Project Number: MQP PPM 1202

Water Quality Control and Improvement Plan for Green Hill Pond, Worcester, MA

A Major Qualify Project

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Abstract

This project involves the development of a water quality control and improvement plan for Green Hill Pond in Worcester for the purpose of addressing concerns associated with a high estimated phosphorus load entering the pond. Samples of pond water, overland runoff, and in-pond sediments were collected and analyzed in the laboratory. Results were analyzed to determine the amount and sources of nutrients entering the pond. Recommendations to improve water quality included a rain garden, water quality swale, and public education.

Acknowledgements

The successful completion of this project would not have been possible without the contributions of following people. First and foremost we would like to express gratitude to our advisors, Professor Paul Mathisen and Professor Suzanne LePage for guiding and coaching us through this project. Also, we would like to thank Mr. Joseph Buckley and Mr. Philip Guerin from the Department of Public Works and Parks, City of Worcester for providing information about Green Hill Pond. Finally, we would like to express gratitude to Mr. Donald Pellegrino for assisting at WPI laboratory and site investigation.

Capstone Design Statement

This project meets capstone design requirements by considering the following factors in the design process: economic considerations, environmental interactions, sustainability, manufacturability, health and safety, social concerns and political issues.

Economic Considerations: When designing plans for water quality control and improvement at Green Hill Pond, especially structural BMPs, the economic constraints should be taken into account. The possible plans were selected appropriate to reduce pollutants in runoff by considering its effectiveness as well as cost.

Environmental Interactions: Environmental interactions are a major component of this project. Water quality is directly related to the pond ecosystem and surrounding environment. Therefore, the design options were developed in order to balance the environmental interaction in this area.

Sustainability: Developing water quality control and improvement plans for the pond can improve the pond water back to a healthy level and increase the serviceability of the pond. More importantly, it can help the pond become a potential water source for public use in the future.

Constructability: Green Hill Pond is surrounded by public participation and recreation areas. There is limited space for structural BMPs, so constructability directly affects the available usable space and the existing landscape. It is important to consider constructability while selecting recommended BMPs.

Health and Safety: It is necessary to consider health and safety for human before operating the designing water quality plan. On the part of water quality control, the selected BMPs need to consider the outcome along with safety of participants. In addition, the results from the laboratory determined that there were e-coli bacteria in the pond water, which is harmful to humans. Therefore, it is important to choose the most appropriate water quality control and improvement plan that has less risk for human health and safety.

Social Concerns: The Green Hill Pond is a recreation place for the Worcester community, so the properties around the pond are intended to be for public use. Therefore, it is vital to keep aesthetic maintenance of the pond so that the design solutions can enhance the social value of the property.

Political Issues: The water quality improvement and control plan for Green Hill Pond will be the responsibility of the Department of Public Works in Worcester. However, the outcomes and consequence of plan need to meet the requirements of water quality as enforced by the US Environmental Protection Agency (EPA).

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Executive Summary

This project investigated water quality and phosphorus loadings for Green Hill Pond, the main environmental source and recreational area of Green Hill Park in Worcester, MA. It used land uses, weather information, and water sample results to model stormwater runoff volume directly to the pond and estimate the phosphorus loads. This project also applied sediment analysis and water quality measurements. This information was used to create a detailed picture of the factors affecting the health of the pond, and to determine effective methods for water quality controls and improvement plans.

The final product of this project is a combination of recommendations for the appropriate Best Management Practices (BMPs) to control and improve the pond water quality and recommendations for the future research groups to continue this project. This result is presented to the City of Worcester and available to other interested parties to restore the health of the pond. The recommendations, which include structural and non-structural BMPs, are included in the report.

On October 27th, 2011 wet weather shoreline water samples were taken from 4 different locations in the pond. These sampling locations include both shore sides near the dam, at the north outlet of Green Hill Pond, and near the playground. On the same day, stormwater runoff samples were taken from 6 different locations around the pond. On November 2nd, 2011 dry weather shoreline water samples were taken from the same locations where the wet weather shoreline water samples were taken. On November 16th, 2011 in-pond water samples were taken by boat from 2 different in-pond locations by Professor Paul Mathisen and Laboratory Manager Don Pellegrino. The geographic information of all the sampling locations was recorded by using a handheld GPS. The water samples were tested for pH, specific conductance, turbidity,

dissolved oxygen, total phosphorus, dissolved ions, total suspended solids, ammonia, and bacteria. On December 8th, 2011 the sediment samples were taken from both shore sides of the dam to test for the sediment leaching conditions.

Nonpoint runoff volume directly to the pond was established by applying onsite investigations, the NRCS method, and the GIS program. The runoff phosphorus loadings were estimated by combining the measured phosphorus concentrations and estimated runoff volumes in each tributary runoff area. The runoff volume and runoff phosphorus loading of the entire Green Hill Pond watershed was also established. It was found that, during the storm event of 0.87 inch total rainfall, there was approximately 4.2 in-acre of runoff and approximately 1090 grams of phosphorus entering the pond. However, over 80% (about 890 grams) of the phosphorus came from location 6 as shown in Figure 5 in section 3.4.5. Also, the sediments in pond were also determined to be a potential source of phosphorus in the pond. The sediment samples tested contained between 16 and 21 parts per million of phosphorus in 1 gram of sediment.

A series of potential BMPs options were developed based on the determined phosphorus loading conditions. Methods for physical removal of phosphorus and suspended solids can restore aesthetic qualities to the pond, but will not necessarily remove all of the phosphorus or suspended solids present. Public Education regarding proper application of fertilizer and pet wastes can reduce the runoff contaminants. Other options, such as dredging, would succeed in removing much of the sediment, but was not recommended due to the potential for environmental damage. A series of inexpensive options, each with the potential to solve a section of the problem, were packaged together to create a plan for overall management of Green Hill Pond, so that over time the pond can be restored for better water quality.

Chapter 1: Introduction

On a global scale, the demand for surface waters for different purposes increases over time as the amount of usable freshwater is getting limited. Freshwater comprises about only 2.5% of the Earth's total volume of water. After subtracting the volumes of freshwater that are locked in ice cap and glaciers, there is only 0.77% left as freshwater[1]. There are a number of established water usages including: industrial use, drinking water supply, transportation, recreation, irrigation, aquaculture, and habitat preservation. The limited amount of water can easily lead to conflicts if there is a shortage in the supply of good quality surface water for these uses. Water pollution is one of the major concerns that decrease the amount of usable water in the world. One kind of water pollution, the overload phosphorus in the water often becomes apparent to the public in many countries as a function of the progressive growth of densely populated areas due to the human activities and waste discharges.

In spite of the efforts to control the water quality in Green Hill Pond, such as total phosphorus loading and turbidity, there is limited information for the Environmental Protection Agency (EPA) and the City of Worcester to determine the sources of pollutants and develop a control plan based on the current water quality in Green Hill Pond[2]. According to the Blackstone River Watershed Report in 2003-2007 by the EPA, it shows there is lack of information about the assessments of the Green Hill pond. The report shows so all uses such as aquatic life, fish consumption, primary contact, secondary contact, and aesthetics are not assessed due to there was no recent quality assured data are available. Also, the observation by the EPA shows that the Green Hill Pond is turbid.

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[1] Barbara J Downes, Monitoring Ecological Impacts: Concept and Practice in Flowing Water, (England: Cambridge Press, 2002).

[2] Massachusetts Department of Environmental Protection, "Blackstone River Watershed 2003-2007 Water Quality Assessment Report," 2007, 25 Sep.2011<http://www.mass.gov/dep/water/resources/51wqar10.pdf>.

The purpose of this project is to develop an appropriate water quality control and improvement plan for the Green Hill Pond. Evidence from other organizations, such as the EPA, the Department of Environmental Protection, and the City of Worcester, shows that Green Hill Pond has a high estimated load of phosphorus. However, the current water quality of the pond is ambiguous. A control plan for the pond has not been developed before. It requires investigation on the actual current water quality of the pond before an appropriate water quality control and improvement plan is developed for the pond.

The research for the project included conducting investigations for the current water quality. During the investigation process, water samples were gathered at different locations of the pond during dry and wet weather. Also, the stormwater runoff samples were obtained during the storm event on October 27th, 2011. In order to confirm the water quality effects from the in-pond sediments, two sediment samples were collected from different locations in the pond. With these collections of water and sediment samples, the team tested the samples for certain qualities including total phosphorus, turbidity, dissolved oxygen, pH value, specific conductance, dissolved ions, ammonia, total suspended solids, and bacteria. Also, a series of analysis for the result from each test were accomplished. The objective was to determine the types and amounts as well as the sources of pollutants. Based on the determinations of the pollutants, a group of possible Best Management Practices (BMPs) to control the pollutants were selected. In order to evaluate the most appropriate BMPs for the pond, comparisons on the advantages and disadvantages between these possible options were established. The result of this project provided the City of Worcester valuable current water quality determinations of Green Hill Pond. From this, proper recommendations for appropriate water quality control plans were delivered.

Chapter 2: Background

2.1 Purpose

This chapter presents information about Green Hill Park, Green Hill Pond, and the reasons for developing water quality control and improvement plans for the pond. This section also includes other information needed to understand the project in order to move forward with the methodology. The major topics in this section includes: Green Hill Park, Green Hill Pond, the current problems of the pond, water quality standards in Massachusetts, case studies, water measurement parameters, sampling and testing.

2.2 Green Hill Park, Worcester Massachusetts

Over 260 years ago, the permanent settlers inhabited the hilly terrain of the land now known as Green Hill Park. Aaron Adams first came up with the idea of managing the landscape. Adams' family managed and expanded the park area from eighty-one acres to one hundred and eighty acres over generations. In 1754, the Adams' family sold the 180 acres of land to Dr. Thomas Green. Green's family expanded and improved the landholding to 287 acres by the time that the park was given to Andrew Green in 1848. Andrew Green was the Commissioner of Central Park in New York City in 1857. His working experience helped him to properly manage the landscape. In 1850, Andrew divided the original family homestead building into two side-by-side parts and made a new forty-two-room "mansion". Andrew's brother, Martin Green, who was trained as a civil engineer, moved into the estate to manage it in 1872. Martin's engineering experience helped him to organize the estate professionally, and in 1878, he decided to dam the Bear Brook valley and create a pond which is Green Hill Pond now.[3]

In 1903, the year Andrew Green passed away, the estate had been expanded to an area of 549 acres. The parkland was left to Andrew's nieces and nephews who sold the parkland to the City of Worcester. From the transaction, Worcester gained a unique park resource to add new facilities and provide recreational opportunities for generations and generations of Worcester residents. Now, Green Hill Park has become the largest municipal park in the City, located atop one of the seven main hills in Worcester. In its over 480 acres, there are two ponds, one farm, one picnic grove, one playground, one league field, one golf course and several handball courts.[4]

2.3 Green Hill pond

Green Hill Pond is a man-made pond which was created in 1878, located inside Green Hill Park in Worcester. It contains a water surface area of 29 acres and provides the community a healthy green natural environment for public outdoor activities. Around the pond, there are Green Hill Farm, a playground, a picnic grove, a barbeque area and a golf course. There are many daily out-door activities surrounding the pond as shown in Figure 1.

Figure 1 Green Hill Pond (Photo from: http://www.worcesterma.gov/dpw/parks-rec/city-parks/green-hill-park)

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[3] City of Worcester, "Green Hill Park," 17 Sep. 2011< http://www.worcesterma.gov/dpw/parks-rec/city-parks/green-hill-park>.

[4] Ibid.

In 2009, the Department of Public Works Worcester published the Green Hill Pond Dam Phase II Inspection and Investigation Report. In the report, it states that the bottom of the pond has an elevation of 633 feet. It normally has a depth of 17.3 feet, and the normal storage volume is 312 acre-feet. Since the Green Hill Pond Dam is located on the southwest side of the pond, the depth of the pond can is controlled and the maximum depth of the pond is 19.2 feet. The maximum storage volume of the pond is 371 acre-feet.[5]

According to DPW Worcester, Green Hill Pond has two outlets. The Green Hill Pond Dam outlet is a vertical spillway shaft connecting to a horizontal outlet conduit. It was the original pond outlet control that connected with combined sewer system in the southwest of the pond. The other outlet is the Northern outlet. In 2005, the weirs controlling both outlets were modified as part of the City of Worcester's Long-Term CSO Control Plan (LTCO) in order to disconnect the dam outlet from the combine sewer system. The functions of the dam outlets were reversed and the northern outlet became the primary outlet that drains to the CSO system in downtown Worcester.

2.4 Current Problems of the Green Hill Pond

In 2002, Massachusetts Department of Environmental Protection published the report about the investigation on the TMDL of phosphorus for selected northern Blackstone lakes. The report showed that Green Hill Pond was estimated to have a phosphorus concentration of 44.2 parts per billion (ppb) while the target level is 25 ppb. Similarly, the estimated total yearly load was 75 kg while the target load is 48 kg.[6] In June 2008, the Environmental Protection Agency published a draft permit about the water pollution in the northern lakes and pond. The permit

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[5] City of Worcester, Green Hill Pond Dam Phase II Inspection/Investigation Report, (Worcester: CMD, 2009).
[6] Massachusetts Department of Environmental Protection, "Total Maximum Daily load of Phosphorus for Selected Northern Blackstone Lakes", 2002, 25 Sep. 2011<http://www.mass.gov/dep/water/resources/blaktmdl.pdf>.

shows that the pollutant in Green Hill Pond was phosphorus and the water body had a turbidity condition[7], the draft permit is also provided in Appendix XI. However, no sample was taken for the investigation process. Therefore, the current water quality in Green Hill Pond is still ambiguous, and further investigation is required to determine the current polluted condition of the pond.

2.5 Water Quality Standards

In order to develop a water quality control plan for Green Hill Pond, it is required to understand the laws and regulations about water quality in the United States and the state of Massachusetts. This section provides information about the Clean Water Act, the total maximum daily load, the National Pollutant Discharge Elimination System.

2.5.1 Clean Water Act

Clean Water Act (CWA) is the Act that establishes the basic structure for regulating discharges of pollutants into the surface water bodies in the United States. It also states the quality standards for the surface waters all over the nation. The Clean Water Act was enacted in 1948, and it was originally named as the Federal Water Pollution Control Act. In 1972, the Act was reorganized and expanded significantly.[8] There are five titles in the CWA document, which are:

1) Research and Related Programs

2) Grants for Construction of Treatment Works

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[7] City of Worcester, "DRAFT NPDES Permit Number MAS010002," 2008, 18 Oct. 2011<http://www.epa.gov/region1/npdes/permits/draft/2008/draftmas010002fs.pdf>.

[8] United States Environmental Protection Agency, "National Pollutant Discharge Elimination System (NPDES)," 2011, 3 Oct. 2011< http://cfpub.epa.gov/npdes/cwa.cfm?program_id=45>.

3) Standards and Enforcements

4) Permits and Licenses

5) General Provisions.

In these titles, different policies for funding and enforcing to maintain allowable water quality, limitations and regulations for permits and licenses are clearly specified in different sections in the titles. A full-text PDF document is also provided on the official website of the U.S Environmental Protection Agency.[9]

2.5.2 Total Maximum Daily Load (TMDL)

As stated in the CWA, all states are required to submit a list of impaired waterbodies for the EPA approval. Each state will identify all waterbodies that require pollution controls or are not sufficient to maintain applicable water quality standards as impaired waterbodies. And also, based on the severity of pollution and the sensitivity of the uses to be made of the waterbody, all states will establish their priorities for development of TMDLs for each impaired waterbody.

Definition of TMDL

The Total Maximum Daily Load (TMDL) represents the maximum amount of a pollutant that can be received by a water body while that water body can still meet the water quality standards. There are two groups of pollutant sources, point and non-point sources. Point sources receive Waste Load Allocations (WLA), and include all sources that subject to regulations under the National Pollutant Discharge Elimination System (NPDES) program. Point sources include wastewater treatment facilities, some storm water discharge and concentrated animals feeding

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[9] United States Environmental Protection Agency, “Federal Water Pollutant Control Act,” 2002, 3 Oct. 2011 < http://epw.senate.gov/water.pdf>.

operations. Non-point sources receive Load Allocations (LA), and include all of the remaining sources of the pollutant. In order to compute TMDLs, one must consider the seasonal variations and include a margin of safety (MOS) while predicting the effects of the pollutant reductions will be resulting in meeting the water quality standard.[10] The equation to calculate a TMDL of a water body is also provided on the EPA's official website:

$$TMDL = \sum WLA + \sum LA + \sum MOS$$

Where TMDL = total maximum daily load

$\sum$WLA = sum of waste load allocations

$\sum$LA = sum of load allocations

MOS = margin of safety

Regulation states that, each pollutant that impairs or threatens a water body can be considered as a water body/pollutant combination, and each of these combinations must have a TMDL developed. For example, if a water body is impaired or threatened by two different pollutants, then two TMDLs are computed.

In regulations, TMDL is a calculation that means to address the pollutant in one part of a water body. However, the concept has become more expansive in content in many states. The regulations have not defined a specific scale of the TMDL and states have been developing TMDLs of water body/pollutant combinations in a large watershed-scale analysis. The goal of developing a TMDL is to design an implementation plan or a watershed plan to meet water quality standards and restore impaired water bodies. In fact, one or more TMDLs analysis can be involved in the process of developing these plans.

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[10] United States Environmental Protection Agency, "Total Maximum Daily Load," 2011, 20 Sep. 2011 < http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/overviewoftmdl.cfm>.

How TMDLs are developed

Under the Clean Water Act, states are responsible to develop TMDLs and submit to the Environmental Protection Agency for approval. The objective of developing TMDLs is to determine the maximum load of pollutant that a water body can take. Determining the maximum load of pollutant helps to manage the allocations of load so the water quality standards can be maintained and appropriate pollutant control actions can be taken.

In the TMDL development process, techniques range from simple mass balance calculations to complex water quality modeling approaches. A variety of factors, such as the water body type, complexity of flow conditions, and the impairment caused by pollutant, determine the degree to which the analysis varies.

In the TMDL development process, several activities are required to be accomplished: selection of pollutant that should be considered; estimation for the loading capacity of the water body that is being studied; estimation of the total load of the pollutant from all sources to the water body; analysis of current load of the pollutant and determination of needed reductions to meet the loading capacity of the water body; and allocation, which includes the margin of safety, of the allowable pollutant load from different sources while retaining water quality standards. The final result of the TMDL development is required to clearly identify the links between the cause of impairment, the level of impairment and the need of pollutant reduction to remain the water quality standards.

2.5.3 National Pollutant Discharge Elimination System

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) controls water pollution by regulating the point sources that discharge pollutants into the water bodies in the nation. Every facility that discharges into a water body must obtain permit. For more transparency, the U.S EPA provides detailed information about the NPDES on their official website.

The pollutants in stormwater runoff are regulated NPDES. When precipitation from rain and snowmelt flows over land or impervious surfaces and does not percolate into the ground, stormwater runoff is generated. It accumulates different materials, such as debris, chemicals, sediment or other pollutants, while it travels over the land the impervious surfaces. These untreated runoff flow into the water body with pollutants could adversely affect the water quality. The use of best management practices (BMPs) is the primary method to control the storm water discharges. Municipal separate storm sewer systems (MS4s), which convey stormwater runoff in urban areas, must also comply with the NPDES program.

Limitations and conditions

EPA issued the memorandum “Interim Permitting Approach for Water Quality Based Effluent Limitations in Storm Water Permits” in September 1996. However, the Clean Water Act (CWA) does not always require numeric limitations to meet technology and water quality requirements. It is believed that it could be very difficult to develop numeric limitations for storm water permits based on the existing knowledge about these types of discharges and their effects on receiving waters. But still, the EPA requires a series of Best Management Practices to be incorporated into a storm water management program and the requirements can be found in the draft permit.[11]

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[11] United States Environmental Protection Agency, “Draft National Pollutant Discharge Elimination System (NPDES) Permit to discharge to the Waters of the United States,” 2008, 17 Sep. 2011< http://www.epa.gov./region1/npdes/permits/draftmas010002fs.pdf>.

Regulatory Basis of Permit Conditions

According to the EPA, federal and state laws and regulations provide the basis for establishing the conditions of the draft National Pollutant Discharge Elimination System (NPDES) permit for the discharge of pollutants from the City of Worcester's Municipal Separate Storm Sewer System (MS4). The permit, which covers all areas that owned and operated by the City of Worcester that are designed to collect and convey storm water, was first issued in 1998 and updated in 2008. The conditions in the draft permit are to ensure that pollutant discharges from Permittee's MS4 are reduced to the maximum extent practicable (MEP), as stated in the draft permit:

> "…reduce pollutants in discharges from the MS4 to the maximum extent practicable, including management practices, control techniques, and system, design and engineering methods…"[12]

MEP is the standard that establishes the level of pollutant reductions that MS4 operators must achieve, and the EPA interpreted it to apply all MS4 operators including the City of Worcester. Meanwhile, the EPA also stated that the MEP standard is applied based on the best professional judgment of the permit writer in case of individual NPDES permits.

2.6 Case Studies on Phosphorus Management in other areas

It is important to review case studies about phosphorus removal in other areas. In this section, there are two case studies which dealt with phosphorus overload: Kezar Lake, New Hampshire; and Lake Eucha near Jay, Oklahoma.

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[12] United States Environmental Protection Agency, "Draft National Pollutant Discharge Elimination System (NPDES) Permit to discharge to the Waters of the United States," 2008, 17 Sep. 2011< http://www.epa.gov./region1/npdes/permits/draftmas010002fs.pdf>.

2.6.1 Phosphorus overload in Kezar Lake, NH

Kezar Lake is located in central New Hampshire. This lake has had an interesting history of water quality problems for environmental engineers. Following a major fish kill and persistent algae blooms beginning in the early 1960s, phase I (Diagnostic/Feasibility Study) of this case study was initiated in 1980 under section 314 of the Clean Water Act. They assessed the problem in the Kezar Lake by conducting an:

I. Examination of the existing water quality and tropic state of the lake
II. Analysis of historical water quality trends
III. Determination of hydrologic and phosphorus inputs and outputs (budgets) for Kezar Lake
IV. Determination of the importance of the lake's sediments in providing phosphorus to support phytoplankton (algae) populations

This assessment established that the lake's problems were from internal loading of phosphorus, and outlined a management strategy to restore the lake.[13] Phase II (Restoration/Protection Project) of this treatment project was commenced in 1984 to implement the recommended management strategy for Kezar Lake.

Two main approaches were employed to reduce phosphorus concentrations in the lake. First, aluminum salts were injected into the bottom layer of water to inactivate sediment phosphorus. Second, upstream riparian wetlands were manipulated by elevating the water level and planting new species to encourage phosphorus removal by sedimentation and vegetative uptake.[14] During the last phase, from 1984 to 1994, comprehensive water quality monitoring programs were conducted to assess the effects of the restoration activities. The results from these

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[13] United States Environmental Protection Agency, “Watershed Protection: Clean Lakes Case Study: Phosphorus Inactivation and Wetland Manipulation Improve Kezar Lake, NH,” 2011, 5 Oct. 2011< http://water.epa.gov/type/lakes/kezar.cfm>.
[14] Ibid.

efforts have generally indicated that water quality has improved following aluminum salts injection.[15]

2.6.2 Phosphorus overload in Lake Eucha near Jay, Oklahoma

The Oklahoma Department of Environmental Quality identified 16,041 miles of Oklahoma streams and 225,421 acres of lake impaired in their 2004 Integrated Water Quality Assessment Report.[16] Similar to Green Hill Pond, the pollutant of concern in many of these impairments was phosphorus. The Oklahoma Department of Environmental found out that phosphorus came from both point and nonpoint sources. In the report, point sources are municipal waste water treatment plants, industrial discharge, large confined livestock operations, and urban stormwater. On the other hand, nonpoint sources are phosphorus from soil erosion and water runoff from cropland.[17]

After the department figured out the sources of phosphorus by calculating soil test phosphorus (STP), the erosion rate, and the application rate and timing of commercial fertilizer or animal manure, they controlled phosphorus runoff. For point sources, special rules are in place in Oklahoma for pollution control at animal feeding operations. Municipal and industrial waste water treatment plants are generally governed by federal and state regulations and permits, same as storm sewer system.[18] For nonpoint sources, they are not subject to regulation by state or federal agencies. Pollution control of runoff from cropland, pastures, forests, and lawns and gardens depends on the voluntary use of Best Management Practices (BMPs).[19]

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[15] United States Environmental Protection Agency, “Watershed Protection: Clean Lakes Case Study: Phosphorus Inactivation and Wetland Manipulation Improve Kezar Lake, NH,” 2011, 5 Oct. 2011< http://water.epa.gov/type/lakes/kezar.cfm>.

