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Coes Pond Stormwater Management

A Major Qualifying Project

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Submitted on April 26, 2017 by:
Brendan Kling and Adam Weiss

Approved by:
Professors Paul Mathisen and Derren Rosbach

Abstract

The goal of this project was to determine stormwater and nutrient loadings and design a best management practice (BMP) to reduce the spread of harmful invasive plant species within Coes Pond, an urban pond in Worcester, Massachusetts. This project involved sampling of stormwater outfalls around Coes Pond and modeling of stormwater and nutrient loadings using Geographic Information Systems (GIS) and hydrologic software. These steps culminated in the design of a rain garden to reduce nutrient loadings entering Coes Pond.

Capstone Design Statement

This project satisfies the requirements for a capstone design in the Department of Civil and Environmental Engineering at Worcester Polytechnic Institute, an ABET accredited program. This project evaluated stormwater loadings into Coes Pond in Worcester, Massachusetts in order to determine the best location for a Best Management Practice (BMP). The BMP designed for Coes Pond was designed to treat nutrient inflows entering Coes Pond. Stormwater and nutrient loadings from locations around Coes Pond were modelled to identify the area with the highest nutrient loading per unit area, where a BMP would have the highest impact for the lowest cost. The BMP was designed for the long-term goal of reducing weed populations around northern Coes Pond. Past experience in hydrologic modelling, GIS mapping, as well as course work were essential in completing this project. Engineering standards as written by the Massachusetts Department of Environmental Protection were followed to design a BMP that would be effective while considering the economic, social, sustainability, and environmental constraints. These constraints are described in the following paragraphs.

Economic: The BMP was selected to treat the most nutrients in the smallest space. As much of the cost of a BMP is excavation, minimizing space was very important. The land chosen is also currently owned by the City of Worcester, and a BMP was already under consideration for this location, eliminating the need to purchase the land from a private owner, and increasing the incentive to grant funding for this BMP.

Social: The Tatnuck Brook Watershed Association (TBWA) played a critical role in completing this design. They shared information about the pond and the surrounding area and provided aid with sampling efforts as well. Close cooperation with the TBWA was essential to the design of the BMP. This project aimed to meet community needs for information about Coes Pond and how to reduce the impact of urbanization around the pond.

Sustainability: A model section view was created for the BMP that can be used for the design of similar BMPs around the pond. This section view shows the soil layers and depths required for a rain garden to effectively treat nutrients coming from stormwater. BMPs constructed using a similar section would be sustainable constructions that would last for many years, reducing human impact on Coes Pond and leaving it in a better condition than it was previously.

Environmental: The rain garden designed for Coes Pond would be a benefit to the environment due to the rain garden's ability to utilize nutrients and other contaminants in stormwater before it reaches the pond. This design is a step towards reducing the impact of urbanization on Coes Pond. Also, because the BMP designed is so close to the shoreline of the pond, erosion of the shoreline was a major concern. To mitigate erosion, hay bales were included in the design in order to reduce erosion the BMP would cause by displacing such a large volume of stormwater.

Professional Licensure Statement

Professional Engineer (PE) licensure is one of the most important certifications a civil or environmental engineer can acquire in their career. All civil engineering projects require a licensed professional engineer's stamp for approval. Risk and cost management are two primary tasks of the PE, who ensures the design has minimal chance of failure and will not place any lives in danger. As this is such an important position, obtaining PE licensure is not an easy process.

PE licensure is regulated differently from state to state, in Massachusetts, licensure is granted by the Division of Professional Licensure, requirements are described in 250 CMR 3.04(4): Table I Engineering Application Requirements. There are many application conditions, someone with a bachelor's degree in engineering from an ABET accredited program, for example, would need 4 years of engineering experience working with a professional engineer. In addition to a varying set of education and experience combinations, an applicant for PE licensure must have first passed the Fundamentals of Engineering (FE) Exam, hosted by the National Council of Examiners for Engineering and Surveying (NCEES). Most sit for the FE Exam right out of college, but it can be taken at any time.

Once the education, experience, and exam requirements have been met, the engineer may apply to take the PE Exam. The PE Exam is also hosted by the NCEES, and requires much preparation. With a passing score on the PE Exam, the engineer is given PE Licensure.

Obtaining PE Licensure is generally the next milestone an engineer will seek after completing the Fundamentals of Engineering Exam.

Acknowledgments

The project team would like to thank their sponsors Pat Austin and John Ferrarone of the Tatnuck Brook Watershed Association for their continued support and assistance. Our contacts at the DPW, Ian Weyburne and Dave Harris, were also extremely helpful in sharing their reports and experience in working on water quality issues in Worcester. WPI's lab manager, Don Pellegrino was essential to the sampling phase of this project, his assistance with lab equipment was invaluable. Lastly we would like to thank our advisors Paul Mathisen and Derren Rosbach for their continued support and guidance.

Executive Summary

Many urban ponds are affected by high volumes of stormwater runoff, which introduce high amounts of nitrogen and phosphorus compounds into the ponds. The high nutrient loadings can increase the growth of algae and invasive plant species, which can severely degrade the pond. Invasive species limit public use of the pond, and can make swimming and boating hazardous as well as unenjoyable. Algae blooms significantly impair urban ponds by creating anoxic zones that fish and plants cannot survive in.

This project focuses on Coes Pond, an urban pond in in Worcester, Massachusetts. This pond has been affected by high nutrient loadings and has significant growth of Eurasian Water Chestnut and Water Milfoil - two types of invasive aquatic weeds. The purpose of this project was to quantify stormwater inflows into the pond and to develop a plan to reduce nutrient inflows to the pond in order to reduce the spread of the invasive species and improve water quality. This goal was accomplished by completing a field sampling and laboratory analysis program to determine inflows and nutrient concentrations, determining stormwater and nutrient loadings, and designing a best management practice (BMP).

The first step of this project was to verify maps of Coes Pond with site visits around the pond. A set of maps of Coes Pond and the surrounding area was prepared using data obtained from MassGIS and provided by the Department of Public Works (DPW). Stormwater outfalls that were absent or inaccurate on the maps were located. Once an outfall was found, the locations were checked with a Global Positioning system (GPS) and were added to the maps. This allowed for the determination of appropriate sampling sites around the pond.

The second step of the project involved a field sampling program. During the field program, soil and water samples were collected at nine sites, and were analyzed in the laboratory to determine concentrations of key nutrients – nitrogen (ammonium and nitrate) and phosphorus (dissolved and total phosphorus). Much of this sampling was done in conjunction with the Tatnuck Brook Watershed Association (TBWA). Using some of their equipment and time from volunteers, a larger volume of samples could be obtained.

Stormwater loadings are a key measure for the quantification of nutrient loads. Accordingly, the third step was to model the inflow of water entering the pond to quantify the stormwater loadings to Coes Pond. Stormwater loadings were initially approximated using the Simple Method, which provided estimates of the locations where the most runoff was entering Coes Pond. Since the Simple Method includes a number of assumptions, a more accurate model of the stormwater inflows were necessary. Therefore, the Hydrologic Engineering Center's Hydrologic Modelling System (HEC-HMS) was used to create a more detailed representation of the Coes Pond watershed and quantification of inflows. This work, which had not been done previously for Coes Pond, provided the volume and the locations where water is entering the system from stormwater runoff.

The fourth step was to combine water sampling analysis and modeling to quantify the nutrient loads. This approach provided a quantitative analysis on the nutrients entering the pond and allowed for the identification of areas with the highest nutrient loadings, and highest loadings relative to the sizes of the various subbasins of interest. The Circuit Avenue outfall, located on the east side of the pond at the entrance to Columbus Park, was deemed the most problematic due to its high nutrient loadings that were generated over a small area.

Based on the results of the previous steps, a BMP was designed to control the high nutrient loadings associated with the Circuit Avenue outfall. Due to the contributing basin's small size and high loadings, a relatively small BMP could filter out the majority of the nutrients before they reached the pond itself. Specifically, when all factors were taken into account, a rain garden was deemed to be the most effective in this case. Rain gardens function by using native plants as well microbiological and physical processes in the deep soil layers to remove unwanted substances from the water acting as a natural filter. The Massachusetts Department of Environmental Protection has found that rain gardens can remove up to 90% of total phosphorus and up to 50% of total nitrogen from stormwater.

The final deliverable for this project was a report that includes the concentrations of ammonium and nitrate, as well as total and dissolved phosphorus in samples collected around the pond. Stormwater flow models, nutrient loadings, and the design of a rain garden are also included in the report. These items represent the culmination of the work conducted in the project. This report recommends the construction of a rain garden at the Circuit Avenue outfall in order to significantly reduce nutrient loadings from stormwater. Additionally, within the report are recommendations for future projects that would build off and expand upon the work conducted over the course of this project. These projects would increase public awareness of stormwater quality as well as improve the overall water quality of Coes Pond and the watershed it belongs to. This project provides a basis for these future projects and provides a first step in addressing nutrient loads entering Coes Pond.

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1 Introduction

Stormwater runoff is an important consideration in urban environments. In many cases this runoff carries the majority of pollutants into ponds and streams. As the stormwater flows, it picks up contaminants from the ground and carries them downstream. The greater the distance that the stormwater travels, the more contaminants will be encountered and carried by the water. Therefore, by the time it reaches a water body, the concentration of nutrients is significantly higher than where it was initially picked up by the stormwater. This can pose a serious threat as it can reduce the overall water quality of the body that it flows into. If the contaminant in question is nutrient loadings, high runoff can increase the concentration of invasive plants that utilize these excess nutrients. This has been the case for Coes Pond.

Coes Pond in Worcester, Massachusetts is a place of enjoyment and recreation for many local residents. Unfortunately, Coes Pond has been beset by invasive plant species that are a significant nuisance to the residents of the pond, who are concerned with the impact these plants have on the pond. Currently there is very little information about the amount of nutrients flowing into the pond. This project takes the first steps in quantifying this inflow and designing a best management plan in order to reduce the nutrient inflows of one contributing basin.

1.1 Goal and Objectives

The goal of this project is to investigate and design a plan to reduce the nutrient inflow with the intention of reducing the invasive weed population of Coes Pond. To accomplish this goal, the following four objectives were accomplished.

1. Modelled hydraulic loading to determine the inflow of stormwater to Coes Pond
2. Acquired data during wet weather conditions to ascertain nutrient concentration
3. Created a comprehensive nutrient loading to determine the inflow and outflow of nutrients with a focus on Phosphorus and Nitrogen
4. Determined a best management practice or best management practices that will reduce the concentration of nutrients entering the pond via stormwater based on these loadings

The data we collected as well as the calculation of the hydraulic loading are crucial to the creation of the nutrient loading. These nutrient loadings give residents on Coes Pond an estimate for annual mass of nutrients entering the system from various stormwater sources around Coes Pond. The nutrient inflows show the problem areas that contribute the largest nutrient inflows into the pond.

1.2 Approach

In order to meet the objectives listed, a combination of field sampling and spatial representation through a Geographic Information System (GIS) and computer modelling using HEC-HMS was conducted. All field sampling was planned and carried out in October and November of 2016. Computer modelling and analysis of the samples gathered followed sampling in December of 2016 and January 2017. Once the sampling was completed and compared with the hydraulic loading, the nutrient loading was modeled and created. From the combination of the two loadings, an informed decision could be reached regarding the development of a best management practice. This report contains the background information necessary to formulate the methods taken, and the results of this major qualifying project.

2 Background

This project involves the estimation of stormwater and nutrient loadings that are used to design a best management plan. This chapter provides general background information related to stormwater and management of nutrient loads. The chapter is split into five sections, including general information on Coes Pond, detail on the threat of invasive aquatic plants, background on stormwater loadings, a summary of nutrients' impacts on urban ponds, and a description of various stormwater control methods.

2.1 Coes Pond

Coes Pond is an important part of many communities of people that live on or near the pond. Coes Pond provides a source of recreation and improves local aesthetics and property value of the area. This section describes the history of Coes Pond, and the physical characteristics that define the pond.

2.1.1 History of Coes Pond

Coes Pond is a small body of water located on Mill Street in southwest Worcester, Massachusetts. It was originally created as an industrial reservoir for the manufacturers of the Monkey Wrench: Coes Knife and Wrench Company. Coes Company created the pond when they built a dam in the early years of their operation. They were in business from the 1840s until the 1980s, when they were forced to close. Their closing resulted in the pond's ownership transferring to the City of Worcester through eminent domain (Dick, 2015).

The pond has long been a source of recreation and entertainment for Worcester residents in the area around the pond. Whether it is going to the beach to relax or taking a canoe out on the pond, residents have enjoyed the many benefits the pond has to offer. Around the time that Coes Knife and Wrench Company was going out of business however, local residents became increasingly concerned about the structural integrity of the century old dam. This concern led to the founding of the Tatnuck Brook Watershed Association (TBWA). The TBWA was active in petitioning the city government to replace the dam and remediate the old Coes Knife land of the PCB contaminated soil. The Watershed Association's efforts were successful, and the city appropriated $4 million for the project, which was completed in 2006 (Dick, 2015).

While the land is now cleaned up of most PCB contamination, the residents are dedicated to the creation of various public works around Coes Pond. The Coes Master Plan details a public park below the dam and a multi-use field and basketball court at the Knights of Columbus, as well as improvements to Columbus Park on the east side of the pond, and to the public beach off Mill Street. The plan was approved by the Worcester City Council in 2006. Residents are also increasingly concerned about the water quality in the pond, specifically with the invasive species that have taken over the local ecosystem.

2.1.2 Characteristics

Coes Pond is relatively large, with a total surface area of 91 acres (Found using City of Worcester GIS data). However, while it may be large, Coes Pond is not deep. Brown and Caldwell performed a study on Coes Pond, to take depth measurements and sediment thickness; the results of this study can be found in Appendix A. The pond is 14 feet at its deepest, with an average of 8 feet (Brown and Caldwell). Notably, the northern section is considerably shallower than the southern half. These shallow conditions make for great swimming; however, they also serve as a perfect growing area for the invasive species present in Coes Pond. Water Chestnut in particular is very successful in these shallow regions of the pond. Due in part to these invasive plants, Coes Pond is classified as 4c by the EPA's Impaired Waters and TMDL report (EPA, 2010). A 4c classification means that the Pond is contaminated by a non-pollutant, in the case of Coes Pond, invasive species.

Figure 1: Aerial image of Coes Pond (Worcester DPW, 2009)

There are four small Islands in Coes Pond; two near the beach and another two in the northwest region. They are too small for construction of any kind, but they make Coes Pond an enjoyable spot for kayaking in the summer months. The City of Worcester owns a few properties on the shore line, most notably the beach on the western shore off of Mill Street, and Columbus Park across from it. Along the shoreline there are both residential and commercial properties. The pond is for the most part surrounded by high density and multi-use residential zoned properties, with the commercial zones on Mill Street. See Figure 2 for a complete map of land uses surrounding Coes Pond. High density residential and commercial zones have a large impact on storm runoff and quality. High density residential and commercial zones are generally very developed, meaning much of the ground is covered in impervious surfaces, so the water that may normally infiltrate into the ground, is instead routed through storm drain systems directly into Coes Pond (Arnold & Gibbons, 1996).

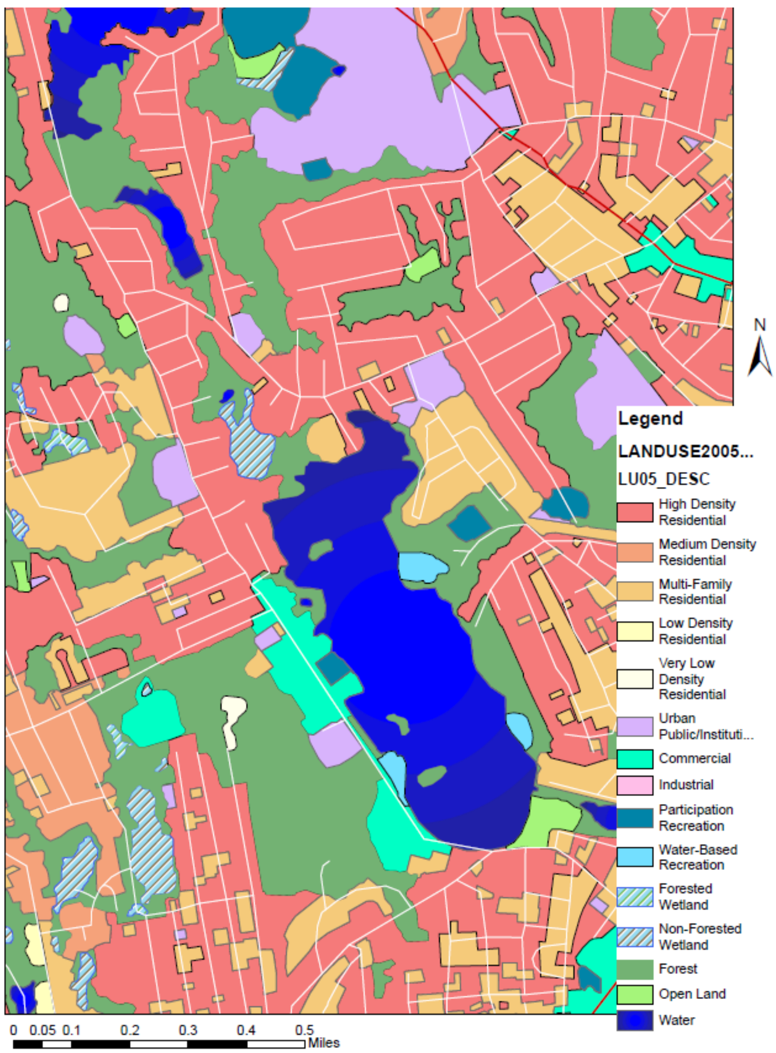

Figure 2: Map of land uses around Coes Pond (City of Worcester GIS)

Soils around Coes Pond are not very consistent, and consist of a mix of soils in the A, B, and C hydrologic soil groups. Hydrologic soil groups are a great way to simplify the many different soil types into just four categories. Group A soils generally consist of sand or sandy loam, and has very high infiltration rates leading to much lower storm runoff. Group B is mostly silt loam, with lower infiltration rates than group A, but higher than group C, which is made up of sandy clay loam. Group D is mostly clay and as such has very low infiltration rates and the highest potential for runoff (NRCS, 2007). These soil groupings are essential when calculating storm runoff into a pond, as they have a large effect on the quantity of water that comes off of a basin.

The primary contributing watershed to Coes Pond is the Tatnuck Brook Watershed, as the majority of inflow into the pond comes through the brook in the northwest corner of the pond. The brook carries water from the Holden Reservoir, two miles to the north, down to Coes Pond. The contributing area to the brook is as such the largest, shown in Brown and Caldwell's subbasin delineation, referenced in Appendix A, as Coes-US, or the large pink area above the pond. There are many smaller, more manageable subbasins contributing directly into Coes Pond, the three main subbasins to note are: the Circuit Avenue subbasin, shown as Coes-E3 on the east of the pond, and the two subbasins that discharge into the same channel next to the liquor store off Mill Street, labelled as Coes-W1 and Coes-W2.The Circuit Avenue and liquor store basins are so significant due to the high concentrations of nutrients that the project team found during field sampling, and are the best candidates for a best management plan to reduce their impact on the pond's water quality.

2.2 Invasive Species

This section seeks to explain how invasive species can be a threat to ecosystems like Coes Pond. Invasive species like the Eurasian Water Chestnut and Water Milfoil currently present can dramatically affect the water quality and thus impact organisms that depend on it for survival.

2.2.1 Danger of Invasive Species to Pond Ecosystems

The United States Department of Agriculture (USDA) defines invasive species as organisms that are not-native to the environment are likely to cause harm to the local ecosystem (USDA). These invasive species are often unintentionally brought to a new location where due to lack of predators, can quickly spread and take over the ecosystem. This can even result in local extinction of native plant and animal life. The Environmental Protection Agency (EPA) has estimated that 70% of all extinctions of native aquatic species over the past century have been due to invasive species (EPA, n.d.).

In addition to damage done to the environment, invasive species cause large amounts of damage in their wake. These damages from invasive species have been “estimated as high as $138 billion per year.” (EPA, n.d.). In addition to the money used due to damages, a sizable sum is also funneled into slowing or reversing the spread of a particular species. This can be done physically or chemically, but in both cases it is often expensive, and can further damage the environment.

2.2.2 Invasive species in Coes Pond and Past Treatment

Coes Pond contains two main invasive species: Eurasian Water Chestnut and Water Milfoil. Water chestnut is fonder of shallow waters, forms rosettes on surface of water, and has huge spiky nut making it very unpleasant to swim with. Milfoil is longer and stringy and can grow in deeper water. They both have rapidly taken over the ponds taking advantage of the excess nutrients which have stimulated their growth. While there have been many attempts to treat the weeds in Coes Pond, none so far have had a long lasting impact. In 2016 in an organized event multiple dumpsters of invasive plants were removed from the pond, however, what remained quickly grew back and filled in the gaps where the removed plants once were. During the winter of 2016 a “drawdown”, an intention lowering of the water level to expose the plants to the cold winter air, was conducted in an attempt to kill them. However, the impact of the drawdown on the weeds has yet to be fully determined. Potential ways to control the weeds in the future are discussed in the conclusion and recommendations section.

