1.36x10^{6}	1.56x10^{4}	4.28x10^{3}
Total Coliforms^{+}	2.71x10^{7}	3.34x10^{7}	4.69x10^{7}	5.40x10^{7}	6.14x10^{7}	7.04x10^{5}	1.93x10^{5}
* Stormwater loads in lbs + Stormwater loads in MPN/100mL							

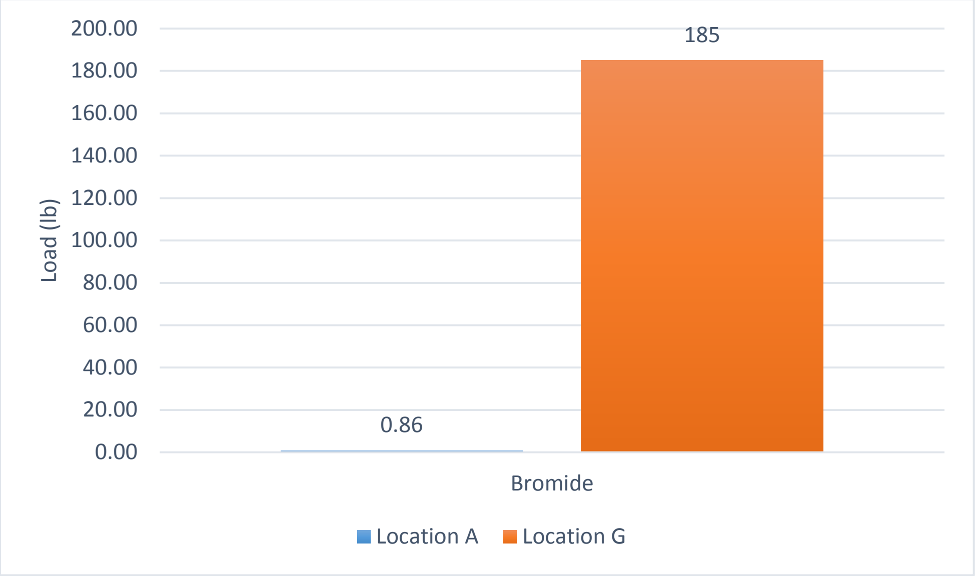
Appendix L: Comparison of CMP Stream & Location G Stormwater Loads for 5 Year Storm Return Period



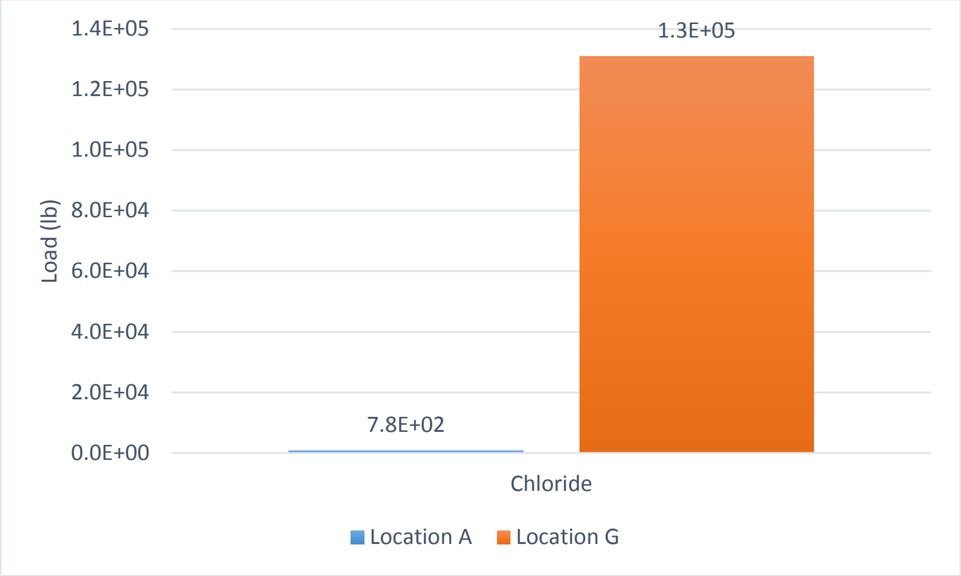


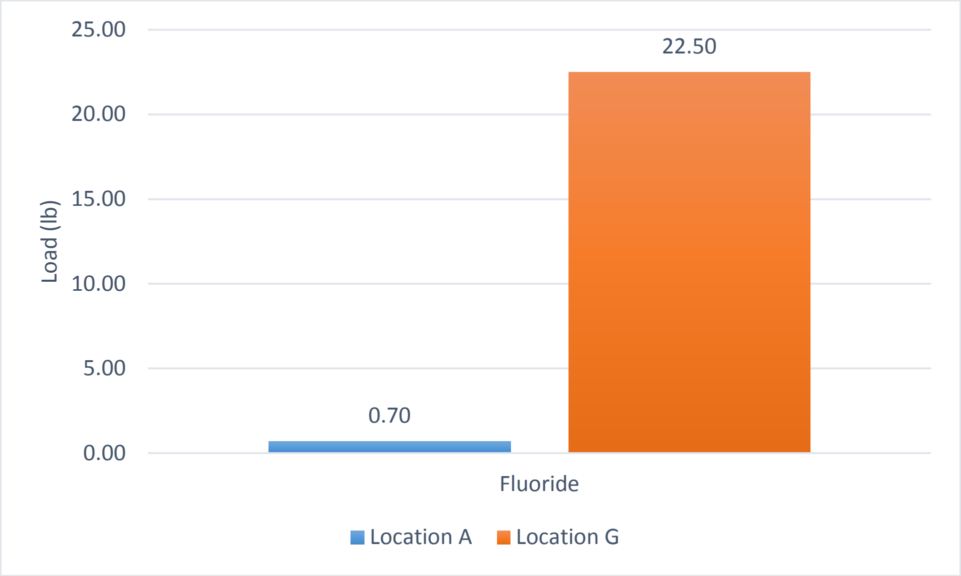


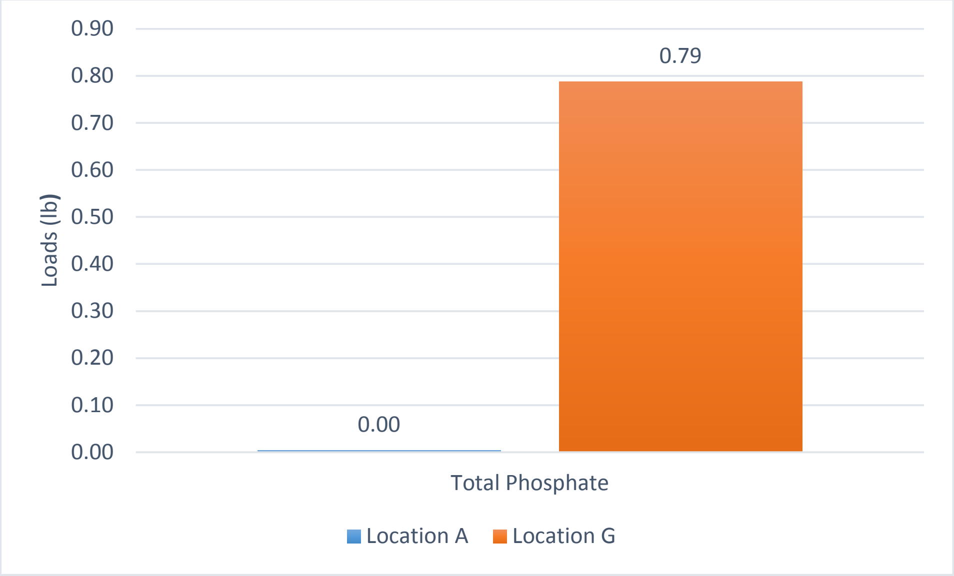
6000
5000
4000
3000
2000
1000
0
Load (lb)
5280
121
Sulfate
Location A
Location G

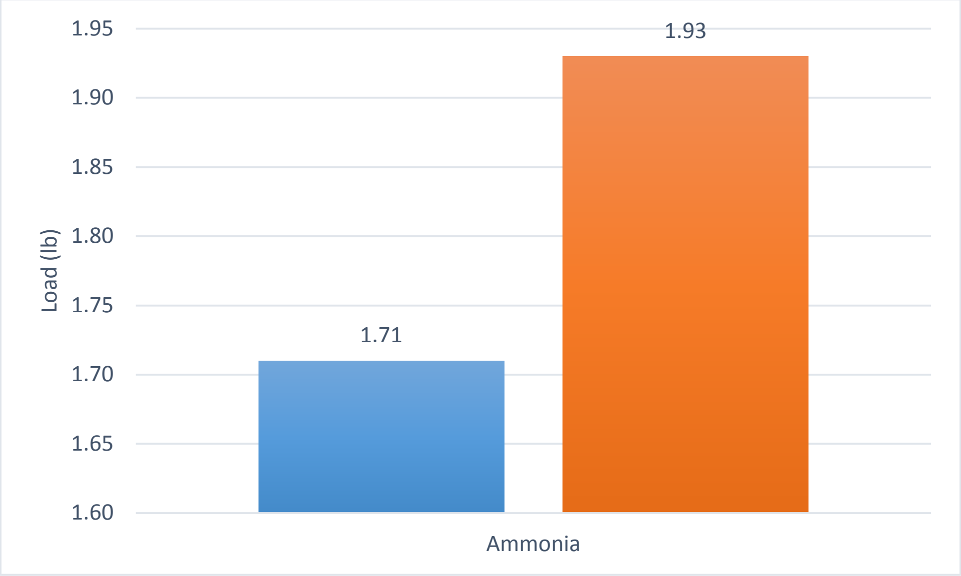


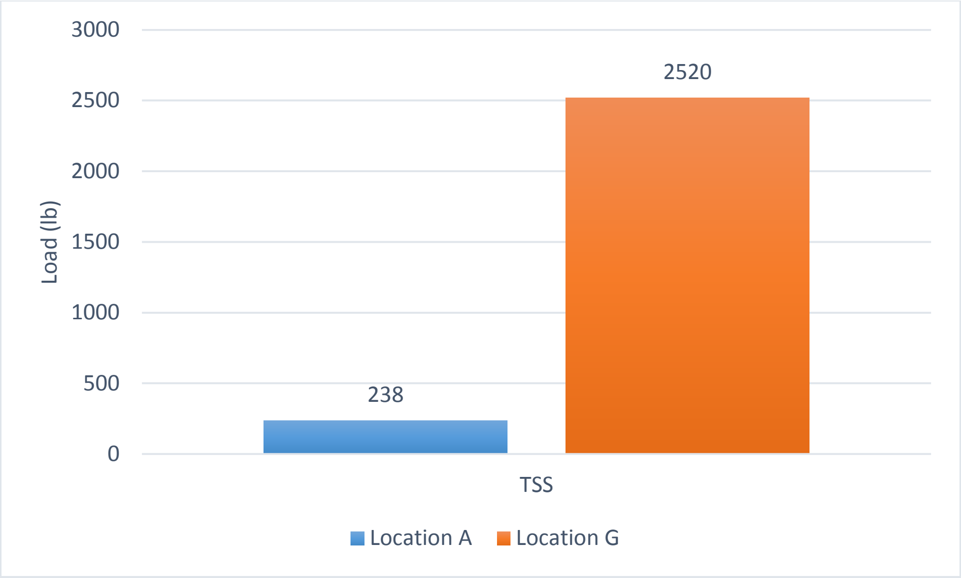
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Load (lb)
185
0.86
Bromide
Location A
Location G