[16] Oklahoma State University, “Phosphorus and Water Quality,” 25 Sep. 2011 < http://www.poultrywaste.okstate.edu/files/BAE-1521web.pdf>.

[17] Ibid.

[18] Ibid.

[19] Ibid.

2.7 Water Quality Measurement Parameters

This section provides water quality measurement parameters and the reason to measure them. The water quality parameters are phosphorus, turbidity, dissolved oxygen, water temperature, water pH, and specific conductance.

2.7.1 Phosphorus

Generally, phosphorus is found in rocks and other mineral deposits. During the natural weathering process, rocks regularly release phosphorus as phosphate ion (PO_4^{-3}) which is soluble in the water. Generally, phosphate ions exist in three forms: orthophosphate, meta-phosphate (or polyphosphate) and organically bound phosphate[20] The difference between each compound is chemical arrangement, and these three forms of phosphate occur in living and decaying plant and animal remains, as free ions or weakly chemically bound in aqueous systems, chemically bound to sediments and soils, or as mineralized compounds in soil, rocks, and sediments.[21]

Importance of Phosphorus in the water system

Phosphorus is important to help achieve a natural healthy aquatic ecosystem. The reason is phosphorus supports the growth of underwater plants, and these plants are the sources of oxygen and habitat production that support the reproduction of aquatic life. Thus, the amount of phosphorus in water can present the structure of the aquatic ecosystem. Theoretically, the proportion among nutrient element in the biomass which is carbon to nitrogen to phosphorus (C:

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[20] Brian Oram, “Total Phosphorus and Phosphate Impact on Surface Waters,” 2011, 9 Sep. 2011< http://www.water-research.net/phosphate.htm>.

[21] Ibid.

N: P) is 106:16:1.[22] Therefore, if an overload of phosphorus is in the water, it will make the nutrient ratio unbalance stress on a receiving ecosystem.

Problems with excessive phosphorus in the water system

As noted previously, phosphorus is important to preserve the health of the organisms in the water system. However, the aquatic ecosystem can become unbalanced when an unsatisfactory amount of phosphorus loading enters the water. This unbalance in the ecosystem consequently causes the increasing productions of algae and aquatic plants and this circumstance is called “Eutrophication.”[23] When the aquatic ecosystems have excessive algae and aquatic plants the following undesirable change will occur:

I. Reduce water clarity
II. Make unpleasant odor and taste
III. Lower dissolved oxygen (DO)
IV. Reduce fish populations
V. Make toxin from green-blue algae

As noted, these effects are likely when there is an overload of phosphorus in the waterbody.

Sources of Phosphorus

Human inventions are the most important factors to increase phosphorus loading in the water. Since humans would like to feel comfortable and convenient, many chemical things are produced to support human life. The human chemical products can directly affect the aquatic

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[22] Robert H Kadlec, Treatment Wetlands, (Florida: CRC Press, 1996).
[23] Sven-Olof Ryding, The Control of Eutrophication of Lakes and Reservoirs, (New Jersey: The Parthenon Publising Group Inc, 1989).

ecosystem to be unbalance with phosphorus if they enter to the aquatic system. The human products that can be source of phosphorus to water are:

Detergents: Detergents are commercial cleaning products that contain phosphorus in form of orthophosphate and polyphosphates. For example, Sodium phosphate was often used as a basic chemical for detergent to increase cleaning power in 1950s to 1960s, and the consequence of using this kind of detergent led to the Eutrophication problem discussed previously.[24] Therefore, the government required detergent manufacturers to reduce the use of phosphates in detergents. The result was satisfied since the amount of phosphorus in waterbody decreased. Limits on the phosphate content of detergent, and additional treatment used in waste water treatment plants to remove phosphorus have been installed since that time. Also, many states have a ban on phosphates in detergents due to its effect.[25]

Fertilizers: Fertilizers generally contain phosphorus in the form of orthophosphate. Phosphate is not transportable in soil, some of it dissolved in water and some remain attached to sediment. Thus, storm runoff and melting snow can be carriers of phosphate to surface waters. Also, soil erosion of fertilized fields and lawns can carry a considerable amount of particulate phosphate to streams.[26]

Animal Waste: Generally, phosphorus is an important nutrient for animal metabolism, so animal waste can produce phosphate as biological body system. Therefore, runoff in the areas of cattle feedlots, hog farms, dairies, and barnyards can make issue in waters with Phosphorus problem.[27]

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[24] Sheila Murphy, “General Information on Phosphorus,” 2007, 25 Sep. 2011 <http://bcn.boulder.co.us/basin/data/NEW/info/TP.html>.

[25] Ibid.

[26] Ibid.

[27] Ibid.

Industrial Discharge: Industrial discharge can contain phosphorus in the form of polyphosphates. Polyphosphates are often added to water to prevent iron oxides or calcium carbonates forming. If this water is released to streams or lakes, polyphosphates will convert to orthophosphate, which can contribute to an eutrophication problem.[28]

Forest Fires: Forest fires can cause soil erosion, which will release phosphorus bound to soil particles. Then the storm runoff can carry phosphorus to the waterbody.[29]

Synthetic Materials: Synthetic materials (construction materials, flame retardant and plasticizers) commonly contain phosphorus in the form of organophosphates.[30] The synthetic materials are a possible phosphorus source since it was a dam construction.

2.7.2 Turbidity

Turbidity is one of physical characteristics of water body. Turbidity is a measure of the presence of suspended materials such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton, microscopic organisms, and other particulate material in the water.[31] Turbidity is possible to be measured in both laboratory and on-site of the waterbody. Typically, turbidity is measured by shining a light through the water and reported in the unit “Nephelometric Turbidity Units (NTU).[32]

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[28] Sheila Murphy, “General Information on Phosphorus,” 2007, 25 Sep. 2011 <http://bcn.boulder.co.us/basin/data/NEW/info/TP.html>.

[29] Ibid.

[30] Ibid.

[31] Mackenzie Davis, Principles of Environmental Engineering and Science, (New York: Mcgraw-Hill Companies, Inc, 2004).

[32] US Geological Survey, “Turbidity,” 2011, 8 Oct. 2011 < http://ga.water.usgs.gov/edu/characteristics.html>.

Problems with turbidity in the water system

There are three main problems if the waterbody is turbid. First, the light penetration of water bodies is significantly reduced. The consequence is reduced photosynthesis of aquatic plants which causes a day time release of oxygen into the water. Second, the high turbidity level means a lot of matter is in the water. Third, the matters in the turbid water can fill the space between rocks which used to be the place for small organisms or eggs to live in. Therefore, the reproduction of small organisms and eggs will be reduced due to the decrease of living space.[33]

2.7.3 Dissolved Oxygen

Dissolved Oxygen (DO) or Oxygen saturation is a relative measure of the amount of oxygen dissolved in the water. Aquatic organisms need oxygen to live by transforming microscopic bubbles of oxygen in the water to their blood.[34] Therefore, low dissolved oxygen can turn a waterbody to an unbalanced aquatic ecological system.

2.7.4 Temperature of Water

Generally, aquatic organisms are cold-blooded animals, which mean they are unable to internally adjust body temperature, and temperature will influence their biological activity and growth. Temperature is also important for water chemistry. When temperature of waterbody is high, rate of chemical reactions will increase, and this will affect biological activities of aquatic organisms. For example, some compounds in the water turn more toxic for aquatic organisms at high temperature. Therefore, it is important to determine temperature of water before analyze the

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[33] Water on Web, "Turbidity," 2006, 13 Oct. 2011 < http://www.waterontheweb.org/under/waterquality/turbidity.html>.

[34] Water on Web, "Dissolved Oxygen," 2007, 13 Oct. 2011< http://www.waterontheweb.org/under/waterquality/oxygen.html>.

water quality. Temperature is commonly reported in degrees on the Celsius temperature scale (C).[35]

2.7.5 pH of water

pH of water is the measurement of the concentration of hydrogen ions (H^+). The pH is scaled from 0 to 14. A pH of 7 is considered as neutral; less than 7 is considered as acidic, and greater than 7 are basic. The pH of water is important to measure because it can determine the solubility of the chemical constituents such as nutrients (phosphorus, nitrogen, and carbon), and heavy metals. The pH value also determines whether aquatic organisms can live.[36]

2.7.6 Specific Conductance

Specific Conductance is a measure of the ability of water to conduct electrical current. The specific conductance is influenced by the amount of dissolved solids in the water. A high level of specific conductance implies high levels of dissolved solids, which can create unpleasant taste and odor. It also affects the solubility of certain constituents in water, and can cause deterioration of plumbing fixtures and appliances.[37]

2.7.7 Bacteria

Bacteria are microscopic, single-celled organisms, which are able to live in many environments including water. They can perform many complex actions, some of which are beneficial and some harmful. Most bacteria are not harmful and do not cause human health

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[35] Water on Web, “Temperature, ” 2008, 13 Oct. 2011,< http://www.waterontheweb.org/under/waterquality/temperature.html>.

[36] Water on Web, “pH,” 2006, 13 Oct. 2011< http://www.waterontheweb.org/under/waterquality/pH.html>.

[37] United States Geological Survey’s, “Specific Conductance,”2011, 7 Oct. 2011 < http://ga.water.usgs.gov/edu/characteristics.html#Conductance>.

problems, but some, such as E. coli, can be detrimental to human health. Criteria for concentrations of indicator bacteria in recreational waters have been developed by the USEPA. The USEPA recommended that E. coli should be used as the indicator in freshwater recreational areas with the number of colony forming units of E. coli organisms per 100 ml. The risk of getting sick increases as total numbers of colonies is exceeded.[38]

2.7.8 Ammonia

Ammonia (NH_3) is generally a gas; however, ammonia is formed by the action of bacteria on proteins and urea. The ammonia consists of nitrogen which is good for growing plants. Therefore, like phosphorus, excessive ammonia in the water can lead to eutrophication. Moreover, ammonia is harmful to fish and aquatic systems even at low concentrations.[39]

2.7.9 Dissolved Ions

Dissolved ions are electrically charged atom or group of atom formed by the loss (+) or gain (-) electrons. Dissolved ions can be measured by ion chromatography. It is able to measure concentration of anions such as fluoride, chloride, nitrate, nitrite, sulfate, phosphate in the unit parts per billion.[40]

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[38] United States Department of Agriculture, “Bacteria and Water Quality,” 2012, 16 Feb. 2012 < http://www.usawaterquality.org/volunteer/ecoli/june2008manual/chpt2_ecoli.pdf>.
[39] Hach Company, “Important of Water Quality Factors,” 2006, 22 Feb. 2012 < http://www.h2ou.com/h2wtrqual.htm>.
[40] Monica Z. Brunkner, “Ion Chromatography,” 2012, 22 Feb. 2012 < http://serc.carleton.edu/microbelife/research_methods/biogeochemical/ic.html>.

2.7.10 Total Suspended Solids

Total suspended solids (TSS) consist of organic and mineral particles in the water column. Total suspended solids are closely linked to amount of the pollutants entering the water body such as phosphorus, metals, and a wide range of industrial and agricultural chemicals.[41]

2.8 Sampling

A sampling plan is required to be designed before the sampling is conducted. There are some factors, such as what to sample, where to sample and when to sample, that have to be considered while developing the sampling plans. This section will present background information about the sampling and sample testing process. Topics in this section include sampling parameter, sampling locations, sampling time and period, and water quality parameter measurements.

2.8.1 Sampling Parameters

In order to obtain the primary causative variables of eutrophication, water quality parameters that can reflect the impacts of eutrophication have to be measured and assessed. It is necessary to collect analytical data for several reasons, such as assessment of the normal condition of the waterbody; classification of the waterbody; assessment of the load and response relationship; selection of appropriate measures for external and internal growth-limiting nutrients; and prediction of changes in tropic status. When selecting the appropriate analytical procedures in order to determine the values of water quality parameters, factors that should be put into

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[41] The United Nations GEMS/Water Programme, “Suspended Solids and Water Quality,” 2002, 22 Feb. 2012< http://www.gemswater.org/atlas-gwq/solids-e.html>.

considerations: 1) the required rapidity of the analysis; 2) the required sensitivity and detection limits; 3) the constraints on accuracy; 4) the total number of analysis in the project[42].

A water sample, which is gathered from the waterbody, should be indicative of the actual condition of the waterbody. It can be considered as a representative sample of the waterbody for the components of interest. Moreover, the sample is required to provide a description of the temporal and spatial variations of the waterbody. In order to achieve this requirement, there are several factors must be considered in designing the sampling process[43]:

Table 1: Validity and Representativeness

Validity of the samples	**Representativeness**
Sampling sites	The necessary sample size
Sampling frequency and timing	• A network of single samples at random versus integrated samples • Sample collection • Sample transportation and storage

After the preservation from the sampling site, dissolved oxygen profile also can be determined in the laboratory. Most of the samples can be stored for a long period of time if the preservation is properly set up, but the shorter the time in between collecting the sample and analyzing, the more reliable the results can be. Microbial activities can change the concentration of dissolved reactive phosphorus and dissolved total phosphorus in the water sample. So ideally, filtration of the sample at the site can achieve the most accurate determinations[44]. In the situations that do not allow the filtration at the site, another way to obtain accurate values is to

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[42] Sven-Olof Ryding and Walter Rast, The Control of Eutrophication of Lakes and Reservoirs, (France: The United Nations Educational Scientific and Cultural Organization, 1989).
[43] Ibid.
[44] Ibid.

control the time period between collecting sample and analyzing under a couple of hours; also, transportation of samples is required to be in a cooler or an appropriate cold storage container, and the samples should be kept in the dark[45]. If sampling techniques are not carefully selected, the results from the samples may be invalid for analysis. Therefore, the samples must be collected and handled in the proper ways so the values of the parameters can remain the same as those in the waterbody at the time of sampling.

2.8.2 Sampling Location

Selecting of sampling sites and frequency of the sample collection is dependent upon the morphometry and hydrodynamic properties of the waterbody. All major tributaries must be considered and included in the measurement and calculation of both the concentrations and the masses of nutrients and other parameters of the waterbody. The selection of sampling locations should contain the possibility of a heterogeneous distribution of the water quality[46].

Consistency in the sampling locations in a waterbody is also important. It provides reliability on assessment of changes in the values of measured water quality parameters over time. Furthermore, the consistency in the sampling location can also insure a reference point to compare the water quality in other locations of the waterbody to be assessed[47]. Therefore, once the sampling process is begun, it is not appropriate to change sampling locations. If it is required to sample another location of the waterbody, it is recommended to add a new sampling location rather than to change the existing locations. At the same location of a waterbody, there are also vertical samples for analysis. The required number of vertical samples depends on the purpose of

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[45] Sven-Olof Ryding and Walter Rast, The Control of Eutrophication of Lakes and Reservoirs, (France: The United Nations Educational Scientific and Cultural Organization, 1989).
[46] Ibid.
[47] Ibid.

the measurement. For a non-stratified waterbody, it usually is adequate to take water samples at 0.5 m below the water surface, mid-depth and 0.5 m above the bottom. For a shallow waterbody, an integrated sample that is selected with a hose lowered through the water column may provide adequate presentable information on average nutrients level in the waterbody[48].

2.8.3 Sampling Time and Period

In some waterbodies, diurnal variations do occur and are relevant to the sampling process. So, sampling times have to be selected very carefully to reflect these diurnal variations. In the waterbodies with high chlorophyll levels, the dissolved oxygen concentration in the surface water is normally the lowest during the sunrise, and the maximum concentration occurs at noon time. If samples are frequently collected at the same time of day and do not reflect the diurnal variations, the results might be inaccurate for the average concentration of the dissolved oxygen. In order to determine a waterbody's diurnal variations in dissolved oxygen, investigation over a 24-hour period is required. An appropriate approach includes measurements at pre-sunrise, noon and pre-sunset[49].

According to "*The Control of Eutrophication of Lakes and Reservoirs*", the following minimum requirements for sampling frequency are recommended in order to obtain adequate data for accurate water quality assessment:

> "1. Samples should be collected monthly from November to March, and approximately biweekly from April to October in northern temperate climates. The same regime would apply over the corresponding growth and non-growth months in southern temperate climates;

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[48] Sven-Olof Ryding and Walter Rast, The Control of Eutrophication of Lakes and Reservoirs, (France: The United Nations Educational Scientific and Cultural Organization, 1989).

[49] Ibid.

> 2. In tropical/sub-tropical regions, samples should be collected biweekly from the start of the rainy season until three months after it is over, as well as during the period of thermal stratification. Samples should be collected monthly at other times of the year.
>
> 3. In both cases above, sampling also should be done during any overturn periods. In addition, if algal blooms occur between the above-noted sampling intervals, samples should be taken during the bloom periods."

2.9 Best Management Practices (BMPs)

This section is given the definition of Best Management Practices (BMPs). There are two topics in this section which are problems that are caused by stormwater, and definition of a BMP.

2.9.1 Stormwater Problems

There are two components for a stormwater pollution problem. First, stormwater increases volume and rate of runoff for waterbody. Second, stormwater also increases the concentration of pollutants in the runoff. These two problems cause the changes in hydrology and water quality of waterbody such as increased flooding, decreased aquatic biological diversity, and increased sediment and erosion. Therefore, it is important to have effective management of stormwater runoff. The preferred outcomes are protection of wetlands and aquatic ecosystem, improved water quality entering surface waters, conservation of water resources, protection of public health, and flood control.[50]

2.9.2 Definition of BMPs

The National Menu of Best Management Practices for Stormwater Phase II was first released in October 2000.[51] BMPs are effective stormwater best management practices which are often achieved from a management systems approach, as opposed to an approach that focuses on individual practices. The pollutant control from this management system is presented on the range of effectiveness associated with each single practice, the costs, and results. Although individual practice is not effective enough, the combination of practices provide high effectiveness of the management system.[52]

BMPs work in both ways of prevention and treatment. For example, it is difficult to treat water quality of waterbodies with pollutants. Therefore, the prevention of entering pollutants is the first way to consider for management system combined with waterbody treatment. BMPs under each of the minimum measures-particularly the obvious category of pollution prevention, as well as outreach, education, and erosion and sediment control-focus on the prevention of pollutants from ever getting into stormwater (United States Environmental Protection Agency, 2007). Currently, there are six minimum control measures that are often recommended for MS4s, as listed below;

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[50] United States Environmental Protection Agency, “Menu of BMPs,” 2007, 14 Oct. 2011 < http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/bmp_background.cfm>.

[51] United States Environmental Protection Agency, “National Menu of Stormwater Best Management Practices,” 2008, 14 Oct. 2011 < http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/index.cfm>.

[52] United States Environmental Protection Agency, “Menu of BMPs,” 2007, 14 Oct. 2011 < http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/bmp_background.cfm>.

I. ***Public Education*** – These BMPs are for MS4s to inform individuals and households about ways to reduce stormwater pollution.

II. ***Public Involvement*** – These BMPs are for MS4s to involve the public in the development, implementation, and review of an MS4's stormwater management program.

III. ***Illicit Discharge Detection and Elimination*** – These BMPs are for identifying and eliminating illicit discharges and spills to storm drain systems.

IV. ***Construction*** – These BMPs for MS4s and construction site operators address stormwater runoff from active construction sites.

V. ***Post-construction*** – These BMPs are for MS4s, developers, and property owners to address stormwater runoff after construction activities have completed.

VI. ***Pollution Prevention and Good Housekeeping*** – These BMPs are for MS4s to address stormwater runoff from their own facilities and activities.

These minimum control measures were evaluated for this project to design the most appropriate water quality control and improvement plan.

2.9.3 Possible Structural BMPs for Green Hill Pond

Considering the landscape, there are nine possible structural BMPS that would be appropriate for Green Hill Pond; sediment fore bays, vegetated filter strips, Bioretention area and rain gardens, constructed stormwater wetland, wet basin, drainage channels, grassed channel, water quality swale, and dredging.

Sediment Fore bays

A sediment forebay is a post-construction practice. It may consist of an excavated pit, bermed area, or cast structure. This type of structural BMPs combines with a weir. The purpose of this BMP is to slow incoming stormwater runoff and facilitate the gravity separation of suspended solids.[53]

Vegetated Filter Strips

Vegetated filter strips are consistently graded surfaces vegetated with grass or close-growing native plants. This type of practice is also known as filter strips, grass buffer strips and grass filters. This practice should be constructed on areas that receive runoff from adjacent impervious areas. The purposes of this design are to slow runoff velocities, to trap sediment, and to promote infiltration. Therefore, this practice thereby helps reducing runoff volumes and pollutants.[54]

Bioretention Areas (Rain Gardens)

Bioretention is a practice using soils, plants, and microbes in order to treat stormwater. The design of this practice is shallow depressions consisting of soil and topped with a thick layer of mulch and local plants. In this process, stormwater runoff is directed into this system, which reduces and eliminates pollutant concentrations. [55]

Constructed Stormwater Wetland

Constructed stormwater wetlands are systems that maximize the removal of pollutants from stormwater runoff through wetland vegetation uptake, retention and settling. This type of practice momentarily stores runoff in the pools. The practice supports conditions suitable for the growth of wetland plants. The advantage of this BMP is that it can work with others such as sediment fore bays.[56]

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[53] Massachusetts Department of Environmental Protection, "Structural BMPs Specifications for the Massachusetts Stormwater Handbook," 2012, 7 Feb. 2012 <http://www.mass.gov/dep/water/laws/v2c2.pdf>.

[54] Ibid.

[55] Ibid.

[56] Ibid.

Wet basin

Wet basins are the practice that uses a permanent pool as the primary mechanism to treat stormwater. The purpose of this pool is to allow sediments in the stormwater runoff to settle. This practice includes storage capacity to controls peak discharge of stormwater runoff. This system has high effectiveness to remove pollutants. However, the efficiency of this system depends on the pool size and the volume of runoff from the surrounding watershed.

Drainage Channels

This practice is a traditional vegetated open channel. The purpose of this design is to provide for non-erosive conveyance. However, infiltration and TSS removal are not anticipated in this practice. Therefore, this system can gather runoff and convey to other structural BMPs in order to treat the limitation of this system.[57]

Grassed Channel

Grassed Channels are treatment systems with a longer hydraulic residence time than drainage channels. The removal mechanisms are sedimentation and gravity separation, rather than filtration. In order to effectively remove total suspended solids, Other BMPs may be needed to complement this system.[58]

Water Quality Swale

Water quality swales are vegetated open channels designed to treat the required water quality volume. There are two different types of water quality swales: dry swales and wet swales. This system is used for conveyance as well as pollutant removal.[59]

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[57] Massachusetts Department of Environmental Protection, “Structural BMPs Specifications for the Massachusetts Stormwater Handbook,” 2012, 7 Feb. 2012 <http://www.mass.gov/dep/water/laws/v2c2.pdf>.