2.3 Hydraulic Loading to Estimate Annual Stormwater Inflow

Hydraulic loading from stormwater is a major part of quantifying a water budget. Hydraulic loadings consist of the total annual inflow from stormwater as well as peak flows that can be expected from regular storms. This section describes hydraulic loadings, and how the many unique characteristics of a watershed affect them.

2.3.1 Urban Hydrology of Coes Pond

Coes Pond is an urban pond, meaning it is surrounded by mostly impervious area that contributes to high stormwater runoff values. Stormwater runoff is of affected by a variety of factors, most important is the average rainfall for the area, because this defines the quantity of water that would be added to the pond. The total amount of rain that falls on a water basin is directly affected by the size of the basin. Since rainfall is measured in height, it must be combined with the area to find the volume of rainfall. Once on the ground water can leave the basin in a few ways. Some water infiltrates into the groundwater table, meaning water passes through the soil layer into groundwater and does not run off into the pond. Infiltration is an extremely beneficial to a watershed, water that infiltrates into the ground is stripped of most contaminants, especially nutrients. This process is affected by land use and soil type. Land use gives a good estimate of how much water would be sent into impervious collection systems with no chance to infiltrate. Soil type determines how quickly water passes through the soil into groundwater.

Water is also returned to the atmosphere via evaporation and evapotranspiration. Water entering the air from the pond's surface is evaporation. Evapotranspiration is water evaporating from the leaves of vegetation. Evaporation is primarily affected by temperature and wind speed. High temperatures encourage more water to vaporize, and high winds exchanges the air above the water/leaf. Thus, wind allows for more water to evaporate into the air from water and plants.

In the case of Coes Pond, there is just one outflow; the dam at the south end of the pond. The dam and spillway are fairly new, finished in 2006 (Dick, 2015), and are 22 feet wide and 100 feet long with a 15-foot drop (City of Worcester GIS). During intense storms that raise the water level above the height of the dam, there is significant flow. This outflow should be calculated in order to complete a water budget for Coes Pond.

2.3.2 Purpose of Water Budgets

A complete water budget is a sum of all inflow and outflow from a water system. This includes stormwater runoff, groundwater flow, stream flow, evaporation, and more. Any way that water would enter or leave the system would be quantified in an ideal loading.

Water budgets have many uses, as it is important to quantify the water that is entering and leaving a system annually, stormwater inflow is a major contributor to inflow. One key use would be for designing best management plans for the pond. In order to determine the size of a management plan for a basin, the expected stormwater runoff values must be known. Additionally, if there were ever a water emergency in the future, Coes Pond may be used as a reservoir once again. While it may not currently be a drinking water reservoir, Coes Pond was used as one in the late 1800s temporarily while Worcester's main dam was under construction (Dick, 2015). In this case, it is essential for planners to know how much water they can expect to come into the pond so they can determine safe draw rates for the water supply. Water budgets are also essential to the development of nutrient loadings, as described in the following section.

2.4 Nutrient Impacts on Urban Ponds

As for many other urban ponds, Coes Pond faces many challenges such as being heavily affected by human activity that impact natural cycles including nutrient loadings. Artificially created stormwater flows and impervious surfaces redirect nutrient flows and in this case significant amounts flow into the pond. It is therefore extremely important to look at nutrient inflows when analyzing water quality in urban ponds.

2.4.1 Nutrients

There is a wide range of nutrients entering Coes Pond. Their large quantities have fueled the explosive growth of the invasive species there. Among them are a category of nutrients called macronutrients, or nutrients that plants need large quantities of to grow and reproduce. Two important macronutrients are nitrogen and phosphorus.

Nitrogen is one of several key nutrients required for the growth of the invasive species in Coes Pond. It is chiefly involved in the production of chlorophyll, the main compound plants use to convert sunlight into usable energy during photosynthesis. It is also involved in nucleic acid and is one the building block of DNA. (Mosaic, n.d.). Nitrogen can consist of many varieties in the soil as different forms. One of the most common forms is Ammonium (NH_4^+). This can occur naturally but is also a common ingredient in many fertilizers.

As is nitrogen, phosphorus is also crucial to plant growth. In surface waters it is generally present as phosphate (PO_4^-) and is the generally limiting nutrient in freshwater systems. On a cellular level phosphorus is used by the plant to create new tissue to grow and expand. As a result, it is common for phosphorus starved plants to have lower growth rates and be of smaller size than what would be typical (Plant and Soil Sciences ELibrary, n.d.). In Coes Pond, the phosphorus enters the water both through the ground, and into the pond via outfalls from storm drains. The latter can often be modified to filter out excess phosphorus before it reached the pond to prevent it from further encouraging the growth of the weeds.

2.4.2 Sediment Sample

In addition to the concentration of nutrients in the water, it is also important to examine the sediment. Much of the nutrient loads that the aquatic plants uptake is through the soil. “The roots of the plants investigated are true absorbing organs, taking from the soil valuable salts..., and furnishing these salts to the growing stems and leaves for the building up of more plant tissue. So dependent upon the soil are these rooted aquatics that they cannot survive a growing season if deprived of it. Thus, instead of taking their mineral food exclusively from the water, these rooted aquatics take their food from the soil” (Pond 1905, 522). Therefore, in order to get a holistic view of the nutrients in the water, one must look both at the nutrients coming into the pond, and those which are already present in the sediment.

2.5 Stormwater Control Methods

2.5.1 Rain Garden Description

While there are many viable options for Best Management Practices (BMPs), one popular solution is to install a rain garden, a type of bioretention system. “Bioretention is a technique that uses soils, plants, and microbes to treat stormwater before it is infiltrated and/or discharged. Bioretention cells (also called rain gardens in residential applications) are shallow depressions filled with sandy soil topped with a thick layer of mulch and planted with dense native vegetation" (Massachusetts Stormwater Handbook, 23). As some plants and microbial organisms naturally pull nutrients from water, rain gardens act as a filter that prevents unwanted compounds from reaching the pond. Rain gardens have been found to remove 30%-90% of phosphorus from the water as well as high amounts of nitrogen, suspended solids, and metals (Massachusetts Stormwater Handbook, 23). Rain gardens can also be used in relatively small spaces, such as near the Circuit Ave outfall, which has size constraints. Another benefit to rain gardens are their aesthetic appeal. The land surrounding Coes Pond is zoned mainly for residential and commercial land uses. As a result, aesthetics is a consideration as homeowners and business owners would want a BMP that looks good and may raise property value.

2.5.2 Rain Garden Case Studies

Rain Gardens have been used to treat similar impaired water bodies and control stormwater across the country. Many of these BMPs were constructed through or analyzed by the American Society of Landscape Architects (ASLA). Two such case studies are presented here to demonstrate the effectiveness of rain gardens. One such example is the Applebee's Support Center in Lenexa, Kansas. Similar to Coes, this site dealt with a relatively small impervious area, but it was still of concern as it fed into a nearby lake. To solve the issue, rain gardens were planted in narrow strips to filter the water that passed through. It was also designed in such a way as to improve aesthetic appeal rather than subtract from it. From start to finish, it was estimated that the installation of the rain gardens cost between $10,000 and $50,000. This is relatively inexpensive compared to many other BMPs that could have been selected. The site has also been monitored since its creation and it has been measured that the rain garden was responsible for removing 56% of total nitrogen and 50% of total phosphorus entering the pond. (ASLA, Applebee's Support Center- Courtyard Rain Gardens, n.d.).

Another example of a successful rain garden project took place in Lawrence, Kansas. For this site, the rain garden was built to control runoff from an impervious area in the range of 5,000 ft^2 to one acre on the campus of the University of Kansas, which borders residential areas that have suffered from problems relating to poor stormwater management. The garden was designed to slow the rate at which the water would move, and to increase infiltration into the ground. It also served as erosion control to protect the stream banks on the site. By primarily using native plants, maintenance costs were driven down, and no fertilizers/pesticides were required. As a result, the final cost was $50,000-$100,000 raised by state funding. In addition to better managing the stormwater, this garden had a large impact on the community. Both on the campus and in the residential zones, the garden was used as an educational tool. Through community involvement, the BMP led to a significantly greater understanding of stormwater management and its importance. (ASLA, Student Rain Garden, n.d.)

These are only two examples of how rain gardens have successfully been able to improve local water quality. These cases demonstrate that when analyzing an area involving a nearby waterbody, rain gardens can in fact remove unwanted substances from the water and in the case of Coes Pond, remove the nutrients that are fueling the growth of invasive species.

3 Methodology

This chapter describes the steps taken to complete the sampling, the hydraulic and nutrient loadings, and the design of the BMP. For the results of these methods, please refer to the Results and Discussion Chapter (Chapter 4).

3.1 Hydraulic Loading

The hydraulic loading normally includes inflows and outflows, important values that are used when designing stormwater management systems for a water body. The loading analysis for this case concentrated on the inflows. For the hydraulic loading, two main methods were used to determine annual stormwater runoff into Coes Pond. First, an estimation was completed following the simple method of runoff. Then, a more complete hydrologic analysis of the watershed was created using HEC-HMS, a hydrologic modelling software created by the US Army Corps of Engineers. While these two methods differ, they require much of the same information.

A complete hydraulic loading quantifies the annual inflows and outflows of water, to find a total change in storage for the pond. Following the principles of mass balance, the inflow subtracted by the outflow is equal to the change in storage (Bedient et al, 2013). This mass balance is the key to calculating a hydraulic loading. At the beginning of this project, a loading for Coes did not exist in any form, so this is the first step to building a complete loading for pond.

In order to know how much water comes from one pipe, the characteristics of the contributing basin must be known. The delineation of the subbasins was provided in Brown and Caldwell's report as shown in Appendix A (Brown and Caldwell, 2015). We cross-checked these subbasins with the GIS maps of storm drain pipes and topography as well as the DPW's map of storm pipe areas (shown in appendix B) to confirm. In addition to these maps, the online GIS application StreamStats was used to confirm subbasins. These subbasins were then analyzed using ArcMap GIS software to determine the area, impervious coverage, soil and land types, and stormwater pipe characteristics. The following sections give more detailed description of each step in the creation of a hydraulic loading.

3.1.1 StreamStats

Developed by USGS to help manage water resources planning in ungaged watersheds, StreamStats uses GIS data as well as nearby gage readings to delineate and estimate flows using streamflow regressions developed in 1999 (USGS). StreamStats is generally used to estimate flows for basins that are smaller than that of Coes Pond, so the flow estimates should be done another way. The basin delineation is based off of local topography, the main use of the application for this project.

The delineation of the basin is quite simple, as it requires just a single click on the outfall. StreamStats draws the basin from GIS topographical data. Figure 4 shows the StreamStats interface when selecting the point to delineate the basin from. Once the delineation is completed, the user may download a custom GIS shapefile to put into the GIS project file that was used for the complete hydraulic loading. This shapefile allows users to clip data layers such as the one for land in the Worcester area.

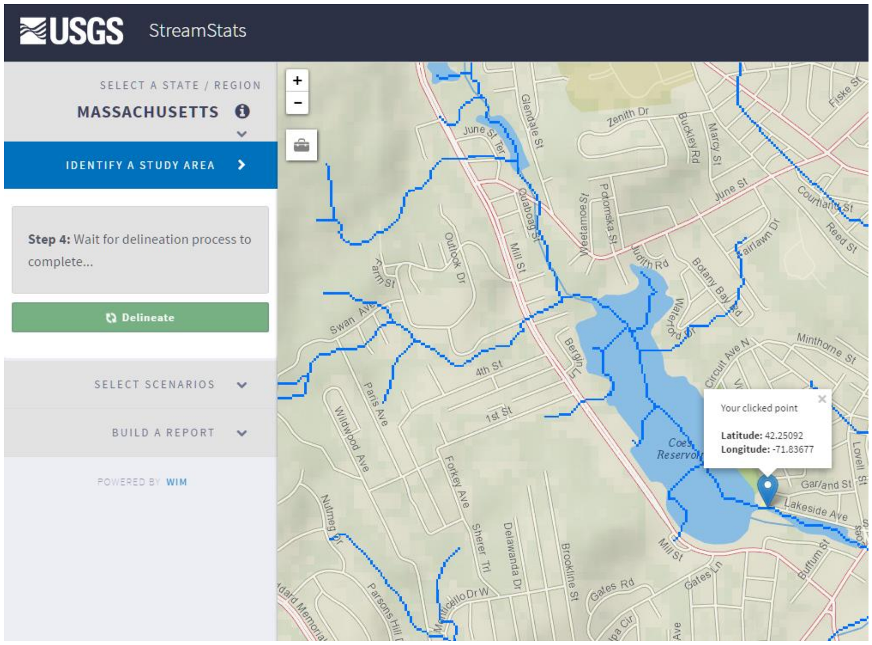

Figure 4: StreamStats interface for selection of delineation point (USGS, 2016)

3.1.2 GIS Applications

Most of the values needed to complete the hydraulic loading can be found using Geographical Information Systems (GIS). For this project, ArcGIS's ArcMap was used for handling, viewing, and presenting data layers. GIS data required included land use, soil type, topography contours, major ponds and streams, stormwater lines and outlet points, as well as impervious area images. The base shapefiles for all of these data layers are publically available through MassGIS.

Most of the data contained more information than was necessary, as they were created for the entirety of Worcester County, while the project only covers the area around Coes Pond. The data layers were clipped down to a more manageable size to reduce load times and make the mapping process much smoother. Some data layers needed specific changes to be workable for a few different reasons. First, the soil types and land uses data sets came in two parts, Worcester North and South, with the split in the northern part of the Tatnuck Brook basin as shown in Figure 5. To use these data layers, they must first be joined together. ArcGIS allows users to join two data sets into one using a shared field.

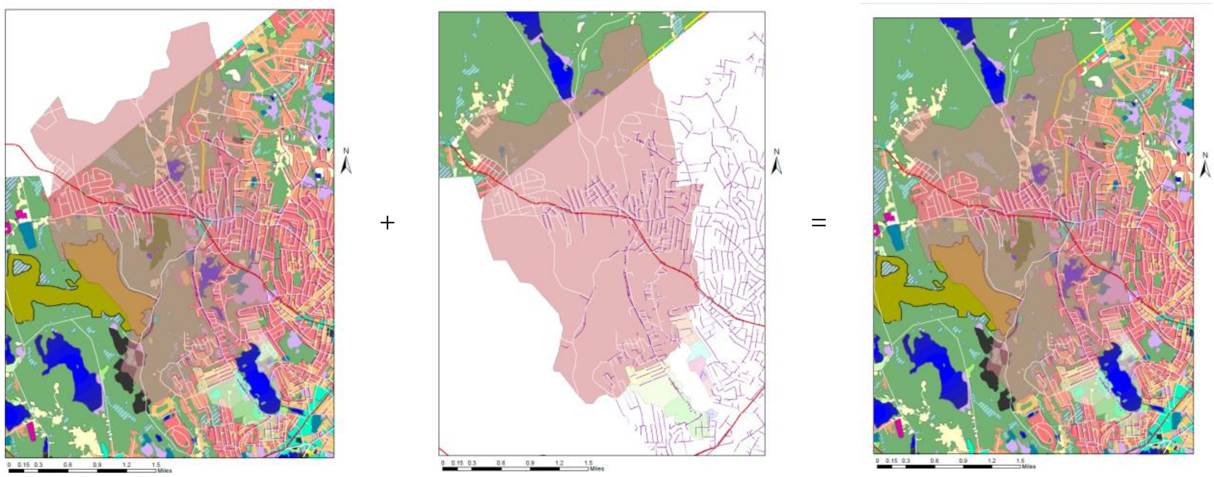

Figure 5: Map of land use around Coes Pond, (Note the white area in the north is where the Worcester North/South data layers meet)

The soil type layer would then need one more change - the addition of a hydrologic soil group field. This can be done by joining the soil layer to a soils information database. The soil layer has a map unit symbol field called "MUSYM" that gives a unique identification value to each soil type. This data can be joined to a database containing detailed information for each MUSYM value. From this the hydrologic soil type, used for calculating the curve numbers for each basin.

Next, the sewer lines layer must be edited to only contain stormwater pipes. The layer already included a "kind" field which differentiates the lines by sanitary and surface pipes, where surface pipes are the ones that stormwater would enter and be routed into the pond. The layer must be edited such that it includes only these surface pipes. This can be done through the attribute table, sorting the lines by "kind", then selecting and deleting all non-surface lines.

The final edit to the data layers needed to complete the hydraulic loading is the conversion of the impervious area image file, as shown in Figure 6, to a usable collection of points. This is done using the spatial analyst extension, an Environmental Systems Research Institute (ESRI) package that is included in ArcInfo, a program that aids in organization of GIS projects. The converted image file contains many points, each representing one square meter, with a value of "zero" or "one". A "zero" means the point is not impervious, and a "one" means that there is an impervious surface located at the point. These are then added up to give an impervious coverage percentage that is used in the simple method.

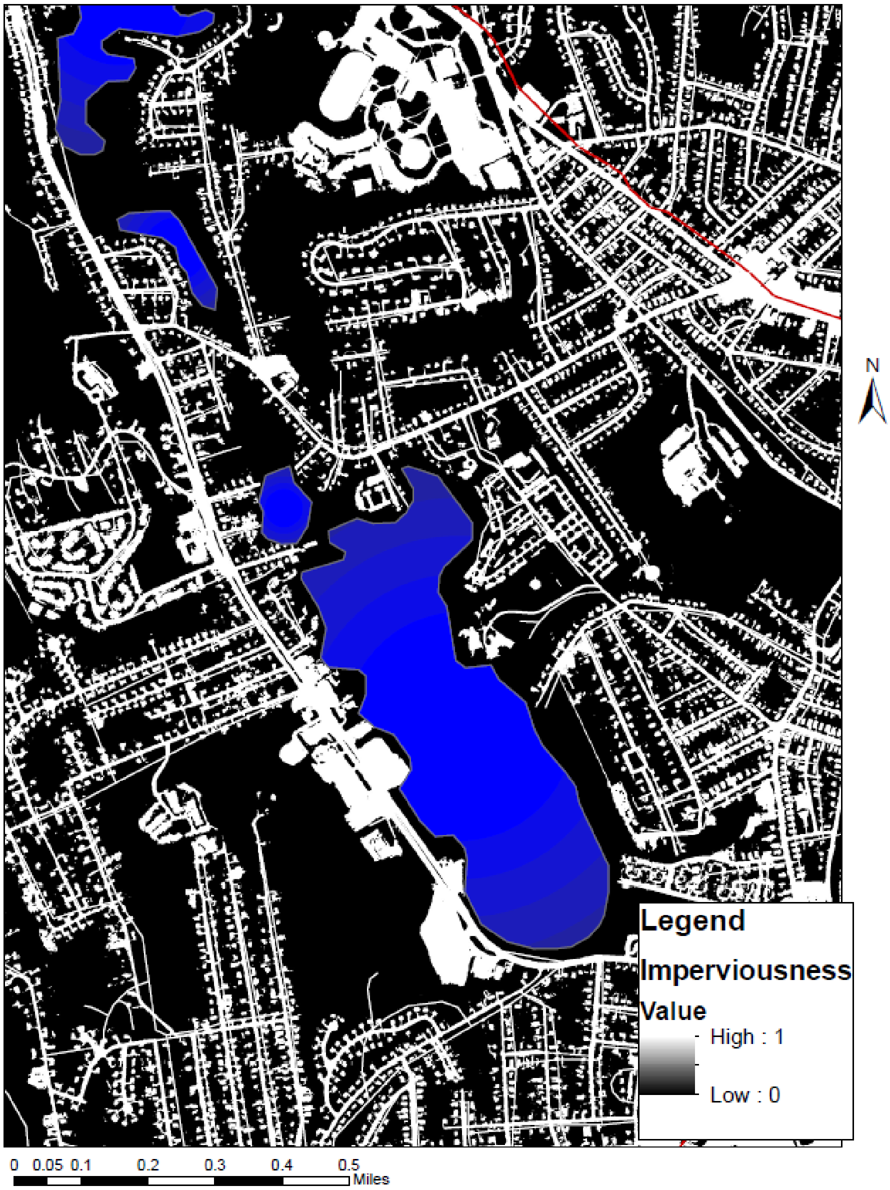

Figure 6: Map of impervious area around Coes Pond, the white areas represent impervious area

3.1.3 Simple Method

The simple method is the most basic way to estimate annual stormwater runoff for a basin. The simple method consists of just one equation, shown in equation 1, that states runoff (R, inches) is equal to the product of annual rainfall (P, inches), the fraction of annual rainfall events that produce runoff (P_j), and the runoff coefficient (R_v).

$$R = P * P_j * R_v$$

Equation 1

Annual rainfall is location specific and for Worcester is found to be 48 inches (US Climate Data, 2017). The fraction of rainfall events that produce runoff is difficult to know, especially since there is no such data available for the watershed contributing to Coes Pond. However, this fraction can be assumed to be 0.9 (Stormwater Center, 2000). The final value we need is the runoff coefficient, which is related to impervious area. Figure 7 shows the relationship between watershed imperviousness and the runoff coefficient. From this scatter plot the line of best fit can be found, and is given below the chart.