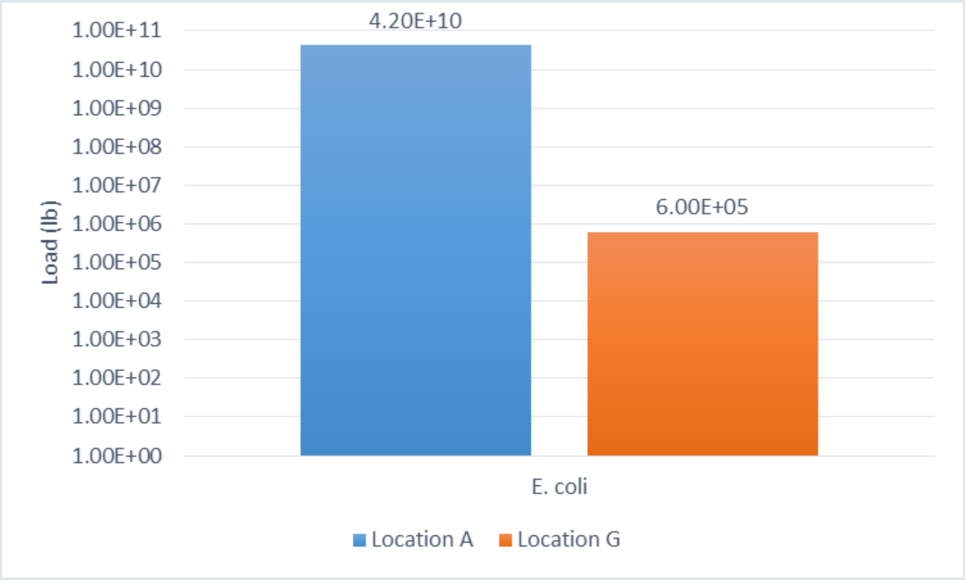

1.4E+05
1.2E+05
1.0E+05
8.0E+04
6.0E+04
4.0E+04
2.0E+04
0.0E+00
Load (lb)
1.3E+05
7.8E+02
Chloride
Location A
Location G

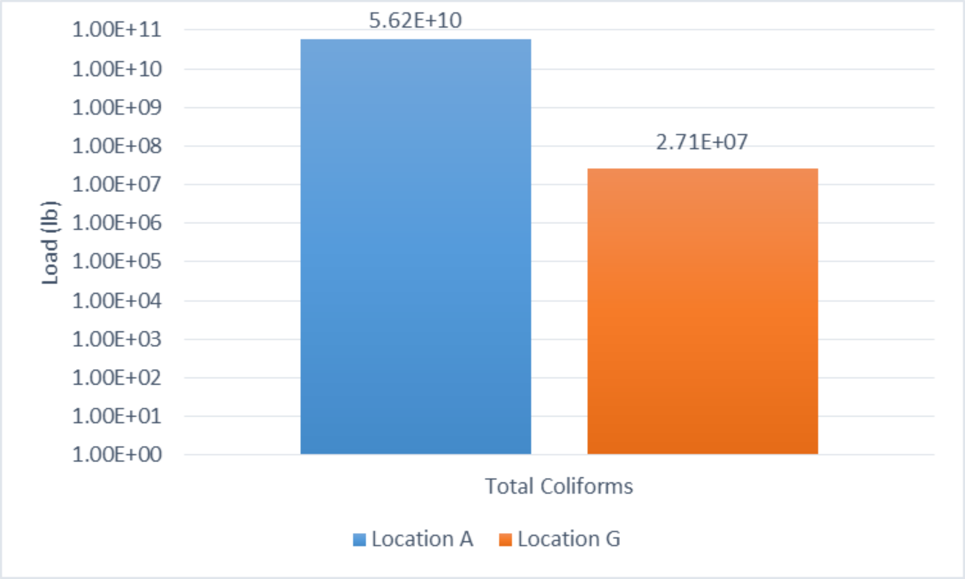

25.00
20.00
15.00
10.00
5.00
0.00
Load (lb)
22.50
0.70
Fluoride
Location A
Location G


0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Loads (lb)
0.79
0.00
Total Phosphate
Location A
Location G


1.95
1.90
1.85
1.80
1.75
1.70
1.65
1.60
Load (lb)
1.93
1.71
Ammonia


3000
2500
2000
1500
1000
500
0
Load (lb)
2520
238
TSS
Location A
Location G

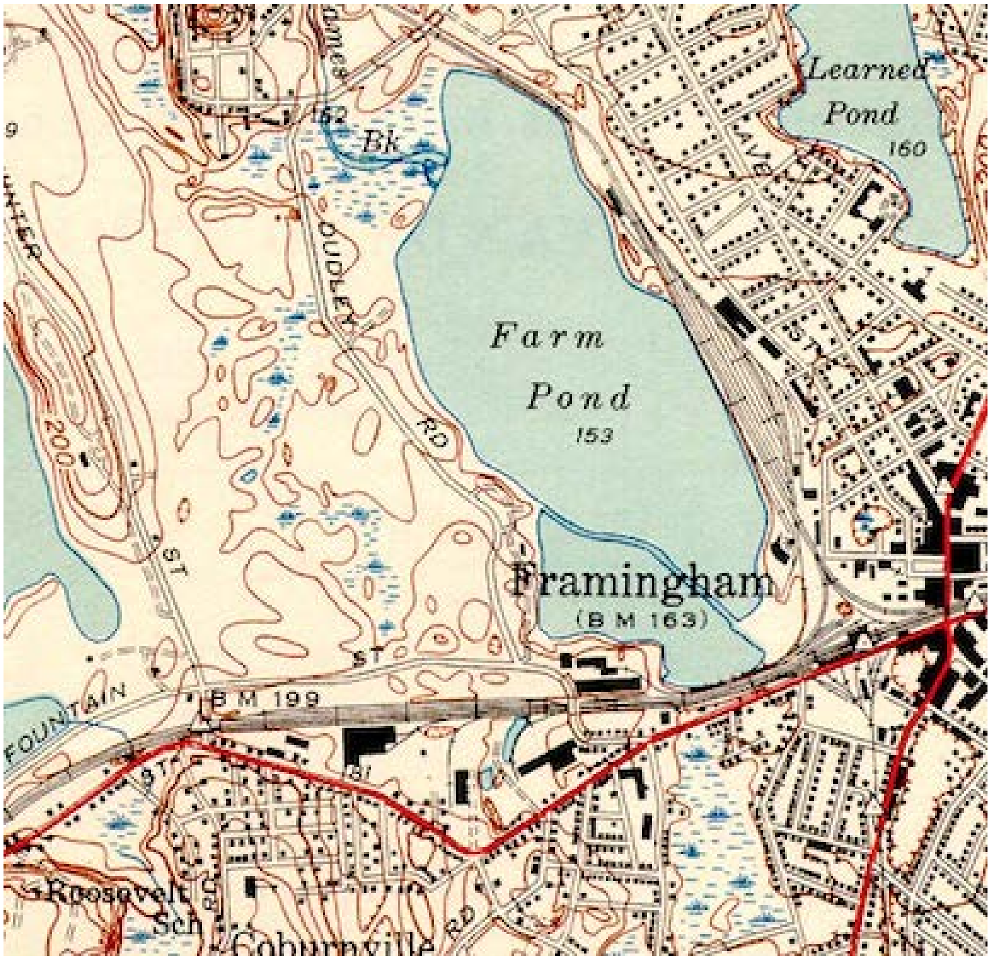

1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
Load (lb)
4.20E+10
6.00E+05
E. coli
Location A
Location G


Load (lb)
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
5.62E+10
2.71E+07
Total Coliforms
Location A
Location G