[58] Ibid.

[59] Ibid.

Dredging

The purpose of dredging would be to remove phosphorus-laden sediments and prevent future release into the water column. A risk assessment is often considered in the potential situation where hazardous materials could be bound to the in-pond sediments as well as phosphorus.

2.9.4 Non-structural BMPs

Advertising and public education is one of the ways to raise public awareness about non-point-source water-pollutant problems. Moreover, this option helps people make appropriate decisions concerning the protection of runoff quality. The benefits of public education programs are better enforcement of construction-site erosion and stormwater regulations, and support for increased fees to help pay for these programs. However, the limitation for this option is difficult to monitor and quantify the direct water quality benefits.

2.9.5 Advantages and Disadvantages of BMPs

There are several advantages and disadvantages to choosing a specific or multiple combinations of BMPs. In order to select the most beneficial options for reducing phosphorus, the following structural BMPs options have been investigated.[60]

Sediment Fore bays

Advantages:

- Provides pretreatment of runoff before delivery to other BMPs
- Slows velocities of incoming stormwater

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[60] Haestad Methods, Stormwater Conveyance Modeling and Design, (Waterbury, CT: Haestad Press, 2003).

- Easily accessed for sediment removal
- Longevity is high with proper maintenance
- Relatively inexpensive compared to other BMPs
- Greater detention time than proprietary separators

Disadvantages:

- Removes only coarse sediment fractions
- No removal of soluble pollutants
- Provides no recharge to groundwater
- No control of the volume of runoff
- Frequent maintenance is essential

Vegetated Filter Strips

Advantages:

- Reduces runoff volumes and peak flows
- Slows runoff velocities and removes sediment
- Low maintenance requirements
- Serves as an effective pretreatment for Bioretention cells
- Can mimic natural hydrology
- Small filter strips may be used in certain urban settings
- Ideal for residential settings to treat runoff from small parking lots and roads
- Can be used as part of runoff conveyance system in combination with other BMPs
- Little or no entrapment hazard for amphibians or other small creatures

Disadvantages:

- Variability in removal efficiencies, depending on design
- Little or no treatment is provided if the filter strip is short-circuited by concentrated flows
- Often a poor retrofit option due to large land requirements
- Effective only on drainage areas with gentle slopes (less than 6 percent).
- Improper grading can greatly diminish pollutant removal

Bioretention Areas (Rain Gardens)

Advantages:

- Can be designed to provide groundwater recharge and preserves the natural water balance of the site
- Can be designed to prevent recharge where appropriate
- Supplies shade, absorbs noise, and provides windbreaks
- Can remove other pollutants besides TSS including phosphorus, nitrogen and metals
- Can be used as a stormwater retrofit by modifying existing landscape or if a parking lot is being resurfaced
- Can be used on small lots with space constraints
- Small rain gardens are mosquito death traps
- Little or no hazard for amphibians or other small animals

Disadvantages:

- Requires careful landscaping and maintenance
- Not suitable for large drainage areas

Constructed Stormwater Wetland

Advantages:

- Relatively low maintenance costs
- High pollutant removal efficiencies for soluble pollutants and particulates.
- Removes nitrogen, phosphorus, oil and grease
- Enhances the aesthetics of a site and provides recreational benefits
- Provides wildlife habitat
- Depending upon design, more land requirements than other BMPs

Disadvantages:

- Until vegetation is well established, pollutant removal efficiencies may be lower than anticipated
- Relatively high construction costs compared to other BMPs
- May be difficult to maintain during extended dry periods
- Does not provide recharge
- Creates potential breeding habitat for mosquitoes
- May present a safety issue for nearby pedestrians
- Can serve as decoy wetlands, intercepting breeding amphibians moving toward vernal pools

Wet basin

Advantages:

- Capable of removing both solid and soluble pollutants
- Capable of removing nutrients and metals
- Aesthetically pleasing BMP

- Can increase adjacent property values when properly planned and sited
- Sediment generally needs to be removed less frequently than for other BMPs
- Can be used in retrofits

Disadvantages:

- Capable of removing both solid and soluble pollutants
- Capable of removing nutrients and metals
- Aesthetically pleasing BMP
- Can increase adjacent property values when properly planned and sited
- Sediment generally needs to be removed less frequently than for other BMPs
- Can be used in retrofits

Drainage Channels

Advantages:

- Conveys stormwater
- Generally less expensive than curb and gutter systems
- Accents natural landscape
- Roadside channels reduce driving hazards by keeping stormwater flows away from street surfaces during storms

Disadvantages:

- Higher degree of maintenance required than for curb and gutter systems
- Roadside channels are subject to damage from off-street parking and snow removal
- Provides limited pollutant removal compared
- to water quality swales

- May be impractical in areas with flat grades, steep topography or poorly drained soils
- Large area requirements for highly impervious sites

Grassed Channel

Advantages:

- Provides pretreatment if used as the first part of a treatment train
- Open drainage system aids maintenance
- Accepts sheet or pipe flow
- Little or no entrapment hazard for amphibians or other small animals

Disadvantages:

- Short retention time does not allow for full gravity separation
- Limited bio-filtration provided by grass lining
- Cannot alone achieve 80% TSS removal
- Must be designed carefully to achieve low flow rates for Water Quality Volume purposes
- Mosquito control considerations

Water Quality Swale

Advantages:

- May be used to replace more expensive curb and gutter systems
- Roadside swales provide water quality and quantity control benefits, while reducing driving hazards by keeping stormwater flows away from street surfaces
- Accents natural landscape
- Can be used to retrofit drainage channels and grass channels
- Little or no entrapment hazard for amphibians or other small animals

Disadvantages:

- Higher degree of maintenance required than for curb and gutter systems
- Roadside swales are subject to damage from off-street parking, snow removal, and winter deicing
- Subject to erosion during large storms
- Individual dry swales treat a relatively small area
- Impractical in areas with very flat grades, steep topography or poorly rain soils
- Wet swales can produce mosquito breeding habitat
- Should be set back from shellfish growing areas and bathing beaches

Dredging

Advantages:

- Will release and remove nutrients from water

Disadvantages:

- Releases toxic substances into Pond
- Expensive

Chapter 3: Methodology

This chapter provides information on methods and techniques which include four subtopics: guiding questions, water quality measurement procedures, data collection, and data analysis.

3.1 Guiding Questions

The following guiding questions directed the procedures to accomplish the goal of this project.

1. What is the current water quality of the Green Hill Pond? In order to answer the question, this project focused on determining levels of turbidity, phosphate, dissolved oxygen (DO), total suspended solid, pH, temperature, total phosphorus, and specific conductance.

2. What are the sources of pollutants? Since Green Hill Pond does not have a stream inlet, three possible sources are stormwater, ground water, or possibly lake-bottom sediments. If these pollutant sources are related to phosphorus loading in the Green Hill Pond, how much pollutants get to the pond from these sources?

3. What are the best possible appropriate for improving water quality in the Green Hill Pond by considering economic, environment, sustainability, manufacturability, ethical, health and safety, and political concerns?

3.2 Decision on the Water Quality Measurement

This section provides the water quality measurement methods, including sample measurement, sampling location, and time.

3.2.1 Decision on sample measurements

In this project, several parameters of the water quality needed to be measured in order to obtain adequate information to determine current water condition of the Green Hill Pond. The minimum requirement of measured parameters for each sample includes:

Amounts of phosphorus: it is important to determine the total amount of the phosphorus in the water body because an excessive amount of phosphorus can lead to reduction of water clarity, unpleasant odor and taste, decrease of dissolved oxygen, reduction in the aquatic population and toxin from the green-blue algae. Also, a large load of phosphorus is estimated while the draft permit is published. The amount of phosphorus in the samples can be proportionally converted to the amount of phosphorus in the pond.

Turbidity: the turbidity of water quality shows the water quality level. In the draft permit, which was published by the EPA in 2008, also stated that the pond is turbid. Finding the turbidity of samples can present the clarity of the current water quality in the pond.

Dissolved oxygen: the amount of dissolved oxygen in the water samples can present the supply of microscopic bubbles of oxygen in the water, which can be proportionally convert to the amount of dissolved oxygen in the pond.

Temperature of the water samples: it is important to measure temperature of the sample because the speed of chemical reactions increases in a high water temperature, which affects biological activities of aquatic organisms.

pH value: pH values of the samples determine the solubility of the chemical constituents and the aquatic living conditions.

Specific conductance: The high specific conductance of water presents the high amount of dissolved solid in the water. This can lead to unpleasant odor and taste which affect the solubility of the water.

Total Suspended Solids: The amount of total suspended solids can effectively link to the amount of phosphorus or other pollutants in the water. It might degrade the water quality.

Bacteria: A water body with high bacteria can be harmful to human and public health; especially there are participation recreational areas around the pond.

Ammonia: Even a low concentration of ammonia is already harmful to fish and aquatic microorganisms as well as algae blooms.

3.2.2 Decision on sampling locations

The objectives of this project were to determine the current water quality of the pond and the sources of the pollutants if there are pollutants in the pond. Therefore, during the sampling process, water samples were collected as shoreline samples, in-pond samples and runoff samples. The shoreline samples were taken at the locations of the southeast of the dam outlet, northwest of the dam outlet, the northern outlet, and the shore adjacent to the playground. The in-pond samples were taken at the center of the pond and at the center where about 20 feet away from the northern outlet. More accurately, the in-pond samples were tanked at the depth of 6 feet. The locations of runoff samples were determined by observations during the storm event. There were three runoff samples on the golf course side, one runoff sample from the shore adjacent to the playground, one from the northwest of the dam outlet, and one from the northern outlet shore. Locations of three types of samples were also recorded by using the handheld GPS.

3.2.3 Decision of sampling time

To obtain more accurate results, the samples were collected in dry and wet weather conditions for comparison as well as a runoff analysis. The wet weather shoreline samples and the runoff samples were taken on the same day during a storm event. The dry weather shoreline samples were taken a week after the storm event. The in-pond samples required a boat to obtain water samples. For safety, the in-pond samples were taken during a day time in a dry weather condition.

3.3 Data Collection

To measure the current water quality parameters, four sets of samples were collected for laboratory testing—dry weather water samples in the pond (November 16th, 2011), stormwater runoff samples from the surrounding areas (October 27th, 2011) and samples of sediment in the pond (December 2nd, 2011).

3.31 Shoreline Water Sample Collection

In order to design water quality control and improvement for the Green Hill Pond, it is important to identify dissolved oxygen value (DO), pH value, turbidity, specific conductance, total phosphorus, ammonia, dissolve ions, total suspended solids and bacteria in the pond under dry and wet weather condition.

The locations of water samples were decided by considering the combination of visibility accessibility, and runoff possibility. Sample bottles for different parameters were then prepared and labeled. Shoreline wet weather samples were taken during the storm event on October 27th, 2011, and the shoreline dry weather samples were taken on November 2nd, 2011. Each sampling location was recorded xy-coordinates by using a handheld GPS before collecting samples. For accuracy, it was required to wash the sampling bottles three times with the sampling water at the specific location (this technique is to ensure the samples would not mix with any leftover materials from the previous use), and then fill the washed sample bottles. After water samples were obtained, sample bottles were kept in the cooler while they were transported back to the lab, where they were refrigerated until analysis.

3.3.2 Stormwater Runoff Sample Collection

Since there is no inflow to the pond, stormwater runoff, precipitation, and groundwater inputs can be considered the main sources of the pond water. For determining the sources of pollutants in the pond, storm runoff samples are required to be collected and tested. To achieve this, locations where the runoff gets in the pond were determined before collecting samples by observations. The runoff samples were transported back to laboratory for tests.

3.3.3 Sediment Sample Collection

In order to determine pollutants source in the Green Hill Pond, it was important to check the condition of sediment in the pond. It was decided to prepare two cylinder sample bottles in order to obtain sediment samples from two different locations in the pond. The sediment samples were gathered by vertically pushing the sample bottle into the sediment layer under the water surface. To avoid the influence to the sample due the contact with the atmosphere, the cylinders with sediment samples were taken out from the bottom of the pond by using a shovel and sealed with the cover under the water surface.

3.4 Data Analysis

The data analysis includes laboratory analysis, meaning of results, pollutant sources and amount analysis, and computer software analysis.

3.4.1 Laboratory Analysis

In order to obtain accurate results to design a water quality control and improvement plan for the pond, laboratory analysis were involved after water samples, runoff samples, and sediment samples were collected from the pond. Parameters that were tested in the laboratory are listed in the Table 2.

Table 2 Summary of Testing Parameters and Methods

Parameters	Tools or methods
Dissolved ions	Ion Chromatography
Turbidity	Turbidimeter
pH	pH meter
Dissolved oxygen	DO meter
Total Phosphorus	Hach DR/3000 Color Spectrophotometer
Ammonia	Hach DR/3000 Color Spectrophotometer
Specific Conductance	SC meter
Total suspended solids	Filter and Laboratory weight scale
Bacteria	Bacteria Test Kits

Dissolved Ions Test

This test used the ion chromatography unit to test dissolved materials including chloride, fluoride, nitrate, phosphate, and nitrite. In order to operate this test, it was required to prepare a 5-ml syringe, a syringe filter, and a test tube for each sample. It also required a numbered test-tube holder. Then the numerical system for each sample in the computer system was set up. After the numerical system was set up, a syringe with filter was taken to obtain water from the sample, and injected the filtered water sample into the corresponding test tube. These two steps were repeated twice for each sample until the water rose to the line mark. Finally, each tube was taken to the corresponding numbered holes of the Ion Chromatographer Machine. The machine ran the analyzed program and the results of the dissolved ions were represented in about 30 minutes.

Turbidity Test

This test used a Turbidimeter to measure the turbid conditions of the samples. It required using only one specific glass bottle for all sample tests. To start the test, the meter was turned on and selected on the unit mode NTU for turbidity. The sample bottle was well shaken and then poured into the glass bottle until line up to the line mark. Finger prints on the bottle were cleared before placing into the meter. After the sample bottle was put into the meter, the result was shown on the screen. To be accurate on the result, first value or highest value was recorded as the result of each sample. Test steps were repeated for all other samples.

Dissolved Oxygen Test

DO meter was used for this test. To operate the test, the meter was turned on, and the probe was put in a dissolved-oxygen bottle with water and turned on. The probe was set in the bottle for 30 minutes so the meter can operate correctly. After the meter was ready to test samples, the probe was turned off and put into the sample bottle and turned on. The measurement was shown on the screen and recorded as the result. Since the meter was ready to test, it did not require another waiting time to test another sample. The probe was simply turned off, put it into another sample and turned on again for the measurement. This step was repeated for every dissolved oxygen sample.

pH Value

The Accumet® AB15 pH Meter was used to test pH value. To prepare this test, the "Mode" key was pressed until the meter displays pH mode to change meter to the pH mode. And then the existing standardization was cleared by pressing the "setup" key twice and then pressed the enter key. The electrode was rinsed with distilled water and immersed into pH 4 (pink) buffer solution. The Standardization mode was accessed by pressing "std" key. When the "stabilize" message appeared on the screen, the "std" key was pressed again to initiate standardization. These steps were repeated the pH 10 (blue) buffer solution. When the meter accepted the second buffer solution, it briefly displayed the percent slope associated with the electrode's performance. The percents slope associated were 99.1%, 96.2% and 98.9%. After the electrode was determined as a "GOOD ELECTRODE", the electrode was rinsed with distilled water and immersed into the sample. The pH value of the sample was displayed on the meter screen, and the number with a "stabilize" message was the actual pH value of the sample. Since the electrode was determined as a "GOOD ELECTRODE", all tests were simply done by rinsing the electrode with distilled water after each test and immersing the electrode into another sample, and recording the value when the "stabilize" message appears upon the completion.

Total Phosphorus Test

Six standards were created at concentrations of 0.2, 0.5, 1.0, 3.0, 5.0, and 10.0 part per million (ppm) as phosphorus. This range of concentrations was based on preliminary total phosphorus testing of the samples that yielded concentrations well below 10.0 mg/L as phosphorus. As a result of these values, the standards and samples were measured only for reactive phosphorus using this procedure. To prepare the standard solutions, it is necessary to digest solutions by pouring twenty five milliliters of each standard solution into clean beakers.

Then five milliliters (5 ml) of concentrated nitric acid (HNO_3) and one milliliter (1 ml) of sulfuric acid (H_2SO_4) were added respectively, and each beaker was covered with watch cover. After that all beakers were gently heated on a preheated hot plate under hood. This heat will finish when samples are "down to fumes" which could be noticed by checking visible white fumes in the beakers and volume of solutions were reduced to the bottom of beakers. The next step was to cool down all left solutions in the beakers.

Measurements of each of the standards using above procedure, presented in Table 3, produced a linear relationship between the concentration of the standard and its absorbance as displayed in Figure 2. This calibration curve was used through interpolation of the water samples to determine the concentration of reactive phosphorus in each of the samples. Detail procedure of this test is provided in Appendix IV.

Table 3: Absorbance Measurements for Phosphorus Standard Solutions

Standard (ppm)	Absorbance (1/cm)
0.0	0.000
0.2	0.039
0.5	0.014
1.0	0.242
3.0	0.625
5.0	1.008
10.0	2.113

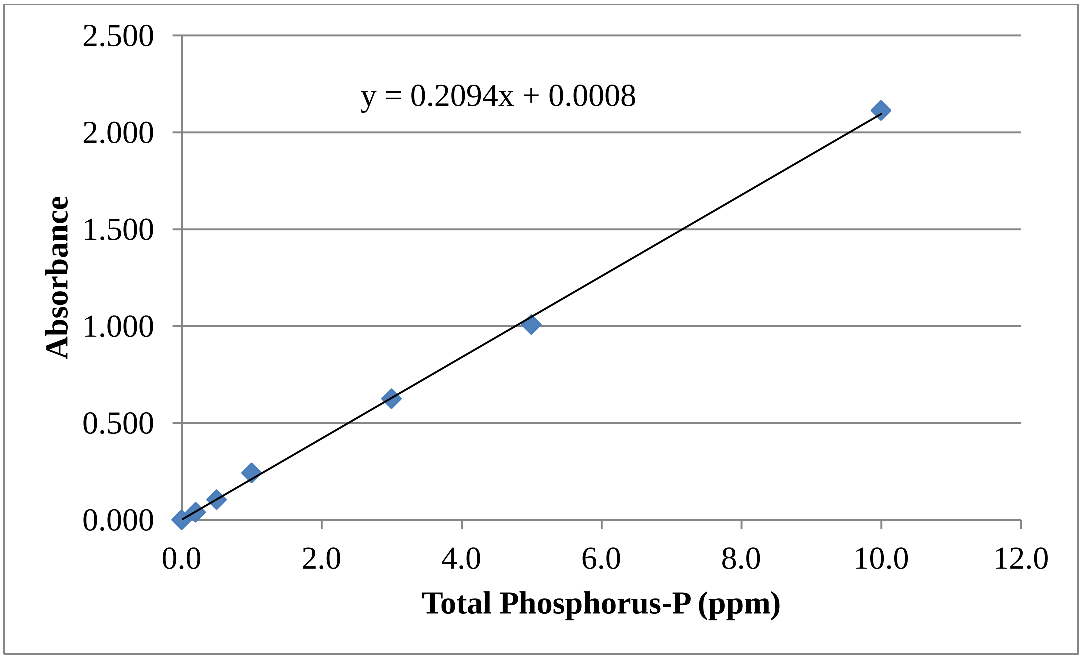

Figure 2: Phosphorus Calibration Curve from Standard Solutions

Ammonia Test

Six standards were created at concentrations of 0.1, 0.5, 1.0, 3.0, 5.0, and 10.0 part per million (ppm) as ammonia. This range of concentrations was based on ammonia testing of the samples that yielded concentrations well below 10.0 mg/L as ammonia. As a result of these values, the standards and samples were measured only for reactive ammonia using this procedure.

In order to test the standard solutions, the procedure starts with zeroing the instrument. Twenty five milliliters of E-pure water was poured into a clean glass sample cell. Then three drops of mineral stabilizer and polyvinyl dispersing agent were added with inversion of the cell taking place after each addition. After that 1 mL of Nessler Reagent was put into the cell beginning a one minute reaction period. It was important to consider that the sample should be analyzed soon after the reaction period terminated as the results obtained 15 minutes later on the sample would not be valid. The sample cell was then inserted into the Hach DR3000 Spectrophotometer to set the "zero" absorbance value.

After zeroing the instrument, the standard solutions could be tested by repeating these steps. Similar to the total phosphorus tests, the measurements, presented in Table 4, prescribe a linear relationship between the concentration of the standard and its absorbance. The resulting calibration curve illustrated by Figure 3 was used to determine through interpolation of the water samples the ammonia concentration present in the samples. Detailed procedures of this test are also provided in Appendix IV.

Table 4: Absorbance Measurements for Ammonia Standard Solutions

Standard (mg/L)	Absorbance (1/cm)
0.0	0.000
0.1	0.053
0.5	0.290
1.0	0.584
3.0	1.672
5.0	2.823
10.0	5.865

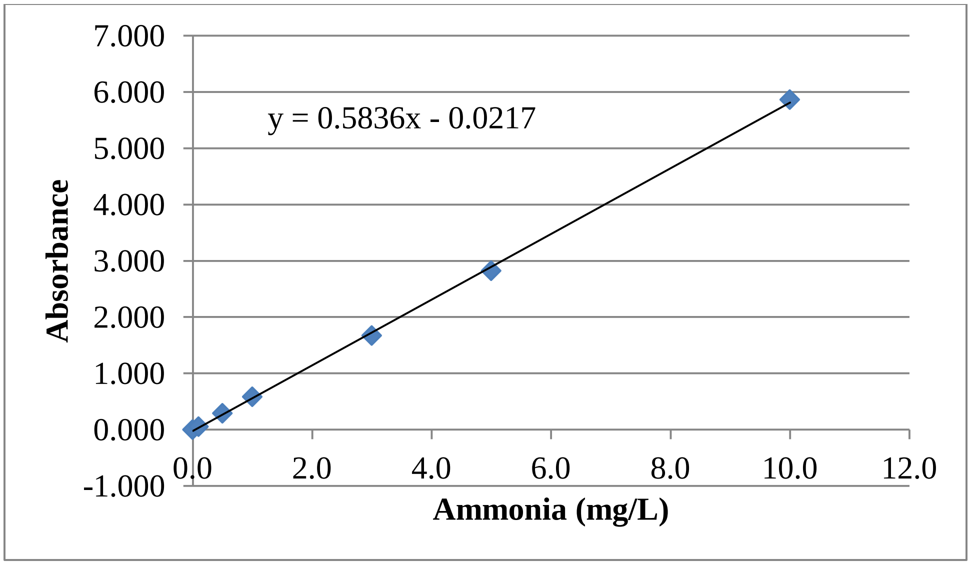

Figure 3: Ammonia Calibration Curve from Standard Solutions

Specific Conductance Test

This test used the SC meter to test the electrical current conductance of the samples. The meter was turned on and waited for a few seconds until numbers and labels appeared on the screen. Each sample bottle was well shaken before tested to make sure the sample was well mixed. And then the probe was put into the water sample to obtain the result. However, it required to make sure the probe was well surrounded by water in the bottle. Due to the reading varies over time, so the highest reading on the screen was recorded after 20 seconds. These steps were repeated for each sample.