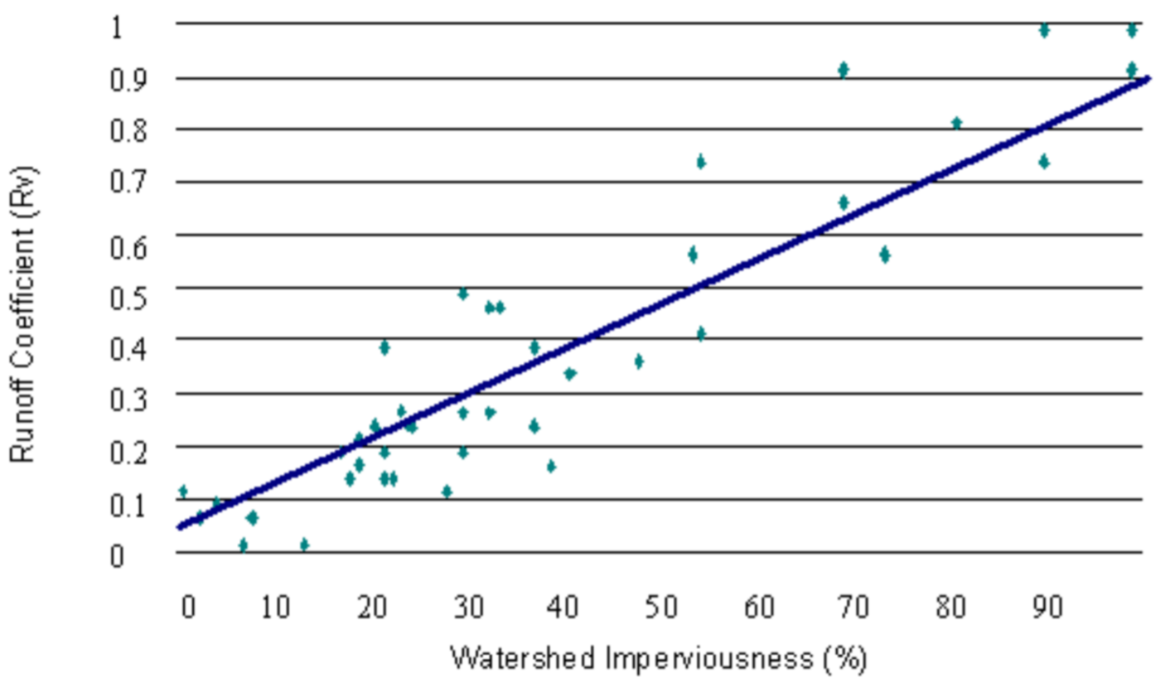

Figure 7: Runoff coefficient chart and regression, best fit equation: $R_v = 0.05 + 0.9I_a$, where I_a is the impervious area percentage. (Sheueler, 1987)

Using the simple method equation, a spreadsheet allows for quick estimation of the annual runoff values for each subbasin.

3.1.4 HEC-HMS

In order to get reliable estimates for hydrologic systems, the US Army Corps of Engineers uses a hydrologic analysis software called HEC-HMS. Using HEC-HMS is different than the simple method in that the results of the model come in the form of hydrographs for single storms rather than annual runoff.

The first step in modelling with HEC-HMS is to create the basin model, which includes each contributing basin as well as a junction that represents the pond. This is shown in Figure 8.

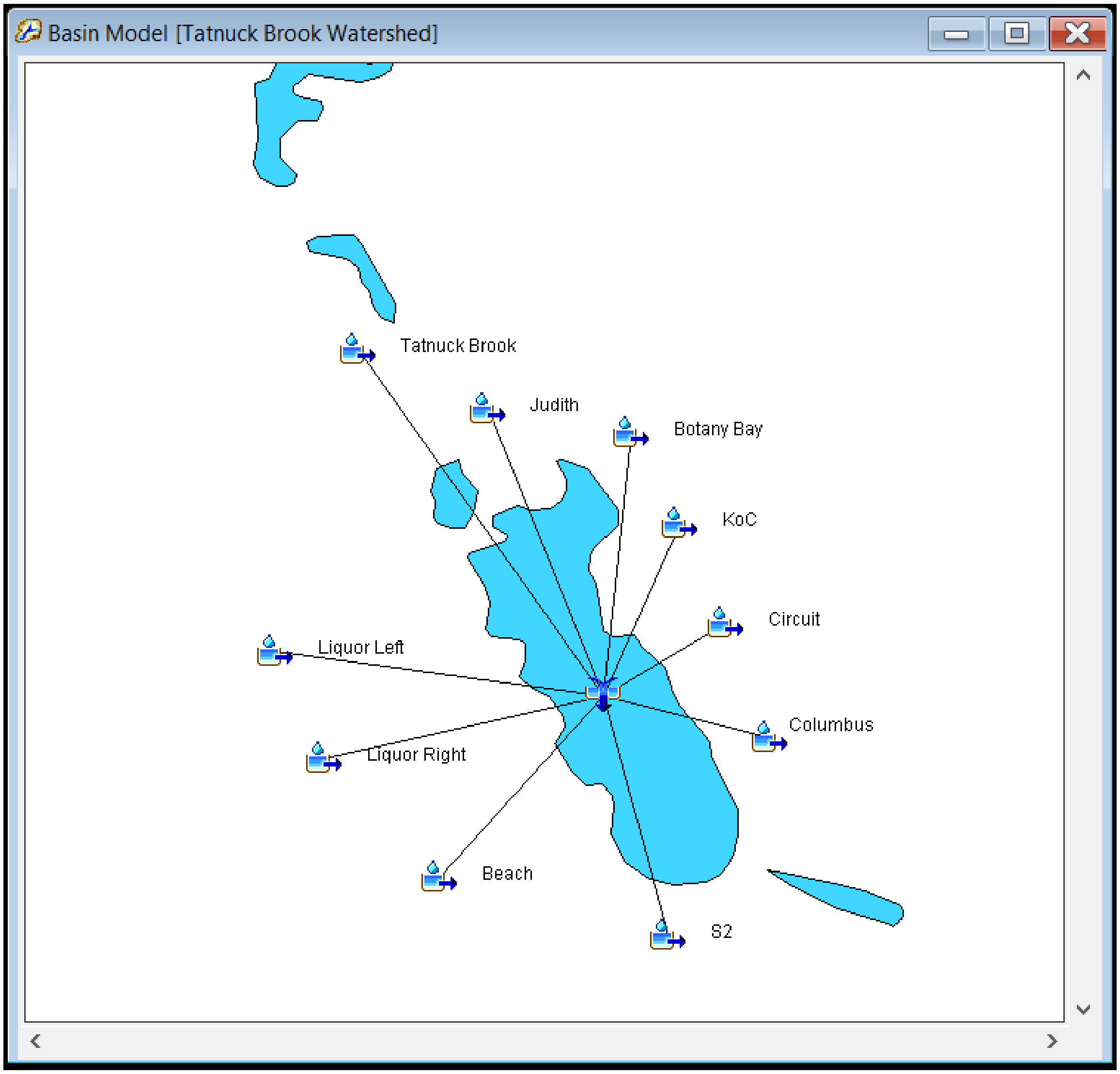

Figure 8: Basin model created in HEC-HMS

From the basin model, values for each contributing subbasin must be filled out. These values include the area, curve number, impervious percentage, and lag time. The lag time must be calculated from available data, whereas area, curve number, and the impervious percent can be found using GIS files provided by the City of Worcester.

To determine the curve number (CN) of an area, the land use and soil types present must be analyzed. Each land use must be combined with a soil type that is located over. This is completed by using the "join" command in ArcGIS. This combined layer must then be exported to a spreadsheet. Each land use/soil type combination has a CN associated with it; the tables used as a reference for this is attached in Appendix C. Once each combination is attributed a CN, the weighted average across the subbasin must be calculated as seen in Equation 2.

$$CN = \sum_{i}^{n} \frac{CN_i A_i}{A_T}$$

Equation 2

Here, CN_i is curve number, A_i is the area related to that CN, and A_T is the total area of the subbasin.

The lag time is defined as the time from the halfway point of the rain duration to the centroid of the hydrograph for a rainstorm (US Geological Survey, 2012). The equation used for lag time over land is shown in Equation 3, where T_l is the lag time in hours, L is the distance the water must travel in feet, S is retention in the watershed measured in inches, but is calculated separately (Equation 4), and finally y is the average slope over the watershed, found from topography contours provided by City of Worcester GIS.

$$T_l = \frac{L^{0.8}(S+1)^{0.7}}{1900 * y^{0.5}}$$

Equation 3

Where $S = \frac{1000}{CN} - 10$

Equation 4

The lag time equation was used to calculate the time it would take for stormwater to travel to the catch basins. From the catch basins, Manning's equation was used as shown in equation 5 to find the time it would take to travel into the pond. Where Q is flow, n is the manning's roughness coefficient (Oregon DOT, 2014), A is area, R is the hydraulic radius, and finally, S is the percent slope.

$$Q = \frac{1.49}{n} * A * R^{\frac{2}{3}} * \sqrt{S}$$ Equation 5

These values are then used to fill out the basin characteristics windows in HEC-HMS shown in Figure 9. It is important to follow the units specified by HEC-HMS, shown in parenthesis.

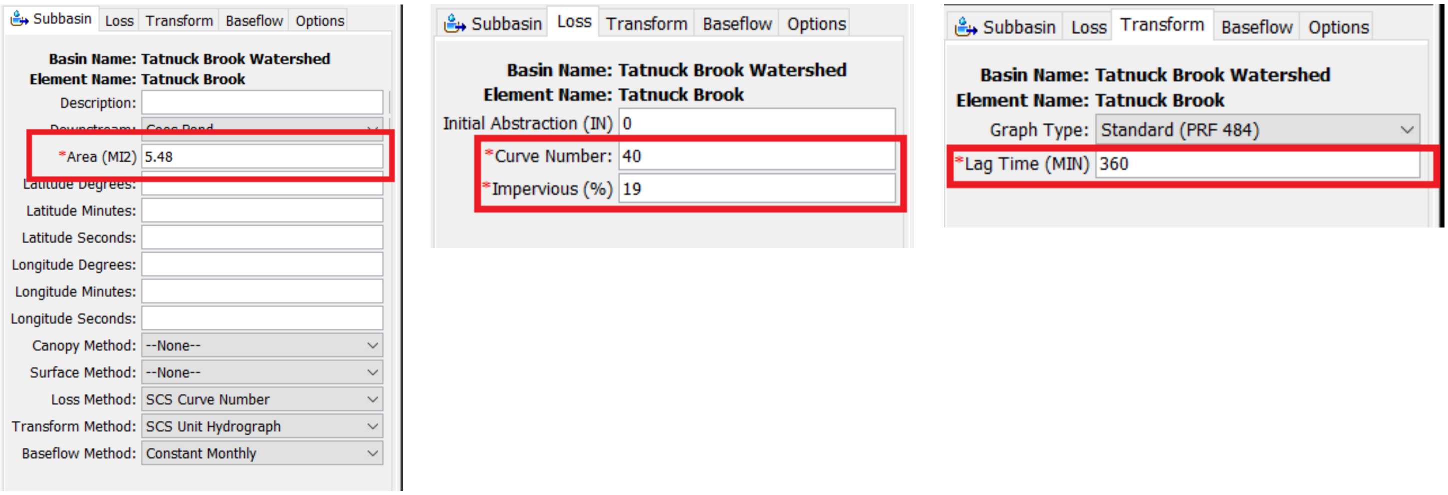

Figure 9: Characteristics necessary for entry into HEC-HMS

HEC-HMS can then be used to calculate the stormwater runoff for a single storm event. For this, IDF curves, as seen in Figure 10, must be consulted to get the rainfall intensity for storms of various return periods.

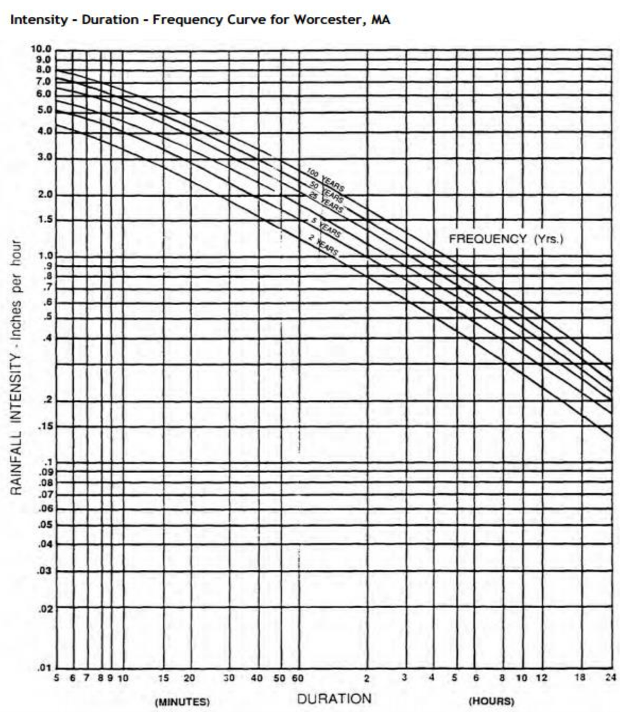

Figure 10: IDF curves for the City of Worcester (MassDOT, 2006)

This IDF curve can be used to determine the magnitudes of for various design storms (i.e. storms with return periods indicated by the curves in the plot). It was also used to approximate occurrences of lower magnitudes storms. For a given duration, the return period can be approximated by a log-linear relationship with intensity. Accordingly, the log of the return period vs intensity was graphed and fit with a regression line to extrapolate to lower magnitude storms with higher frequency, such as 1 inch or 2 inch storms. From the exceedance probability, the quantity of storms of certain volume were estimated by adding up the volumes of each storm such that the total volume of rainfall matched the average rainfall for Worcester, and that the distribution of storms would be consistent with o the exceedance probability if it curve were extrapolated to lower magnitudes (and higher frequencies).

The storm depths can then be entered into HEC-HMS as seen in Figure 11. This project used the Soil Conservation Service’s (SCS) storm model, and assumes a duration of 24 hours.

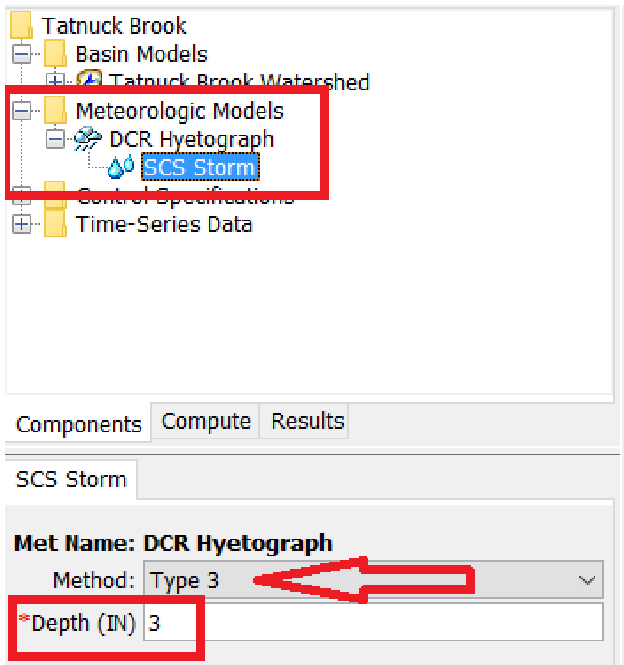

Figure 11: Entry of rainfall data in HEC-HMS

The “Type 3” method should be chosen as Worcester is in the type III storm area according to the map created by the USDA (1986). Once the depth has been entered, then the storms can be calculated, yielding a volume of runoff. These runoffs are multiplied by the number of storms of that depth that could be expected in an average year. The sum of these runoffs is the total annual runoff.

Once annual runoff values are computed by both the simple method and with HEC-HMS, the two should be compared to ensure that the values are similar, which values to use is the choice of the team. These annual runoffs are crucial for the calculation of the nutrient loading, as the concentrations obtained during sampling can be combined with flow to find a total mass loading.

3.2 Sampling

By collecting samples at locations throughout the pond boundaries, it is possible to determine which areas are contributing the most nutrients, making them a larger concern relative to other areas. To do this, the students or volunteers would fill multiple bottles from each of the locations sampled (A copy of the sampling guide can be found in Appendix D). While the bottles were being filled, care was taken to avoid including excess suspended solids too much soil. The samples were then refrigerated until they could be analyzed in the lab, the details of which are described below. The sampling locations chosen were Coes Beach, Mill St., Circuit Ave, Judith Rd, and the Tatnuck Brook. A map of all of the sampling locations can be seen in Figure 12. All of the sampling conducted for nutrient information was done either for water quality at the outfalls, or soil samples at edges of the pond. The water quality sampling was conducted during wet weather conditions allowing for an analysis during peak flows. These samples were taken specifically with the intention of analyzing the concentration of phosphorus and nitrogen, two important macronutrients, nutrients required in large amounts for growth. While there are many nutrients that plants require, due to the sheer quantity of macronutrients required, it is important to focus on them.

The soil samples, were collected in a relatively similar way to the water samples. A bottle was filled with the soil from a given location, avoiding excess water. They were then refrigerated and stored awaiting analysis in the lab.

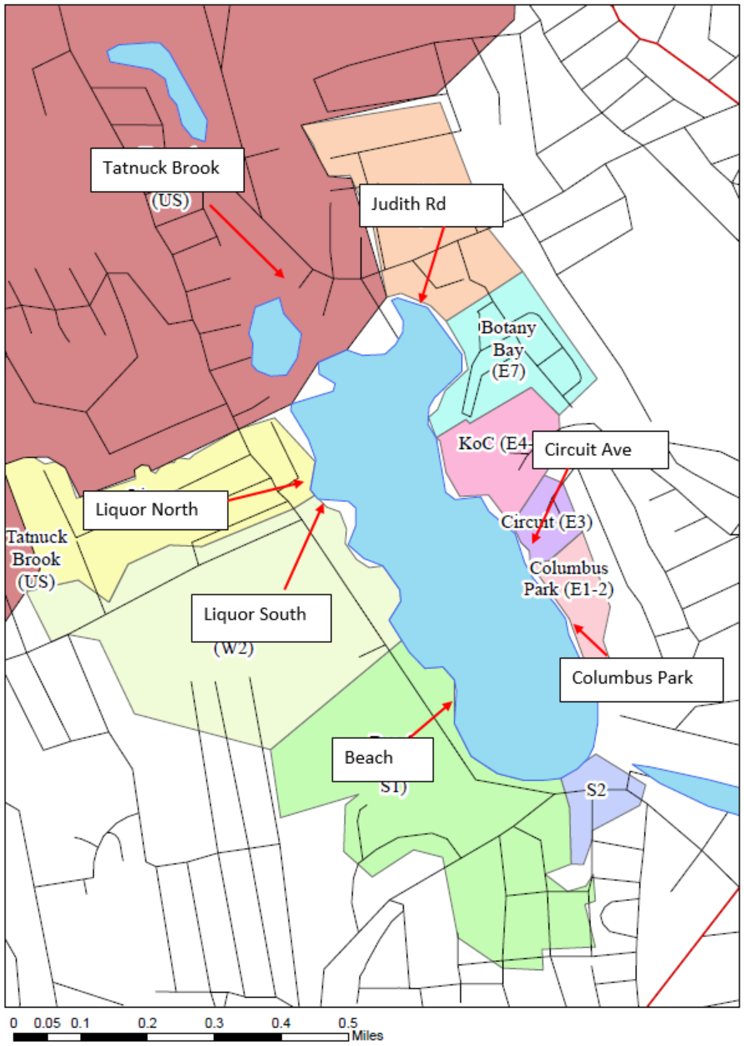

Figure 12: A map of water sampling sites

3.2.1 Water Sample Preparation

From the raw water sample from Coes Pond, a few steps had to must be taken before it could be analyzed for nitrogen and phosphorus. Twenty-five ml of the raw sample was mixed with 5 ml of nitric acid (HNO_3) and then 1 ml of sulfuric acid (H_2SO_4). The sample was then covered and heated gently to 1 ml and allowed to cool. It is then ready to be tested in a spectrophotometer as described in section 3.2.3.

3.2.2 Sediment Sample Preparation

The soil sample had to be purified before the phosphorus analysis could be done. To do this, it was heated in an oven overnight to drive of excess moisture and then ground to a powder. Once in this state, acid digestion could be conducted. This dissolved the organic matter and removed unwanted substances, leaving behind the nutrient being tested for. First 0.5 g of the soil was added to 40 ml of pure water. 10 ml of nitric acid (HNO_3) was added and then heated while covered for a few hours and left overnight Then it was forced through a “#4” filter and the sample was brought up to 25 ml (depending on the sample it is possible a larger volume is required). 1 ml of sulfuric acid (H_2SO_4) was added and heated gently in a fume hood while covered until only 10 ml remained. The penultimate step was to add drops of hydrogen peroxide (H_2O_2) until bubbling ceased or the sample became clear. Lastly it continued to be heated while covered until only 1 ml remained and white fumes appeared. The sample could then cool and be tested it in a spectrophotometer as described in section 3.2.3.

3.2.3 Lab Analyses

Much of the lab work involving the concentration of nutrients in the soil and water of Coes Pond conducted over the course of this project was completed by making use of a spectrophotometer. The electronic spectrophotometer is a device that uses light intensity to determine the concentration of a substance in solution. The preparation for using the device was adapted from a Worcester Polytechnic Institute lab guide and is as follows. Before the samples collected could be analyzed, the device was first calibrated using a series of 100 ml stock solution. This allowed for a calibration curve to be generated. By comparing it to the results of the analysis, the concentration of a given substance was determined. These stock solutions are created by diluting pure solution with distilled water to reach the desired concentration.