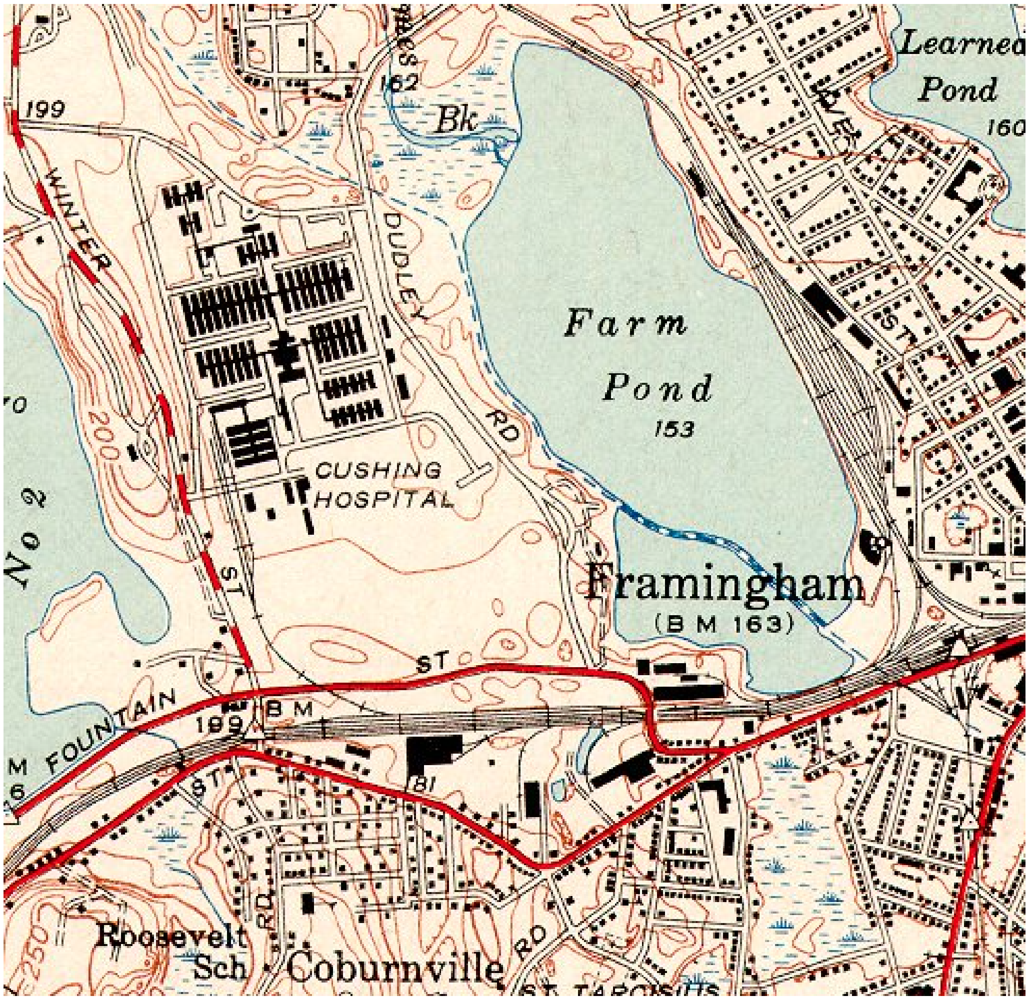
Appendix M: Historical Land Use Maps

1894

1943

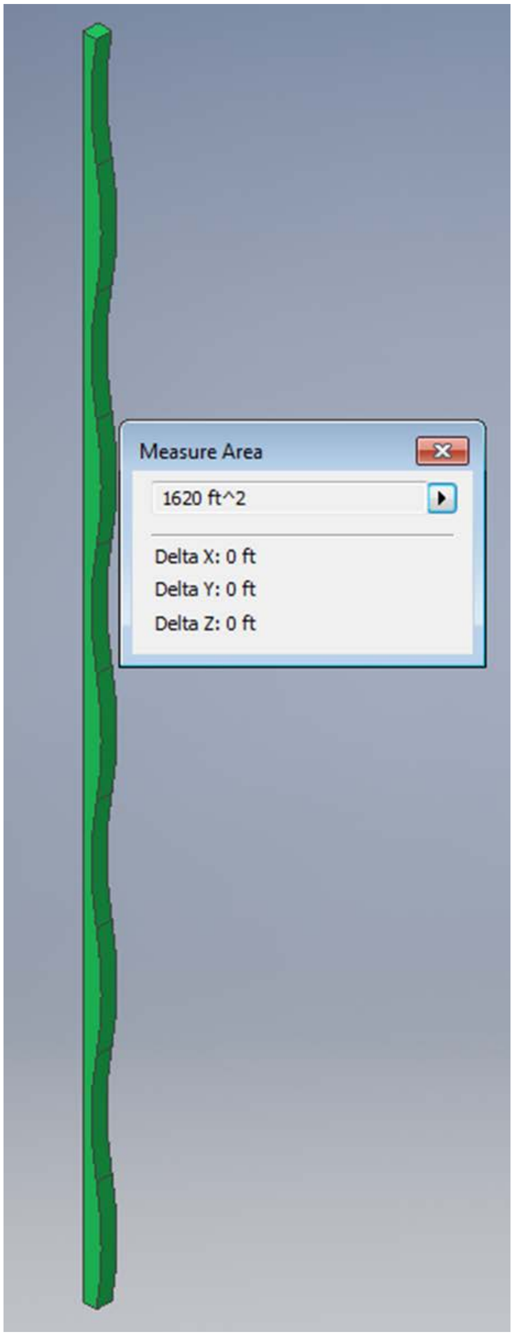

Learned
Pond
160
Bk
162
DUDLEY
RD
Farm
Pond
153
200
ST
Framingham
(B M 163)
ST
FOUNTAIN
B M 199
Roosevelt
Sch
Coburnville
RD

1951


Learned Pond
160
Bk
162
Farm Pond
153
DUDLEY RD
WINTER ST
CUSHING HOSPITAL
No 2
199
200
Framingham
(B M 163)
FOUNTAIN ST
BM
199
ST
181
RD
Roosevelt Sch
Coburnville
250