Total Suspended Solids

To operate this test, it prepared one small dish plate and one filter paper for each sample, an Erlenmeyer flask with another small hole on the top for vacuum suction tube, a stopper, a water volume measuring cylinder, an electric scale for weights and a vacuum for suction. To start this test, all dish plates were labeled and weighted. Each filter paper was weighted and then placed into a dish plate. Every dish plate with filter paper was weighted together to obtain the total original weight. The oven was turned on and set to 104 ^{o}C. After the preparation, the stopper was put on top of the Erlenmeyer flask to seal the flask. And the filter paper was placed inside the stopper. 200ml of the sample was measured and poured into stopper. The vacuum was connected with the Erlenmeyer flask and turned on for suction. After all water was filtered, top part of the stopper was rinsed with distilled water. Since the distilled water does not contain any suspended solids, the volume of the distilled water was not recorded for determinations. For those samples that did not contain lots of solids, it was decided to add another 200ml of sample to filter. After the filter paper obtained enough solids for calculations, it was taken out and put back into the labeled dish plate. The filtration process was repeated for each sample.

After obtained the suspended solids from all samples, the labeled dish plates and filter paper with suspended solids were put into the oven which was preheated to 104^{o}C for one hour. After the dish plates and filter paper with solids were taken out from the oven, they were placed in the plastic container and cooled down to room-temperature level. After the cooling period, each dish plate with filter paper inside was weighted as the total weight of those three items in the plate. The concentrations of total suspended solids of all samples were conducted. The detail calculation equations are provided in Appendix IV.

Bacteria

This test is to determine the amount of the bacteria in the samples by using the LaMotte ColiQuant EZ. 1 ml of water was obtain from each sample and mixed with one bottle of Coliscan Easygel. All mixtures were poured into a dish and placed into a 35-^{o}C incubator. After the mixtures were hardened, all dishes were flipped over. After 24 hours, the amounts of Coliform in each dish were counted. Detail procedures are provided in Appendix IV.

3.4.2 Sediment Analysis

In order to determine the role of the sediment in Green Hill Pond to the total phosphorus loading, each of the cores were analyzed to assess the potential for desorption of phosphorus. Since the sediment is in solid form, a different method of analysis had to be developed to accommodate this source. Once the core was extracted from its tube, it was mixed by hand, and about 20 grams were placed in a ceramic dish to dry in the oven at 110^{o}C over night in order to remove water present in the sample. After allowing the samples to cool to room temperature, approximately 1.0 gram of each sediment core was placed into beakers to prepare for the test.

Phosphorus Loading Test

Two beakers with approximately 1.0 g of sediment from each core were prepared. Then 40 ml of e-pure water was poured into each beaker. Then 10 ml of nitric acid (HNO_3) was added under the hood. Beakers were covered with a watch cover and were heated gently overnight. Beakers were rinsed with about 15 ml of e-pure water. Then the steps of total phosphorus test in the Section 3.4.1 were applied.

Phosphorus Release Test

In this test, approximately 1.0 grams of each sediment core was put into two beakers, so there was a total of 4 beakers in this test. Then about 30 ml of e-pour water was poured into each beaker, and 30 ml of pond water from sample location 6 was added to the other two beakers. All beakers were stirred for about an hour. Then 25 ml of filtered water from each beaker was taken. Next the steps of total phosphorus test in Section 3.4.1 were applied (The result of this test was dissolved phosphorus, not the total phosphorus because the samples were filtered.)

Sediment Result Analysis

In order to convert the absorbance value to the amount of total phosphorus, the calibration curve illustrated in Figure 4 was used. Results were converted to equivalent concentrations of phosphate when comparing with results for dissolved phosphorus obtained by ion chromatography.

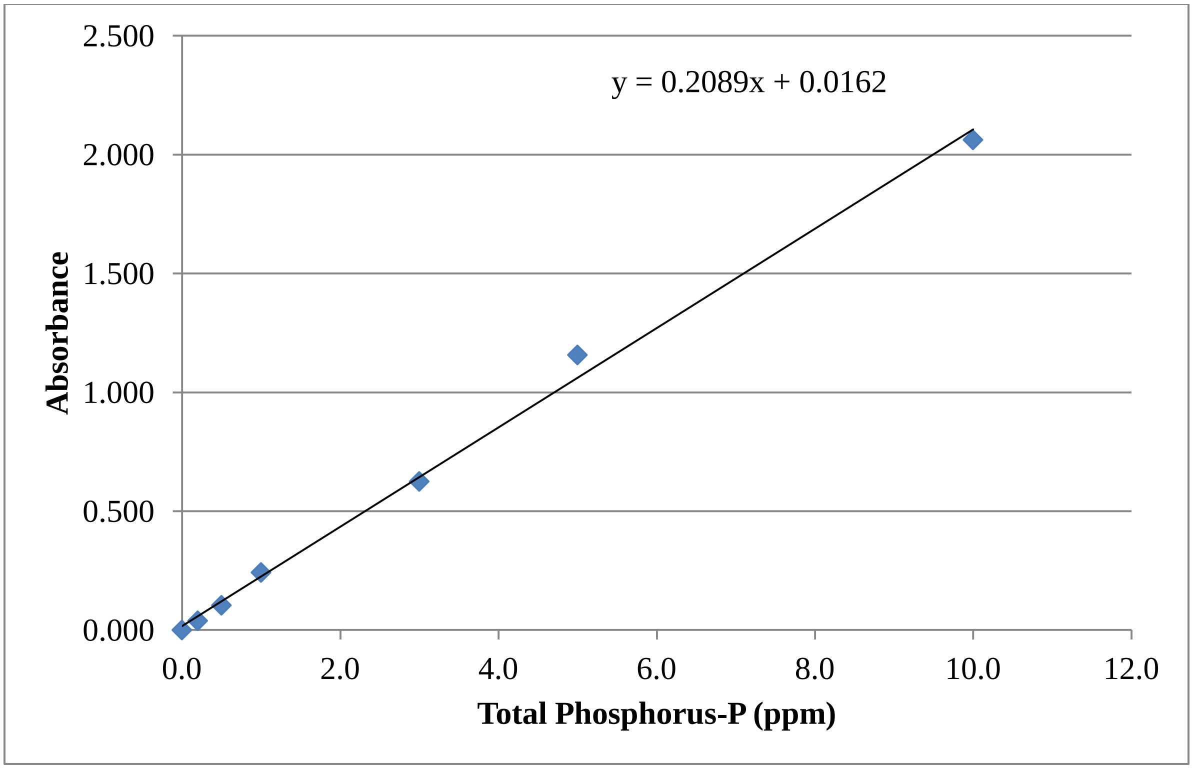

Figure 4: Phosphorus Calibration Curve from Standard Solutions

3.4.3 Interpretation of the Results

The results of each tested parameter were recorded and compared with the results from other locations. After the results were obtained, the determined current water quality would be compared with the estimated water conditions that are listed in the EPA draft permit. The comparisons provided differences or similarities of the determined and estimated water qualities, and also provided evidence for the City of Worcester to update the current condition of the Green

Hill Pond. An appropriate water quality control and improvement plan would be designed based on the determinations of the amounts of pollutants in the pond and the sources of these pollutants.

3.4.4 Computer Software Analysis

In order to determine the elevation of the Green Hill Pond watershed, computer software called Geographic Information System (GIS) was used. GIS is one of many information technologies that have transformed the ways geographers conduct research and contribute to society. In the past two decades, these information technologies have had tremendous effects on research techniques specific to geography, as well as on the general ways in which scientists and scholars communicate and collaborate.

3.4.5 Pollutant Sources and Amount Analysis (NRCS Method)

In order to apply the NRCS method to estimate the total runoff volume during the sampling storm event, it is required to obtain the curve number by using the information of land use areas and soil types of the Green Hill Pond sub-basin. To obtain this information, the ArcGIS program was used.

Runoff samples were taken from six different locations. As such, the Green Hill Pond sub-basin was broken down into different sub-areas to represent the contributing area for each runoff samples. Even though there was no runoff sample taken from the football field area, this area was also included as a sub-area for runoff estimations. The sub-area outlines were created by analyzing the contour lines in the sub-basin. Each sub-area outline is perpendicular to the contours that it passes through to approximately identify the runoff contribution area, and each sub-area was numbered corresponding to the runoff sample in the sub-area. Figure 5 shows the sub-area distribution.

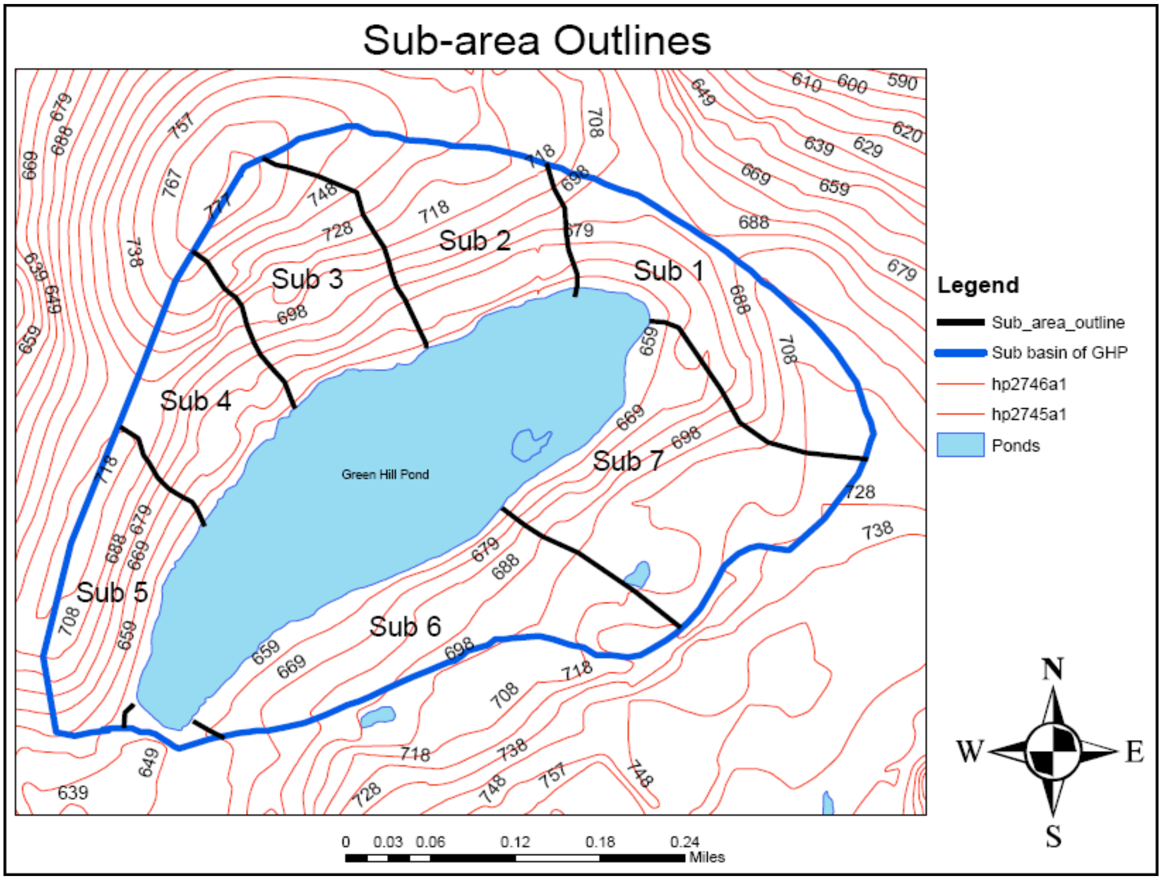

Figure 5: Sub-area Outlines with Contours around the Pond

As shown in Figure 6, the land-use layer was clipped to show only the land uses in the sub-basin. It includes Forest (light blue), Golf Course (pink), Participation Recreation (light grey), Urban Public/Institutional (light yellow), and Water/Wet Land (light purple). After the Land-use layer was modified, a soil layer with the soil code was added into the map. This layer was modified to be hollow with an outline thickness of 2.00 so it would be clear to observe a soil type in a particular land use. In order to obtain the soil code in a particular land use, the "Information" tool of GIS program was utilized. The soil codes were referred to the "Acreage and Proportionate Extent of the Soils" table to obtain the type of the soil. After obtaining the type of the soil, the “Massachusetts Hydrologic Soil Group List” was used to identify the soil class. In each sub-area, the area of a land use with same soil type and class was calculated by using the “measuring tool” in the program. The figure below shows the land uses in the sub-basin. However, the soil types cannot be displayed in the map. Instead, the detailed sub-area analysis and the reference tables are provided in the Appendix VII.

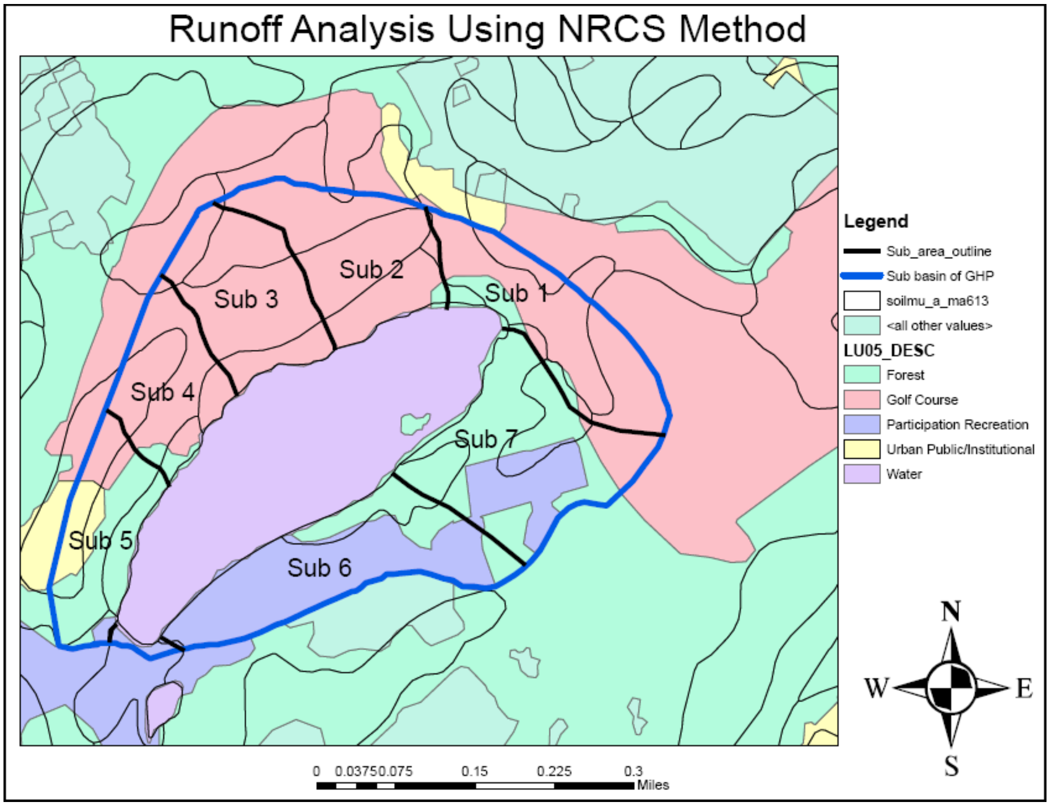

Figure 6: Runoff Sub-areas with Land Uses

After obtaining the areas of different land use with the same type and lass of soil, the total area of each sub-area and the total area of all sub-basin areas were calculated. To confirm this sub-areas summation of the entire sub-basin, the total area of the sub-basin of Green Hill Pond was used (minus the surface area of the pond). The result from the subtraction was very close to the sub-areas summation, so it was decided to use the land-use areas for the runoff calculations.

As the sub-areas were confirmed, the curve numbers for each land use due to different soil classes were obtained from Table 23, Table 24 and Table 25, which are provided in Appendix VI. The composite curve number was calculated by using the equation $CN_{com} = (\sum A_i * CN_i) / (\sum A)$. After developing the composite curve number, the storage at saturation condition $S^{'}$ was computed by using the equation of $S' = \frac{1000}{CN} - 10\ (in)$. In order to apply the equation of $R = \frac{(P-0.2S')^2}{P+0.8S'}$ to estimate the rainfall excess, the P which represents the total precipitation during the storm event was obtained from the official online weather service, which was 0.87 inch in Worcester. The total runoff volume was calculated by using the rainfall excess to multiply with the sum of different land use areas.

3.5 Discovery and Analysis of Control and Improvement Plan

The goal of this process was to identify as many options as possible, such that any or all could be implemented, and then to choose the most applicable and effective design options for the pond. With the analysis of loadings complete, critical areas of control were identified to identify the locations generating the most significant sources of phosphorus, and focus on those for elimination. These areas served as the target of design. Design methods were compiled from EPA methods, structural BMP specifications for Massachusetts stormwater handbook, and stormwater conveyance modeling and design. Any method in these sources was considered, provided it had either been implemented elsewhere or was considered for use, or if there was valid scientific evidence to prove its effectiveness.

3.5.1 Evaluating and adapting alternatives

Research into water quality control and improvement plans yielded a variety of different ways to suppress or eliminate phosphorus loading entering the pond. Analysis of these design options resulted were chosen from many practical means in this situation. This phase required careful and delicate consideration of the effectiveness of removing contaminants of any construction required, impacts to the view of the pond as well as potential effects on water quality. The criteria were efficiency and cost of implementation, as compared to removal efficiency for the phosphorus removal.

Chapter 4: Results and Analysis

Laboratory analyses for water samples were used to determine the current water quality of Green Hill Pond, and runoff and sediment analyses were used to determine pollutant load entering to the pond. Using the results, it was possible to determine the most significant pollutant contributions to Green Hill Pond, and consider possible designs to control and improve water quality of the pond.

4.1 Green Hill Pond Basin Delineation

In order to assess the contributing watershed of the pond, a Geographic Information System (GIS) software package was used to develop maps for the pond. These maps include information on: outline of the Green Hill Park, elevations, slope classes, road system, and sub-basin information.

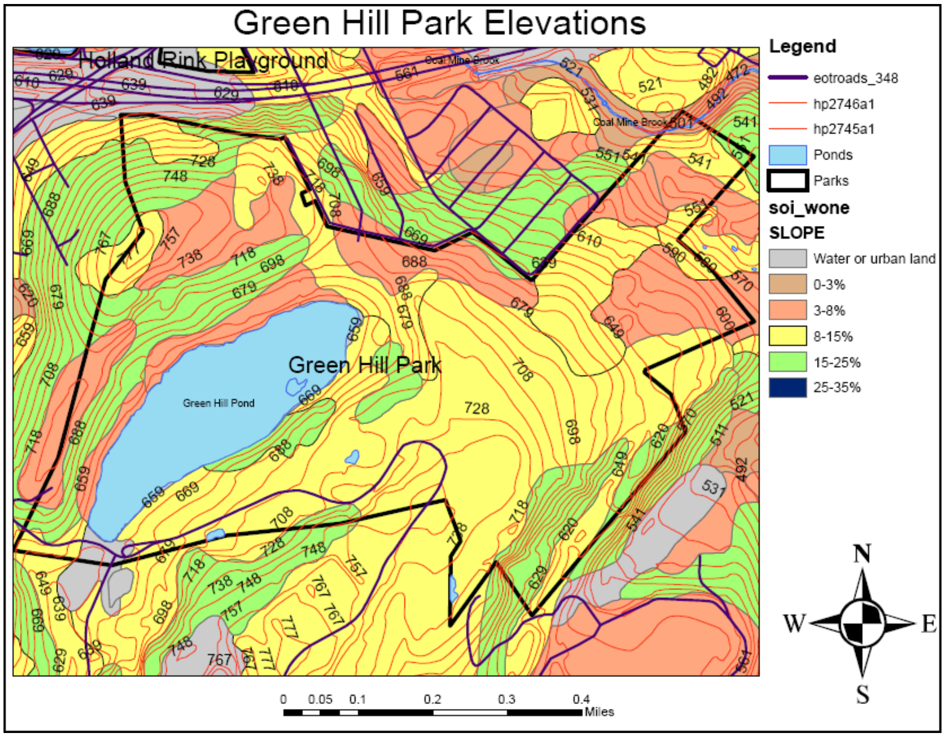

Figure 7: Green Hill Park Elevations

As shown in Figure 7, Green Hill Pond is in the western side of the Green Hill Park. The elevations around the pond vary from 659 feet at the pond to 777 feet. The pond receives stormwater runoff from the surrounding area. On the north side of the pond, where the Green Hill Golf Course is located, slopes vary from 3% to 25%. On the southeast side of the pond, the slopes are between 8% and 15%, and some small areas have steeper slopes of 15% to 25%.

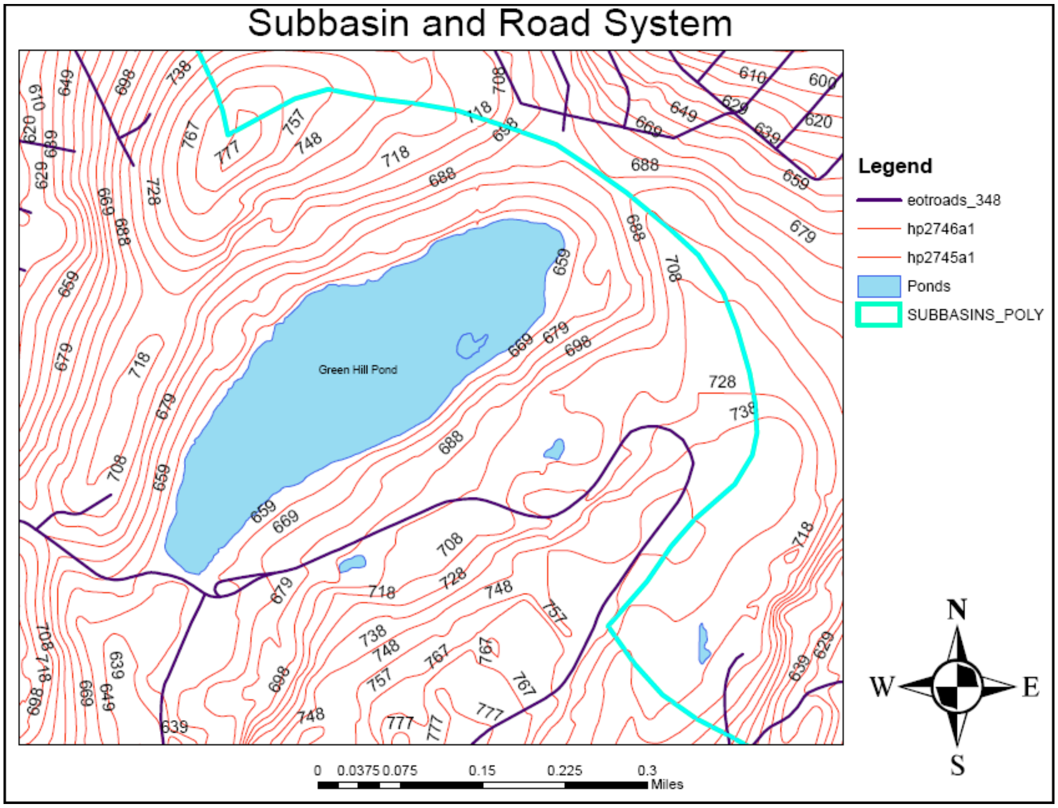

Figure 8: Sub-basin and Road System around Green Hill Park

To have better understanding of the runoff entering the pond, Figure 8 was prepared to show the elevations, roads and the sub basin boundary around the pond. The map represents the sub-basin boundary of the Blackstone watershed. However, this sub-basin covers an area larger than the actual drainage area to the pond. It was not possible to determine the runoff volume to the pond with this information. Also, from the observations on the site, catch basins are located along the road in the park. Therefore, there is a sewer system under the road and the runoff from the other side of the road are likely collected and delivered to the sewer system. Therefore there is no runoff from the outside of the road that enters. As shown in Figure 9, the runoff from the area that is inside of the subbasin boundary is expected to flow to the pond. Based on this information, the subbasin of the Green Hill Pond was determined. The method to obtain this subbasin was to delineate the subwatershed (i.e. draw the boundary along the road and the subbasin boundary line of the Blackstone watershed, and connect it with the highest elevations around the pond). A plan view of the sub basin of the pond is provided in Figure 9. This sub-basin contains 84.4 acres of land.