The spectrophotometer is then zeroed. For each standard the following steps were performed. First, one drop of phenolphthalein indicator solution and small amounts of 5N sodium hydroxide (NaOH) solution to the blank until a faint pink tint appears. Then pure water was added until 25 ml total volume was obtained. Following this, 1 ml of molybdovanadate (H_3MoO_7V) was added. After three minutes passed, the desired wavelength of 400 nm of selected on the spectrophotometer. Lastly, the sample was placed within the machine with the volume marker facing the experimenter, the door was closed, and the zero abs. button was pressed. When the display did not read 0.000 ABS, this last step was retried until it does. This section was repeated for each standard. At this point, the samples could be loaded into the machine and the same steps were followed for the samples as was done with the standards except abs. was pressed at the end for each sample to display absorbance. This absorbance reading can be then used to calculate the concentration at the location of the sample’s origin: an important step in developing the nutrient loading.

3.3 Nutrient Loading

Given the hydraulic loading and the nutrient concentrations, the next step was to convert the total runoff volumes into areal loadings. Areal loading is the load of mass per unit area. A high mass or a low area will result in a larger areal loading rate.

The following steps were performed to calculate the areal loading rate. First the area was converted to acres and the volume to liters. Secondly the mass of the nutrients was found by multiplying the concentration by the volume in liters. This was then converted to kilograms. Lastly the areal loading of a subbasin is the mass loading divided by its area. In this case the mass loading in kilograms was divided by the volume in acres. This results in areal loading in kilograms per acre.

3.4 Best Management Practice (BMP) Design

From the nutrient loading, the subbasins with the highest areal loadings will be the best candidates for a Best Management Practice (BMP). This subbasin will have the highest efficiency, as BMPs are designed based on the total area of the subbasin, so a higher load per area directly correlates to space efficiency. For the following BMP design section, the Stormwater Handbook published by the Massachusetts Department of Environmental Protection (MassDEP, 2016) was used as a resource to plan the design of the BMP. The first step was to determine good candidates for nutrient removal in stormwater.

3.4.1 Possible BMP types

The Stormwater Handbook separates stormwater BMPs into five categories: Structural Pretreatment BMPs, Treatment BMPs, Conveyance BMPs, Infiltration BMPs, and Other BMPs. Structural Pretreatment BMPs focus on settling and target suspended solids such as oil or grit. Treatment BMPs focus on removing organic material as well as nutrients. Conveyance BMPs are used to channel runoff long distances, while avoiding impervious surfaces. Infiltration BMPs are generally large fields of gravel that form pools and gradually infiltrate into groundwater. Other BMPs cover unique cases such as green roofs and porous pavement. From this it is clear that Treatment BMPs will be best for the case of Coes Pond as they are most effective at nutrient removal, the goal of this project. Of the Treatment BMPs, the choice of which to go with will be a BMP that is efficient and effective in a small area that is also not an eyesore to local residents. This choice will be made in the results section to follow. The results section follows the methods laid out above to quantify the hydrologic processes contributing nutrients to Coes Pond, gives the design for a BMP to reduce the impact of one subbasin on Coes Pond, and discusses the implications of the project.

4 Results and Discussion

This chapter includes measurements of the stormwater loading, nutrient loading, and BMP design specifications. The hydraulic loading includes estimates taken by both the simple method as well as results of hydrologic modelling done in HEC-HMS. A sampling program was also carried out to determine concentrations of nutrients around Coes Pond. These were combined in the nutrient loading which describes where nutrients are entering the pond, and in what quantities. These results are displayed in both tabular and graphical form.

4.1 Hydraulic Loading

This section will provide the results of the various steps taken for the hydraulic loading, including the StreamStats delineation, GIS applications involved, a simple method analysis, and the final HEC-HMS model.

4.1.1 StreamStats

USGS's StreamStats was used primarily as a way to confirm the watershed delineations done by Brown and Caldwell (2015) shown in Appendix A. The main basin of concern was the basin that contributes to the Tatnuck Brook, shown as "Coes-US" on Brown and Caldwell's delineation. The Tatnuck Brook basin is the largest by area, and would contribute the highest quantities of water, thus, it was very important to verify the boundaries of this basin. When the brook was selected in the application, StreamStats provided the delineation shown in Figure 13 which was then converted to a GIS file.

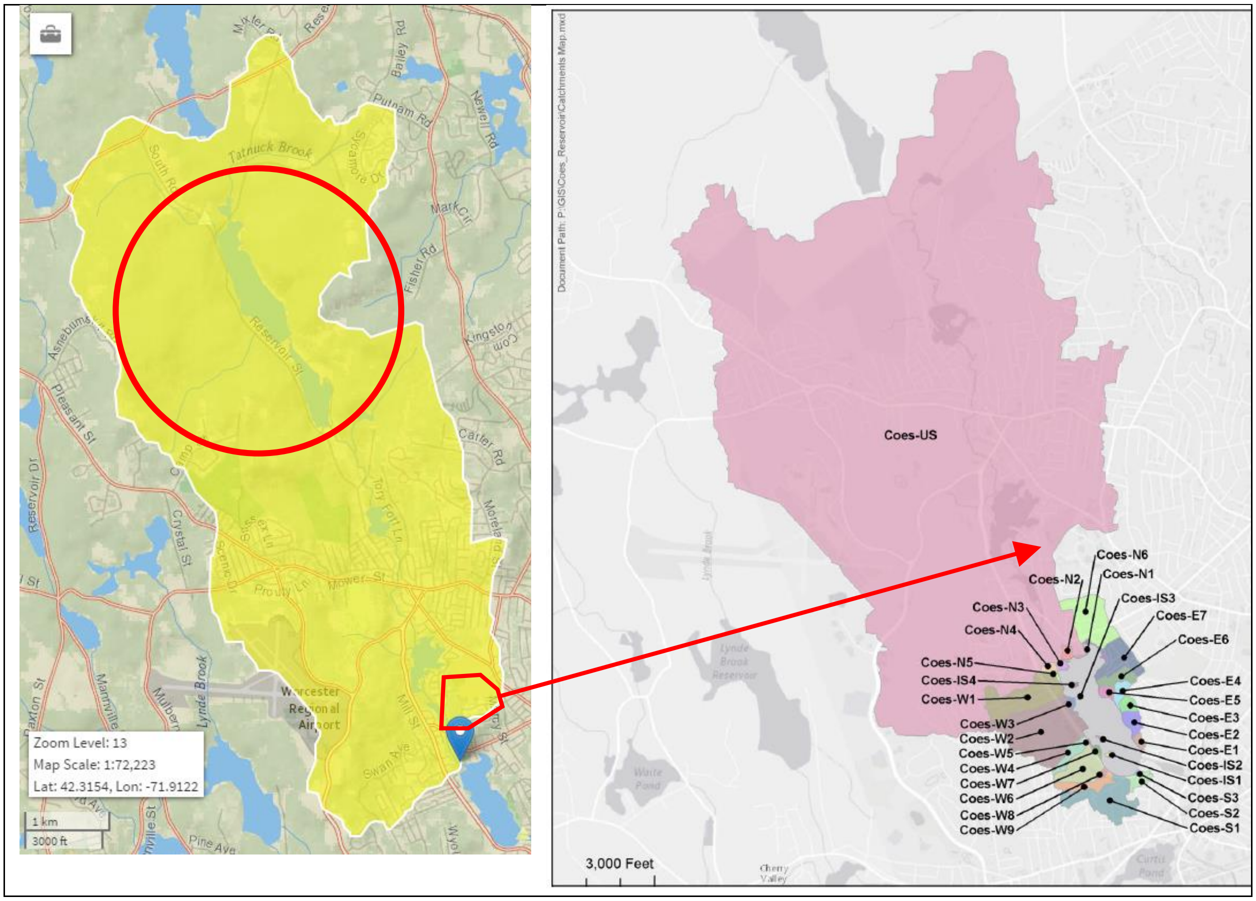

Figure 13: StreamStats delineation (left) compared to Brown and Caldwell's (2015, Right)

The two delineations are very similar, as one would expect. However, StreamStats follows the Tatnuck Brook all the way to its source - five and a half miles to the north. This differs from Brown and Caldwell's delineation, which stops just before the Holden Reservoirs. The Holden Reservoirs are in use as a water supply for the City of Worcester, and are closely monitored. This means that the outflow and inflow are controlled, and the water quality is kept to drinking water standards. This project mainly focused on stormwater runoff near Coes Pond, so this project was not concerned with inflow from the Holden Reservoirs.

The StreamStats delineation also differed on the east side just above the pond, as the application does not account for existing stormwater drainage, and the area that it included is routed further east out of the Tatnuck Brook Watershed. As such this area was also not included from the StreamStats delineation. Other than these differences, the StreamStats delineation was very useful for creating a GIS shapefile to use as described in the GIS applications section.

4.1.2 GIS Applications

Global Information Systems (GIS) was mainly used to acquire the values necessary for the simple method and HEC-HMS loading calculations. Once the subbasin layers created were clipped and the soil and land use layers were clipped to match, they were joined together and exported to a spreadsheet. From this, the curve numbers were calculated as shown in Table 1.

The impervious areas were also calculated using GIS. After converting the image file to a usable point file and clipped/joined to the subbasins, the impervious points were summed up for each basin. Knowing the total area of each basin, the impervious coverage percent was calculated for use in the simple method as shown in Table 1.

Table 1: Summary of GIS application results

	Total Area (sq. m)	Impervious	%	CN
Tatnuck Brook	12551078	2335590	19	40
Judith	140305	32315	23	84
Botany Bay	80296	28076	35	63
KoC	56533	7761	14	45
Circuit	21515	4741	22	68
Columbus	29855	1075	4	78
S2	27614	9444	34	76
Beach	292499	73454	25	82
Liquor South	307723	90812	30	76
Liquor North	160708	57103	36	81

4.1.3 Simple Method

Using the values obtained with GIS, the simple method as shown in Equation 1 was followed to get annual stormwater loadings for each subbasin. These results are shown in Table 2. The Rv values calculated from the best fit equation given in Figure 7, P is assumed to be 48 inches of rainfall per year, and Pj was assumed to be 0.9. The simple method calculates for R, a runoff in inches relative to the watershed area. When multiplied by area, a total volume of rainfall can be found.

Table 2: Summary of Simple Method results

Subbasin	Total Area (acres)	Impervious	%	Rv	R (in)	V Acre-ft.
Tatnuck Brook	3100	577	19	0.22	9	2771.3
Judith Rd	34.7	8.0	23	0.26	11	32.4
Botany Bay	19.8	6.9	35	0.37	16	26.3
KoC	14.0	1.9	14	0.17	8	8.8
Circuit	5.3	1.17	22	0.25	11	4.8
Columbus Park	7.4	0.27	4	0.08	4	2.2
S2	6.8	2.33	34	0.36	16	8.9
Beach	72.3	18.2	25	0.28	12	72.5
Liquor South	76.0	22.4	30	0.32	14	87.2
Liquor North	39.7	14.1	36	0.37	16	53.4

As expected, Tatnuck Brook contributes the most stormwater runoff by a large margin, but the smaller basins are of particular interest. Review of the Circuit Ave and Columbus Park outfalls reveals the important effect impervious area has on runoff. While the two basins have comparable areas, Circuit Ave has more than double the volume of runoff. The R value, runoff volume per acre of basin area, is entirely dependent on the impervious area, this is the main flaw of the simple method. It is a good way to quickly estimate runoff, but is prone to inaccuracies as a result. For example, a key parameter that the simple method does not consider is soil type, which the HEC-HMS method uses in the Curve Number.

4.1.4 HEC-HMS

Before the watershed could be modelled with HEC-HMS, the lag time needed to be found. Accordingly, the lag time was calculated separately for each subbasin following Equations 3 and 4. The lag times entered into HEC-HMS are shown in Table 3.

Table 3: Lag times for each subbasin around Coes Pond

Subbasin	Tatnuck Brook	Judith	Botany Bay	KoC	Circuit	Columbus	S2	Beach	Liquor South	Liquor North
T_l (min)	360	114	306	291	54	22	56	61	118	149

The lag times as well as curve numbers, impervious coverage, and contributing area were then plugged into the program for each subbasin. The next step was to run the program for various storm conditions. Hydrographs were computed were for storms with precipitation volumes of: half-inch, one-inch, 1.5-inch, 2.5-inch, and three inch storms over one day. These represent both minor and severe storms that can be expected on an average year, based on the IDF curve for Worcester.

The hydrographs resulting from these simulations can be found in Appendix F. The combined hydrograph for the one-inch storm is shown in Figure 14. The hydrograph plots flow rate by time for each subbasin as dashed lines, with a solid line that represents the total flow over the watershed.

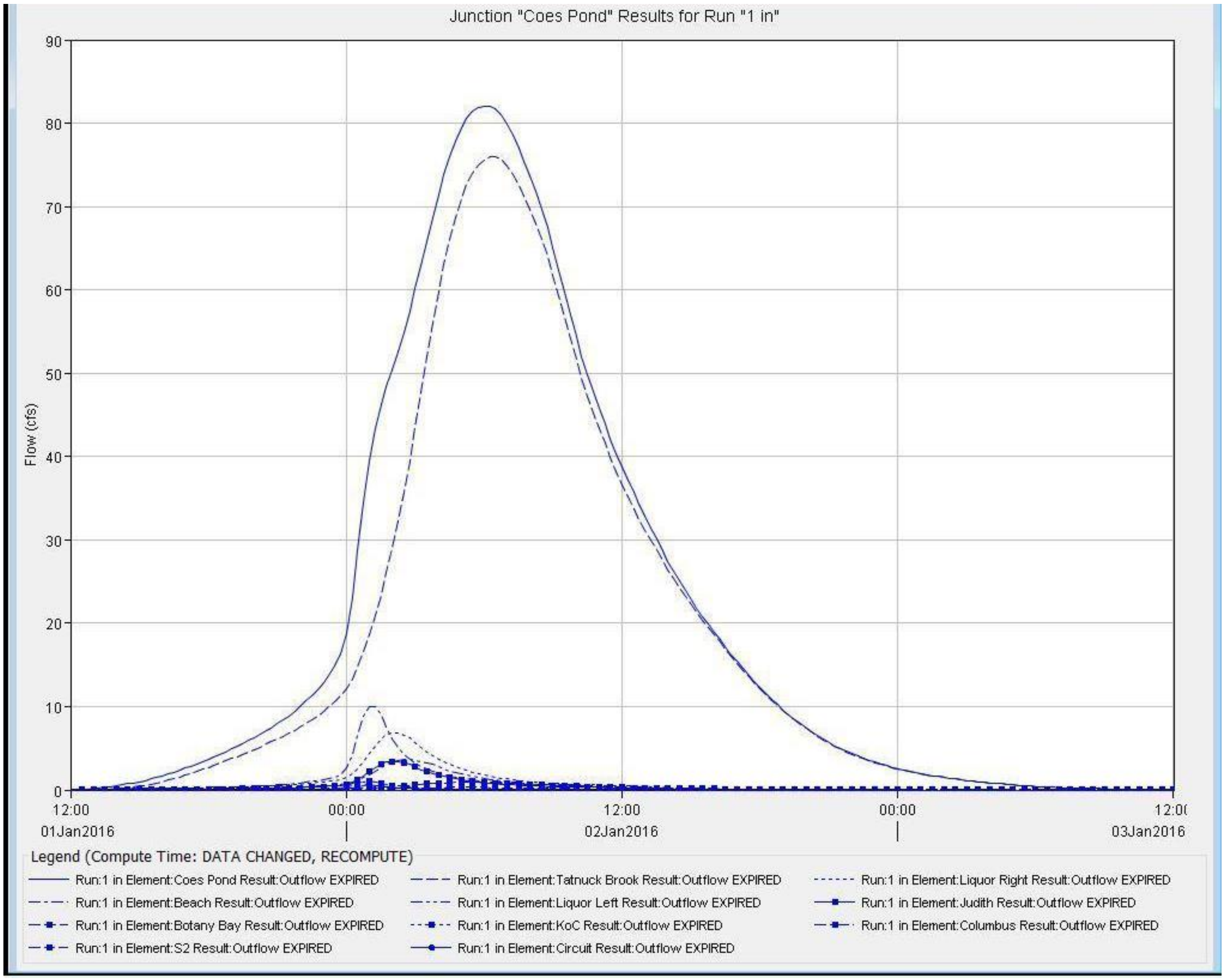

Figure 14: Combined hydrograph for Coes Pond

The peak flows, found using HEC-HMS, can be found in Table 4. Peak flow is useful for designing stormwater controls and piping, as they represent the most extreme flows that can be expected for a given design condition. A design must be able to handle these extreme flows in order to be constructed, this minimizes the risk of failure and loss of a large investment of time and money.

Table 4: Peak flows for each storm considered

	Peak Discharges (cubic feet per second)				
	0.5"	1"	1.5"	2.5"	3"
Tatnuck Brook	34.2	76	125	242.2	309.3
Judith	1.3	3.4	6	11.8	15
Botany Bay	0.4	0.9	1.5	2.8	3.5
KoC	0.1	0.3	0.5	1	1.4
Circuit	0.2	0.6	1	2	2.6
Columbus	0.3	1	2	4.4	5.8
S2	0.4	1	1.7	3.3	4.2
Beach	4	10.1	17.5	34.6	44
Liquor South	2.9	6.9	11.6	22.8	28.9
Liquor North	1.5	3.6	6.1	11.6	14.5

In addition to peak flows, HEC-HMS also gives a total volume of runoff in acre-feet, as presented in Table 5. This is done by taking the area under the hydrograph, which the program is able to do automatically. These values are used to calculate the total annual stormwater loading.

Table 5: Total volume of individual storm events

Subbasin	0.5 Inch	1 Inch	1.5 Inch	2.5 Inch	3 Inch
Tatnuck Brook	31.6	70.3	115.6	223.3	284.9
Judith Rd	0.6	1.4	2.5	4.8	6.1
Botany Bay	0.3	0.7	1.2	2.2	2.8
KoC	0.1	0.2	0.4	0.8	1.1
Circuit	0.1	0.2	0.3	0.5	0.7
Columbus Park	0.1	0.2	0.3	0.8	1
S2	0.1	0.3	0.5	0.9	1.1
Beach	1.2	2.9	5	9.7	12.3
Liquor North	0.8	1.8	3	5.7	7.2
Liquor South	1.3	3	5	9.7	12.3
Total	36	81	134	258	330

The first step in the calculation of the annual loading is to quantify the occurrences of each storm event that can be expected in a year. Worcester's IDF curve was analyzed and the return periods of 2, 5, 10, and 100 years were associated with an intensity over one day. The result is shown in Table 6. From these intensities, the log of the return period was taken to linearize the data, allowing for a line of best fit to be found as shown in Figure 15. This best fit line gave a regression equation which was used to extrapolate the data in order to find the return periods of the storms used in the HEC-HMS computations. The resulting rainfall distribution is shown in Table 7.

Table 6: Return periods and intensities for storms used to find line of best fit

Tr (years)	ln(Tr)	I (in/hr)
2	0.7	0.15
5	1.6	0.18
10	2.3	0.23
100	4.6	0.3

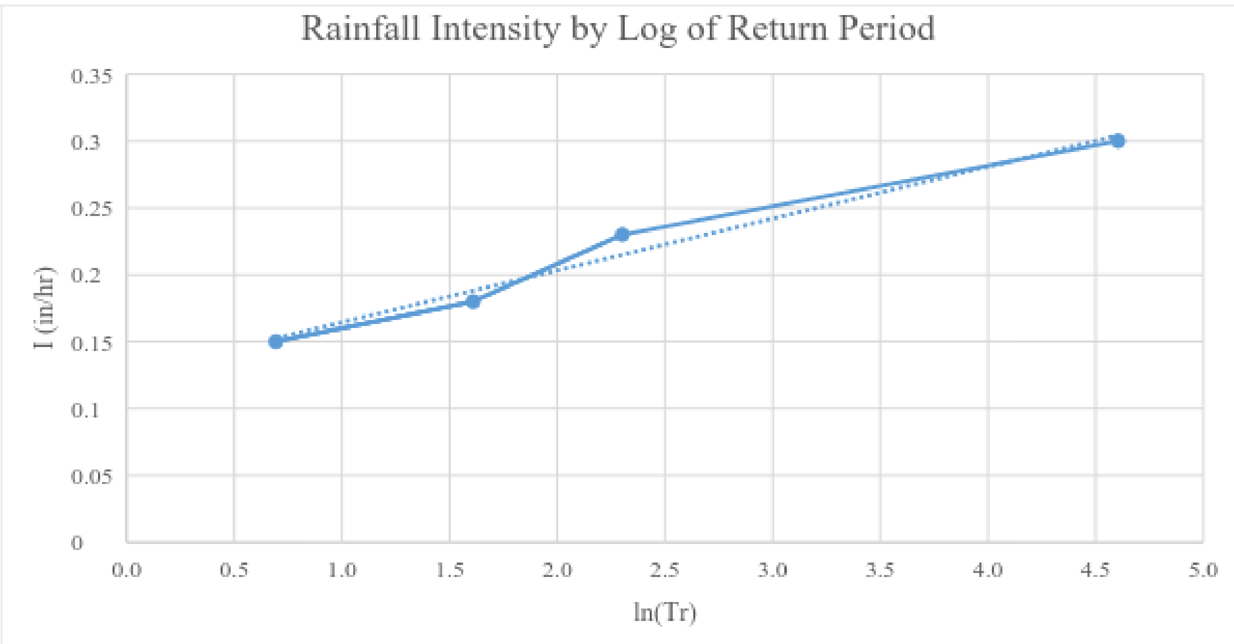

Figure 15: Plot of Table 6, yielding the regression equation

Table 7: Rainfall distribution for Coes Pond

Storm	0.5 Inch	1 Inch	1.5 Inch	2.5 Inch	3 Inch	Total
# of Events (/year)	24	12	7	3	2	48
Total Rainfall	12	12	10.5	7.5	6	48

In order to calculate the total volume for a year, the product of volume for each individual storm and the number of events per year was taken as seen in Table 8.