Appendix N: BMP Design Specifications

Semi-wet Area



Measure Area

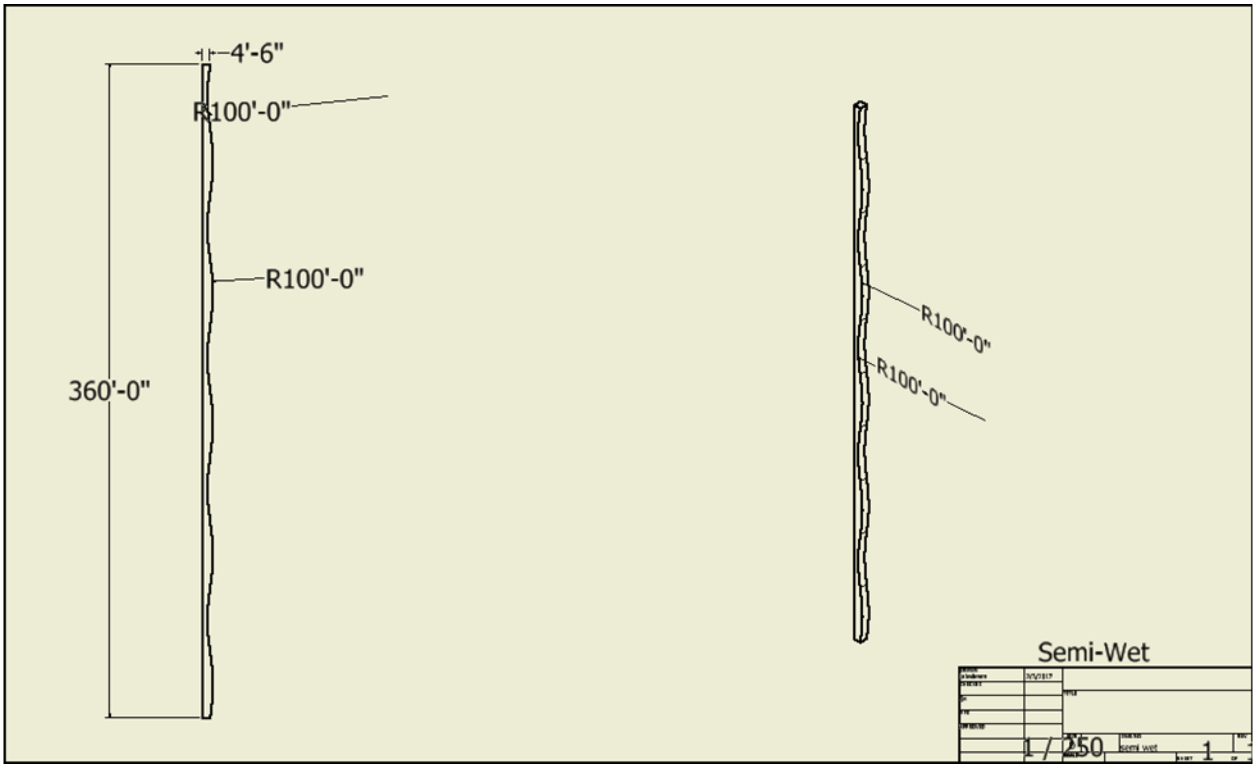
1620 ft^2

Delta X: 0 ft

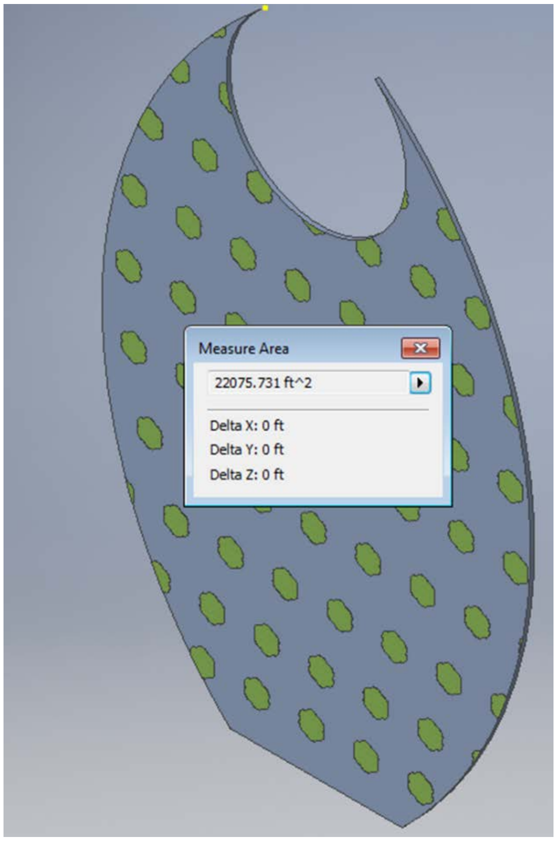
Delta Y: 0 ft

Delta Z: 0 ft

Semi-wet Schematic



Low Marsh Area



Measure Area

22075.731 ft^2

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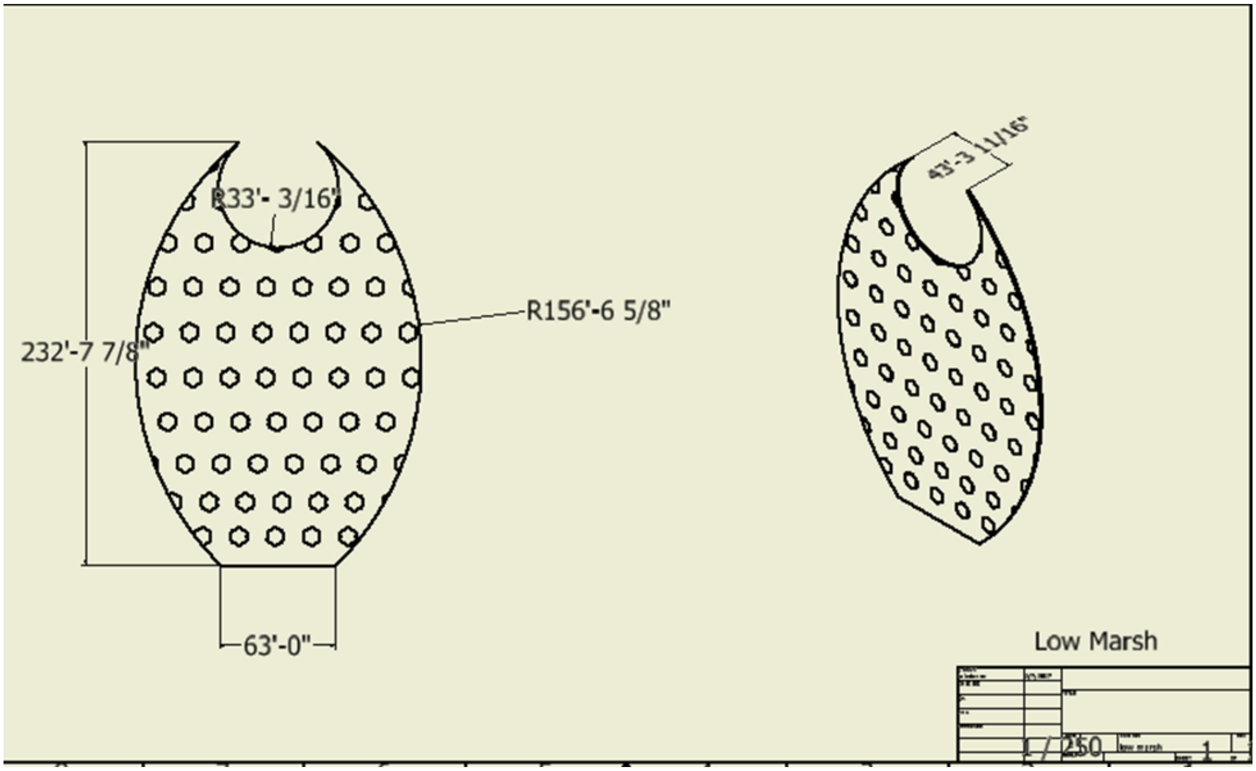
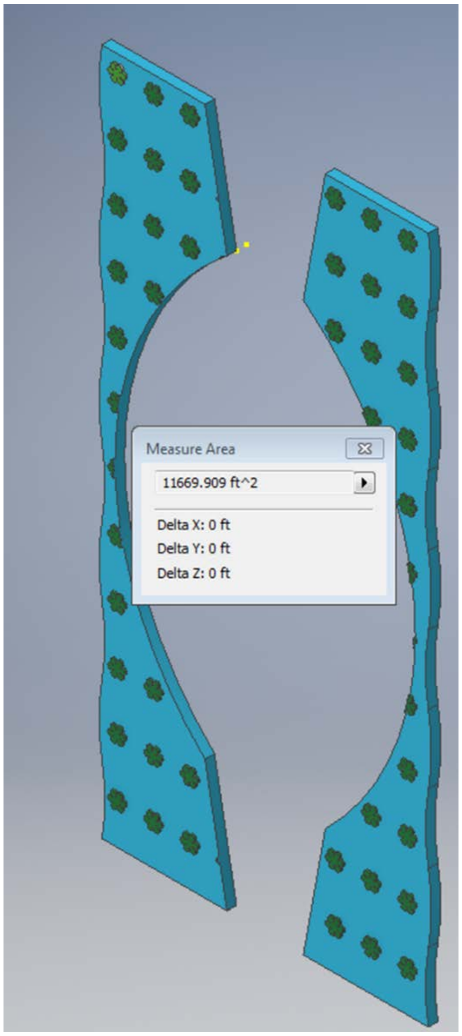
Delta Y: 0 ft