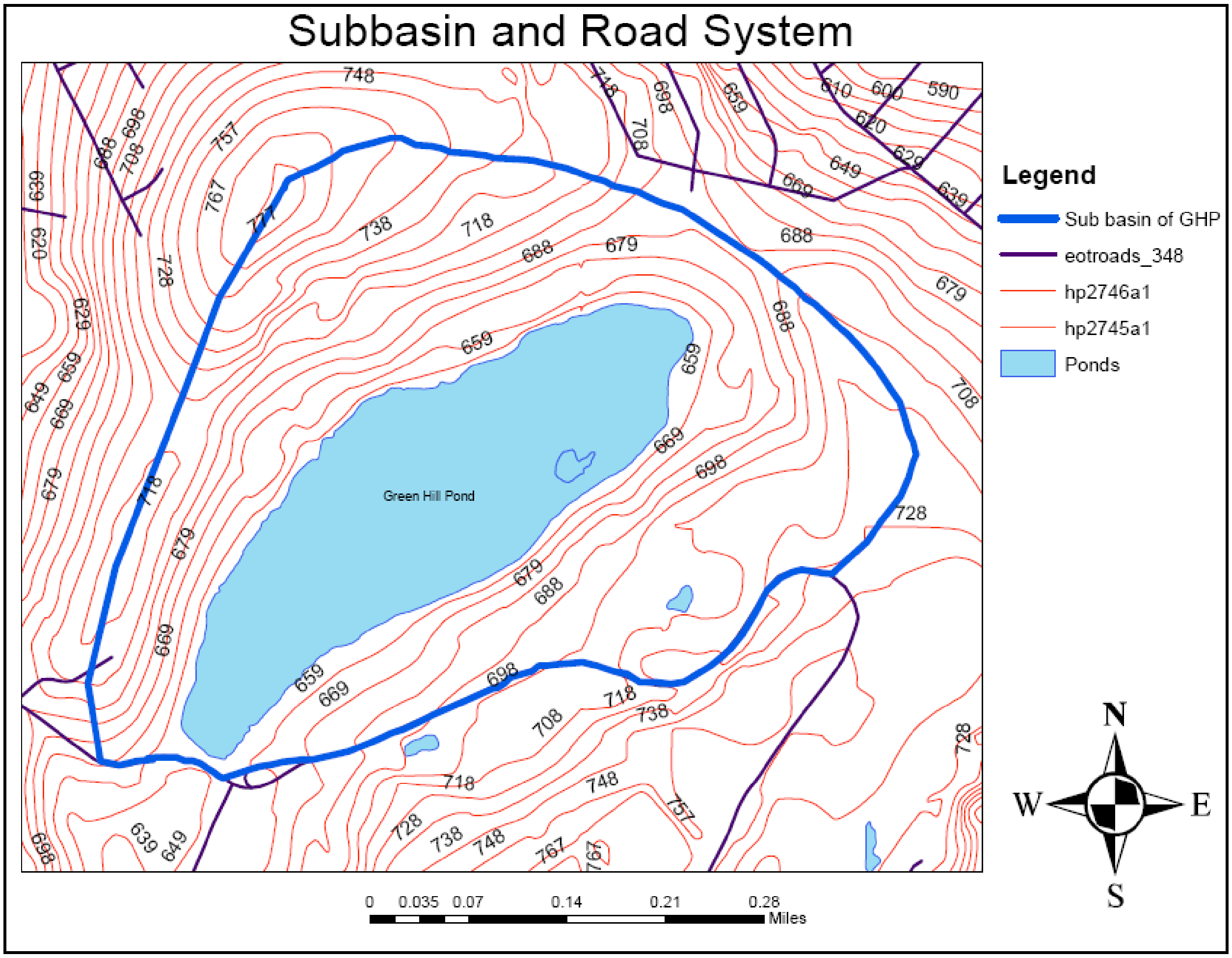

Figure 9: Green Hill Pond Sub-basin

4.2 In Pond Water Quality Results and Analysis

In order to determine the water quality of the pond, water samples were collected from water along the shoreline, and central region of the pond. The sample locations are shown in the Table 5 and Figure 10.

Table 5: Information of Samples' Location

Location	Location of Pond	Latitude	Longitude	Notes
1	South East	N42^{o} 16.907’	W71^{o} 47.013’	Shoreline
2	South West	N42^{o} 16.137’	W71^{o} 47.058’	Shoreline
3	East	N42^{o} 16.981’	W71^{o} 46.873’	Shoreline
4	North	N42^{o} 17.167’	W71^{o} 46.654’	Shoreline
5	Middle	N/A	N/A	Sample was take about 6 feet deep
6	Middle North	N/A	N/A	Sample was take about 6 feet deep

Figure 10: Water Sample Location

The results of samples analyzed in the laboratory include dissolved oxygen (DO), pH, specific conductance (SC), turbidity, total phosphorus, ammonia, bacteria, and total suspended solids (TSS) for both dry and wet weather. These parameters are important to determine current water condition of the Green Hill Pond. The results are shown in Tables 6 and 7.

Table 6: In Pond Water Sampling Results - Wet Weather

Location	DO (mg/L)	pH	SC (uS)	Turbidity (NTU)	Total phosphorus (ppm)	Ammonia (mg/L)	Ecoli (CFU/100 ml)	TSS (mg/L)
1	10.77	6.95	310	15.43	0.579	0.258	16000	48.50
2	11.05	6.46	318	17.03	0.650	0.432	5500	9.50
3	10.49	7.31	325	4.51	0.560	0.481	900	7.00
4	11.06	7.01	331	4.83	0.579	0.422	3100	41.75
5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 7: In Pond Water Samples Result - Dry Weather

Location	DO (mg/L)	pH	SC (uS)	Turbidity (NTU)	Total phosphorus (ppm)	Ammonia (mg/L)	Ecoli (CFU/100 ml)	TSS (mg/L)
1	10.74	6.21	332	20.8	0.541	0.377	12900	47.25
2	10.37	6.81	327	9.61	0.665	0.333	5600	8.25
3	10.96	6.51	328	6.2	0.622	0.364	4600	0.5
4	10.84	6.46	329	12.03	0.622	0.379	2500	10.25
5	N/A	6.30	328	4.91	0.536	0.352	N/A	1.5
6	N/A	6.72	330	3.51	0.517	0.382	N/A	1.5

After testing all samples for dry and wet weather conditions, comparisons were conducted by plotting bar graphs. Locations 5 and 6 were only taken in the center of the pond during dry weather, so there is no comparison between wet and dry weather conditions for these two locations. However, results from these locations are still considered with respect to overall water quality.

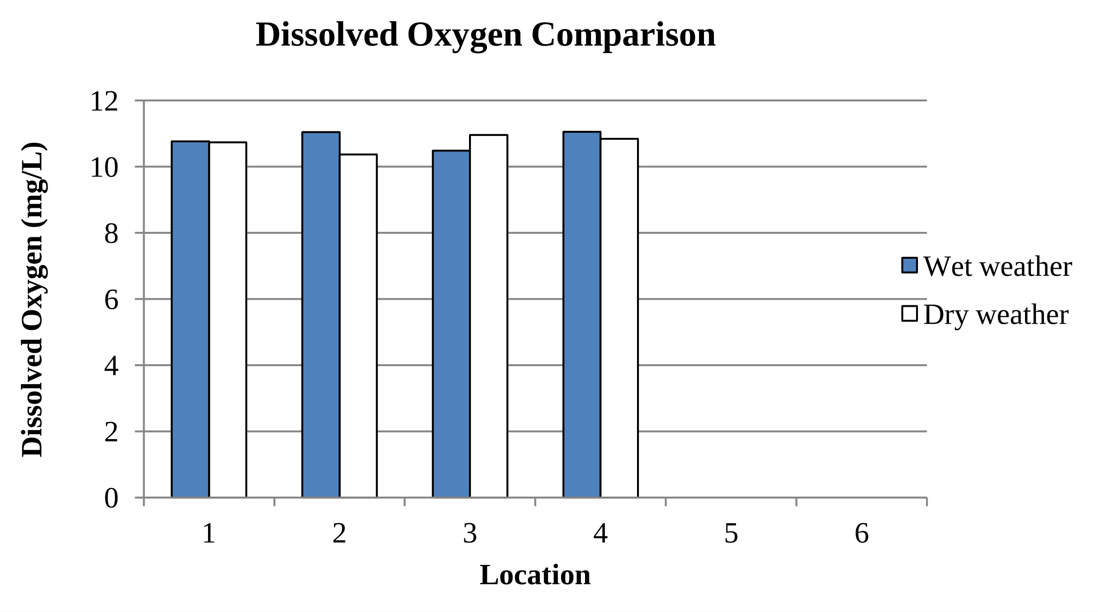

Figure 11: Dissolved Oxygen Comparison

As shown in Figure 11, all samples from the shoreline locations under both wet and dry weather conditions contain 10 – 11 mg/L of dissolved oxygen. These samples can be considered good quality with respect to dissolved oxygen because it exceeds the required concentration for aquatic organisms. Results from location 2 have the biggest change which is a drop of 0.68 mg/L. However, this drop does not significantly affect the amount of dissolved oxygen in the water sample, so it is considered to be negligible.

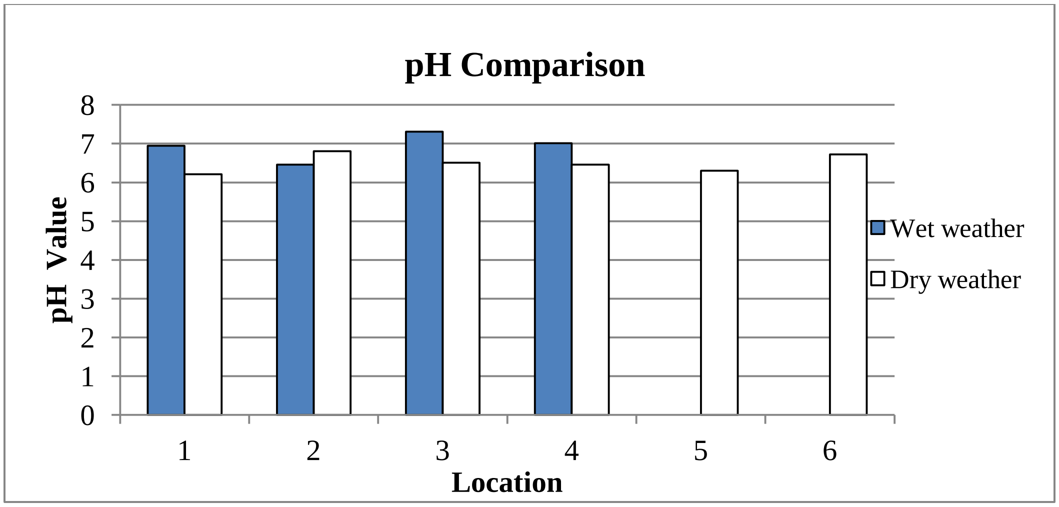

Figure 12: pH Comparison

In Figure 12, the pH values of all samples vary from 6.2 to 7.3. Overall, these results are neither acidic nor basic, and appropriate for surface water. The sample from location 1 under the dry weather condition had the lowest pH value of 6.2 and the sample from location 3 under the wet weather condition had the highest pH value of 7.3. The largest difference between wet and dry pH value was founded at location 1. Although the wet weather sample was lower than dry weather sample, the dry weather samples generally had a lower pH value than the wet weather value.

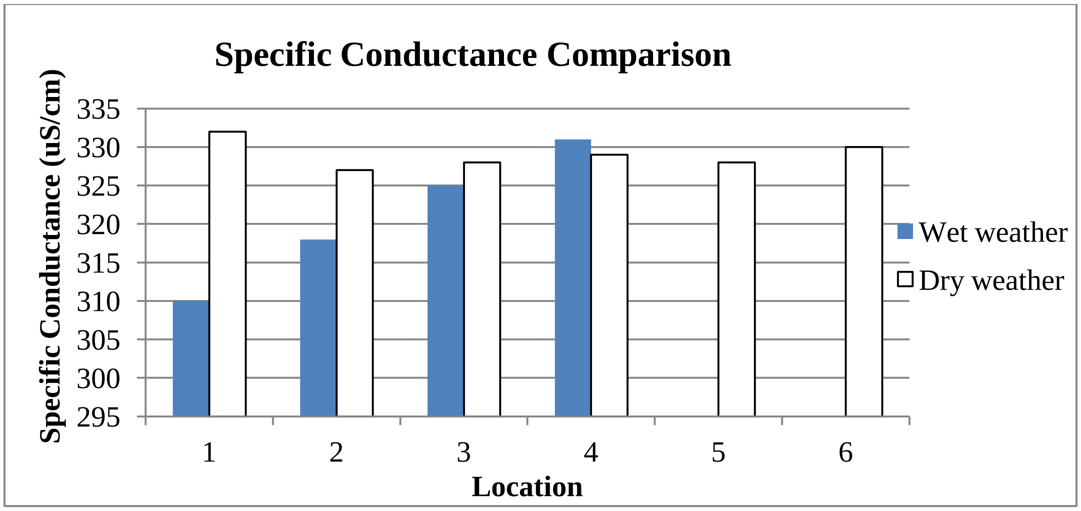

Figure 13: Specific Conductance Comparison

According to Figure 13, the specific conductance results of all samples vary from 310 uS/cm to 332 uS/cm. The sample from location 1 during wet weather had the lowest specific conductance of 310 uS/cm and the sample from the same location during dry weather had the highest result among all samples. In comparison, the samples from location 4 were higher in wet weather then in dry weather. However, overall, the specific conductance results tended to be a higher under dry weather conditions.

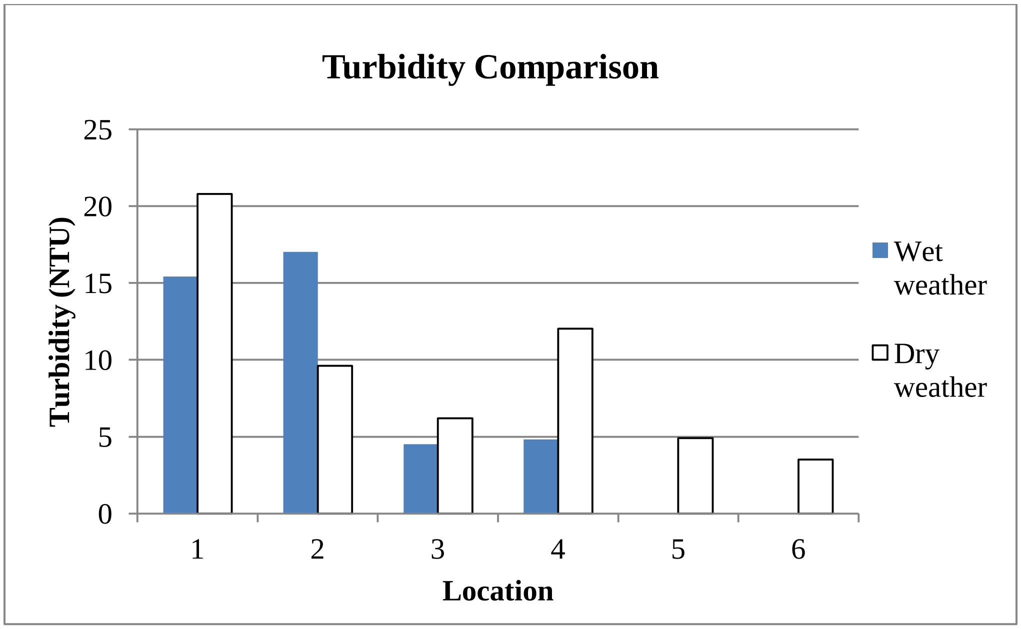

Figure 14: Turbidity Comparison

As shown in Figure 14, the turbidity results of all samples vary over a wide range of 3 to 21 NTU, which indicates that there is a large variation in turbidity for different locations. The highest turbidity was found in the sample collected from location 1 during dry weather. The lowest result was found in the in-pond sample at location 6. In comparison, the samples collected from location 2 for wet weather were about 8 NTU lower than dry weather condition. However overall, the turbidity results for dry weather tended to be higher than those for weather.

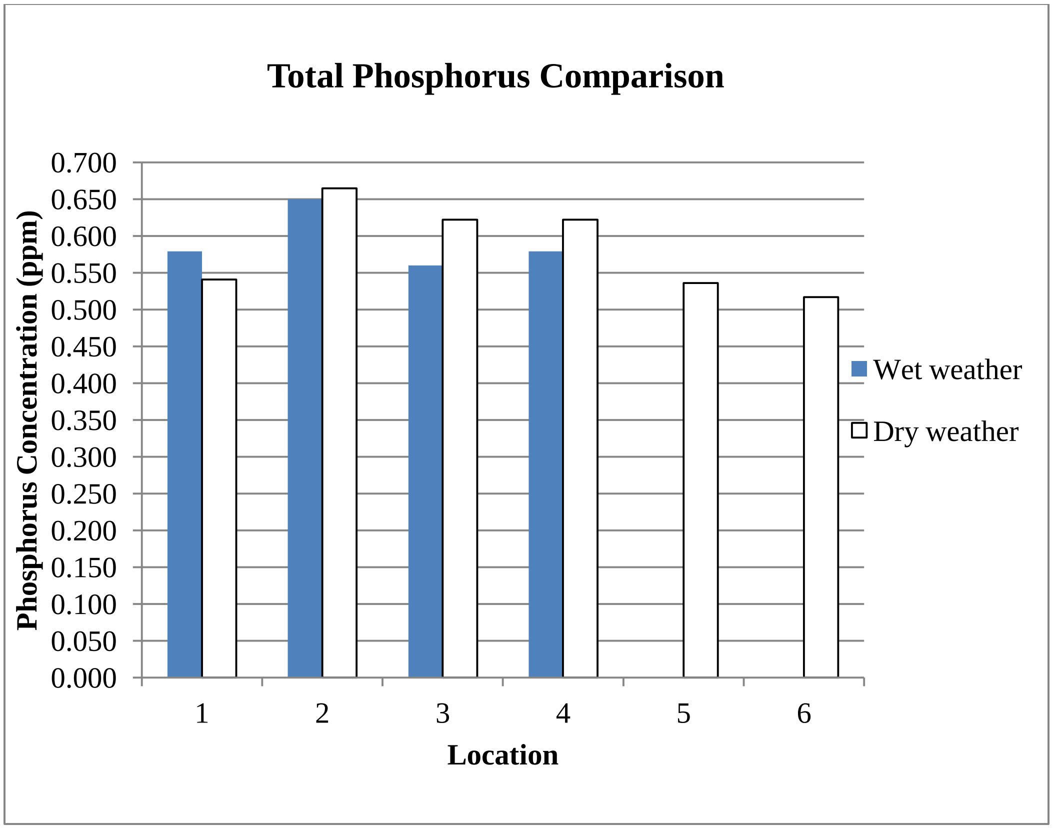

Figure 15: Total Phosphorus Comparison

In Figure 15, the total phosphorus results (Total Phos-P) from all samples vary from 0.517 to 0.665 ppm. Overall, these results are considered to be relatively high phosphorus concentrations. The dry weather sample from location 6 had the lowest total phosphorus result of 0.517 ppm. The dry weather sample from location 2 had the highest total phosphorus result of 0.665 ppm. The samples from location 1 decreased about 0.03 ppm from wet to dry weather. However, the overall results for total phosphorus tended to be higher in dry weather conditions.

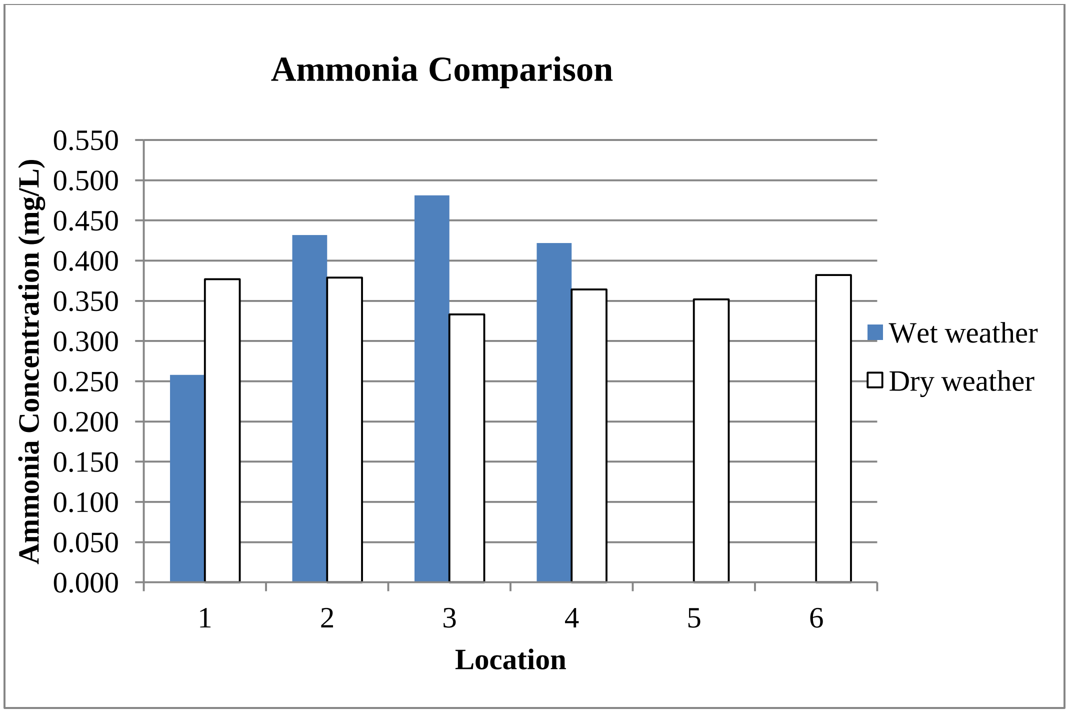

Figure 16: Ammonia Comparison

Ammonia results for all samples, which vary from 0.25 to 0.48 mg/L, are presented in Figure 16. These results are considered to be relatively high ammonia concentrations. The wet weather sample from location 1 had the lowest ammonia result of 0.25 mg/L, and the wet weather sample from location 3 had the highest result of 0.48. Although the samples from location 1 increased about 0.13 mg/L from wet weather to dry weather condition, the overall results of ammonia concentration during dry weather tended to be higher than wet weather conditions.