Table 8: Total runoff volumes for subbasins around Coes Pond

Subbasin	Tatnuck Brook	Judith	Botany Bay	KoC	Circuit	Columbus	S2	Beach	Liquor South	Liquor North	Total
Runoff (ac-ft.)	3616	74.5	35.9	12	9.8	11	14.4	150.8	92.5	154.4	4171

The total runoff for all subbasins was estimated to be 4171 acre-feet. The results for most basins is much higher than those of the simple method. On average, results from the HEC-HMS method are 2.1 times larger than those found by the simple method. This difference is rather significant. However, for the purpose of this project, the loading is primarily used to identify the area that contributes the highest nutrient loading per area. Therefore, these results are considered reasonable for this purpose, and subsequent analysis is required for a more detailed verification. The next steps for this effort would be to verify the HEC-HMS model through a sampling program focused on measuring flow rates. A sampling program would not be necessary if stream gages existed in the Tatnuck Brook, because the data provided by the gages for various storm events could be used to verify the flows coming out of the brook. If the error for the brook is found, adjustments could then be found across the entire watershed, as the area around the pond can be assumed to react similar to the brook. A hydrological sampling program would still be extremely useful, however, because the basins around Coes Pond have varying levels of impervious area and stormwater piping systems. For this project, sampling was focused on nutrients, which addressed the immediate need for nutrient loadings into Coes Pond.

4.2 Sampling

4.2.1 Water Sampling

From the initial sampling and lab work, concentrations of nitrogen and phosphorus were recorded at a variety of sites along the pond to determine water quality. The resulting phosphorus concentrations can be found in Table 9.

Table 9: Total Phosphorus and NH_4 Water Concentrations

Subbasin	Phosphorus (ppm)	NH_4 (ppm)
Brook outlet	0.53	0.36
Judith	0.15	0.14
Beach	0.14	0.061
Brook Stream	0.12	0.16
Merriweather	None Detected	0.22
Circuit	0.37	0.84
Liquor North	0.41	0.51
Liquor South	0.28	0.33
Bergin	No Data	0.053
Columbus	No Data	0.12

These concentrations were then compiled into a single graph to demonstrate the range of phosphorus and nitrogen at the various sampling points, shown in Figure 16. The fact that phosphorus concentrations are lower than that of nitrogen is typical in most freshwater systems. However, it is still important to analyze this to aid in the determination problematic areas. These concentrations were used in the creation of the nutrient loading as described in section 4.3.

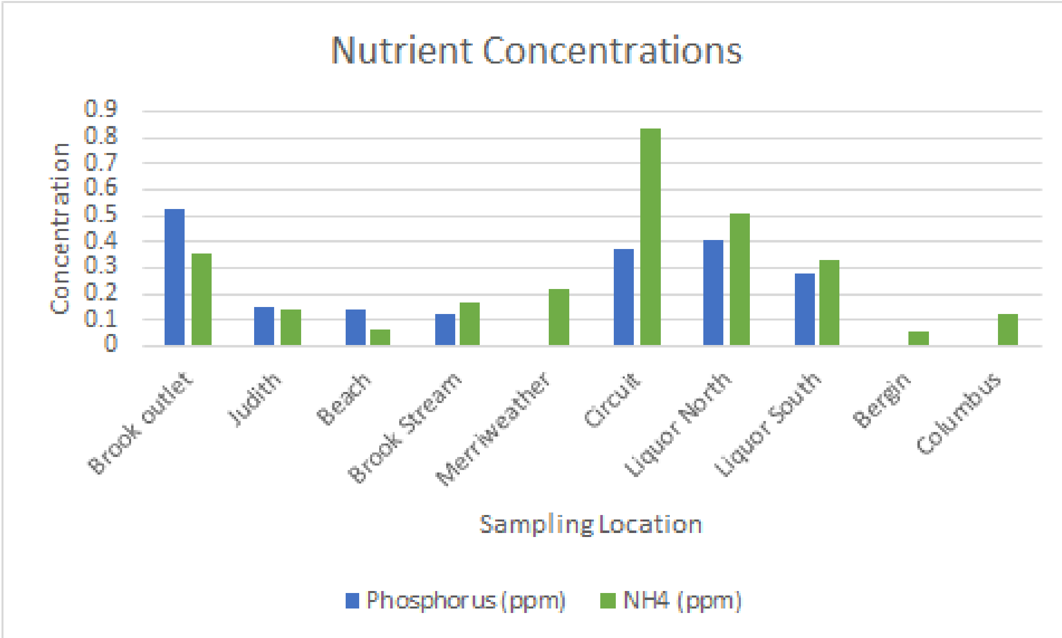

Figure 16: Graph of Phosphorus and Nitrogen Concentrations

In addition to the samples analyzed in the spectrophotometer, five samples were run through the ion chromatography system (ICS) in the lab to find concentrations of compounds that were not detectable on the spectrophotometer. This analysis gives a broader range of compounds and other macronutrients required to sustain plant growth. These ICS results can be seen in Table 10. These values varied significantly among the different compounds. The chloride ions were present in high concentrations. Interestingly, there was no nitrate in the sample taken at Circuit Avenue, although Circuit Avenue reported the highest ammonium concentration of the spectrophotometer results. Dissolved phosphate concentrations were low, and were only detected at Circuit Avenue, which was also the location with one of the highest total phosphorus values.

Table 10: ICS Results for select samples around Coes Pond

	Cl^- (ppm)	NH_4^+(ppm)	NO_3^-(ppm)	SO_4^-(ppm)	PO_4^-(ppm)
Merriweather	150	0.2	0.14	ND	ND
Circuit	790	0.8	0	6.2	0.23
Columbus	87	0.1	0.066	0.053	ND
Judith	90	0.2	0.054	0.065	ND
Beach	86	0.1	0.016	0.052	ND

4.2.2 Sediment Sampling

When the total phosphorus concentrations in the sediment are high, it allows for aquatic plants including the invasive species to thrive. Unfortunately, Eurasian Water Chestnut and Water Milfoil are able to take advantage more so than the native species allowing them to spread. Additionally, if the sediment is disturbed, the phosphorus it contains can be released back into the water, increasing the water concentration.

The analysis conducted on the soil sample yielded high results. As can be seen in Table 11, the concentration of phosphorus in the soil at both locations were larger than typical with Judith especially being problematic. This amount of phosphorus in the soil only leads to further weed growth there due to its proximity to the source, and is likely due to the decaying plants in the sediment. While it is typical for sediment concentrations to be larger than water for phosphorus due to its nature of binding to soil particles rather than easily dissolving, these numbers would ideally be lower than at present.

Table 11: Phosphorus Concentrations in Sediment

Sediment Concentrations Phosphorus	
Judith	89,000 mg/kg
Circuit	9,760 mg/kg

Unfortunately, there are no regulations for phosphorus in the soil at a state or national level as there is for water concentrations. When studies have been conducted the sediment concentrations in other freshwater bodies, the concentrations are significantly lower. Even Circuit Avenue, the lower of the two sites tested, was twenty times larger than other high concentrations from studies on freshwater bodies (Mau, n.d.). This site did not have an invasive weed or nutrient problem as Coes does, highlighting the difference in concentrations.

4.3 Nutrient Loading

The resulting nutrient loading primarily focused on water concentration loadings. This provides the areal loading rate for both phosphorus and nitrogen in the form of NH_4^+. These can be seen in Table 13 and visually in the form of a graph in Figure 17. Generally speaking, the nitrogen loading rate was higher than or equal to that of phosphorus at any given site, however both nutrients expressed elevated levels. The sites with a high concentration of one nutrient also had elevated levels of the other one: Circuit Ave, Liquor North, and Liquor South had both the highest areal loading for phosphorus and nitrogen.

Table 12: Areal Loadings of Ammonium and Phosphorus around Coes Pond in Table Form

Areal Loading		
Subbasin	Phosphorus (kg/acre)	NH_4 (kg/acre)
Circuit Ave	0.8	1.81
Judith Rd	0.35	0.33
Beach	0.32	0.14
Liquor North	1.06	1.32
Liquor South	0.63	0.73
Tatnuck Brook	0.14	0.41

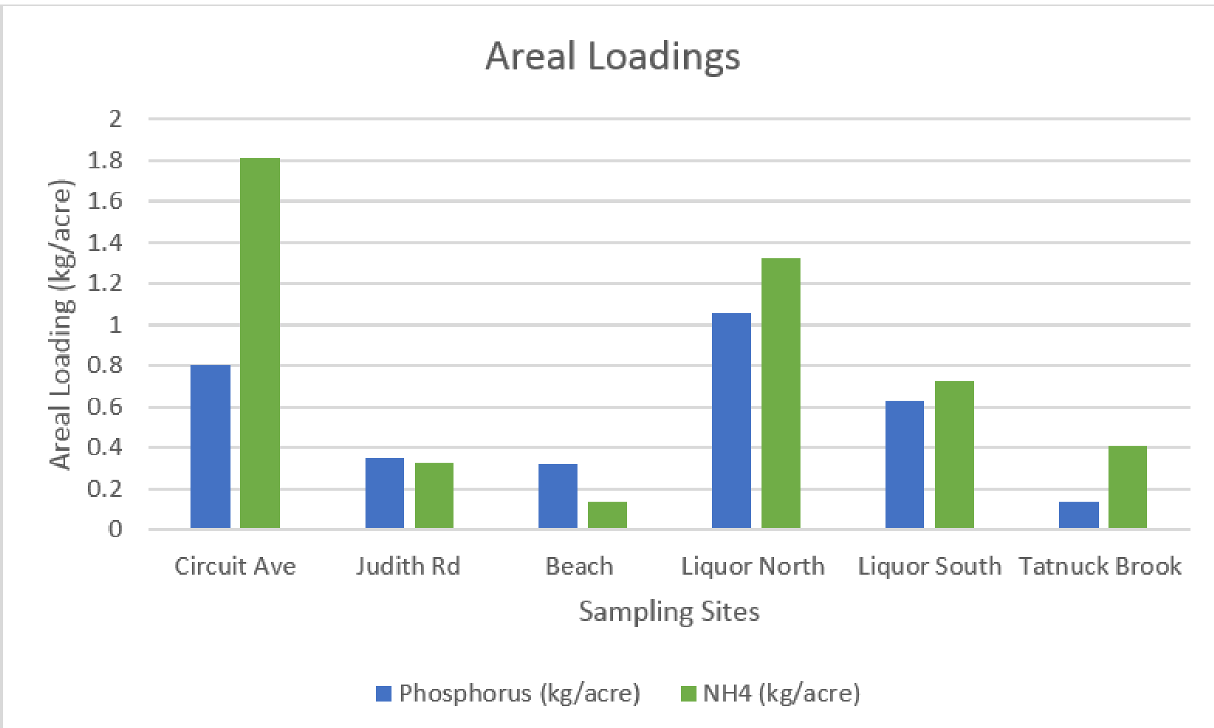

Figure 17: Areal loadings of ammonium and phosphorus around Coes Pond in graphical form

4.4 BMP Design

As discussed in Section 3.4.1, a treatment BMP would be the most effective BMP type for nutrient removal. The Stormwater Handbook (MassDEP, 2016) lists six Treatment BMPs: Bioretention Areas & Rain Gardens, Constructed Stormwater Wetlands, Extended Dry Detention Basins, Proprietary Media Filters, Sand & Organic Filters, and Wet Basins. For each BMP type, the handbook lists average expected nutrient removal percentages, size recommendations, and all of the design details needed to install a management plan. Due to the size constrictions of urban environments, the BMP choice should be effective at relatively small percentages of the subbasin's total area. This efficiency of the BMP is the most important design consideration for Coes Pond. Cost was another primary concern, as the less expensive a BMP is, the more likely it is to be well received by the public and Department of Public Works. Given all this, a rain garden would be the best choice for Coes Pond, because it is efficient and aesthetically pleasing. This section provides the design characteristics, including the location, size, soil sections, plant recommendations, and erosion controls.

4.4.1 Location

Due to the small size and high areal loading at the Circuit Ave subbasin, the rain garden was designed to be placed at the outfall at the base of Circuit Ave North. This will allow for a reasonably priced management plan that would have a high relative efficiency compared to other basins. The location is shown in an aerial image of the area in Figure 18. The outfall discharges over land less than 20 feet from the shoreline, giving enough space for a long BMP that follows along the beach.

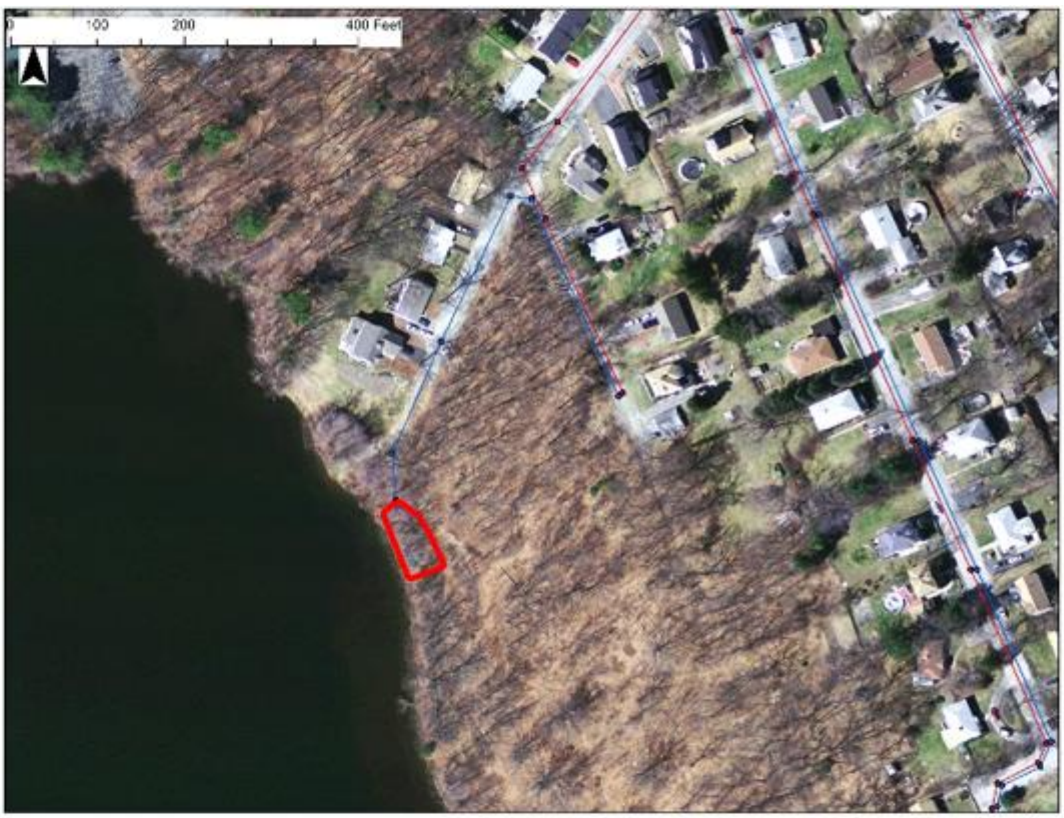

Figure 18: Aerial imaging of the Circuit Ave outfall courtesy of Massachusetts DPW

4.4.2 Rain Garden Design

As discussed in the Methodology chapter, the MassDEP's Stormwater Handbook (2016) was used as reference for designing the rain garden at Circuit Ave. The handbook recommends sizing the garden to be 5-7% of the total impervious area that would contribute to the garden. The Circuit Ave subbasin has 50,000 square feet of impervious area, so it should have a plan area of between 2500 and 3500 square feet for maximum effectiveness. Unfortunately, there was not enough space at the outfall location to fit such a large excavation. Nevertheless, there was room for a smaller garden that treats a portion of the total nutrient inflow, and serves as an educational tool for local residents.

The garden was designed to take up an area of about 1,700 square feet. This fits between the footpath in Columbus Park and the beach. The garden stretches for 70 feet along the beach, with a maximum width of 34 feet, a 15-foot width at the outfall, and an average width of 24 feet. The plan view for the design can be seen in Figure 19. In the drawing, the blue outline represents the boundaries of the garden.

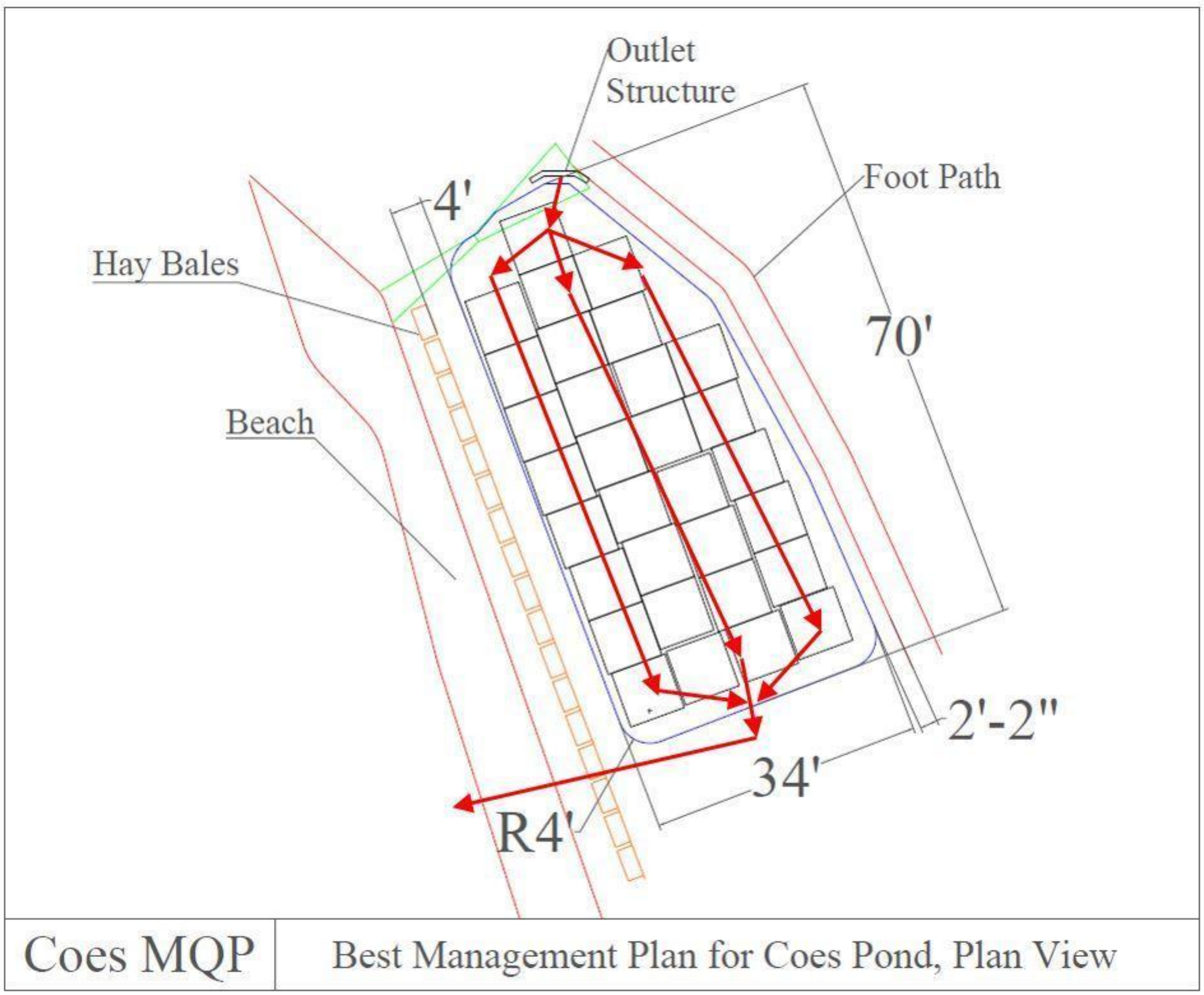

Figure 19: Plan view of the rain garden

Of note in the drawing are hay bales, the beach, the outfall structure, and the footpath for Columbus Park. The beach, outfall structure and footpath were all located using GPS, and their locations were then put into AutoCAD. This area may need a professional survey to confirm these locations, but GPS was sufficient for the preliminary design. The hay bales were necessary for erosion protection as the excavation would be so close to the water line, a requirement for approval by Worcester's Conservation Commission. The hay bales were placed four feet downhill from the boundary of the garden and spaced six inches apart. The flow directions are also marked on the plan, represented by the red arrows. Water would exit the outfall structure and immediately be routed into the rain garden where it would spread across the garden and eventually reach a maximum ponding height. The ponded water would infiltrate through the sandy soil layer and into a pervious pipe, as shown in Figure 20, where it would be sent directly into the pond.