Delta Z: 0 ft

Low Marsh Schematic



High Marsh Area



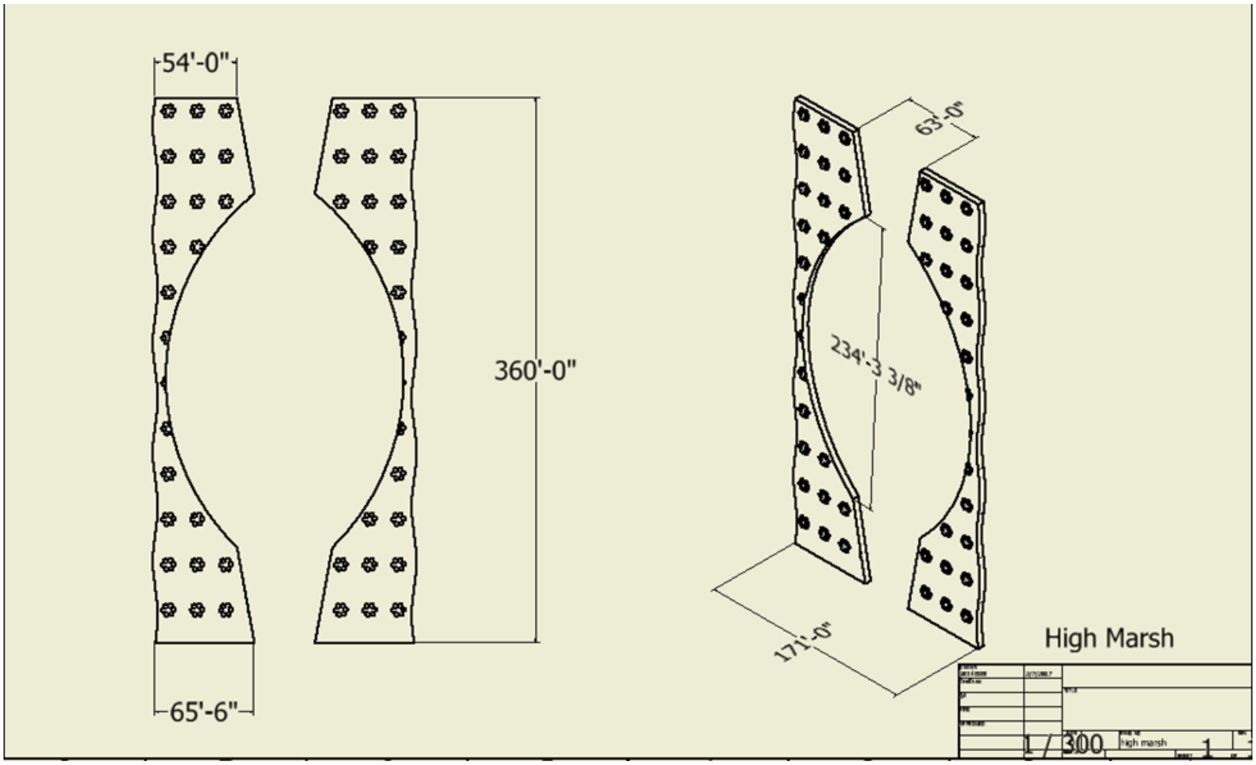
11669.909 ft^2

Delta X: 0 ft

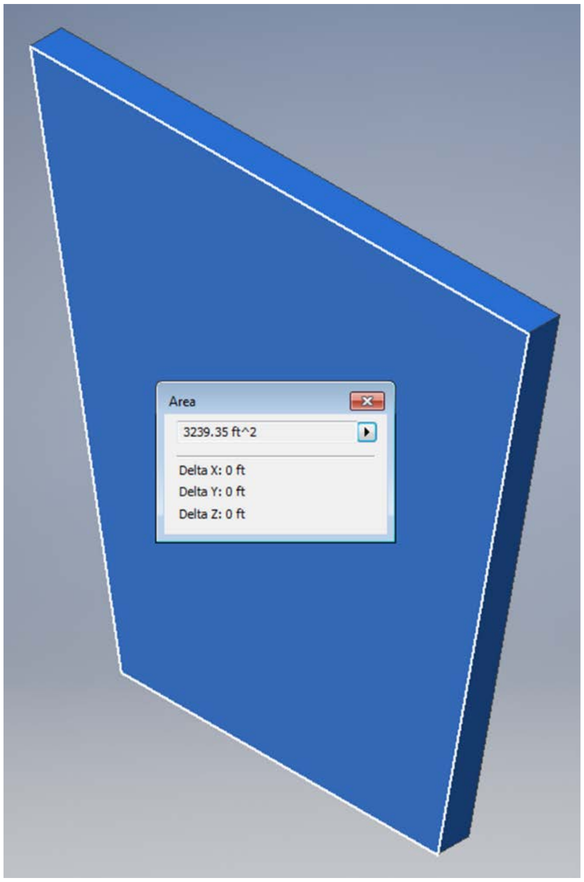
Delta Y: 0 ft

Delta Z: 0 ft

High Marsh Schematic



Micropool and Sediment Forebay Area



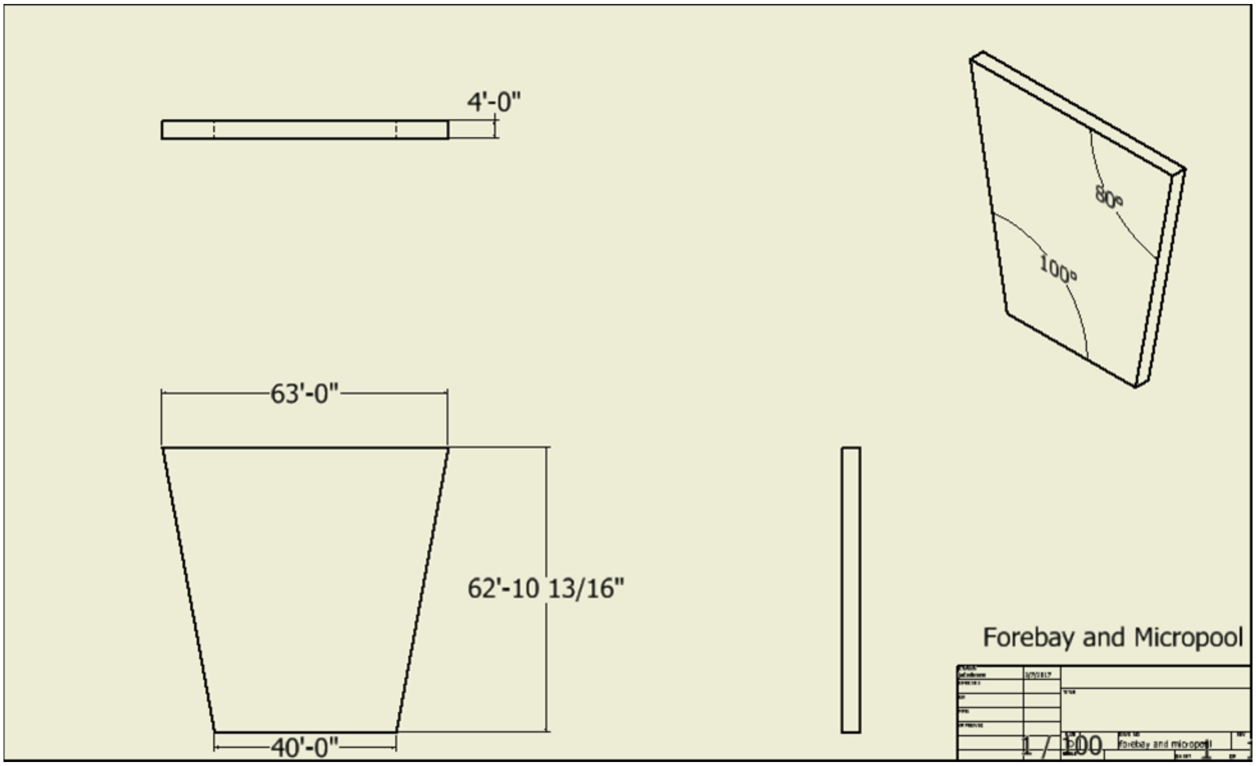
3239.35 ft^2

Delta X: 0 ft

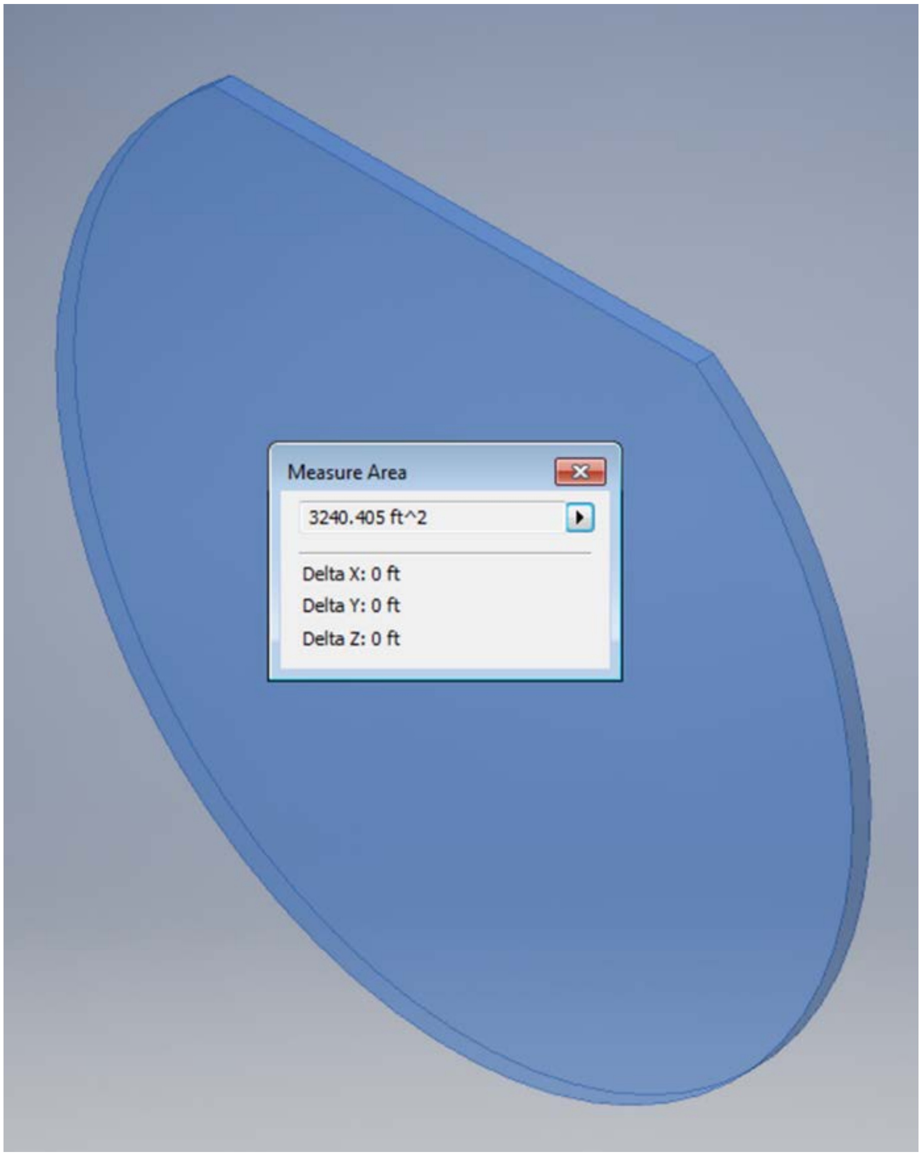
Delta Y: 0 ft

Delta Z: 0 ft

Micropool and Sediment Forebay Schematic



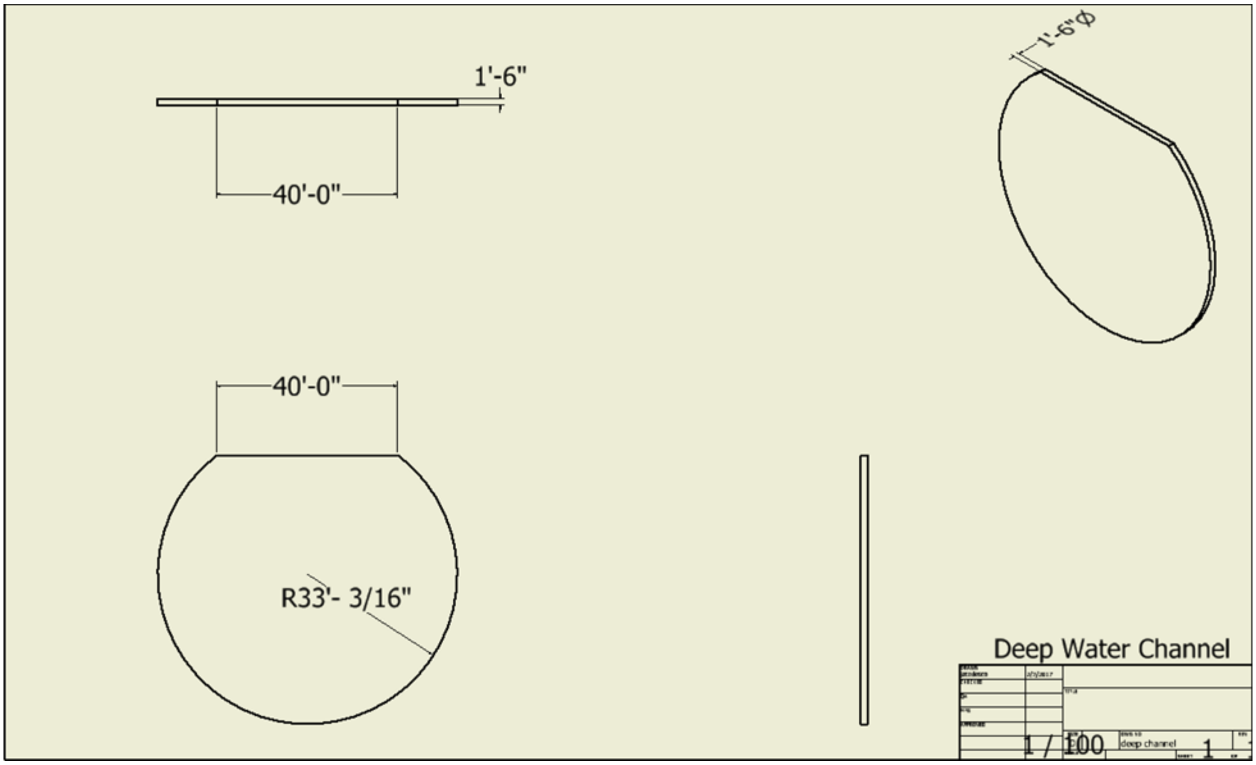
Deep Water Channel



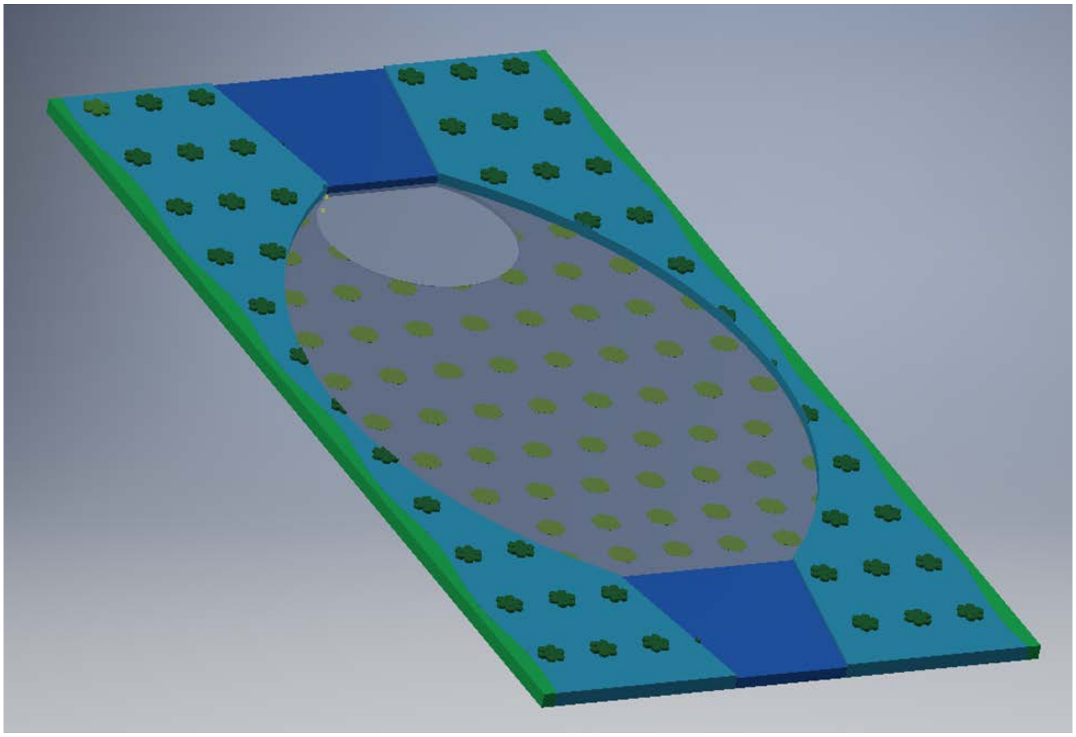
3240.405 ft^2

Delta X: 0 ft
Delta Y: 0 ft
Delta Z: 0 ft

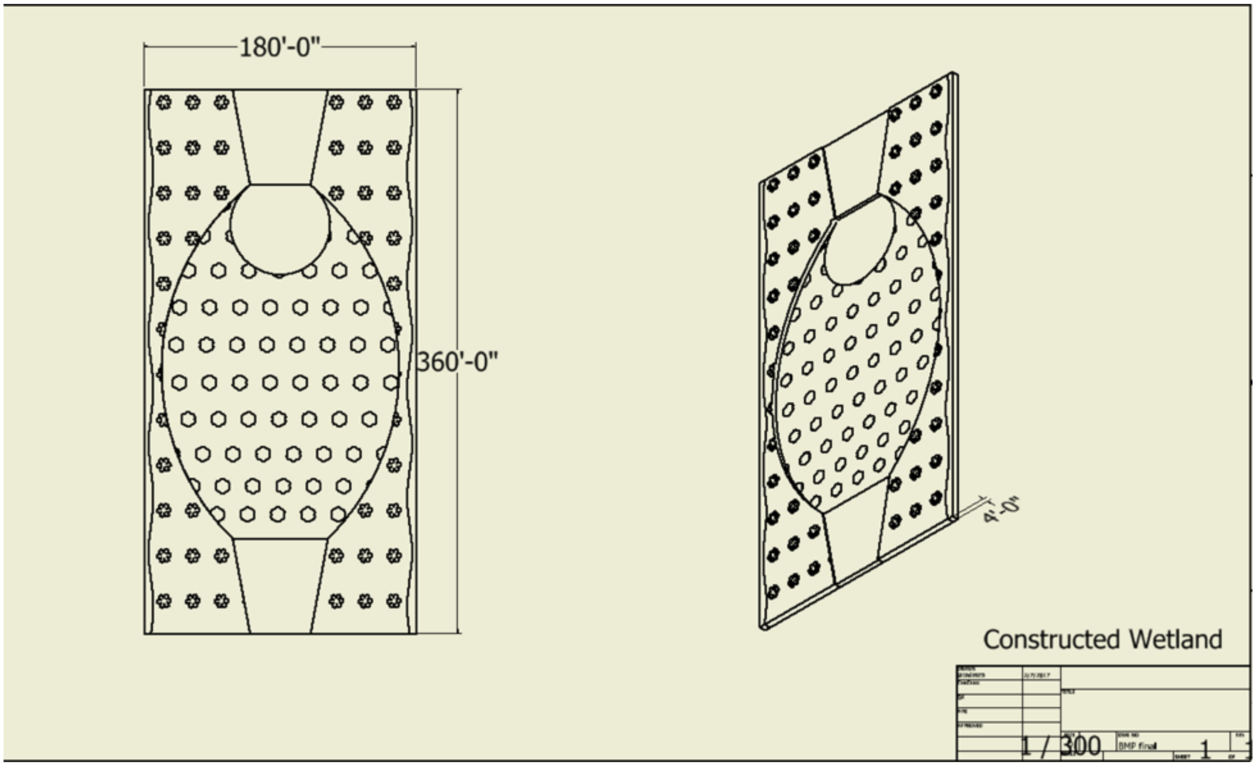
Deep Water Channel Schematic



Constructed Wetland



Constructed Wetland Schematic



Appendix O: Proposal

Chapter 1: Introduction

One of the main reasons why waterbodies become impaired in urban areas is due to stormwater runoff. When it rains, water either seeps into the ground or is carried across impervious surfaces such as sidewalks or roadways. While the stormwater is being transported, it picks up many pollutants such as bacteria and sediment, which is then dumped into a nearby body of water. It is important to keep the quality of surface water high because bodies of water are often used for recreation or even drinking water. One waterbody that is heavily affected by stormwater is Farm Pond. Farm Pond is located in Framingham, Massachusetts, which is about 20 miles west of Boston. A map of Framingham and Farm Pond is shown in Figure 1. The pond is used for recreational purposes and is a backup emergency water supply for Boston. The surrounding area is highly residential, and its population has been rapidly increasing throughout the years. Currently, Farm Pond is not an ideal candidate for a water supply because it has high turbidity and algal growth. The pond has many outfalls flowing into it that contribute unknown quantities of contaminants. In order to ensure that Farm Pond is ready for an emergency situation and complies

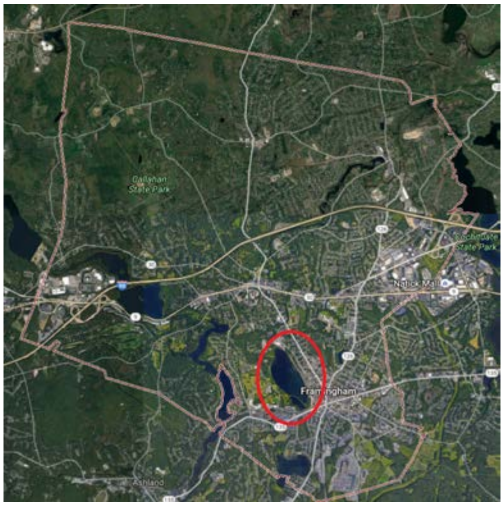


Figure1: Aerial View of Framingham with Farm Pond Circled

with new Municipal Separate Storm Sewer Systems (MS4) regulations, the water quality must be improved.

As the largest town in Massachusetts, it is important that the water quality in Framingham's ponds and rivers is maintained. This is needed because the Town has transitioned from a rural to urban area. Over the years, a rise in population density has resulted in an increase of impervious surfaces by 30% in Farm Pond's drainage area, which increases the amount of stormwater runoff. According to Framingham's Stormwater Master Plan, stormwater runoff is one of the biggest pollutant contributors to Farm Pond and its inability to meet water quality standards (S E A Consultants, 2008).

Previous studies have been completed on Farm Pond and its watershed. On the eastern side of the pond, multiple infiltration basins and deep sump catch basins have been installed. The purpose of these projects was to improve stormwater management by reducing flooding, providing environmental protection in case of a spill, and improving the water quality of stormwater runoff from the watershed. An ongoing capital improvement project in Farm Pond's watershed is the removal of paved surfaces from Cushing Memorial Park, which is located on the western side of Farm Pond. Cushing Memorial Park has the potential to be used in additional conservation and water quality improvement projects (Town of Framingham, n.d.b). There is a town initiative to reduce sediment and nutrient loadings into Farm Pond by using stormwater Best Management Practices (BMPs), or effective and practical improvement projects. In doing so, the Town works collaboratively with other capital improvement projects occurring in the watershed area (Town of Framingham, n.d.a.). Despite these efforts, there is still a need for continued improvement of the water quality surrounding Farm Pond. The Town wants to promote green infrastructure projects and raise awareness of the amenities that Farm Pond and the surrounding area can offer.

The goal of our project is to identify the impacts of urbanization on the water quality of the Farm Pond watershed and to evaluate and design a BMP to improve its water quality. We will focus our analyses on the Cushing Memorial Park (CMP) stream, a small body of water flowing from Cushing Memorial Park near the western side of Farm Pond. Our first step is to estimate contaminant loadings in both the pond and the CMP stream. To do this, we will conduct sampling in a number of locations and perform calculations. We will then identify potential sources of the contaminants by researching past and current land uses of the area. Finally, after exploring various BMP options, we will make a recommendation and design a BMP. The results of our investigation will provide the Town of Framingham with a way to help reduce the contaminants affecting Farm Pond and its surrounding waterbodies. Because the CMP stream is located adjacent to both Cushing Memorial Park and Farm Pond Park, the implementation of our recommended BMP will also have the potential to educate the public about water contamination.