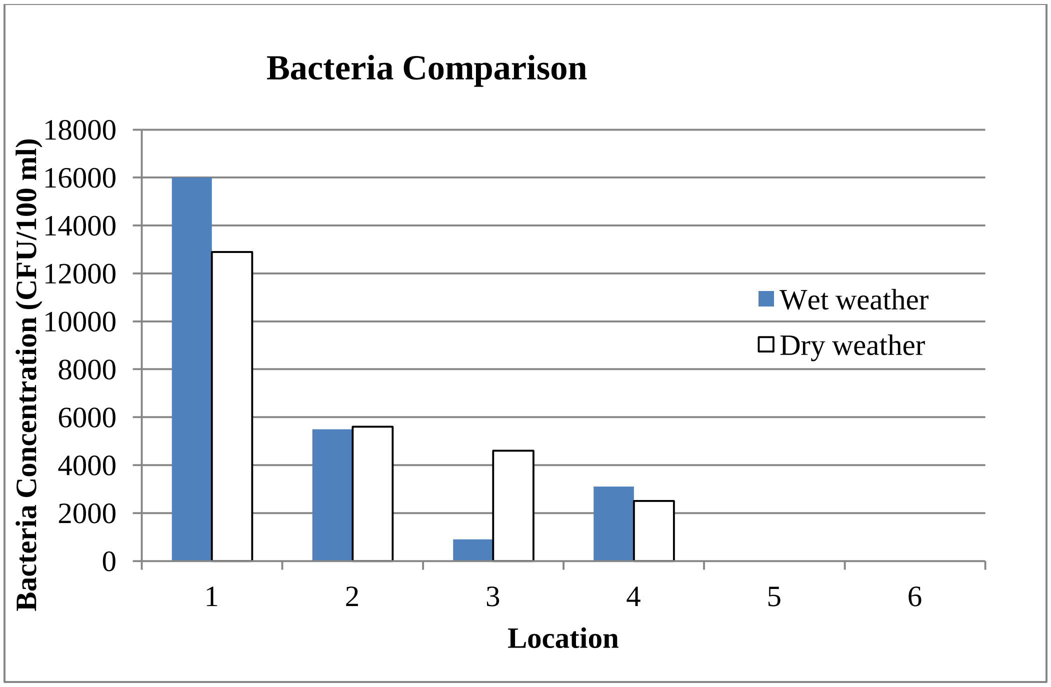

Figure 17: Bacteria Comparison

Bacteria results from the samples at location 1 were significantly higher than the other results as shown in Figure 17. The result from the wet weather sample at location 1 shows that there were 16000 CFU per 100 milliliters, and from the wet weather sample, it shows that there were about 12500 CFU per milliliters. From observations, location 1 can be considered as the most active area for pets and geese due to it is close proximity to the parking lot and barbeque and picnic area.

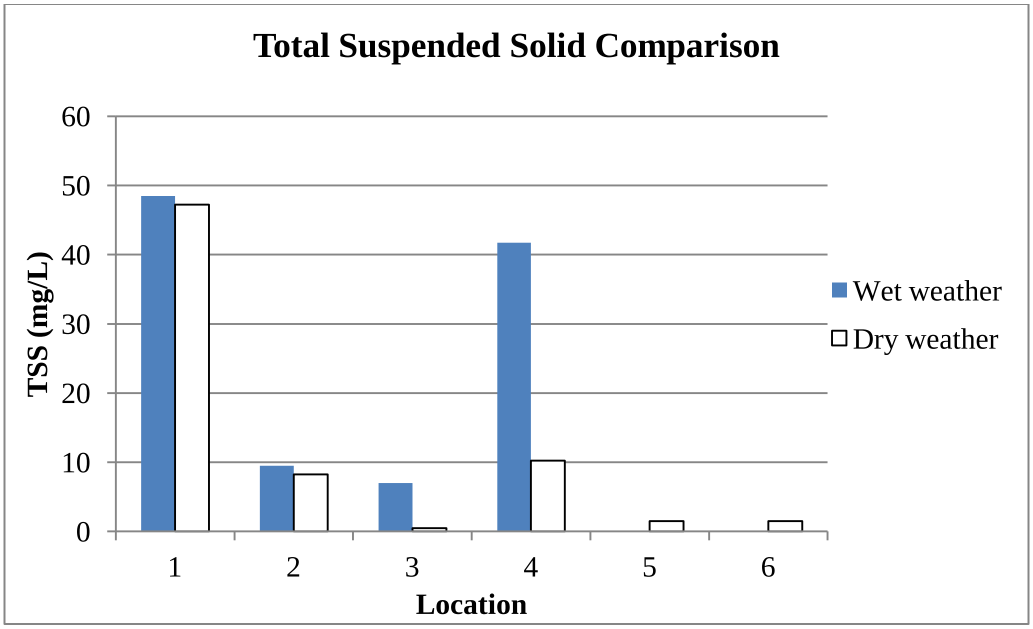

Figure 18: Total Suspended Solids Comparison

Total suspended solids in the shoreline samples vary widely as shown in Figure 18. Samples from location 1 during both wet and dry weather contained about 48 mg/L of suspended solids. This might be because the location is right next to the dam and the dam is currently under construction. The solids might be from the construction. However, the wet weather sample from location 4 also had a high solids loading, which might indicate that the runoff at that location contains a large amount of the suspended solids.

Table 8: Ion Chromatography Test Results of In Pond Samples-Wet Weather

Location	Fluoride (ppb)	Chloride (ppb)	Sulfate (ppb)	Nitrate (ppb)	Phosphate (ppb)
1	99.13	35209.31	10476.04	329.93	0
2	96.60	34778.24	10782.67	291.50	0
3	101.23	34219.09	10005.75	233.21	0
4	103.01	35845.54	10614.74	505.72	0
5	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A

Table 9: Ion Chromatography Test Results of In Pond Samples-Dry Weather

Location	Fluoride (ppb)	Chloride (ppb)	Sulfate (ppb)	Nitrate (ppb)	Phosphate (ppb)
1	100.27	35570.80	10732.79	489.92	0
2	100.90	36890.91	11136.97	389.56	0
3	94.41	33712.15	10153.80	525.17	410.22
4	99.49	35286.24	10774.42	563.30	0
5	100.51	36688.16	11269.71	450.39	0
6	105.13	36347.56	11196.73	733.12	0

Since the main focus of project is to address the potential implications of phosphorus in the Green Hill Pond, phosphate results in Tables 8 and 9 were the main focus of this discussion. In the tables, only the dry weather sample from location 3 contains a measurable concentration of phosphate. The sample from location 3 under the dry weather condition contains 0.41 ppm phosphate as the dissolved phosphorus in the sample. (Recall that these samples were filtered through a 0.45-micron filter before injection into the IC unit.) The samples from all other shoreline and in-pond samples did not contain any phosphate. This only indicates that dissolved phosphorus was not presented in the collected samples.

4.3 Runoff Samples Result and Analysis

In order to identify the pollutant loading entering the pond, runoff samples were collected from water that was flowing into the pond. Each runoff sample was taken from different location as shown in the Table 10 and Figure 19.

Table 10: Information of Runoff Samples' Location

Location	Location of Pond	Latitude	Longitude	Notes
1	North	N42° 17.117’	W71° 46.653’	Runoff was from detention pond
2	North West 1	N42° 17.179’	W71° 46.732’	Runoff was from Golf Course
3	North West 2	N42° 17.145’	W71° 46.800’	Runoff was from Golf Course
4	West	N42° 17.117’	W71° 46.917’	Runoff was from Golf Course
5	South West	N42° 16.137’	W71° 47.058’	Runoff was from recreation space
6	East	N42° 16.981’	W71° 46.873’	Runoff was from forest

Figure 19: Runoff Samples Location

The results of the runoff analyses in the laboratory included dissolved oxygen (DO), pH values, specific conductance (SC), turbidity, total phosphorus, ammonia, bacteria, and total suspended solids (TSS). These parameters are important to assess the runoff condition in order to develop the water quality control and improvement plan. The results of runoff samples are shown in the Table 11.

Table 11: Runoff Samples Result

Location	DO (mg/L)	pH	SC (uS)	Turbidity (NTU)	Total phosphorus (ppm)	Ammonia (mg/L)	Ecoli (CFU/100 ml)	TSS (mg/L)
1	10.65	7.13	241	19.67	2.484	0.410	23800	555
2	N/A	6.36	69.3*	9.77	0.775	0.785	N/A	46.7
3	10.77	6.96	151.5	19.47	1.543	0.751	15400	89.0
4	10.81	6.67	215	15.47	0.884	0.785	16500	26.75
5	N/A	5.90	148.9*	17.26	1.362	4.999	N/A	12.82
6	N/A	5.23	74.2*	225.67	3.196	2.983	N/A	1478.2

After the condition of each runoff water sample was determined, the data for each parameter was analyzed by using column graphs as shown in Figures 20 through 27.

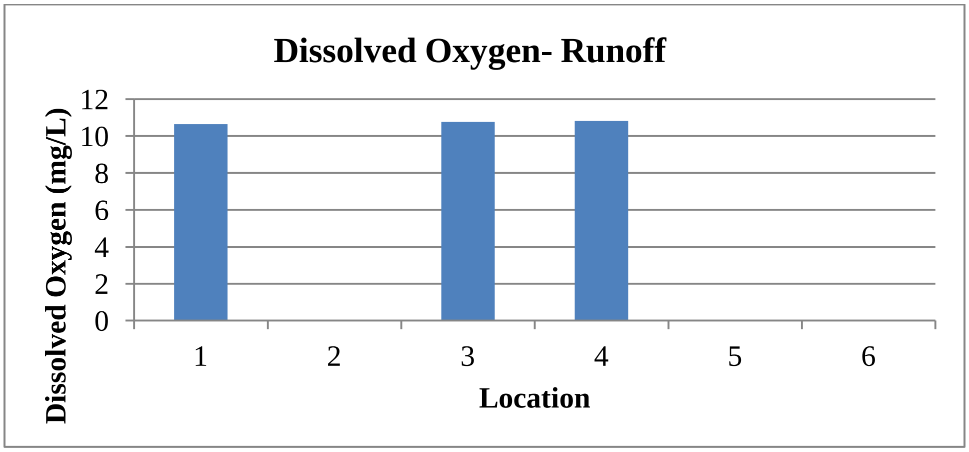

Figure 20: Dissolve Oxygen Analysis – Runoff

Only three out of six locations provided a flow rate and sampling location adequate for the collection of sample to be analyzed for DO. As shown in Figure 20, dissolved oxygen was about 10 mg/L which is an adequate concentration for aquatic life.

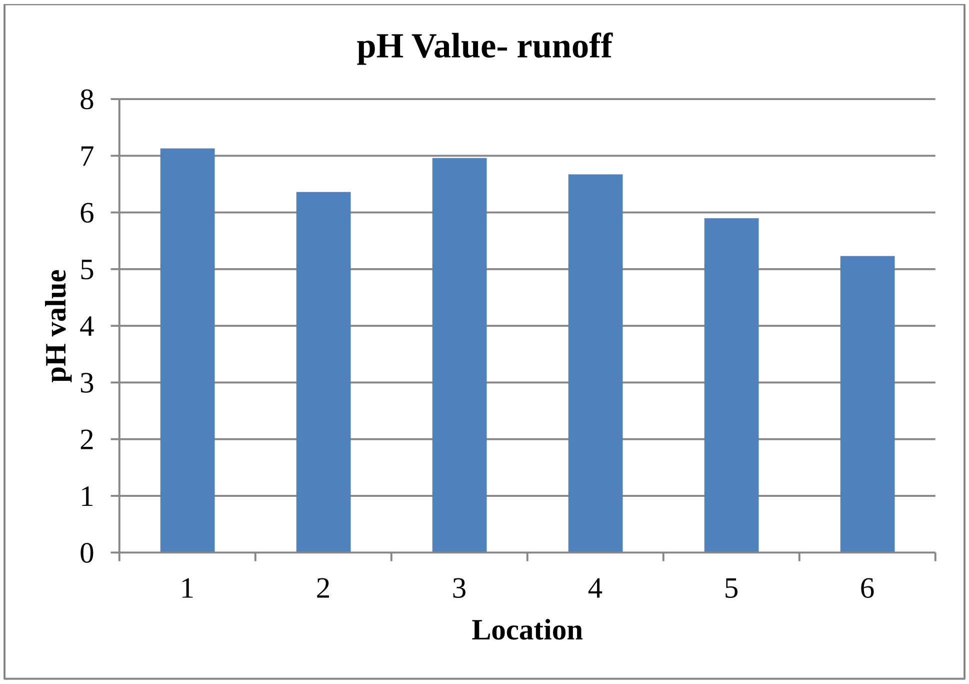

Figure 21: pH Value Analysis- Runoff

In Figure 21, most pH values for runoff were about 6-7 which is proper for aquatic life. However, there were two locations 5 and 6 that presented pH value lower than 6. These pH results mean that runoff from locations 5 and 6 tended to be more acidic which indicates the runoff in these areas could be less buffered possibly by movement through vegetation or soil.

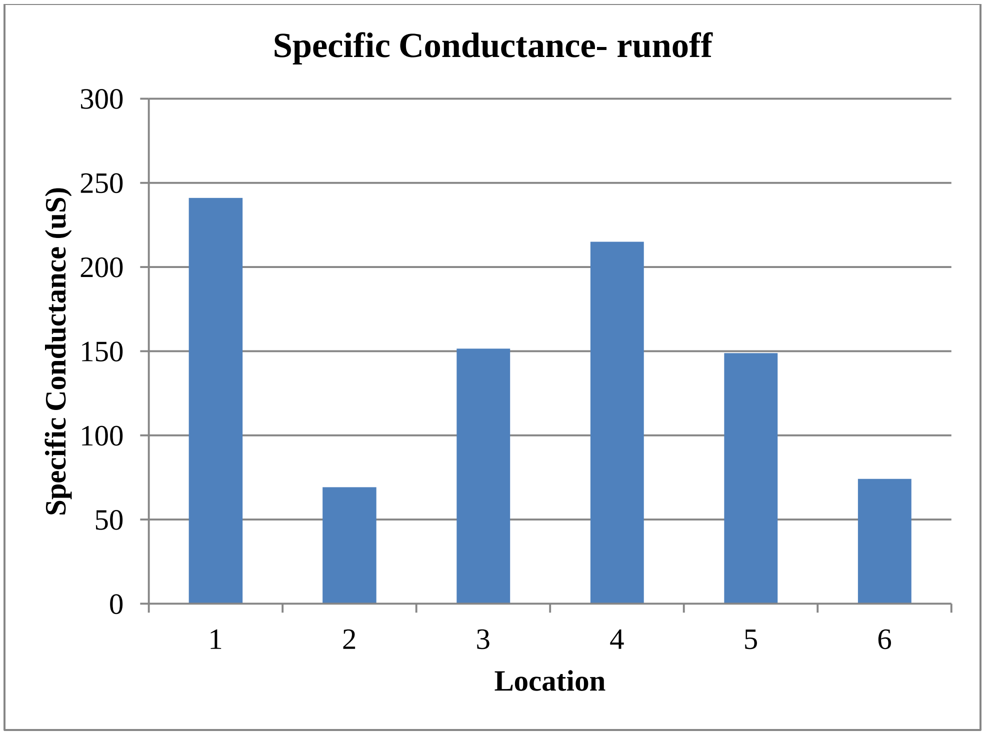

Figure 22: Specific Conductance Analysis-runoff

Specific Conductance is the parameter to determine the electrical conductance of the water. As shown in Figure 22, the values were variable and it was not possible to estimate tendencies since some of the runoff samples were collected by using 60-ml bottles which were smaller than the prepared bottles which should be 250ml bottle. Measurement of this parameter provides an indication of the dissolved ions in the solution.

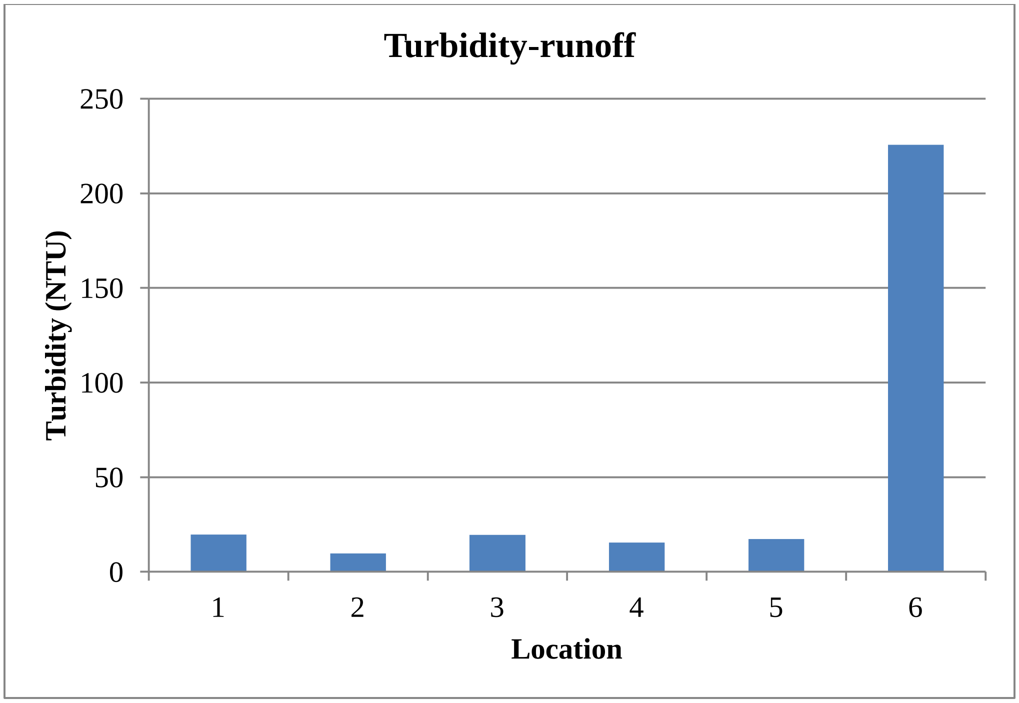

Figure 23: Turbidity Analysis-Runoff

As already noted, turbidity is one of the concerns for Green Hill Pond. Runoff water is a possible source that could affect turbidity. According data in Figure 23, most of turbidity values were generally less than 20 NTU. However, the turbidity result from location 6 was about 230 NTU which is specifically higher than other results. From this result, it is concluded that location 6 could be a critical place that needs to be considered for any water quality control plan.

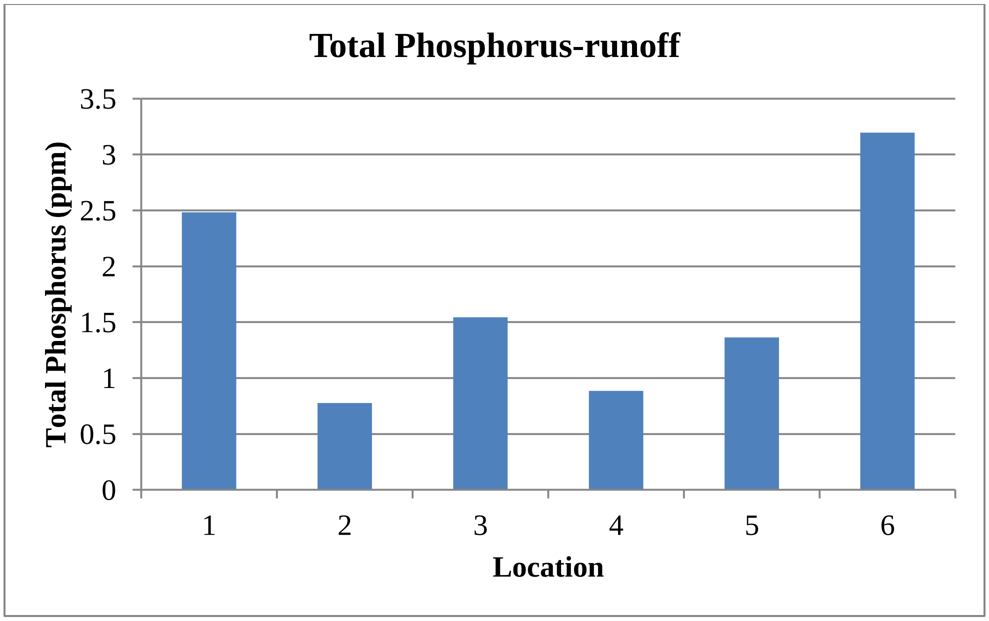

Figure 24: Total Phosphorus Analysis- Runoff

Total phosphorus is one possible factor that can degrade water quality in Green Hill Pond. As presented in Figure 24, the phosphorus concentration at location 1, 3, 5 and 6 were higher than 1 part per million (ppm). These measurements are reported as total phosphorous as phosphorous (Total Phos-P). These four locations could be considered as the critical places for the control and improvement of runoff water condition.

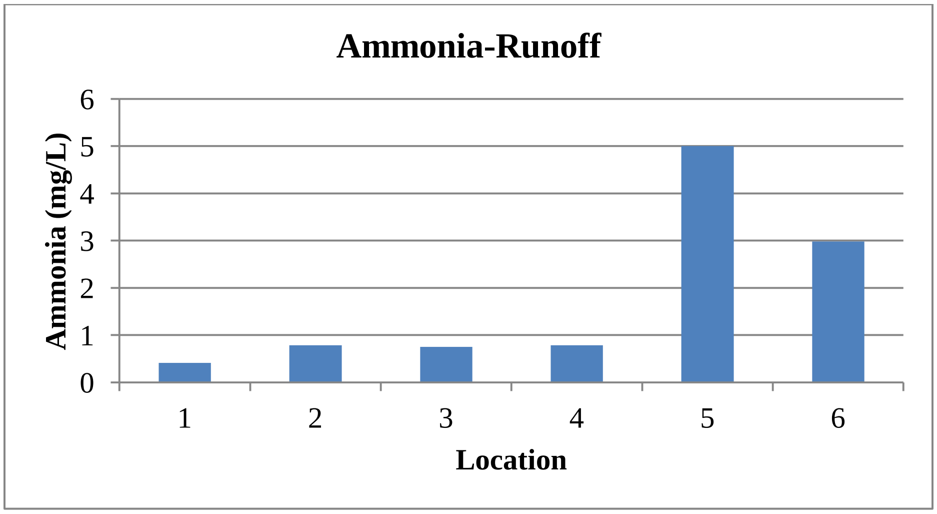

Figure 25: Ammonia Analysis- Runoff

In the Figure 25, the concentration of each runoff sample was less than 1 mg/L. However, locations 5 and 6 have different ammonia concentrations than other locations.

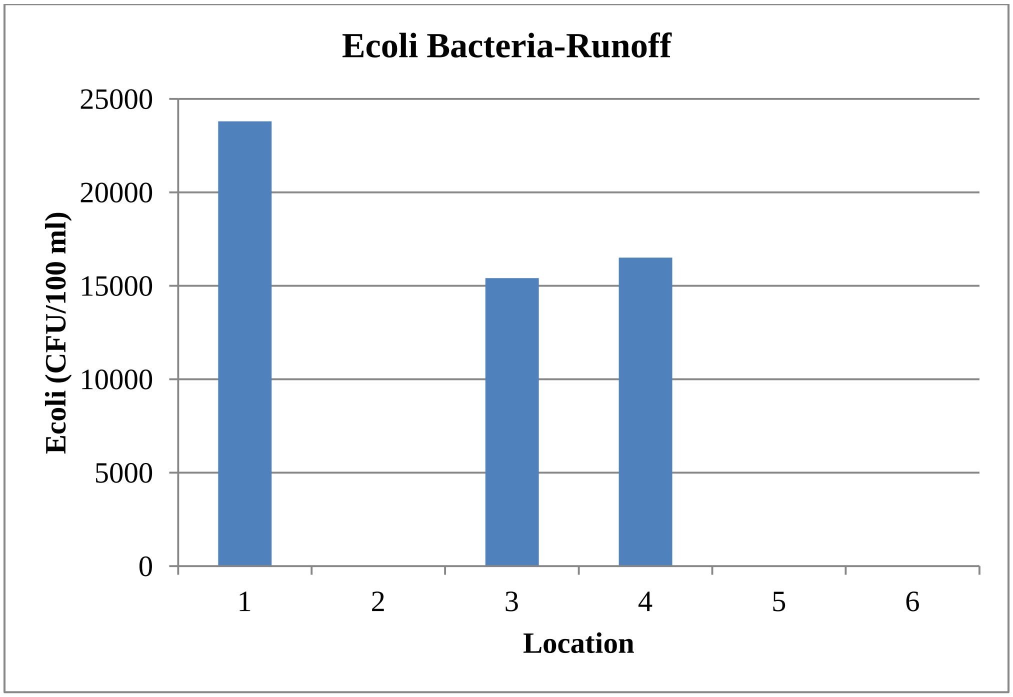

Figure 26: Ecoli Bacteria Analysis- Runoff

An Ecoli test was completed since the health of people is an important consideration. In this test, only three water runoff samples were collected. The Ecoli counts were high. As noted previously, animal waste was observed along the shoreline of those contributing areas.