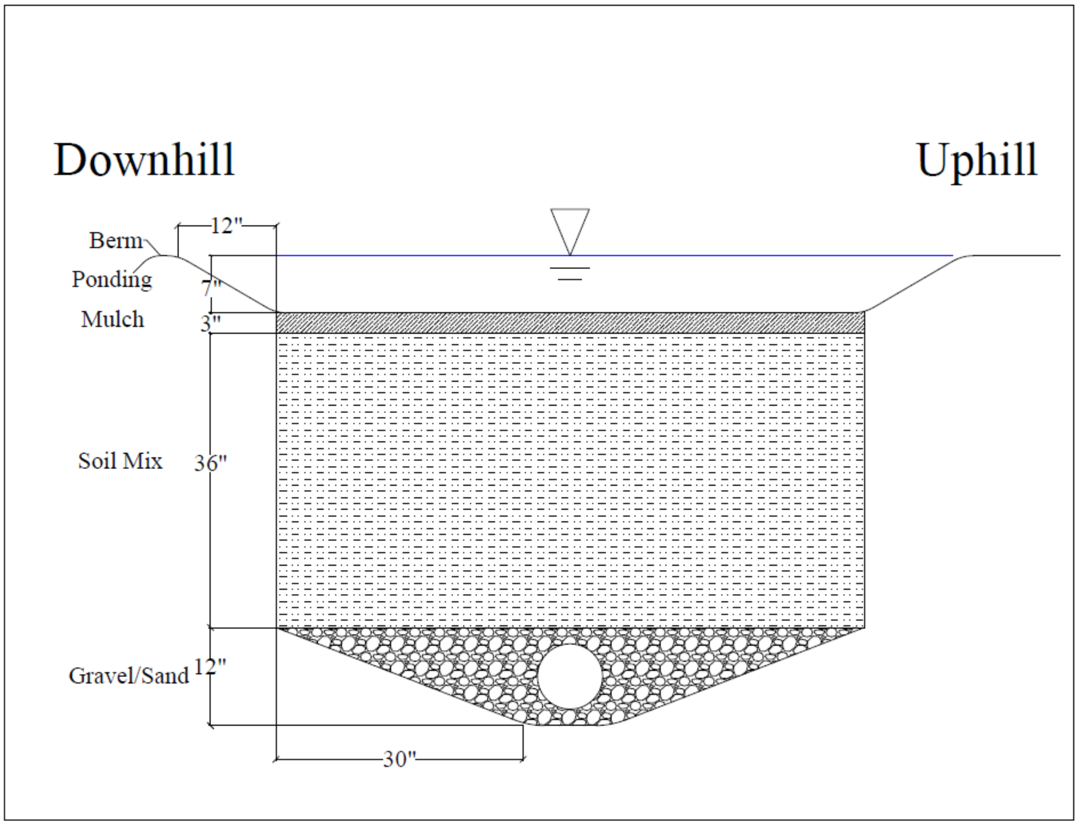

Figure 20: Section view of the garden, showing the various layers of backfill

Rain gardens are designed to let water infiltrate through a soil layer to an outbound pipe. Accordingly, determination of the depth the depth of this soil layer was the next step. Depths of 2-4 feet are suggested, but the MassDEP notes that the depth must be more than 3 feet for adequate nitrogen treatment. The soil layer must also be more than 30 inches if trees are to be planted in the garden, as such, the BMP should have a soil depth of 3 feet. In accordance with MassDEP guidelines, the soil mix consisted of 40% sand, 25% topsoil, and 35% compost. The sand met ASTM D422 standards, which defines the sand particles size ratios as sent through a sieve, as shown in Table 14. Sandy loam makes up the topsoil layer, with a pH of around 6, and an organic content between 1.5 and 3 percent. Compost must come from yard waste as described by MassDEP guidelines (MassDEP, 2014). Above the soil layer is a thin, 3-inch mulch layer.

Table 13: ASTM D 422 sand size particle characteristics

Sieve Size	Percent Passing
2-inch	100
¾-inch	70-100
¼-inch	50-80
U.S. No. 40	15-40
U.S. No. 200	0-3

The soil layer was filled above a gravel layer that makes up the bottom of the rain garden. Consisting of “coarse gravel, over pea gravel, over sand” (MassDEP, 2016), this gravel layer is where the pervious pipe leading to the pond would be placed. Gravel allows for fast infiltration, and permeation into the pipe that directs the stormwater out of the rain garden and into Coes Pond. The garden’s sides were graded such that 6-8 inches of ponding can be contained in the rain garden. The ponding depth, along with infiltration rates determine the ponding time, a key parameter to consider when choosing plants to populate the rain garden.

In order for plants to survive in a rain garden, they must be able to survive in a wetland like environment, while being able to last through droughts. The handbook identifies 64 plant species that have been used in rain gardens and are well documented, see Appendix E for this list. The list details the characteristics of each plant such by indicator status, a way of describing where the plants are generally found, tolerance, which describes how well the species can survive in various conditions, and morphology, which describes the physical characteristics such as plant height and root depth. The plants for this garden should have an indicator status of FAC or FACW, meaning that the plants are regularly found in wetland environments. Due to the close proximity to the water line, the plants should be able to withstand a ponding time of over 2 days. The plants should also be able to survive with partial sun cover, as the garden is being placed in a wooded environment with no guarantee of getting sun every day. The plant species chosen to use in the garden are up to the discretion of the contractor, as there is no way to know just what plants they would be able to produce for the garden, as long as they meet the needs specified by the handbook.

Construction of the rain garden mostly involves excavation and backfilling, and as such excavation is generally the most expensive part of constructing a rain garden. In this case, four feet below the level of the rain garden must be excavated. Since the outfall is in a ditch in the ground, this area must be leveled out, which includes digging up an additional estimated five or six feet of soil just to level out the garden. Across the area of the garden, up to 600 cubic yards of soil may need to be excavated in order to construct the garden.

5 Conclusion and Recommendations

5.1 Conclusion

This project combined nutrient and stormwater loadings, modelled by the project team, which informed the design of a BMP at Circuit for Coes Pond to help reduce the spread of invasive species. It was determined that Coes Pond receives the majority of its water from Tatnuck Brook, which has a high nutrient load overall, but has relatively low nutrient concentrations. As such, smaller, more manageable subbasins around Coes Pond were emphasized for this design portion of this project. These subbasins were found to have high concentrations of nutrients due to the urbanized environment in the areas surrounding the pond. The Circuit Avenue subbasin was found to have high areal loading of nutrients in relation to the runoff volume. This meant that Circuit Ave was an ideal candidate for a rain garden BMP, because the small runoff volume allows for a smaller-sized, manageable garden, and the high areal loading means the garden would treat more nutrients. This design would allow for unwanted nutrients to be absorbed naturally by the plants instead of entering the pond directly. The results of this project have been shared with the TBWA with hopes of obtaining a grant to help pay for the rain garden's construction.

5.2 Recommendations

The recommendations made in the following sections are ways that the TBWA can continue the work done by this project in order to make a significant impact on Coes Pond. This project was focused mainly on modeling the inflows into the pond. There are many ways that the TBWA can use this data, some of which are presented below.

5.2.1 Construction of Rain Garden at Circuit Avenue

This project first recommends the construction of the rain garden designed for the Circuit Avenue outfall. This is a great location, as the first garden located on the pond would show residents how effective a rain garden BMP can be. This rain garden would serve as an educational tool for the area, while providing useful data on how well a rain garden would perform in this watershed. This initial BMP would help to inform future decisions on BMPs in the area, and they could be adjusted for more or less flow depending on the performance of this one. Funding from outside sources would be required for this project to happen, and there are a number of grant options the TBWA could apply for in order to secure funding for this rain garden.

5.2.2 Upstream Load and Outflow Modelling

The calculated stormwater and nutrient loadings will be used by the TBWA to make informed decisions on how best to manage runoff into the pond with these loading estimates. Additional analysis to refine these estimates would be recommended. Due the extremely high runoff coming into Coes Pond from the Tatnuck Brook, more extensive modelling should also be conducted upstream. The Tatnuck Brook Watershed is a complex and varied area that consists of densely populated spaces, and large stretches of forest. Hydrologic modeling upstream would split this basin up, yielding more accurate results.

At present, the hydrologic and nutrient budgeting for Coes Pond only includes loadings, the amount of water coming into the pond. Due to an ongoing construction site and lack of previously published data, it was impossible to quantify the water leaving the pond through the dam at the southern side or downwards through the soil. Future projects therefore may wish to incorporate these into the current model to better account for outflows and to better determine the amount of a given nutrient in the pond at a given time.

5.2.3 Analysis for other nutrients or contaminants

It is important to be aware of the fact that nitrogen and phosphorous are not the only macronutrients required by aquatic plants. Other key macronutrients include potassium, calcium, magnesium, and sulfur. While these other nutrients are not as important to the plant, they are still essential for the overall growth of the plant (Barak, n.d.). As the scope of this project did not extend to these nutrients, future studies into the nature of Coes Pond should take this into account. This would allow for a holistic view of the nature of all the macronutrients, not just two of the most important ones.

5.2.4 Construct additional rain gardens around the Liquor Store outlets

As previously discussed, the most efficient and practical location for a BMP for Coes Pond was near Circuit Avenue. While this would reduce the nutrient loadings coming into the pond, it would only do so the smallest subbasin in the watershed. The Liquor Store outfalls are two other significant contributors of nutrients to the pond. Constructing multiple rain gardens at residences around these subbasins would reduce the incoming loadings significantly without having to construct one massive rain garden. Due to spacing limitations it would not be possible to create one large rain garden as was the case for Circuit Avenue; instead, a series of smaller rain gardens, totaling 5-7% of the impervious area of the contributing area (about 2 acres across the Liquor North and South basins), would have to be constructed throughout the area. These gardens could use a similar section design as the BMP designed for this project, as well as similar plantings.

5.2.5 Similar work for Patch Reservoir

This project has provided a comprehensive analysis of the flow of nutrients and water into Coes Pond. Nearby waterbodies in the same watershed impact Coes Pond. To best improve the overall quality of the watershed it is important to analyze and improve more than just Coes Pond. Patch Reservoir for example, is a waterbody located upstream of the pond that currently has a need for a future project to improve its water quality as well.

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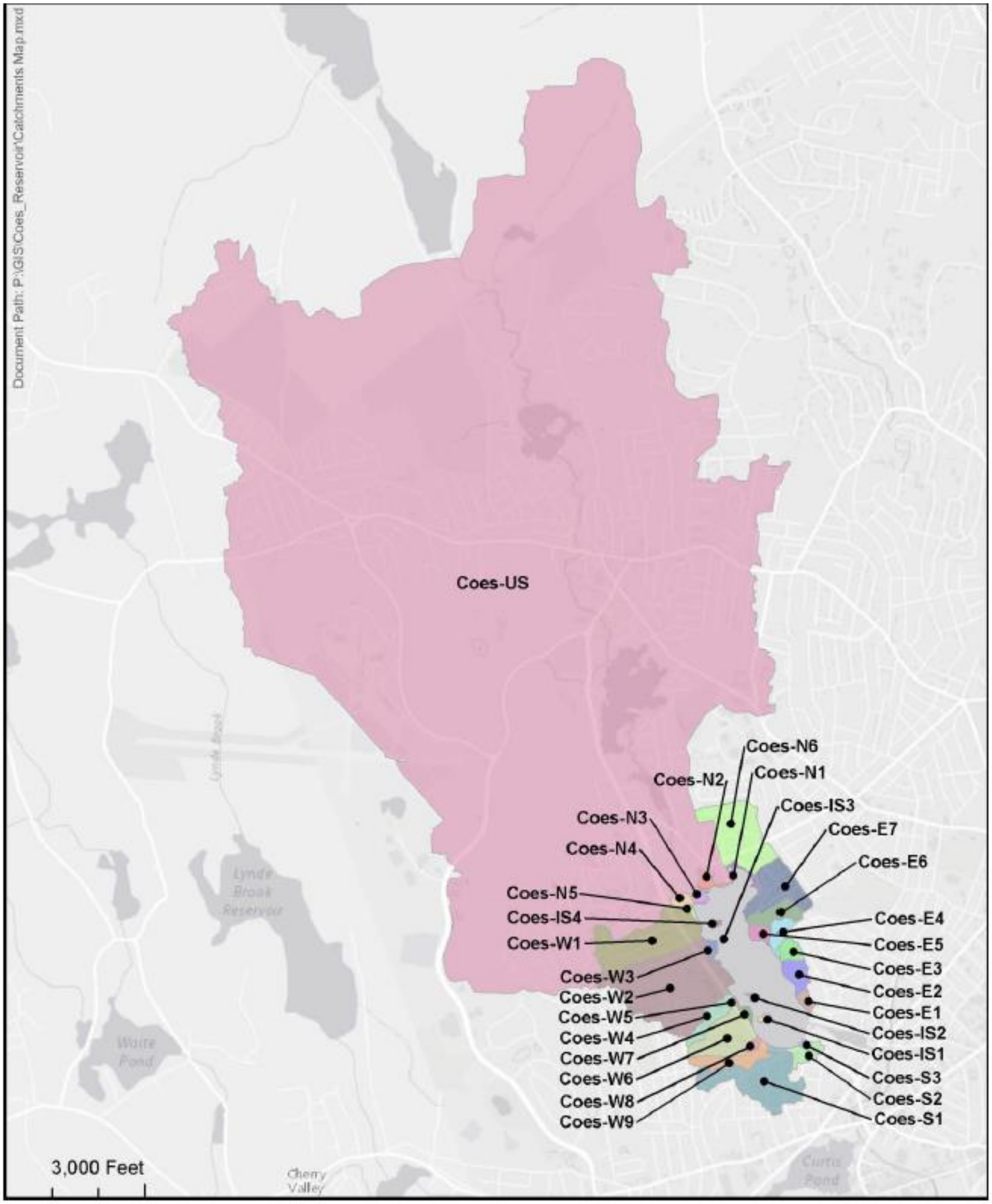
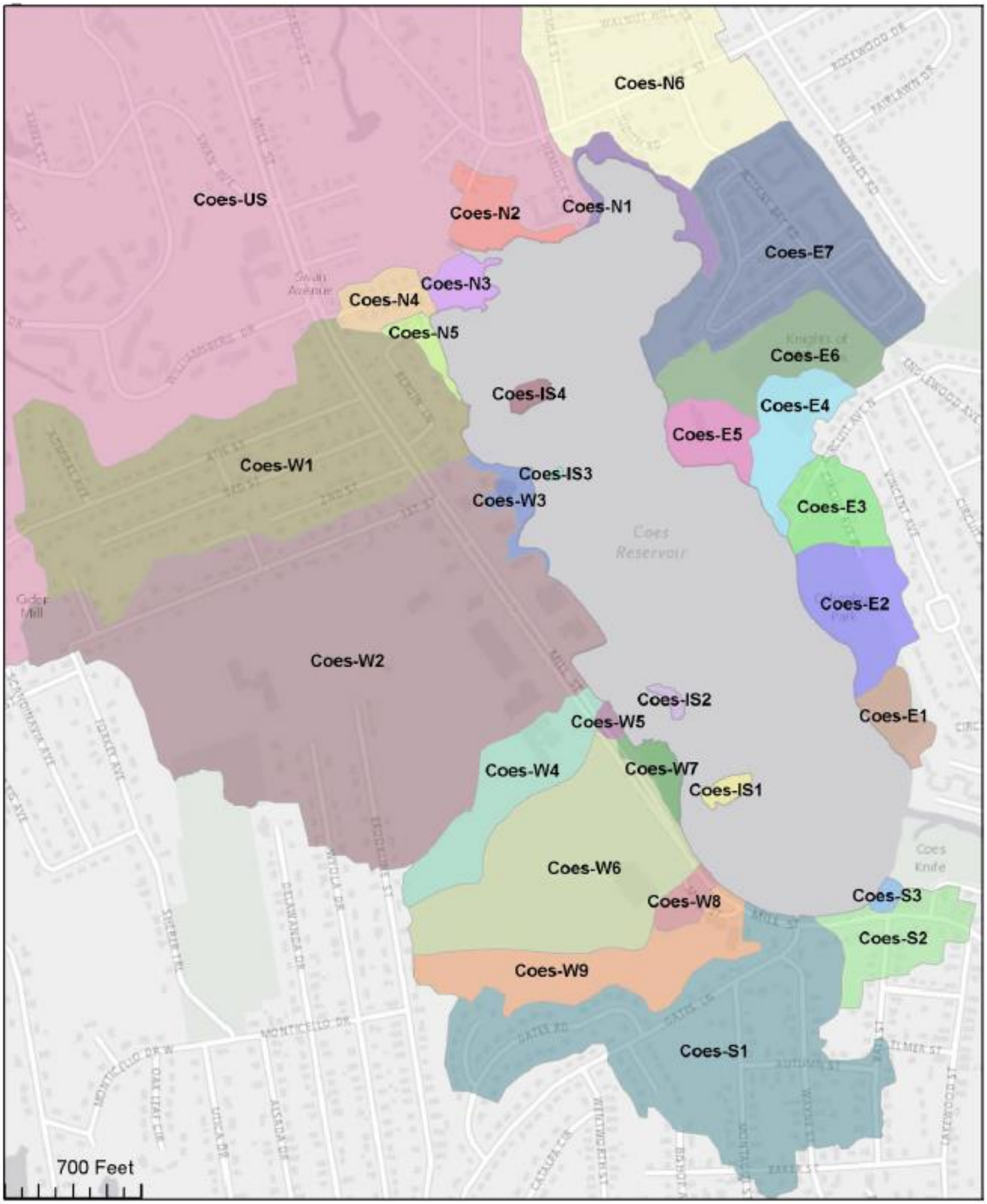
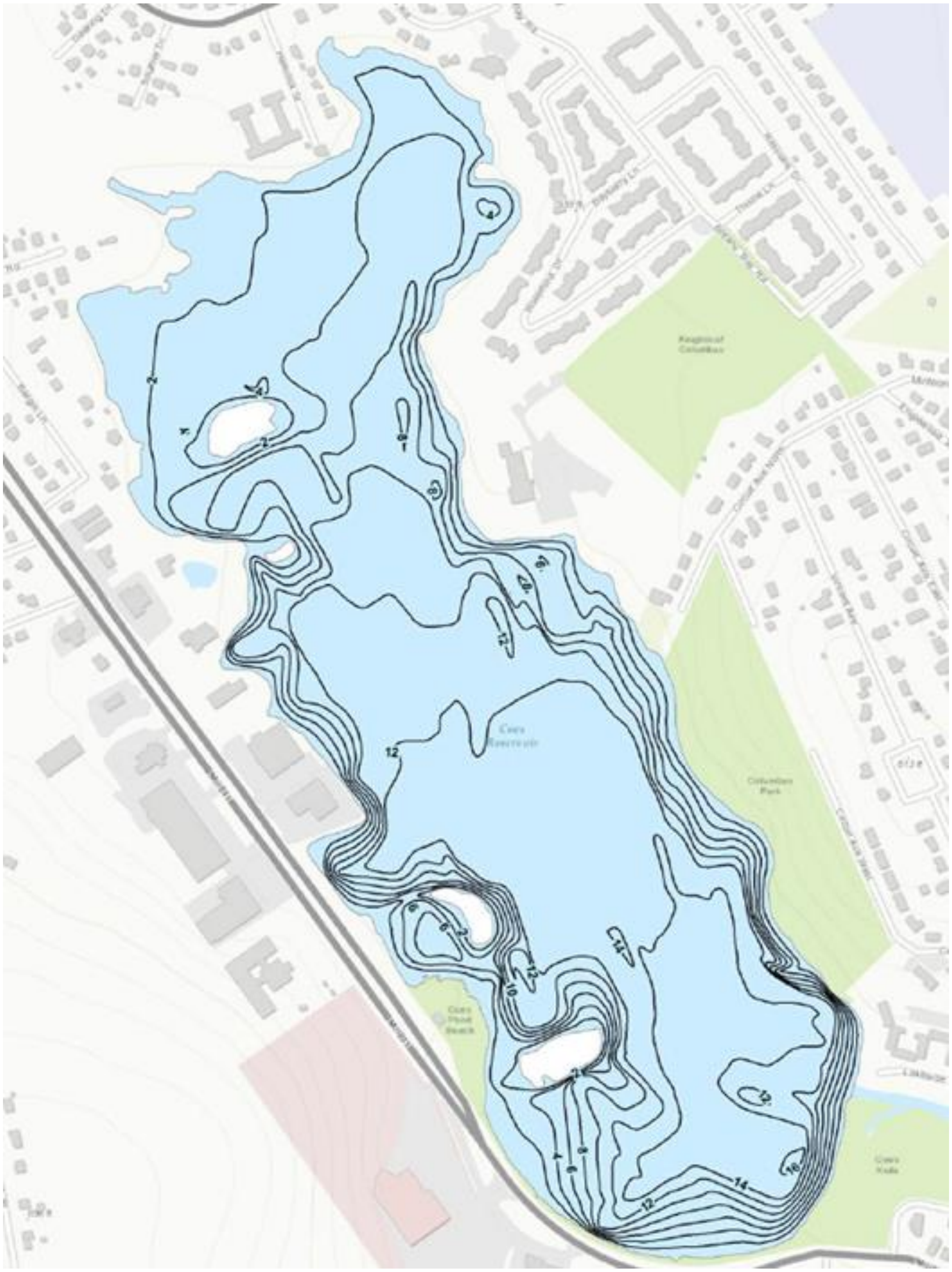
Appendix A: Brown and Caldwell Basin Delineation and Depth Survey