To provide a better understanding of the project, we have divided this proposal into three chapters: Introduction, Background, and Methodology. We discuss pertinent information about regulations, the history of Farm Pond, and its current issues in the Background Chapter. In Chapter 3, we explain our methodology, which includes three main objectives, to achieve our project goal of identifying water quality impairments and designing a BMP to decrease the impacts of the CMP stream.

Chapter 2: Background

In this chapter, we discuss important factors that encompass our project and why we are working to achieve our goal. We provide background information about stormwater control and contaminant loadings, including point and nonpoint source pollution. We discuss Best Management Practices (BMPs) and their implementations. Next, we explain the history of the Town of Framingham and how it has evolved over the years. We then discuss the history of Farm Pond and changes in the area that may contribute to the pond's current impairments. We examine the connection between the Town's growth and the decreasing quality of the pond.

2.1 Stormwater Control

Ideally, stormwater draining to a waterbody should be pure and uncontaminated. However, stormwater often carries pollutants straight into waterways - untreated. For this reason, in order to discharge stormwater, municipalities must obtain a Municipal Separate Storm Sewer Systems (MS4) permit by complying with a number of pollutant regulations. The most recent Massachusetts MS4 regulations will become effective in July 2017. The regulations require discharges to meet water quality standards, pollutants to be reduced to the maximum extent practicable (MEP), and development of a Stormwater Management Plan (SWMP) with updated Best Management Practices (BMPs) (USEPA, 2016a). Stormwater control has become an important topic of interest in recent years, and many municipalities have had to re-evaluate their current systems and make the appropriate changes to reduce contaminant loads.

2.2 Contaminant Loads & Nonpoint Source Pollution

Contaminant loads are a measure of the amount of pollutant(s) entering a waterbody and are useful for gauging water quality. Contaminant loads are regulated through the Total Maximum Daily Load (TMDL). TMDLs are "the greatest amount of a pollutant that a waterbody can accept and still meet the water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation, and fishing" (MassDEP, 2016, p. 1). The Massachusetts Department of Environmental Protection (MassDEP) has a TMDL strategy that focuses on identifying and prioritizing impaired waterbodies, developing TMDLs, implementing controls to meet water quality standards, and assessing the effectiveness of the control measures (MassDEP, 2016). Waterbodies are classified in five categories to determine whether or not they are impaired. These categories are shown in Table 1 below.

Table 1: TMDL Category Classifications (Massachusetts Division, 2015)

TMDL Categories	**Meaning**
Category 1	Unimpaired and not threatened for all designated uses
Category 2	Unimpaired for some uses and not assessed for others
Category 3	Insufficient information to make assessments for any uses
Category 4a	TMDL is completed
Category 4b	Impairment controlled by alternative pollution control requirements
Category 4c	Impairment not caused by a pollutant - TMDL not required
Category 5	Impaired or threatened for one or more uses and requiring a TMDL

In order to determine a TMDL, point and nonpoint sources of pollutants must be identified. The United States Environmental Protection Agency (USEPA) identifies any point source pollutant as a source that has "any discernible, confined, and discrete conveyance…from which pollutants are or may be discharged" (USEPA, 2016b, p. 1). All other pollution sources are considered nonpoint sources. Common sources of nonpoint source pollution are any sources from land runoff, precipitation, atmospheric deposition, drainage, or seepage (USEPA, 2016b). Land runoff includes fertilizers or pesticides from residential or agricultural areas, grease and toxic chemicals from urban runoff, and sediments from improperly managed construction sites or eroding soil (MassDEP, 2014). To address nonpoint source pollution, the MassDEP has a nonpoint source pollution program. The goal of the program is to "bring the citizens and the state together to restore surface and groundwater impaired by nonpoint source pollution, to protect water quality in healthy watersheds, and to plan and address human-induced and naturally-occurring changes in the environment" (MassDEP, 2014, p. 1).