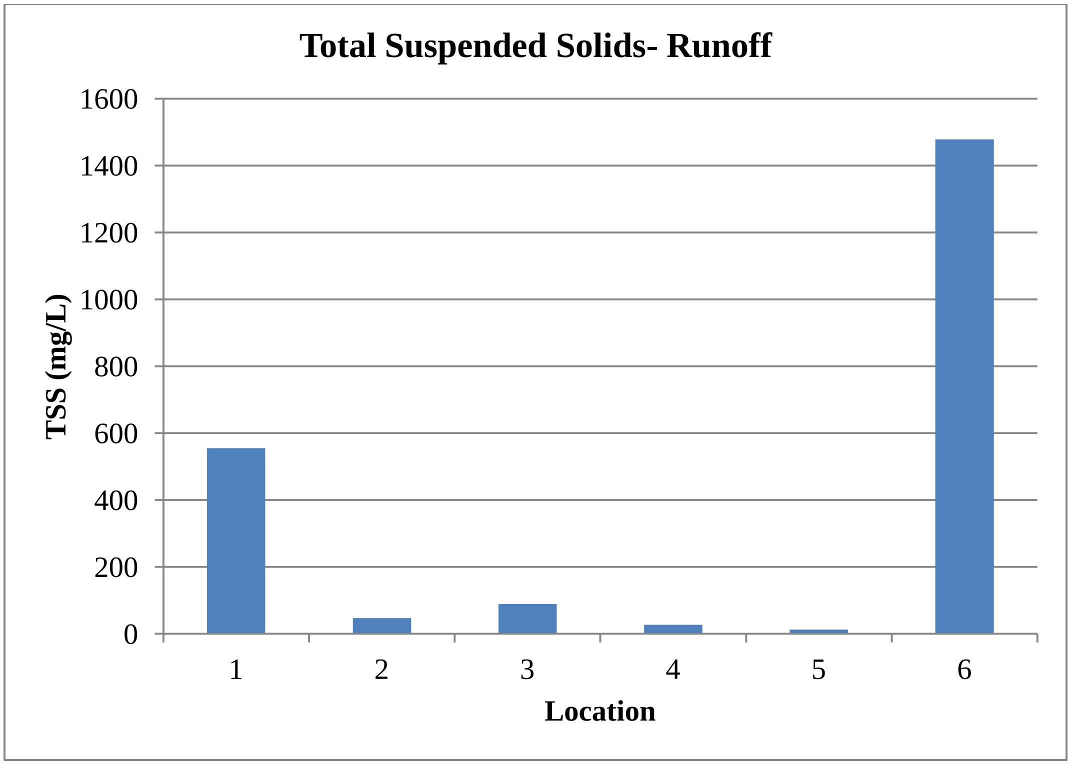

Figure 27: Total Suspended Solid Analysis

Total suspended solids are an important parameter to determine since some materials in the water such as turbidity or total phosphorus are affected by it. According to Figure 27, locations 1 and 6 were higher than other samples. These two locations should be considered to develop a plan since these two locations were top two of high total phosphorus concentration as well.

Table 12: IC Test Result of Runoff Samples

Location	Fluoride (ppb)	Chloride (ppb)	Sulfate (ppb)	Nitrate (ppb)	Phosphate (ppb)
1	51.70	7303.09	10613.21	4163.07	0
2	32.93	2629.02	2411.39	0	0
3	51.96	4770.51	7719.04	7704.80	385.62
4	62.53	8001.68	13867.90	7779.17	378.73
5	0	6677.45	2042.62	286.38	391.31
6	34.31	7797.06	3929.34	273.30	0

Similar to the pond water sample test, runoff samples were also analyzed to determine dissolved ions by ion chromatography (IC). As shown in the Table 12, locations 3, 4, and 5 were found to have measurable phosphate concentrations. Recall that total phosphorus was measured in runoff from all six locations.

4.4 Sediment Samples Result and Analysis

In order to assess the possible impact of the sediments of Green Hill Pond on the phosphorus loading of the water, two cores of sediments were taken and analyzed from two locations as shown in the Figure 28.

Figure 28: Locations of sediment samples

The amount of phosphorus contained in the sediment was determined as shown in Table 13.

Table 13: Sediment Test-Phosphorus

	Total Phosphorus (ppm)	**amount of sediment (g)**	**Total P in sediment(ppm/g)**
Sediment 1	17.060	1.0243	16.655
Sediment 2	22.500	1.0505	21.418

According to result in the Table 13, the sediment from location 1 included a total phosphorus concentration of 16.7 ppm/g. The total phosphorus in the location 2 was 21.4 ppm/g.

Table 14: Sediment Releasing Test-Phosphorus

	Total P Releasing (ppm/g)
Sediment 1+EI	0.199
Sediment 1+water sample	0.068
Sediment 2+EI	0.445
Sediment 2+water sample	0.337

Results in the Table 14 were calculated in spreadsheet on Appendix XII. According to Table 14, total phosphorus released from laboratory-grade e-pure water with sediment 1 was 0.199 ppm/g, and 0.068 ppm/g for the pond water sample with the same sediment. On the other hand, e-pure water and water sample with sediment 2 released 0.445 ppm of phosphorus per gram of sediment (ppm/g), and 0.337 ppm/g respectively.

Phosphorus in the sediment is a concern because it can be released from both sediment samples as shown in Table 14, which can impact water quality. Since phosphorus was released from the sediment samples in the e-pure water more than in the pond water sample, it means that the sediment can effectively release more phosphorus to the pond if the water has capability to store ions before reaching equilibrium. Therefore, one can conclude that the sediment is a potential pollutant source of phosphorus in the pond.

4.5 Runoff NRCS Result and Analysis

The runoff volume that entered the pond during the storm event when the runoff samples were taken was estimated by using the NRCS method which is presented in section 3.4.5. The details of the analysis are provided in Appendix VII. Figure 29 recalls the contributed areas of each runoff sample, and Table 15 shows the significant results that were obtained from the runoff analysis.

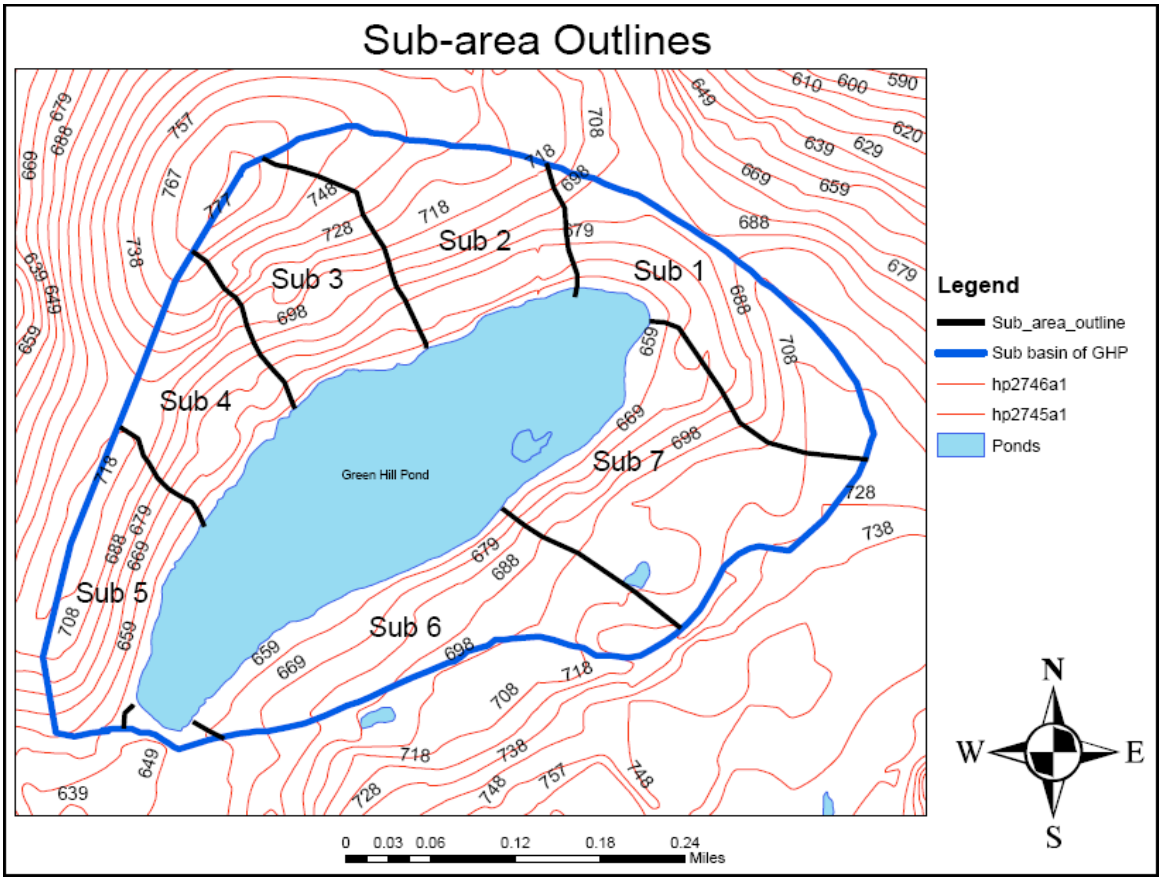

Figure 29: Subarea of the Green Hill Pond

Table 15: Sub-area Runoff Estimates

Sub-area	Total area (acres)	Runoff Volume (acre-ft)	Phosphorus Concentration (ppm)	Estimated Phosphorus Load (gram)	TSS Concentration (mg/L)	Estimated TSS Load (kg)
1	12.23	0.0067	2.484	20.65	555	4.59
2	11.73	0.033	0.775	31.76	46.7	1.90
3	10.83	0.032	1.543	59.93	89	3.51
4	8.32	0.013	0.884	14.07	26.75	0.43
5	8.96	0.041	1.362	69.36	12.82	0.65
6	14.73	0.227	3.196	891.76	1478.2	413.9
7	15.32	0.0013	1.707	2.83	368	0.59

As shown in the Table 15, most runoff volumes for each sub-area are 0.025 to 0.042 acre-feet. However, the runoff volume of location 6, 0.23 acre-feet, is significantly higher than all other locations. This runoff volume is about 8 times higher than other areas. Since samples could only be collected from Locations 1 through 6, the loading analysis was only completed for these six areas. To obtain an estimated load for the area associated with Location 7, the phosphorus concentration in location 7 was taken to be the average concentration from all 6 runoff samples. According to the data that were collected from the total phosphorus tests, location 6 has the highest phosphorus concentrations (3.20 parts per million) as well as highest total suspended solids (1478.2 mg/L). The highest runoff volume from this contributed area is estimated to be about 0.23 acre-feet during the storm event. Due to these highest significant values, location 6 has the highest phosphorus load and highest total suspended solids load, which are 892 grams and 413.9 kg respectively during this event. Also, location 3 and location 5 also have a comparative high phosphorus loads which are 59 grams and 69 grams; location 1 and location 3 have a comparative high total suspended solid loads which are 4.59 kilograms and 3.51 kilograms.

Table 16: Sub-basin Runoff Estimation of Loads for 10-27-2011 Storm Event

Total Area	82	acre
Total V	0.35	Acre-feet
Total Phosphorus Loads	1090	grams
TSS Loads	35463.6	grams

As shown in Table 16, the total area of the Green Hill Pond watershed is approximately 82 acres. This area was confirmed with two approaches (summing all sub-areas and subtracting watershed area from the pond surface area). Since the watershed includes different land uses and soil types, the GIS software was used to estimate a composite curve number. Runoff volume was later estimated from the result of composite curve number. The total runoff volume of the entire sub-basin was calculated by summating all runoff volumes, and it is resulted to be 0.35 acre-feet. Therefore, the total phosphorus entering the pond during this storm event was estimated to be 1090 grams.

Chapter 5: Water Quality Control and Improvement Plan

According to the results and analysis, the sources of phosphorus and turbidity are assumed to be associated with stormwater runoff and sediment in the pond. In this section, possible structural and non-structural options for addressing these inputs are listed. Also, the advantages and disadvantages are compared by considering factors such as efficiency, cost, and environmental impact. The results from the comparison are evaluated to develop a recommendation for a water quality control and improvement plan.

5.1 Evaluation of the BMP Alternatives

5.1.1 Structural BMPs Evaluation

Table 18 compares different BMPs in order to evaluate the most appropriate BMPs for Green Hill Pond with consideration to economics and the determined in-pond and runoff water loads affecting the pond, these categories include: 1) cost, such as construction cost and maintenance cost; 2) the environmental impacts that the plan will create; 3) the effectiveness of removing suspended solids; 4) the effectiveness of removing phosphorus; and 5) the difficulty level of implementing the BMP at the site.

For each consideration, there are three levels: low, medium, and high. To compare the BMPs, these levels are given different points. The highest point is given to the level that fits the best for the economy and the pond. For example, in the "Cost" consideration, it is preferable to use a BMP that costs less for installation and maintenance, so a "low cost" level would be given the highest score which is 3, whereas a "High cost" is given the lowest score of 1. For the "Effectiveness of Removing Phosphorus" consideration, it is preferred to have a BMP that can remove more phosphorus, so the "High" level is given a 3 score and the "Low" level for 1. Based on the advantages, disadvantages, implementation, and maintenance requirements of each possible BMP, the scores for each consideration were determined. If a BMP has many advantages in a certain consideration, that BMP would receive a high score of 3 for that consideration. If a BMP has mostly disadvantages in a certain consideration, that BMP would score the lowest point which is 1 for the consideration. If a BMP has neither the advantages nor the disadvantages with respect to a particular consideration, it would be assumed as "medium" for that consideration, which is 2 points. Therefore, the BMPs that score the higher total points would be more preferred for the pond. Table 17 shows the scores of each BMP in each consideration and the total score of each BMP.

Table 17: Evaluation of Structural BMPs

Consideration	**Sediment Fore bays**	**Vegetated Filter Strips**	**Bioretention Areas and Rain Gardens**	**Constructed Stormwater Wetland**	**Wet basin**	**Drainage Channels**	**Grassed Channel**	**Water Quality Swale**	**Dredging**
Cost	**1**	**3**	**2**	**1**	**1**	**2**	**2**	**2**	**1**
Environmental Impact	**3**	**3**	**3**	**1**	**1**	**2**	**3**	**2**	**1**
Effectiveness of Removing Suspended Solid	**2**	**2**	**3**	**3**	**3**	**1**	**2**	**3**	**1**
Effectiveness in Removing Phosphorus	**2**	**1**	**3**	**3**	**3**	**1**	**1**	**3**	**3**
Difficulty of Implementation	**2**	**2**	**2**	**1**	**1**	**1**	**2**	**2**	**1**
Total	**10**	**11**	**13**	**9**	**9**	**7**	**10**	**12**	**7**

As shown in Table 17, of the possible structural BMPs, vegetated filter strips, bioretention areas and rain gardens, and water quality swales scored more than 11 out of 15 possible points. These three BMP options are the most preferred BMPs for the pond. However, these BMPs contain different characteristics as well as different installation requirements for different geographic conditions. In order to select the appropriate BMPs, it requires a better understanding of the applicability of each preferred BMPs and the landscape features surround the pond.

5.1.2 Nonstructural BMPs Evaluation

For non-structural BMPs, public education is an appropriate option for this project. Public education can increase public awareness about non-point-source water-pollutant problems as well as help people to make proper decisions concerning runoff quality protection. Since the results indicate that runoff is one of the sources to degrade water quality in pond with high phosphorus, total suspended solid loads, and bacteria counts, public education can compliment structural BMPs in Section 5.1.1 to give people knowledge on controlling pet waste and trash as well as fertilizer use. However, the limitation for this option is the difficulty in monitoring and quantifying the direct water quality benefits.

5.2 Applicability of Possible BMPs

This project aims to develop a water quality control and improvement plan for the Green Hill Pond. The main goal is to reduce the phosphorus amount and the turbidity of the pond. Therefore, the possible structural BMPs, which had high scores in the evaluation and also can provide high effectiveness in removing phosphorus and removing TSS, would be recommended for the Green Hill Pond. According to the evaluation in section 5.1.1, structural BMPs include vegetated filter strips, bioretention areas and rain gardens, and water quality swales, all of which had high scores in the assessment. However, each of these BMPs contains different implementation requirements.

According to the Structural BMP for the Massachusetts Stormwater Handbook[61], a vegetated filter strip requires a minimum soil slope of 2% and maximum slope of 6% within a minimum length of 25 feet. According to Figure 7 in section 4.1, subareas 2-5 contain soil slope of 3% to 8%. However, this BMP provides a low TSS removal effectiveness and medium phosphorus removal effectiveness. Therefore, this BMP might not be an appropriate option for the pond. Instead of length requirements, bioretention areas and rain gardens require soil depths of at least 30 inches in order to remove nutrients. However, the applicability of this BMP must be considered carefully, since it is not recommended in the areas with steep slopes. Based on the information provided in Figure 7 in section 4.1, the slopes around the pond vary from 3% - 15%. Therefore, this can potentially be constructed in all subareas. Also, with pretreatment, this BMP provides high effectiveness in removing phosphorus and TSS, so it can be applied in the critical areas. A wet water quality swale is one of the best BMP for the areas where the lawns are located, so this option could be appropriate for the golf course. Base on the applicability of each selected BMP, some recommendations were provided for the pond.

5.3 BMP Alternatives and Recommendations for Green Hill Pond

In order to investigate which BMP would be the most appropriate for a particular region within the watershed for Green Hill Pond, it is important to consider which parameter is the

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[61] Massachusetts Department of Environmental Protection, “Structural BMPs Specifications for the Massachusetts Stormwater Handbook,” 2012, 7 Feb. 2012 <http://www.mass.gov/dep/water/laws/v2c2.pdf>.

target to be controlled in each subarea. Since this project only included stormwater runoff samples from one particular storm event, the estimated phosphorus loads and TSS loads in each subarea might be not be fully representative of annual loads because the phosphorus loads can vary during different storm events. However, this single storm still provided a basis for determining the types of BMPs that may apply in different areas. Therefore, in order to install appropriate BMPs for each subarea, it is important to consider the calculated phosphorus loads. In this case, it is also important to consider the loads of total suspended solids in the stormwater runoff since the suspended solid particles can possibly carry phosphorus into the pond. Table 18 provides a summary of the phosphorus and total suspended solids loads that were determined in the section 4.5 (Detailed information for the various sub-areas is also provided in section 4.5).

Table 18 Summary of Phosphorus and TSS Loads

Sub-area	1	2	3	4	5	6	7
Estimated Phosphorus Load (grams)	20.7	31.8	59.9	14.1	70.0	891.8	2.8
Estimated TSS Load (grams)	382.2	158.4	292.7	35.7	54.0	34491.4	49.2

As shown in the table, Sub-areas 1 and 6 have higher phosphorus and total suspended solid loads estimated for the October 27 rain event when samples were taken; Sub-areas 2 and 4 contain relatively low phosphorus and TSS loads; Sub-areas 3 and 5 have similar phosphorus loads but sub-area 5 contains a much lower TSS load.

Based on this summary and the observations from the on-site investigation, some recommendations for the appropriate BMPs were developed. Figure 30 shows the locations of recommended structural BMPs, and Table 19 shows the summary of recommendations.

Discussions regarding the recommendations for the various subareas are also included in this section.

Table 19: List of Recommended Structural BMPs

Subarea	Recommended Structural BMPs
1	Bioretention area and rain garden
2	Water quality swale
3	Water quality swale
4	Water quality swale
5	Bioretention area and rain garden
6	Grass channel and bioretention area and rain garden
7	N/A

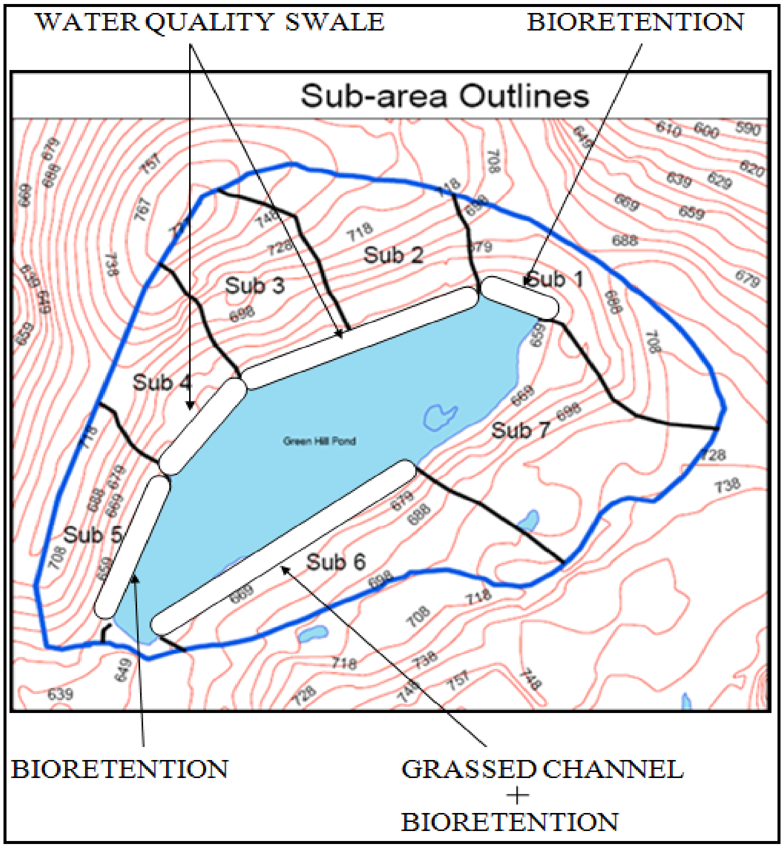

Figure 30: Summary of Recommended BMPs

Subarea 1 - Sub-area 1 contains some forest area and some golf course area. Most of the stormwater runoff is collected by a detention pond before it enters the Green Hill Pond. The runoff from the roadway is also filtered by a gravel area where the outlet of the detention pond is located. Figure 31 shows the detention pond, runoff path, and the sample location. However, since the runoff samples were collected after the gravel area where the runoff entering the Green Hill Pond, it was determined that there were still high phosphorus and TSS loads. Since a BMP is already present in this subarea, maintenance for the detention pond is recommended. Additionally, in order to control these contaminants, a bioretention area and/or a rain garden is recommended because the area between the gravel area and the pond has not been developed yet. Estimates indicate that installation of this BMP can remove up to 90% of TSS and 30% - 90% of phosphorus from the stormwater runoff.