Watershed delineation for Coes Pond. (Brown and Caldwell, 2013)

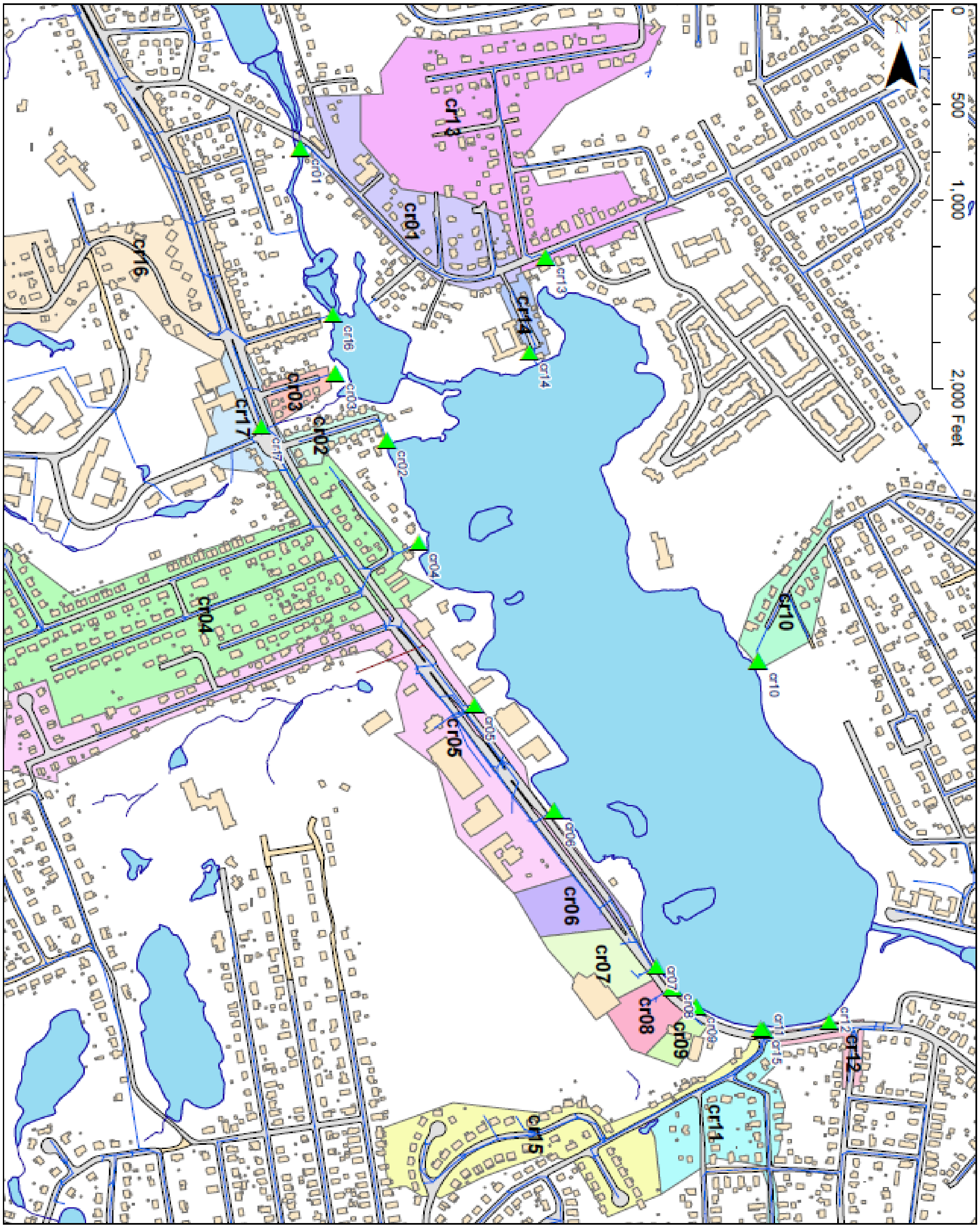


Close-up of individual subbasins. (Brown and Caldwell, 2013)



Depth survey for Coes Pond. (Brown and Caldwell, 2013)

Appendix B: DPW Storm Pipe Network



(Worcester DPW, 2016)

Appendix C: Curve Number by Land Use and Soil Type

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: 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.

(USDA, 1986)

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

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

[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

[3] Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

(USDA, 1986)

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

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

2 ***Poor:*** <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3 ***Poor:*** <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

4 Actual curve number is less than 30; use CN = 30 for runoff computations.

5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 ***Poor:*** Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

(USDA, 1986)

Appendix D: Volunteer Sampling Guide

<u>Guide for Volunteer Samplers at Coes Pond</u>

Thank you for volunteering to assist in our senior project. Our goal is to improve the water quality of Coes Pond; Specifically we are looking at the invasive plants present. To do this, we are collecting data through repeated water sampling.

The following steps should be able to be completed without needing to wade into the water. Instead samples can be collected while on the land. Gloves and labeled bottles, will be provided to you. It is strongly recommended that you wear gloves while sampling. The sampling should be conducted shortly after the end of a rainstorm, one sample per site, for each storm.

1. Remove the cap of the bottle while being careful not to contaminate the lid while sampling.
2. Submerge bottle underwater as close to the inlet as possible.
3. Shake the bottle to rinse the interior of the bottle then dump it out. Repeat this process twice more.
4. Fill the bottle while trying to avoid large amounts of sediment/ grit. If some ends up in the bottle do not worry but try to avoid excessive amounts if possible
5. Cap the bottle and using a permanent marker, label it with the date, and time of day.

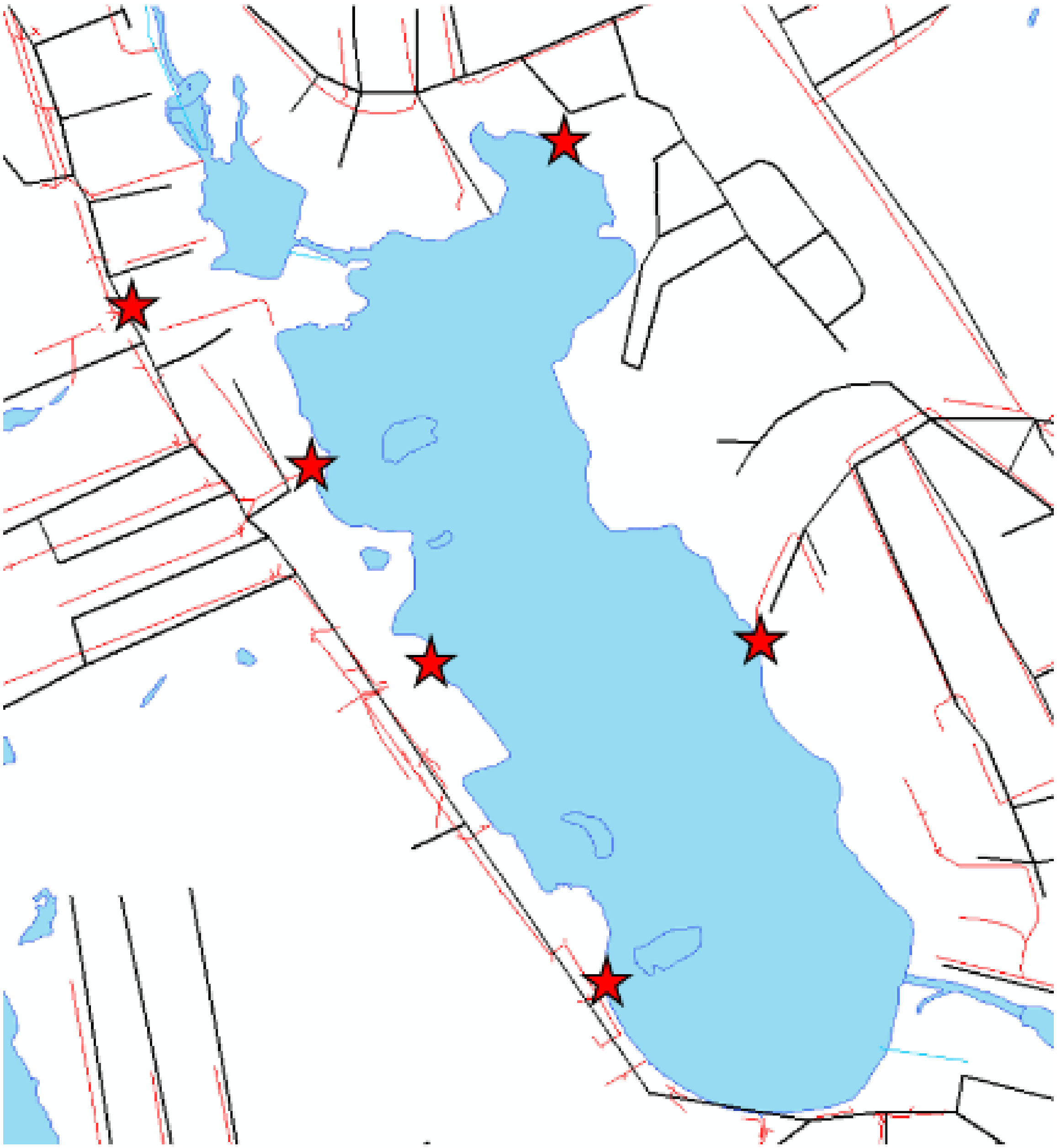
Note: Please keep any samples taken on ice or refrigerated until they can be analyzed to allow us to obtain the most accurate information possible

Thank you again for offering to help us in our project to improve the water quality of Coes Pond. If you have any questions, we can be reached at:

Adam Weiss:
781-686-2665
ahweiss2@wpi.edu

Brendan Kling:
781-258-3882
blkling@wpi.edu

Merriwether - Brook access from Mill St to the left of Merriwether Road
Bergin - Hesitant to send someone other than the homeowner down there
Beach - On the side closest to the dam, where the grass starts
Circuit: on the beach itself
John's: Hesitant to send someone other than the homeowner down there
Liquor store: Two outfalls side by side merge and flow into the pond together. Take a sample from this mixed flow rather than the pond itself.



Appendix E: Plant Recommendation for Rain Gardens

Plant Species Suitable for Use in Bioretention - Herbaceous Species															
Species	**Moisture Regime**		**Tolerance**						**Morphology**			**General Characteristics**		**Comments**
***Scientific Name* Common Name**	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Agrostis alba redtop	FAC	Mesic-Xeric	1-2	H	–	H	H	Shade	Grass	2-3'	Fiberous Shallow	Yes	High	–
Andropogon gerardi bluejoint	FAC	Dry Mesic-Mesic	1-2	–	–	–	–	Sun	Grass	2-3'	Fiberous Shallow	Yes	High	–
Andropogon virginicus broomsedge	–	Wet meadow	1-2	L	–			Full sun	Grass	1-3'		Yes	High	Tolerant of fluctuating water levels and drought.
Carex vulpinoidea fox sedge	OBL	Freshwater marsh	2-4	L	–			Sun to partial sun	Grass	2-3.5'	Rhizome	Yes	High	–
Chelone glabra														
Deschampsia caespitosa tufted hairgrass	FACW	Mesic to wet Mesic	2-4	H	–	H	H	Sun	Grass	2-3'	Fiberous Shallow	Yes	High	May become invasive.
Glyceria striata fowl mannagrass, nerved mannagrass	OBL	Freshwater marsh, seeps	1-2	L	–			Partial shade to full shade	Grass	2-4'	Rhizome	Yes	High	–
Hedera helix English Ivy	FACU	Mesic	1-2	–	–	–	H	Sun	Evergreen ground cover	–	Fiberous Shallow	No	Low	–
Hibiscus palustris														
Iris kaempferi														

(MassDEP, 2016)

Plant Species Suitable for Use in Bioretention - Herbaceous Species

Species	Moisture Regime		Tolerance						Morphology			General Characteristics		Comments
Scientific Name Common Name	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Lobelia siphilitica														
Lotus Corniculatus birdsfoot-trefoil	FAC	Mesic-Xeric	1-2	H	L	H	H	Sun	Grass	2-3'	Fiberous Shallow	Yes	High	Member of the legume family.
Onoclea sensibilis sensitive fern, beadfern	FACW							Shade		1-3.5'			H	
Pachysandra terminalis Japanese pachysandra	FACU	Mesic	1-2	–	–	–	M	Shade	Evergreen ground cover	–	Fiberous Shallow	No	Low	–
Panicum virgatum switch grass	FAC to FACU	Mesic	2-4	H	–	–	H	Sun or Shade	Grass	4-5'	Fiberous Shallow	Yes	High	Can spread fast and reach height of 6'.
Vinca major large periwinkle	FACU	Mesic	1-2	–	–	–	H	Shade	Evergreen ground cover	–	Fiberous Shallow	No	Low	Sensitive to soil compaction and pH changes.
Vinca minor common periwinkle	FACU	Mesic	1-2	–	–	–	H	Shade	Evergreen ground cover	–	Fiberous Shallow	No	Low	–
Indian grass														
Little bluestem														
Deer tongue														
Green coneflower														

Plant Species Suitable for Use in Bioretention - Herbaceous Species

Species	Moisture Regime		Tolerance						Morphology			General Characteristics		Comments
Scientific Name Common Name	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Aronia arbutifolia (Pyrus arbutifolia) red chokeberry	FACW	Mesic	1-2	H	–	H	M	Sun to partial sun	Deciduous shrub	6-12'	–	Yes	High	Good bank stabilizer. Tolerates drought.
Clethra alnifolia sweet pepperbush	FAC	Mesic to wet Mesic	2-4	H	–	–	H	Sun to partial sun	Ovoid shrub	6-12'	Shallow	Yes	Med	Coastal plain species.
Cornus Stolonifera (Cornus sericea) red osier dogwood	FACW	Mesic-Hydric	2-4	H	H	H	M	Sun or shade	Arching, spreading shrub	8-10'	Shallow	Yes	High	Needs more consistent moisture levels.
Cornus amomum silky dogwood	FAC	Mesic	1-2	L	–	–	M	Sun to partial sun	Broad-leaved	6-12'	–	Yes	High	Good bank stabilizer
Euonymous europaeus spindle-tree	FAC	Mesic	1-2	M	M	M	M	Sun to partial sun	Upright dense oval shrub	10-12'	Shallow	No	No	–
Hamamelis virginiana witch hazel	FAC	Mesic	2-4	M	M	M	M	Sun or shade	Vase-like compact shrub	4-6'	Shallow	Yes	Low	–
Hypericum densiflorum common St. John's wort	FAC	Mesic	2-4	H	M	M	H	Sun	Ovoid shrub	3-6'	Shallow	Yes	Med	–
Ilex glabra inkberry	FACW	Mesic to wet Mesic	2-4	H	H	–	H	Sun to partial sun	Upright dense shrub	6-12'	Shallow	Yes	High	Coastal plain species.
Ilex verticillata winterberry	FACW	Mesic to wet Mesic	2-4	L	M	–	H	Sun to partial sun	Spreading shrub	6-12'	Shallow	Yes	High	–

(MassDEP, 2016)

Plant Species Suitable for Use in Bioretention - Herbaceous Species

Species	Moisture Regime		Tolerance						Morphology			General Characteristics		Comments
Scientific Name **Common Name**	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Itea virginica tassel-white, Virginia sweetspire	OBL	Mesic	1-2	M	–	–	M	Sun or shade	Broad-leaved, deciduous shrub	6-12'	–	Yes	Low	–
Juniperus communis "compressa" common juniper	FAC	Dry Mesic-Mesic	1-2	M	H	H	M-H	Sun	Mounded shrub	3-6'	Deep taproot	No	High	Evergreen
Juniperus horizontalis 'Bar Harbor' creeping juniper	FAC	Dry Mesic-Mesic	1-2	M	H	H	M-H	Sun	Matted shrub	0-3'	Deep taproot	No	High	Evergreen
Lindera benzoin spicebush	FACW	Mesic to wet Mesic	2-4	H	–	–	H	Sun	Upright shrub	6-12'	Deep	Yes	High	–
Myrica pennsylvanica bayberry	FAC	Mesic	2-4	H	M	M	H	Sun to partial sun	Rounded, compact shrub	6-8'	Shallow	Yes	High	Coastal plain species.
Physocarpus opulifolius ninebark	FAC	Dry Mesic to wet Mesic	2-4	M	–	–	H	Sun	Upright shrub	6-12'	Shallow	Yes	Med	May be difficult to locate.
Viburnum cassinoides northern wild raisin	FACW	Mesic	2-4	H	H	H	H	Sun to partial sun	Rounded, compacted shrub	6-8'	Shallow	Yes	High	–
Viburnum dentatum arrow-wood	FAC	Mesic to wet	2-4	H	H	H	H	Sun to partial sun	Upright, multi-stemmed shrub	8-10'	Shallow	Yes	High	–
Viburnum lentago nannyberry	FAC	Mesic	2-4	H	H	H	H	Sun to partial sun	Upright, mlti-stemmed shrub	8-10'	Shallow	Yes	High	–

Plant Species Suitable for Use in Bioretention - Herbaceous Species

Species	Moisture Regime		Tolerance						Morphology			General Characteristics		Comments
Scientific Name **Common Name**	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Acer rubrum red maple	FAC	Mesic-Hydric	4-6	H	H	H	H	Partial sun	Single to multi-stem tree	50-70'	Shallow	Yes	High	–
Amelanchier canadensis shadbush	FAC	Mesic	2-4	H	M	–	H	Partial sun	Single to multi-stem tree	35-50'	Shallow	Yes	High	Not recommended for full sun.
Betula nigra river birch	FACW	Mesic-Hydric	4-6	–	M	M	H	Partial sun	Single to multi-stem tree	50-75'	Shallow	Yes	High	Not susceptible to bronze birch borer.
Betula populifolia gray birch	FAC	Xeric-Hydric	4-6	H	H	M	H	Partial sun	Single to multi-stem tree	35-50'	Shallow to deep	No	High	Native to New England area.
Fraxinus americana white ash	FAC	Mesic	2-4	M	H	H	H	Sun	Large tree	50-80'	Deep	Yes	Low	–
Fraxinus Pennsylvanica green ash	FACW	Mesic	4-6	M	H	H	H	Partial sun	Large tree	40-65'	Shallow to deep	Yes	Low	–
Ginko biloba Maidenhair tree	FAC	Mesic	2-4	H	H	H	H	Sun	Large tree	50-80'	Shallow to deep	No	Low	Avoid female species-offensive odor from fruit.
Gleditsia triacanthos honeylocust	FAC	Mesic	2-4	H	M	–	M	Sun	Small caopled large tree	50-75'	Shallow to deep variable taproot	Yes	Low	Select thornless variety.
Juniperus virginiana eastern red cedar	FACU	Mesic-Xeric	2-4	H	H	–	H	Sun	Dense single stem tree	50-75'	Taproot	Yes	Very high	Evergreen
Liquidambar styraciflua sweet gum	FAC	Mesic	4-6	H	H	H	M	Sun	Large tree	50-70'	Deep taproot	Yes	High	Edge and perimeter; fruit is a maintenance problem.
Nyssa sylvatica black gum	FACW	Mesic-Hydric	4-6	H	H	H	H	Sun	Large tree	40-70'	Shallow to deep taproot	Yes	High	–

(MassDEP, 2016)

Plant Species Suitable for Use in Bioretention - Herbaceous Species															
Species	**Moisture Regime**		**Tolerance**						**Morphology**			**General Characteristics**		**Comments**
Scientific Name **Common Name**	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Sophora japonica Japanese pagoda tree	FAC	Mesic	1-2	M	M	_	M	Sun	Shade tree	40-70'	Shallow	No	Low	Fruit stains sidewalk.
Taxodium distichum bald cypress	FACW	Mesic-Hydric	4-6	_	_	M	H	Sun to partial sun	Typically single stem tree	75-100'	Shallow	Yes	Low	Not well documented for planting in urban areas.
Thuja occidentalis arborvitae	FACW	Mesic to wet Mesic	2-4	M	M	M	H	Sun to partial sun	Dense single stem tree	50-75'	Shallow	No	Low	Evergreen
Zelkova serrata Japanese zelkova	FACU	Mesic	1-2	M	M	_	H	Sun	Dense shade tree	60-70'	Shallow	No	Low	Branches can split easily in storms.