It can be difficult to estimate nonpoint source pollution concentration and loads. First, water quality assessments are used to gather data to develop a baseline for the current contaminants. After an initial assessment is completed, water quality monitoring should be maintained to evaluate how the nonpoint source changes over time through continued water quality sampling (MassDEP, 2014). Nonpoint source pollution is frequently measured through supplemental water quality tests including analyses for metals, sediments, and nutrients. To estimate a nonpoint source load, it is useful to have an idea of where the pollution may be originating based off of the land use in the watershed. Some typical modeling can be done to help in this endeavor. A variety of modeling software can be used to simulate the conditions in the watershed based on estimations for soil erosion potential, wind erosion potential, animal manure loading potential, and agricultural chemical loading potential (He & Croley, 2005). Some of these models are Areal Nonpoint Source Watershed Environment Simulation (ANSWERS), Groundwater Loading Effects of Agricultural Management Systems (GLEAMS), and Soil and Water Assessment Tool (SWAT), among many others (He & Croley, 2005). By using these tools and estimations, one can gain an understanding of how nonpoint source pollution can affect stormwater management.

2.3 Best Management Practices (BMPs)

Best Management Practices (BMPs) are tools designed to reduce the release of toxic and hazardous compounds into water bodies. According to the Clean Water Act, BMPs are traditionally used to control site runoff, chemical spills, waste disposal, and draining from material storage. BMPs are practices used to prevent pollutants from reaching receiving waterbodies. They are designed to be cost effective, easily implemented, and low maintenance (USEPA, 1993). BMPs can reduce the concentration of specific contaminants.

When selecting a BMP, the land area's characteristics, such as population density, land use, soil types, and topography, should be taken into account (USEPA, 2015). Some other factors that may affect the selection of a BMP include whether the current management programs are adequate to meet water quality goals or if the system can be retro-fitted. Additionally, population growth and land development factors play a role in developing the BMP design. Common stormwater BMPs for land that is unavailable or has been previously developed include the use of porous pavement, first flush diversion systems, lawn maintenance controls, and road salt application management (USEPA, 2015). These examples show that BMPs can be either structural or nonstructural.

It is important to note that many different management practices and procedures can be used to achieve the same environmental goals. For example, to reduce stormwater runoff and to control nonpoint source pollutants, vegetated swales, bioretention basins, rainwater harvesting, sand filters, and riparian buffers all work to adjust the rate of infiltration and absorption of stormwater (MassDEP, 2014). Other nonpoint source pollution BMPs focus on preventing pollution, controlling erosion, protecting stream banks and streambed, and restoration of habitats. The EPA requires that any state nonpoint source pollution plan must "identify best management practices and measures to control each category and subcategory of nonpoint sources" (MassDEP, 2014, p. 12). BMPs are typically used to reduce pollutants to the MEP to protect water quality (USEPA, 2015). Placing emphasis on reducing pollutants to the MEP is important because any implemented BMP needs to have a reasonable operation and maintenance plan. For example, trying to reduce pollutant concentrations to very low levels may be too expensive and therefore not effective to install the BMP based on the cost-benefit analysis. BMPs are an excellent tool to reduce the impacts of stormwater and nonpoint source pollution.

2.4 History of Framingham

Framingham, located 20 miles west of Boston, is one of the fastest growing towns in Massachusetts, which puts a strain on its water supplies. Its population is approximately 68,000 residents, with about 2,792 people per square mile. Because of this high population density and the fact that 30% of the drainage area is impervious, the Town is struggling with a stormwater runoff problem (Town Charts, n.d.). The Town itself has significant historic value and is considered "the hub of the MetroWest region" (Town of Framingham, n.d.a, p. 1). There are many natural, urban, rural, and suburban areas spread throughout the Town, including recreational facilities such as Farm Pond.

2.5 History of Farm Pond

Farm Pond has a vast history, serving as a gathering place as well as a drinking water source. In the 1800s, it was a popular stop for the Chautauqua lecture series, an educational movement, in addition to temperance and abolition societies. Today, the pond is one of the Town's public recreation areas. The western side of Farm Pond includes a playground, bocce ball courts, and walking paths. A public boat ramp is located on the northern side of Farm Pond. On the eastern side of the pond is the CSXT Framingham train yard, which is next to downtown Framingham. As of 2016, the Town had several ongoing projects near Farm Pond, including a skate park and an uptown revitalization. The Keefe Technical Regional Vocational High School, Barbieri Elementary School, Loring Arena Ice Skating Rink, and the MBTA's Framingham Commuter Rail Station are all located within the Farm Pond subbasin (Town of Framingham, n.d.b).

The pond is located at the edge of downtown Framingham. Its location and the surrounding developments are shown in Figure 2 below. For a number of years, Farm Pond was the start of the Sudbury Aqueduct that extended to the Chestnut Hill Reservoir and provided water to the City of Boston. The aqueduct was later extended past Farm Pond due to concerns about the water quality. Today, the pond is still an emergency backup water source, which is the one of the reasons Framingham has been focusing on improving the water quality (Town of Framingham, n.d.b).

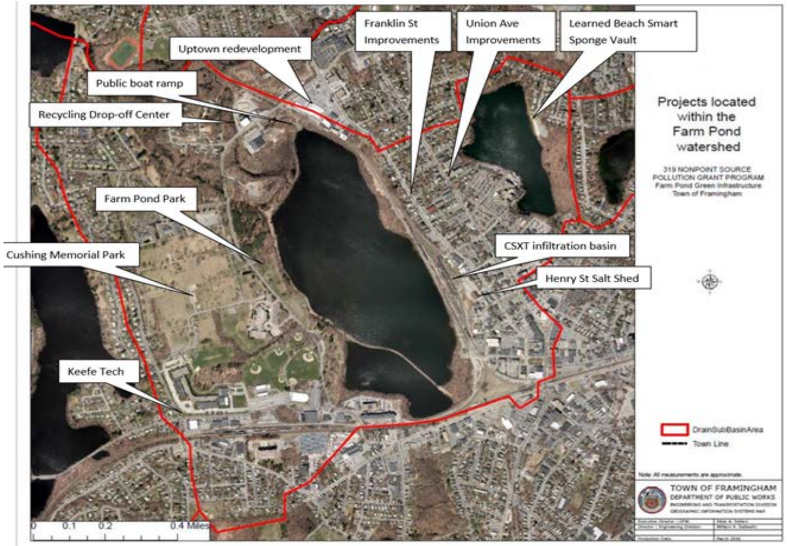


Figure 2: Map of Farm Pond

Over the past century, the area around the pond has rapidly urbanized. This rapid growth has led to poor water quality issues including algal growth, bacteria, and turbidity. As the Town of Framingham grew, the amount of impervious surfaces also grew, creating more stormwater runoff. Framingham developed a strategy to integrate water quality improvements into all new and redevelopment projects. The Town has also enacted plans to increase public education and awareness about preserving and improving Farm Pond's natural resources. Framingham has implemented development restrictions in both resource areas and areas in need of stormwater management. Additionally, Framingham has developed a Stormwater Master Plan and an Aquatic Management Program to help combat these water issues (Town of Framingham, n.d.b).

Prior to 2014, Farm Pond was considered a Category 3 waterbody, having insufficient information to make a water quality determination. At the time, the largest pollutant source was from stormwater runoff from nearby neighborhoods. During 2007, the Town of Framingham replaced the open swale at the outfall with an in-series BMP that consisted of a Downstream Defender® hydrodynamic separator water quality structure and an AbTech Smart Sponge® vault to help address some issues the pond had. These systems separated and removed hydrocarbons, sediment, and nutrients from the water, but they did not address the pond's bacterial issues. The project cost the Town $96,500, which came from its general fund. Post-project testing showed a reduction of 72 percent of pollutants. As of 2014, Farm Pond was listed as a Category 5 waterbody, which means that it was considered impaired and needed a TMDL completed. As previously mentioned, Farm Pond was considered impaired for excess algal growth and high turbidity. It was also noted that there were non-native aquatic plants present in addition to Eurasian Water Milfoil and Myriophyllum, but these do not require a TMDL (Massachusetts Division, 2015). With all of the changes in and around Farm Pond over the years, it has become increasingly difficult to identify all the sources of the contaminant loads entering the pond (Town of Framingham, n.d.b).

2.5.1 Farm Pond Stormwater Control

Some stormwater research has already been completed in Framingham to work toward continued MS4 permitting and the cleaning of its water bodies, but more analysis can be done. A significant amount of stormwater pollution in Framingham can be attributed to impervious surfaces such as roads, sidewalks, parking lots, and buildings. In the area surrounding Farm Pond, development and urbanization have sparked an increase in large, connected impervious surfaces. About 30 percent of the pond's drainage area is impervious (Town of Framingham, n.d.a). The addition of the skate park in Farm Pond Park will soon add even more impermeable surfaces to the area (Pillar Design, n.d.). Impermeable surfaces contribute to the inability of stormwater to seep into the ground. This causes an unnatural flow along man-made surfaces and increases the likelihood of contamination and flooding.

The stormwater drainage system in Framingham was designed to handle a 2-year to 5-year storm event with mild to moderate flooding (S E A Consultants, 2008). These storms are expected to occur, on average, once every 2 years and 5 years, respectively. Framingham's Stormwater Management Plan states, "The closed drainage system that serves [the Farm Pond] sub-basin does not have the capacity to service the area during intense storms under today's built-out conditions, either in terms of hydraulic or water quality treatment capacity" (S E A Consultants, 2008, p. 1-11). This drainage infrastructure, which was built for less flow, greatly contributes to Farm Pond's pollutant loading.

Some progress has been made to address stormwater issues in Framingham, including the installation of Stormceptors, infiltration basins, and deep sump catch basins, all of which trap and contain sediment and pollutants (Town of Framingham, n.d.b). Although these efforts are helpful and promising, more can be done to improve the quality of Farm Pond.

2.6 Cushing Memorial Park Stream

Adjacent to Farm Pond lies a stream, which we will hereafter refer to as the Cushing Memorial Park (CMP) stream. This stream flows under Cushing Memorial Park, which is across the street from Farm Pond. It flows underground because it was previously culverted in order to build a military medical facility in World War II. In 1991, the hospital was shut down after it was deemed a surplus medical facility. There were over 100 buildings across the 67.5 acre area, including roadways, parking lots, and the hospital. In 2001, a Master Plan was developed to turn the area into a major public park. Today, hundreds of Framingham residents use the park on a daily basis and take advantage of its features, including a promenade, open meadows, and extensive lawns (Town of Framingham, 2013).

The outflow of the CMP stream is currently unknown. It is possible that there are siphons underneath the Sudbury Aqueduct connecting the stream to Farm Pond. Additionally, there is some hydrologic indication that the stream could flow into Eames Brook during a wet weather event (K. Reed, personal communication, September 6, 2016). The outfall for Farm Pond is Eames Brook. Although the outfall of the CMP stream is unknown, the close proximity of these three waterbodies indicates that groundwater infiltration is a possible connection between them. Since both Farm Pond and Eames Brook are Category 5 impaired waterbodies, it is important to determine the possible contaminant loadings the CMP stream could contribute to them (USEPA, n.d.).

Since Farm Pond is downstream from CMP, there could be contaminant loads entering the pond from the park. The fertilizer and pesticides used on the lawn might leach into the pond or brook through the CMP stream. This would contribute to the nutrient loads, which could be a source of the algal growth. Because of the former hospital, there is potential that medical waste was dumped on-site, which could have impacted the surrounding area. Currently, it is unclear if CMP is contributing any contaminant loads to Farm Pond (Town of Framingham, 2013). It is also possible that an upstream residential neighborhood in the watershed is a source of stormwater loads. The urbanization of the watershed area has had a significant impact on the surface water quality and stormwater control.

Chapter 3: Methodology

The goal of our project is to identify the impacts of urbanization on the water quality of Farm Pond and its surrounding waterbodies and to evaluate and design a Best Management Practice (BMP) to improve the water quality. In order to accomplish this goal, we developed the following three objectives:

1. Perform hydrologic, hydraulic, and environmental analyses to estimate the flows and contaminant loadings into Farm Pond and the Cushing Memorial Park (CMP) stream.
2. Characterize the tributary watershed and identify and assess potential sources of contaminants contributing to the CMP stream's water quality degradation.
3. Evaluate, select, identify, and design a BMP for the stream to reduce contaminant loadings and to improve the overall water quality of the pond.

In the following sections, we explain the methods we will use to fulfill our objectives and achieve our goal. A proposed timeline for the project is shown in Appendix A.

3.1 Perform hydrologic, hydraulic, and environmental analyses to estimate the flows and contaminant loadings into Farm Pond and the Cushing Memorial Park (CMP) stream.

In order to estimate the hydrologic contaminant loadings in Farm Pond, we will first identify the current runoff from the watershed in both Farm Pond as well as the CMP stream. Next, we will conduct water quality sampling to determine the concentration of the pollutants in the two waterbodies. Finally, we will calculate the contaminant loadings. These tasks will involve using Geographic Information System (GIS) to quantify the watershed's characteristics and completing fieldwork to monitor the water quality.

3.1.1 Stormwater Runoff Quantification

With the charts and equations found in Appendix B, we will use the National Resources Conservation Service (NRCS) Method to estimate runoff. The NRCS Method estimates stormwater runoff based on the amount of rainfall and the potential maximum retention after runoff begins. In order to determine the maximum retention, a curve number is estimated. This number is dependent on the watershed's "hydrologic soil group, cover type, treatment, hydrologic condition, and antecedent runoff condition (ARC)" (NRCS, 1986, p. 2-1). There are four hydrologic soil groups, A-D. The groups range from Group A soils, which have low runoff potential when thoroughly wet, to Group D soils, which have high runoff potential when thoroughly wet (NRCS, 2007). We will use the Massachusetts Department of Environmental Protection's (MassDEP) GIS database to identify the hydrologic soil groups found in Farm Pond's watershed area. Additionally, we will use GIS to determine the different land uses within the pond's watershed. The information we obtain about the watershed's soil groups and land uses will allow us to calculate the curve number using the NRCS worksheet shown in Appendix B.

The NRCS Method has a couple of limitations. Curve numbers relate to the average conditions over the watershed and therefore lose accuracy if the method is being used to model historical storms (NRCS, 1986). However, the NRCS Method can account for rainfall duration or intensity by using follow-up methods to generate hydrographs based off of various rainfall intensities. Once the watershed runoff is calculated, we will then sample Farm Pond and the CMP stream for various contaminants.

3.1.2 Contaminant Quantification

We will take samples of both bodies of water and test them for total phosphorus, nitrates, ammonia, turbidity, dissolved oxygen, pH, total suspended solids (TSS), and coliforms. While phosphorus and nitrogen are found naturally in water, excess amounts cause rapid algal growth, which leads to eutrophication. The overgrowth of algae can cause damage to water sources, food sources, and animal habitats. In addition, oxygen levels are reduced to dangerous concentrations in which fish and other aquatic life cannot survive. These algal blooms can become harmful to humans because they produce elevated toxins and bacterial growth that can cause illness (USEPA, 2016c).

The pH of the water indicates if it is too acidic or basic for aquatic life to thrive. Coliforms are found in animal and human waste and cause bacterial issues that can lead to illness or death. Since Farm Pond is an emergency back-up water supply for the Massachusetts Water Resources Authority (MWRA), it is important to ensure coliform levels are minimized. Turbidity is a measure of the amount of particles suspended or dissolved in water that cause the water to appear cloudy. It is affected by silt, clay, algae, inorganic matter, and other microscopic organisms. All of these issues can be measured through basic lab tests.

To test for the turbidity, dissolved oxygen, and pH of the water in the stream and the pond, we will use a Horiba U-52 Water Quality meter. A Horiba U-52 Water Quality meter is used for fieldwork and can log multiple parameters at the same time. When testing for phosphorus, nitrate, and ammonia, we will use a Hach DR890 Colorimeter. This colorimeter is a handheld field meter that measures wavelengths to determine concentrations of metals and other chemicals. Using aseptic techniques, we will use the Quanti-tray Sealer to determine total coliforms. This test will take several days to complete. In order to test for TSS, we will filter the water and let the filter paper dry. We will then weigh the filter paper and determine the amount of TSS in the water sample by calculating the change in weight from the original filter paper. We will perform these tests either in the Kaven Hall laboratory at Worcester Polytechnic Institute or in the Town of Framingham's Department of Public Works' laboratory. We will run these tests on samples from both dry and wet weather events to determine how much stormwater runoff contributes to the water quality issues in the pond and the CMP stream. If we cannot make it to Framingham during a wet weather event, Kerry Reed, Senior Stormwater and Environmental Engineer for Framingham, will collect some samples. We plan to take two sets of samples at each location during at least one dry weather and two wet weather events.

Along with sampling during different weather events, we will also sample from multiple locations along the pond and the stream. An overview of the sampling locations is shown in Figure 3; the points are labeled A through G as shown in Figures 4 and 5. We will sample at the first accessible stream location (Point A), halfway between the road and the pond (Point B), and across the aqueduct in the pond (Point D). Another pond sample will be taken from the southwestern shore near Farm Pond Park (Point G). We will also sample near the organic composting facility (Point E) and at the outflow of Farm Pond into Eames Brook (Point F). During a wet weather event, we will sample at Point C in order to quantify another possible source of stormwater runoff into the stream. In case the outfalls or surface waters are dry due to the current drought or lack of rain, we will sample at the closest possible location to our previously determined sampling points. In addition to water quality sampling, a field instrument will be used to measure the flow of the CMP stream. Once we have determined the contaminant concentrations in the pond and the CMP stream, we will calculate the contaminant loadings into the two bodies of water during wet and dry weather events.

Figure 3: Proposed Sampling Locations

Figure 4: Sampling Locations at Northwestern Section of Farm Pond

Figure 5: Sampling Location at Southwestern Section of Farm Pond

3.2 Characterize the tributary watershed and identify and assess potential sources of contaminants contributing to the CMP stream's water quality degradation.

In order to reduce contamination in the CMP stream, it is helpful to know the origin of the pollutants affecting it. To accomplish this, we will first conduct research on what has previously been known to produce the contaminants that we find in the CMP stream. Next, we will research historical land uses located within the watershed. We will gather this information through research databases and GIS data files. GIS will also be used to identify the current land uses within the watershed and to determine what waterways drain into the stream. All of this information will allow us to understand how the surrounding land was and is used as well as how these uses may impact the water quality of the stream. We will compare our research about what typically produces the stream's specific contaminants to the watershed to determine potential sources of contamination.

As part of this objective, we will look into any differing contaminant loadings that occur along the stream. If a downstream sampling location has more of a specific contaminant than the location directly upstream of it, we will look for ways that contaminants may be entering the stream between these two locations. This method of analyzing different loadings at different locations in the stream will assist us in our objective to track potential contamination sources. Knowing these potential sources within the watershed will provide us with some of the necessary criteria to develop a BMP.

3.3 Evaluate, select, identify, and design a BMP for the stream to reduce contaminant loadings and to improve the overall water quality of the pond.

The final step in our project is to design a BMP for the stream to reduce contaminant loadings and to improve the overall water quality of the pond. In order to do this, we must first investigate different design options that are best suited for the stream. Once we obtain results from our water samples, we will be able to analyze the types of contaminants and the contaminant loads in order to determine the best available treatment options for them. We will also research other BMPs that are currently used in the Town of Framingham, the types of contaminants they address, and their effectiveness. When this information is gathered, we will then decide if the best option is to design a treatment system for the stream itself or at the source of the contamination. After the site of the BMP is chosen, we will rate the different types of BMPs based on a point scale that we will develop including factors such as cost, constructability, effectiveness of removal, and maintainability. Each factor will be awarded a level of importance, based on our research and the opinions of Framingham town officials, and the BMP with the highest overall rating will be chosen. Once the BMP is chosen, we will determine the exact location and develop its design specifications, including the layout, sizing of all components, and complete cost analysis. Finally, we will devise a long-term plan for the maintenance and management of the BMP.

Section 3.4 Expected Outcomes

When we test our samples, we expect to find higher contaminant levels in the CMP stream than in Farm Pond. This is because of the stream's many unknown characteristics as well as its close proximity to the composting facility. Because the stream does not appear to flow directly into Farm Pond or Eames Brook during dry weather, we suspect that neither will have loadings significantly impacted by the stream at those times. We hypothesize that contaminants are entering the stream from the upstream residential area, Cushing Memorial Park, and surrounding streets. Finally, taking into consideration a number of parameters, we will provide Framingham with our opinion of the best possible BMP to implement to reduce contaminants entering Farm Pond and/or Eames Brook. We will provide our findings and recommendations to Framingham in the form of a written report. We believe that the results of our research will be useful information for the Town and will benefit its stormwater management program. A timeline for our proposed work from October through March is provided in Appendix A.