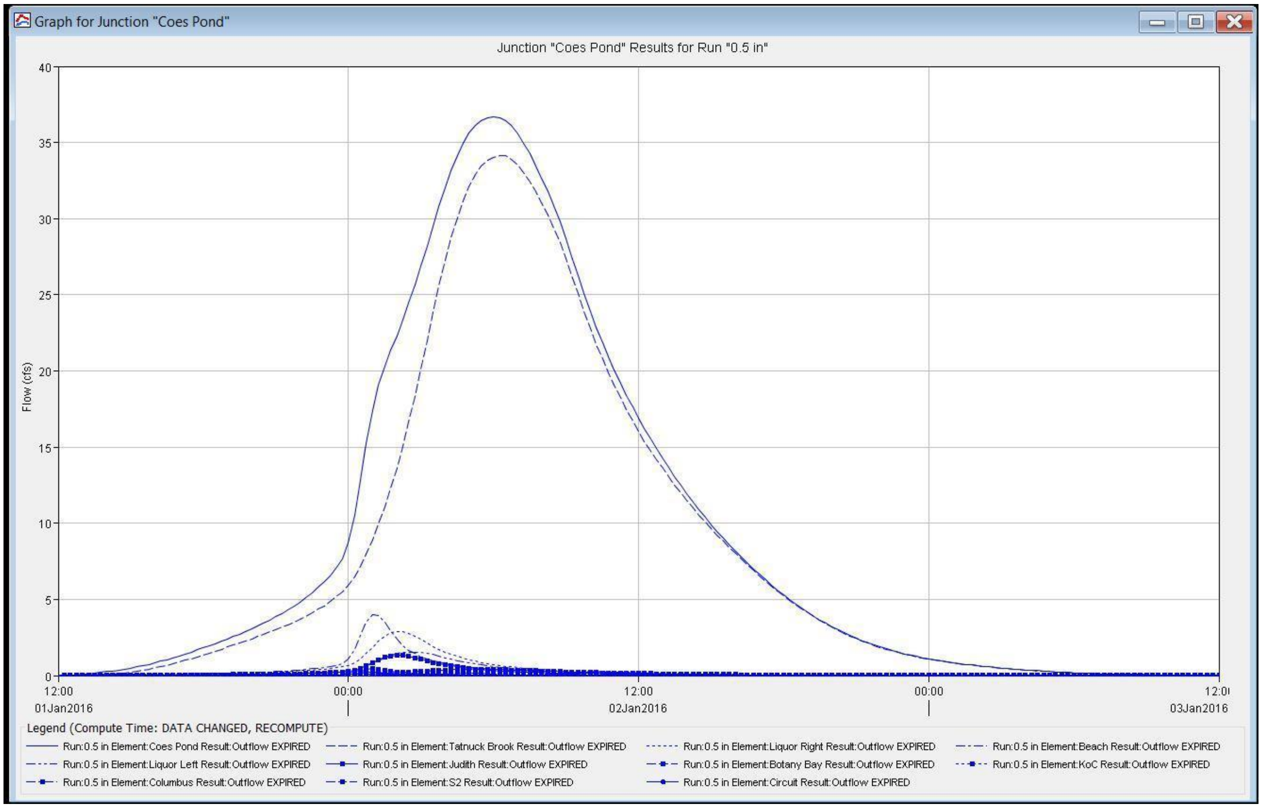
H High Tolerance
M Medium Tolerance
L Low Tolerance

FACU Facultative Upland - Usually occur in non-wetlands, however, occasionally found in wetlands.
FAC Facultative - Equally likely to occur in non-wetlands and wetlands.
FACW Facultative Wetland - Usually occur in wetlands, however, occasionally found in non-wetlands.
OBL Obligate Wetland - Almost always occur in wetlands.

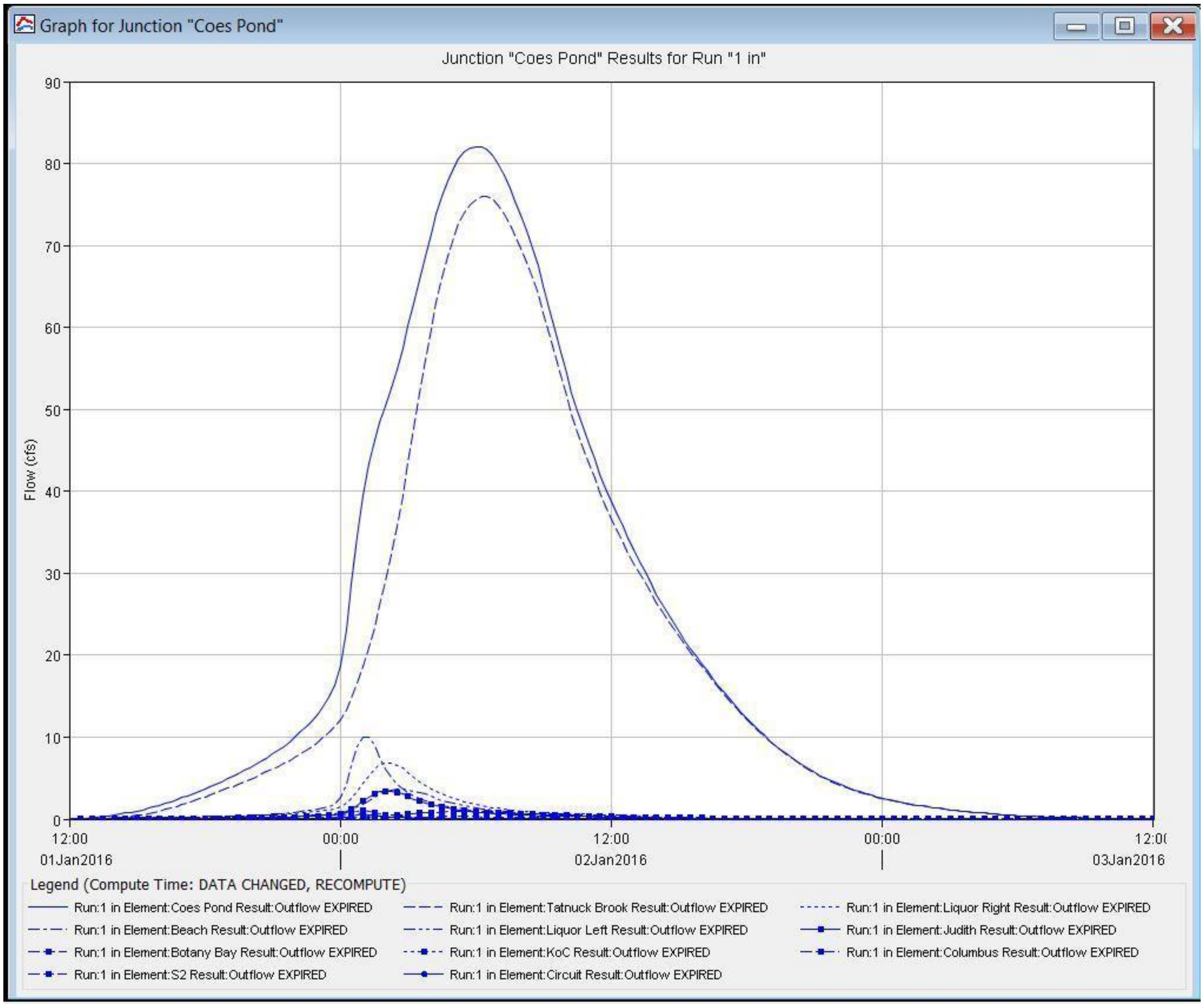
(MassDEP, 2016)

Appendix F: Hydrographs resulting from HEC-HMS simulations

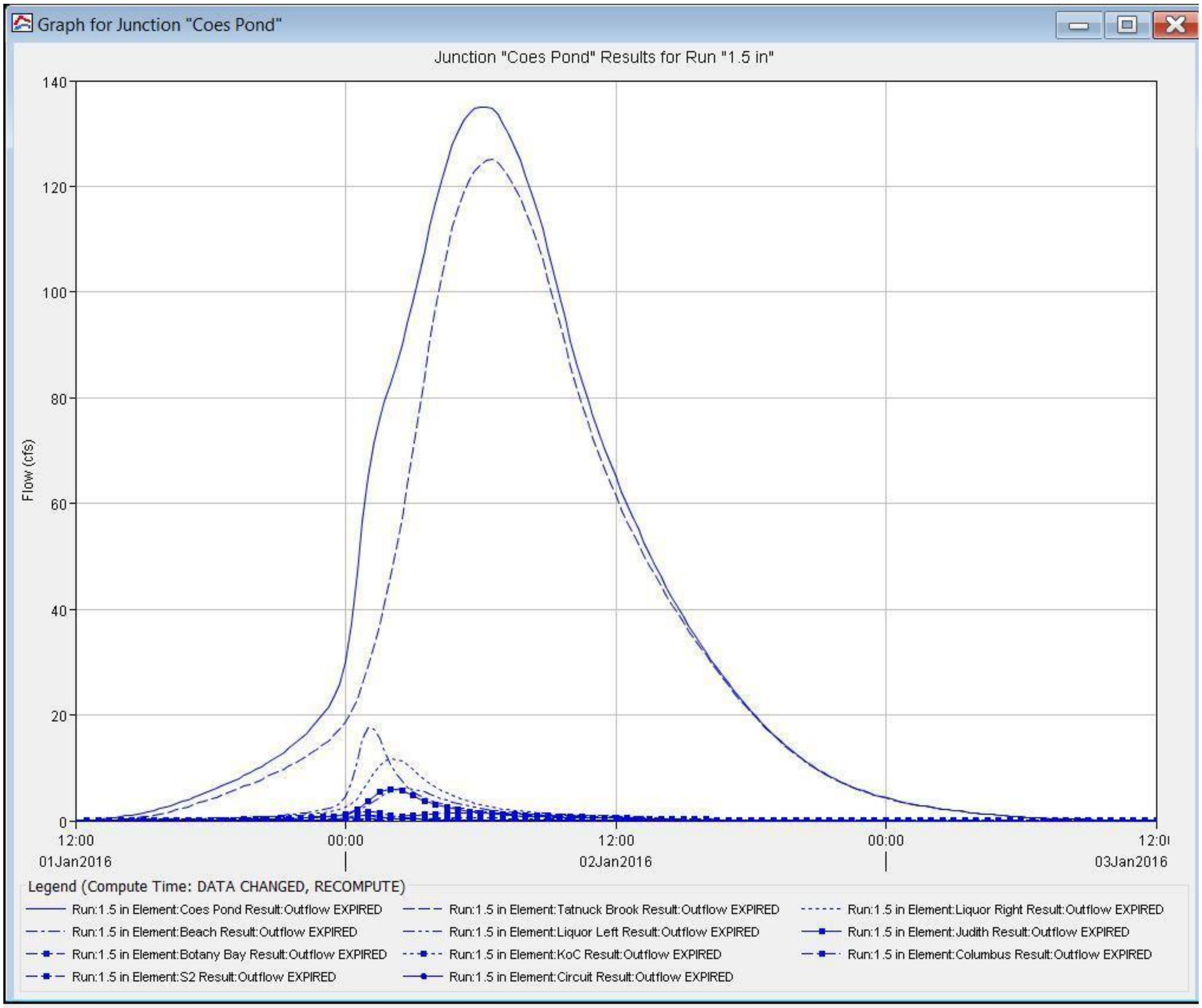
0.5 Inch storm



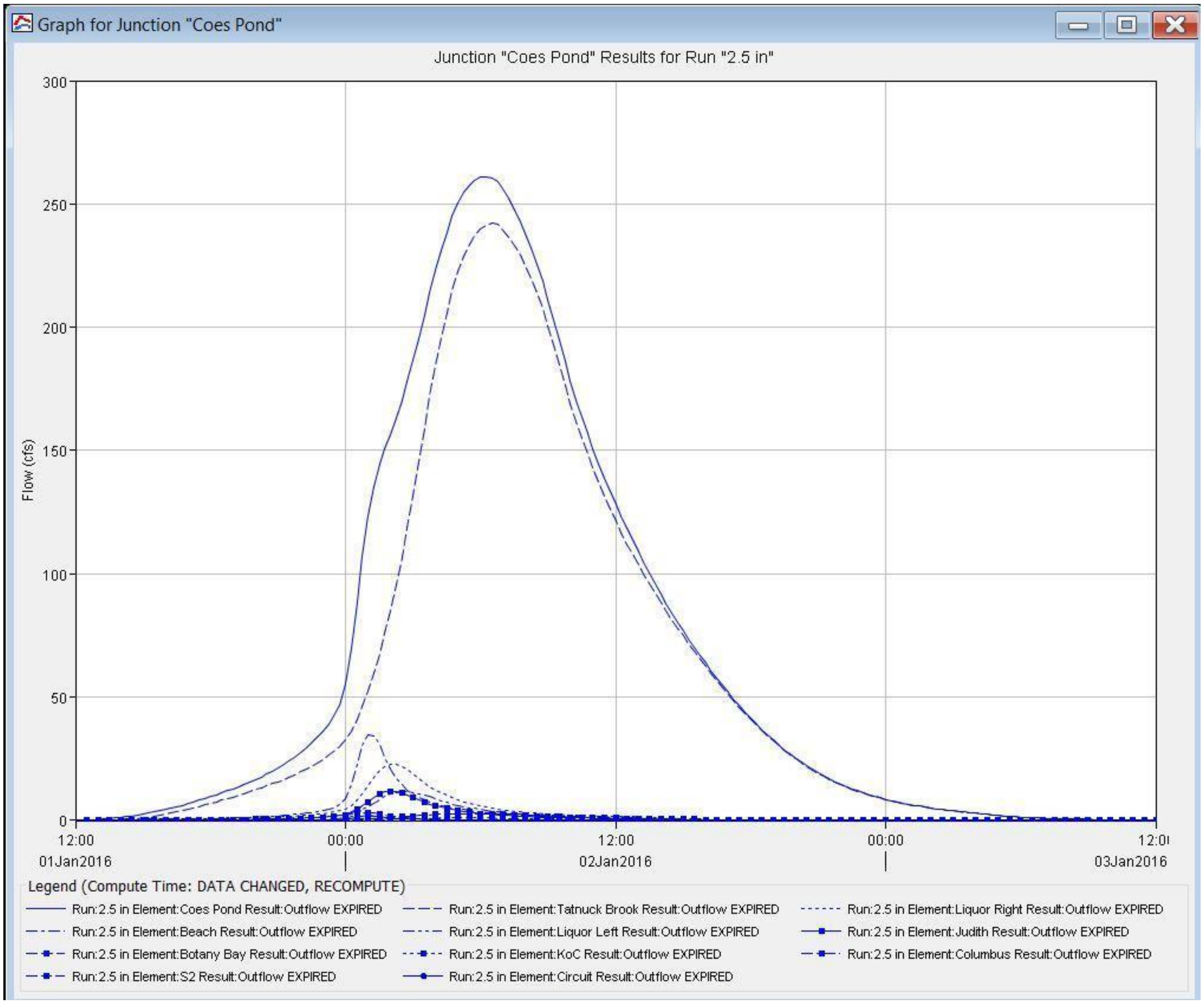
1 Inch Storm


Graph for Junction "Coes Pond"
Junction "Coes Pond" Results for Run "1 in"
Flow (cfs)
12:00
01Jan2016
00:00
12:00
02Jan2016
00:00
12:0(
03Jan2016
Legend (Compute Time: DATA CHANGED, RECOMPUTE)
Run:1 in Element:Coes Pond Result:Outflow EXPIRED
Run:1 in Element:Tatnuck Brook Result:Outflow EXPIRED
Run:1 in Element:Liquor Right Result:Outflow EXPIRED
Run:1 in Element:Beach Result:Outflow EXPIRED
Run:1 in Element:Liquor Left Result:Outflow EXPIRED
Run:1 in Element:Judith Result:Outflow EXPIRED
Run:1 in Element:Botany Bay Result:Outflow EXPIRED
Run:1 in Element:KoC Result:Outflow EXPIRED
Run:1 in Element:Columbus Result:Outflow EXPIRED
Run:1 in Element:S2 Result:Outflow EXPIRED
Run:1 in Element:Circuit Result:Outflow EXPIRED

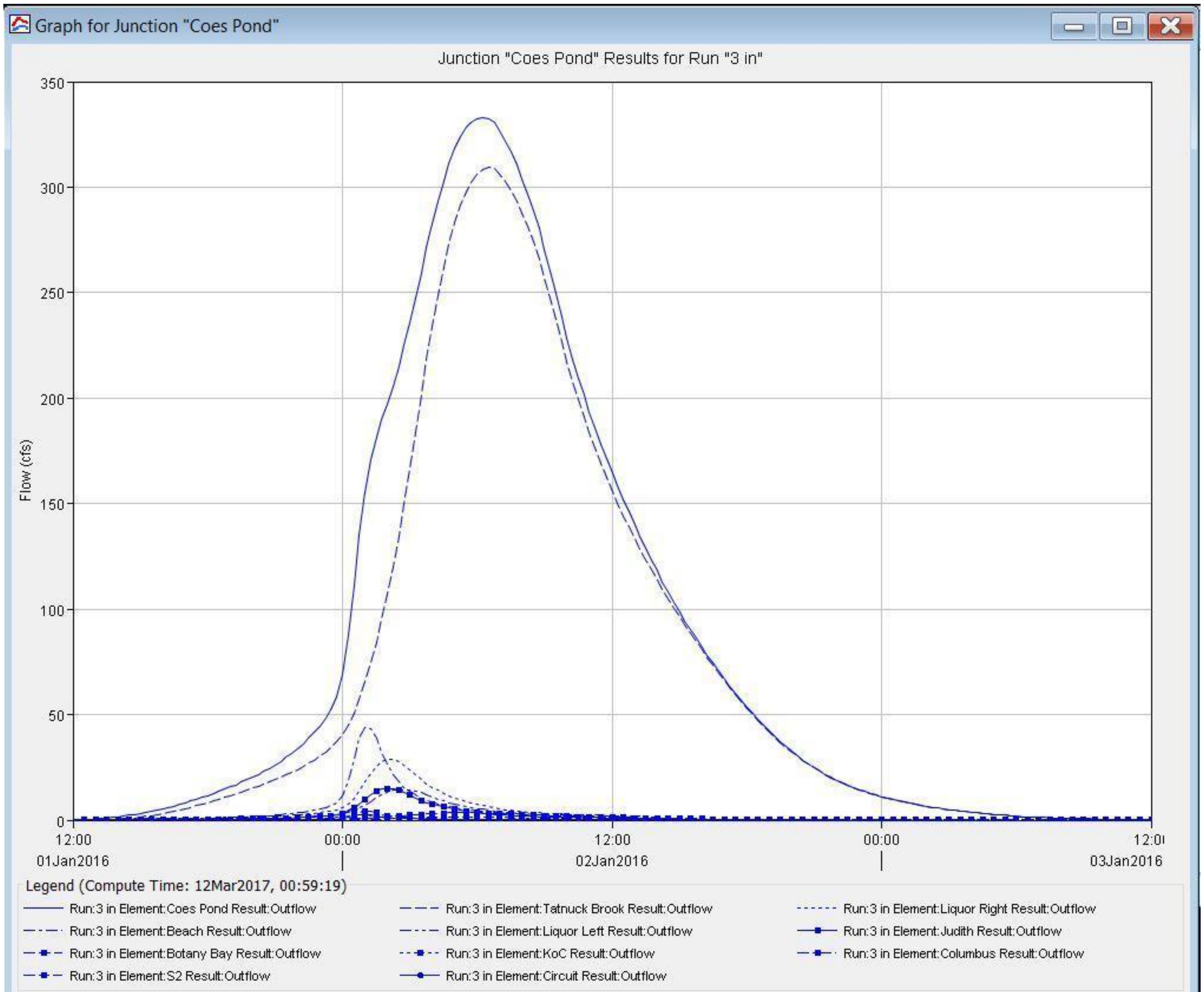
2 Inch Storm


Graph for Junction "Coes Pond"
Junction "Coes Pond" Results for Run "1.5 in"
Flow (cfs)
140
120
100
80
60
40
20
0
12:00
01Jan2016
00:00
12:00
02Jan2016
00:00
12:0
03Jan2016
Legend (Compute Time: DATA CHANGED, RECOMPUTE)
Run:1.5 in Element:Coes Pond Result:Outflow EXPIRED
Run:1.5 in Element:Tatnuck Brook Result:Outflow EXPIRED
Run:1.5 in Element:Liquor Right Result:Outflow EXPIRED
Run:1.5 in Element:Beach Result:Outflow EXPIRED
Run:1.5 in Element:Liquor Left Result:Outflow EXPIRED
Run:1.5 in Element:Judith Result:Outflow EXPIRED
Run:1.5 in Element:Botany Bay Result:Outflow EXPIRED
Run:1.5 in Element:KoC Result:Outflow EXPIRED
Run:1.5 in Element:Columbus Result:Outflow EXPIRED
Run:1.5 in Element:S2 Result:Outflow EXPIRED
Run:1.5 in Element:Circuit Result:Outflow EXPIRED

2.5 Inch Storm



3 Inch Storm



Graph for Junction "Coes Pond"
Junction "Coes Pond" Results for Run "3 in"
Flow (cfs)
350
300
250
200
150
100
50
0
12:00
01Jan2016
00:00
12:00
02Jan2016
00:00
12:0
03Jan2016
Legend (Compute Time: 12Mar2017, 00:59:19)
Run:3 in Element:Coes Pond Result:Outflow
Run:3 in Element:Tatnuck Brook Result:Outflow
Run:3 in Element:Liquor Right Result:Outflow
Run:3 in Element:Beach Result:Outflow
Run:3 in Element:Liquor Left Result:Outflow
Run:3 in Element:Judith Result:Outflow
Run:3 in Element:Botany Bay Result:Outflow
Run:3 in Element:KoC Result:Outflow
Run:3 in Element:Columbus Result:Outflow
Run:3 in Element:S2 Result:Outflow
Run:3 in Element:Circuit Result:Outflow