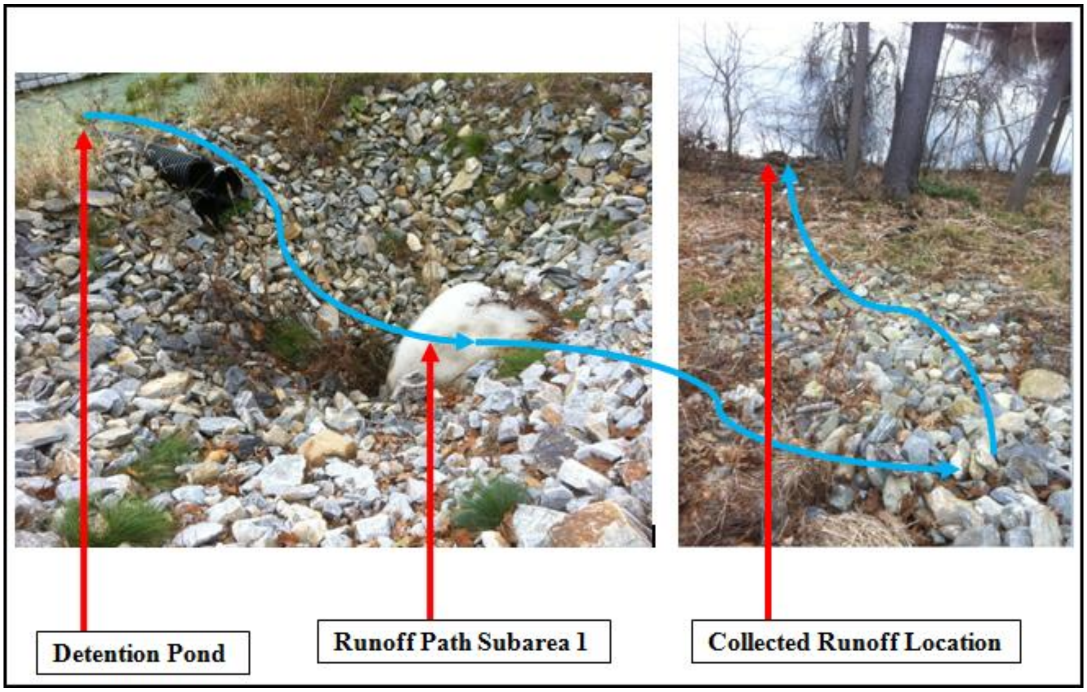

Figure 31: Subarea 1 Runoff Sample Location

Subareas 2, 3, and 4 - The phosphorus and TSS loads for sub-area 3 are estimated to be higher than sub-areas 2 and 4. However, for these three sub-areas, a common BMP is recommended since these areas contain the same landscape characteristics. These sub-areas are golf course areas with layered lawns. Based on these landscape features and the determined loads of phosphorus and TSS, it is recommended that a water quality swale be located between the pond and these sub-areas. The purpose of installing these swales is to collect and infiltrate the stormwater runoff from the golf course. Achieving this purpose, there will not be stormwater runoff directly enter the pond unless the overflow conditions occur during large storms, such as during 50-year or 100-year return period storms. It is estimated that this BMP has the ability to remove up to 70% of TSS and 20% - 90% of phosphorus in the stormwater runoff.

Subarea 5 - As shown in the summary in Section 4.5, the phosphorus load of sub-area 5 was high while the TSS load was relatively low. For this sub-area, the important goal is to reduce the phosphorus concentration. Since this area contains open land and forest area, the construction of a bioretention area and/or rain garden is recommended. Even though this BMP's effectiveness of removing TSS may not be necessary in this area, the high phosphorus concentration in this sub-area is significant. Installing this BMP can remove approximately 40% - 90% of phosphorus.

Subarea 6 - According to the result of the runoff analysis, sub-area 6 contains the highest phosphorus and the highest TSS load. This area contains recreational areas, such as barbeque and picnic areas, and it is adjacent to the parking lots along the main driveway of the park. It is important to maintain most of the existing landscape features and public areas while selecting appropriate BMPs for this sub-area. To achieve this, grassed channels, bioretention areas, and rain gardens are recommended. The bioretention area and/or rain garden should be installed between the grassed channel and the pond, since the grassed channel is intended to provide pretreatment. This combination can efficiently remove about 90% of TSS and about 70% - 90% of phosphorus in the stormwater runoff. There will be more standing water areas in the participation area after installing this combination. For public safety concerns, construction of protection surrounding the bioretention area is also recommended.

Subarea 7 - Since the team was unable to collect stormwater runoff samples from sub-area 7, there is no information about the phosphorus and the TSS concentrations. In order to determine whether the stormwater runoff from this sub-area contain contaminants, further investigations are needed. Accurate recommendations for appropriate BMPs should be developed based on the results from these investigations.

Non-structural BMPs - Another important result that was discovered in this project is there were high bacteria concentrations in some water samples. However, the locations where contain high bacteria concentrations varied between different sampling locations. Recalling the on-site investigations, it was found that the areas that contained high bacteria were the areas where pets and wild animals actively participate. So it was assumed that the high bacteria concentrations were caused by the pets' and wild animals' wastes. Based on this assumption, public education is also recommended as a nonstructural BMP for the pond. Putting signs in the active participation area to remind public to clean up pets' wastes will directly and effectively help to reduce the amount of animal wastes around the pond. By achieving this, the bacteria concentration will be reduced. However, this cannot guarantee the removal of all bacteria around the pond since it is difficult to control the activities of geese and other wild animals' activities, and the amount of bacteria that is released from the wild animal's wastes was unable to be determined.

Chapter 6: Summary and Recommendations

6.1 Project Summary

This project included collection of water samples from Green Hill Pond, samples of runoff flowing to the pond during a storm event, and sediment samples from the bottom of the pond. These samples were analyzed in the laboratory to measure a number of different water quality parameters. In addition, land uses and the drainage system around the pond were investigated. Based on the results from all samples analysis, this project has documented various sources of the phosphorus in Green Hill Pond. It has also investigated some possible approaches for pond water quality control and improvement.

The sources of the phosphorus in pond include stormwater runoff and in-pond sediment release. Groundwater inputs were not investigated as part of this project, but the absence of septic systems in the vicinity indicates that phosphorus inputs from groundwater may likely be negligible. A major source of phosphorus is the stormwater runoff from the surrounding area of the pond. Also, information on phosphorus in the sediments, which had not been considered previously, was defined as another likely source of phosphorus in the pond.

This project has involved the NRCS runoff method to determine the approximate runoff volumes of each contributing area of each runoff sample. Based on these estimated runoff volumes, the phosphorus loads in each area during this specific storm event were estimated. The runoff analysis in Section 4.5 showed that during the storm event of a rainfall intensity of 0.87 inches, there was approximately 4.238 in-acres runoff entering the pond. Along with this amount of runoff, there were approximately 1090 grams of phosphorus in the runoff water entering the pond. A notable result is that about 890 grams of this phosphorus were estimated to come from one particular region. The result of the sediment analysis shows that the phosphorus concentrations of the sediment were about 16 - 21ppm, and release of phosphorus from these sediments into the water column could reach between 0.2 and 1.4 PPM per g of sediment under turbulent conditions. Therefore, the results showed that reductions of phosphorus loads in stormwater runoff and sediments have the potential to make significant effects to improve the pond water quality. For these conclusions, specific recommendations to improve the water quality can be made with regards to land uses and nutrients control around the Green Hill Pond.

6.2 Recommendation

Based on the conclusions from the results of sample testing results, analysis and onsite investigations, there are several recommendations that can help the City of Worcester manage and reduce the phosphorus load in Green Hill Pond. Instead of one specific method for addressing phosphorus entering the pond, a combination of different prevention and reduction methods are recommended.

The most effective methods for phosphorus reduction of Green Hill Pond are stormwater runoff controls and sediment controls. Green Hill Pond, which is surrounded by a golf course, forest areas, and recreational areas, is located inside the Green Hill Park. In order to maintain the existing landscape around the pond, especially the natural green environment and the open view of the pond, it is recommended that the damages or changes to landscape be limited when developing structural BMPs for reducing phosphorus loads to the pond.

Besides the structural BMPs, non structural BMP is also recommended. For this project, public education is the only recommended nonstructural BMP for the Green Hill Pond. This option can help the public make appropriate decisions on the pet wastes and fertilizer disposal. It can help to reduce the nutrient loads and contaminants from the public activities and the maintenance of golf course.

According to the result of the runoff analysis from sections 4.3 and 4.5 and the result of the on-site investigations, each subarea contains different features and contaminant concentrations. Among the subareas, subarea 6 contains the highest runoff volume, the highest total phosphorus and TSS loads. It is recommended to construct a bioretention area and/or rain garden for subareas 1 and 5; water quality swale for subareas 2, 3 and 4; grassed channel as the pretreatment, and bioretention areas and rain gardens for subarea 6. Recommendation for subarea 7 was unable to be developed since no actual data were gathered for this area. Table 20 provides a summary of the recommended BMPs. Along with these recommendations, it is also suggested that a public education program be developed to encourage better practices for reducing pet waste, fertilizer use, and other potential sources that may impact the pond.

Table 20: Summary of Recommended Structural BMPs

Subarea	**Recommended Structural BMPs**
1	Bioretention area and rain garden
2	Water quality swale
3	Water quality swale
4	Water quality swale
5	Bioretention area and rain garden
6	Grass channel and bioretention area and rain garden
7	N/A

6.3 Recommendations for Future Research

This project has included sample collection of dry weather and wet weather shoreline water, stormwater runoff, and bottom sediments, as well as onsite investigations. However, the time frame and scope limited the research and investigations that could be completed. Based on the limitations that were encountered in this project, some recommendations were developed for the future research to continue this project for Green Hill Pond.

It is recommended to complete a field monitoring and sampling program during the spring or summer season or throughout the entire year. Changing the time period can avoid New England's cold weather conditions or the freezing period of the pond, so the future project can monitor the in-pond water quality more frequently and also have more chances to obtain stormwater runoff samples from different storm events. Since the runoff conditions in sub-area 7 are still ambiguous, further investigation is encouraged. In addition, there are two important results discovered in the analysis. These include the phosphorus release from the in-pond sediments and high bacteria concentration in the shoreline in-pond water and runoff. Dredging is a considerable BMP for in-pond sediments control. However, this project was unable to determine if this is appropriate for Green Hill Pond. Further investigation is needed in order to determine the applicability of dredging. It is also recommended the future research to investigate bacteria reduction for the pond. By addressing these various issues, future research would be beneficial to determine the pond water quality more accurately and make more specific recommendations for Green Hill Pond water quality controls and improvement.

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Appendix I: Milestone for Project

Table 21: Milestone for Project

Month	Date	Task	Type
October	24th-31th	Collect water sample (wet weather and runoff)	Data Collection
November	1st-7th	Test samples Laboratory (wet weather and runoff)	Data Analysis
	8th-14th	Collect water sample (dry weather)	Data Collection
	15th-21st	Test samples Laboratory (dry weather)	Data Analysis
	22nd-30th	Write (methodology) first draft	Writing
December	1st-7th	Write (result, and analysis) first draft	Writing
	8th-15th	Write (methodology, result, and analysis) final draft	Writing
January	11th-18th	Analyze Green Hill Pond Sub-basin Analysis	Data Analysis
	19th-26th	Determine Pollutant Source- Runoff	Data Analysis
	27th-31st	Determine Pollutant Source- Ground water	Data Analysis
February	1st-7th	Research different options for water quality control and improve plan	Data Collection
	8th-15th	Design the most appropriate plan	Data Analysis
	16th-23rd	Write report- first draft	Writing
	24th-29th	Write report- second draft	Writing
March	1st-2nd	Write report- final	Writing

Appendix II: Goal and Objectives

The goal of the project is to design water quality control and improvement plans for the Green Hill Pond. In order to reach the goal, it is necessary to accomplish the following objectives:

I. Reviewed related literatures and reports of the Green Hill Pond

II. Identified and analyze water quality of the Green Hill Pond by determining levels of turbidity, phosphate, dissolved oxygen (DO), total suspended solid, pH, temperature, total phosphorus, and specific conductance

III. Determined possible sources and amounts of pollutants entering the pond by sampling and analyzing quality of runoff, and investigating bottom sediment of the pond

IV. Design a water quality control and improvement plan by considering both pollutant prevention and improvement by following steps.

    a. Identify and evaluate best management practices (BMPs)
    b. Select set of BMPs
    c. Provide details on preliminary design for selected BMPs

V. Recommend the most appropriate water quality control and improvement plan by considering on economic consideration, environmental interactions, sustainability, manufacturability, health and safety, social concerns and political issues.

Appendix III: In Pond Water Sample Location

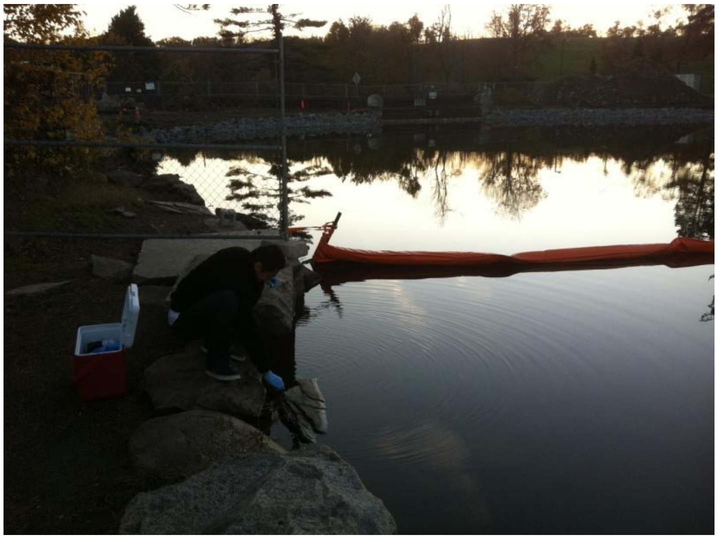


Figure 32: In Pond Water Sample- Location 1

Figure 33: In Pond Water Sample- Location 2

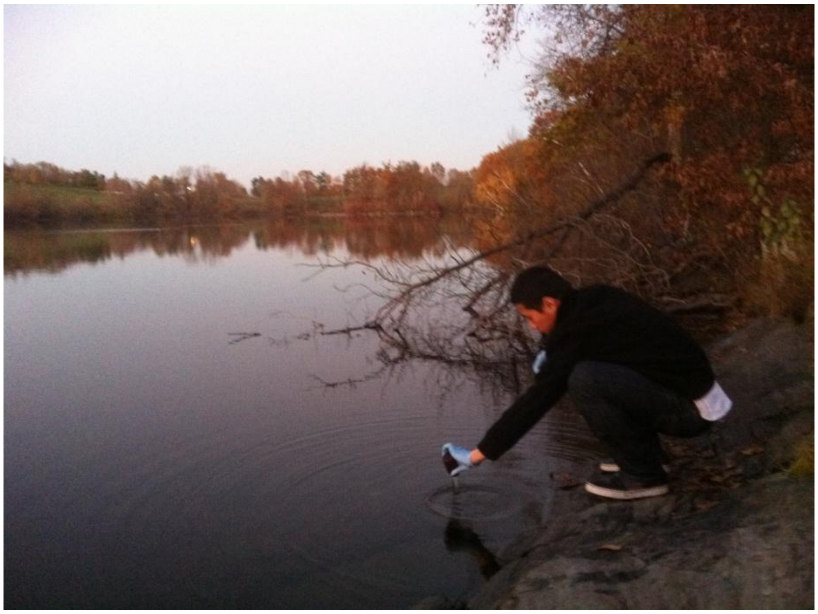


Figure 34: In Pond Water Sample- Location 3

Figure 35: In Pond Water Sample- Location 4

Figure 36: In Pond Water Sample- Location 5 and 6

Appendix IV: Laboratory Procedures

Worcester Polytechnic Institute

Department of Civil & Environmental Engineering

Determining Ammonium using a Hach DR/3000 Color Spectrophotometer

Preparations

1. Turn the color spectrophotometer on. Rotate the wavelength selector dial to a setting of 425 nm. It will need approximately 2 hours for the lamp to warm sufficiently to prevent drifting of absorbance readings.
2. Prepare a set of standards with known concentrations of ammonium including and just beyond the range of expected results. Use the Nitrogen, Ammonium Standard Solution 100 mg/L (as NH_3-N) to prepare the standards. The analysis of these standards will provide the calibration curve from which the unknown samples will be analyzed.

Analysis with DR/3000 Color Spectrophotometer

Zero instrument with a blank.

1. Fill a clean sample cell with DI water.
2. Add three drops of Mineral Stabilizer. Plug the cap and invert it several times
3. Add three drops of Polyvinyl Alcohol Dispersing Agent. Plug the cap and invert it several times
4. Add 1 ml Nessler Reagent(Cat. 21294-49) Plug the cap and invert it several times
5. Press: **3 Timer** (a 3-minute reaction period will begin. The display will indicate 3 minutes and then decrease in increments of tenths until 0 is reached.)
6. Press: **Manual Program**, (check to be sure that the wavelength selector dial is set to 425 nm.)
7. After the timer beeps, place the sample cell into the cell holder. The 25-ml mark on the cell should face the front of the instrument for proper orientation. Close the compartment door.
8. Zero the instrument by pressing **Zero Abs**. The display should then read 0.000 Abs. If not, press the **ZERO** key again.
9. Empty and rinse the sample cell. Use the same cell for each successive standard and unknown sample.

Note: When there is no sample cell in the compartment, the absorbance will read a negative number. If this reading does not stay stable between sample analyses, the lamp may not have warmed up sufficiently. Delay further testing until the absorbance readings remain stable.

Analyze standards and samples

a. Fill the same sample cell used to analyze the blank and zero the instrument with the standard or unknown.
b. Repeat steps 2-7 above.
c. Pres **Abs.** and read the absorbance or %T from the display.
d. Empty and rinse the sample cell. Use the same cell for each successive standard and unknown sample.

Worcester Polytechnic Institute
Department of Civil & Environmental Engineering
Determining Total Phosphorus using Sulfuric Acid-Nitric Acid Digestion and a Hach DR/3000 Color Spectrophotometer

adapted from Wen, Huajing, "Analytical Procedures for Nutrients in Water," WPI (2005)
with input from Don Pellegrino, WPI CEE Lab Manager

Preparations

1. Turn the color spectrophotometer on. It will need approximately 2 hours for the lamp to warm sufficiently to prevent drifting of absorbance readings.
2. Prepare a set of standards with known concentrations of phosphorus including and just beyond the range of expected results. The analysis of these standards will provide the calibration curve from which the unknown samples will be analyzed.

- Using a stock solution, standards can be prepared as follows:

$$(\text{ml})=(\text{mg/L})\times ml/0.1\ mg\times 100\ \text{ml}\times 1\ L/1000\ \text{ml}$$

where x = volume (ml) of stock solution needed
C mg/L represents the desired standard concentration
0.1 mg/ml is the concentration of the stock solution
100 ml represents the volume of standard that will be prepared
1 L/1000 ml is used to convert ml to L

- For example, if a 0.5 mg/L (PPM) standard solution is desired, the above equation determines that 0.5 ml (or 500 µl) of 0.1 mg/ml stock solution would be needed

$$(\text{ml})=0.5(\text{mg/L})\times ml/0.1\ mg\times 100\ \text{ml}\times 1\ L/1000\ \text{ml}=0.5\ \text{ml}$$

Digestion of Aqueous Samples

All aqueous samples, standards, and blanks should be digested using the same procedure, as follows:

1. Pour 25 ml of sample or standard (or e-pure water for blank) into a clean beaker
2. Add 5 ml conc. HNO_3 and 1 ml conc. H_2SO_4. Add the nitric acid first.
3. Cover the beaker with a watch cover – making sure there is a small gap between the cover and the top of the beaker to allow room for release of evaporated gases. Heat gently on a preheated hotplate under hood. The sample should simmer, but not boil. Heat until the sample is "down to fumes," which means that there will be visible white fumes in the beaker, and the sample will have been reduced down to a volume of about 1 ml.
4. Remove watch covers, remove beakers from hot plate, and allow to cool.

Digestion of Soil, Sediment, and/or Plant Material

Solid samples, such as sediment or plant material should be digested using the following procedure:

1. Place a known mass of sample into a clean beaker
2. Add ~40 ml of e-pure water to the sample in the beaker
3. Add 10 ml conc. HNO3
4. Cover the beaker with a watch cover – making sure there is a small gap between the cover and the top of the beaker to allow room for release of evaporated gases. Heat gently on a preheated hot plate under hood. The sample should simmer, but not boil. Heat for a few hours and then leave overnight, stirring occasionally as needed.
5. Next day, warm slightly and filter through #4 filter paper, rinsing all solid material very well with e-pure water. Add enough e-pure to bring the filtrate up to a known volume. The preferred volume is 25 ml, but dilution to higher volumes may be necessary if phosphorus levels are anticipated to be high. For example, for soil in the range of 500-800 mg Tot-P/kg, diluting the filtrate up to 500 ml produced results within the standard calibration curve for the spectrophotometer (0.2-10 PPM).
6. Pour 25 ml of filtrate into a clean beaker.
7. Add 1 ml conc. H2SO4.
8. Cover the beaker with a watch cover – making sure there is a small gap between the cover and the top of the beaker to allow room for release of evaporated gases. Heat gently on a preheated hot plate under hood. The sample should simmer, but not boil. Heat until the sample has been reduced to about 10 ml. Carefully add a few drops of hydrogen peroxide to the beaker and observe. Vigorous bubbling indicates consumption of organic matter. Continue to carefully add hydrogen peroxide drop wise until sample remains a clear color or until bubbling has ceased.
9. Continue to heat sample until “down to fumes,” which means that there will be visible white fumes in the beaker, and the sample will have been reduced down to a volume of about 1 ml.
10. Remove watch covers, remove beakers from hot plate, and allow to cool.

Analysis with DR/3000 Color Spectrophotometer

Zero instrument with a blank.

1. Transfer digested blank from beaker into a clean sample cell.
2. Add 1 drop of phenolphthalein indicator solution, and as much 5N NaOH solution as required to produce a faint pink tinge.
3. Once the pink tinge has appeared, add E-pure water to the 25-ml mark.
4. Add 1 ml Molybdovanadate to the sample cell. (Note: a small amount of yellow tinge might be present in the blank because of the reagent. Darker tinges will develop in samples with higher concentrations of phosphorus.)

5. Press: **3 Timer** (a 3-minute reaction period will begin. The display will indicate 3 minutes and then decrease in increments of tenths until 0 is reached.)
6. Press: **Manual Program**, then rotate the wavelength selector dial to a setting of 400 nm. (This will likely already be set appropriately)
7. After the timer beeps, place the sample cell into the cell holder. The 25-ml mark on the cell should face the front of the instrument for proper orientation. Close the compartment door.
8. Zero the instrument by pressing **Zero Abs**. The display should then read 0.000 Abs. If not, press the **ZERO** key again.
9. Empty and rinse the sample cell. Use the same cell for each successive standard and unknown sample.

Note: When there is no sample cell in the compartment, the absorbance may range between -0.075 and -0.081 or so. If this reading does not stay stable between sample analyses, the lamp may not have warmed up sufficiently. Delay further testing until the absorbance readings remain stable.

Analyze standards and samples

1. Transfer digested standard or sample from beaker into the same sample cell used to analyze the blank and zero the instrument. Filter if necessary to remove particulate material or turbidity. Use up 5 ml E-pure water to rinse the beaker (and filter).
2. Repeat steps 2-7 above.
3. Pres **Abs.** and read the absorbance or %T from the display.
4. Empty and rinse the sample cell. Use the same cell for each successive standard and unknown sample.

Total Suspended Solids

To prepare this test, it is required to have one small dish plate and one filter paper for each sample, an Erlenmeyer Flask with another small hole on the top for vacuum suction tube, a stopper, a graduated cylinder for measuring the volume of samples, an electric scale for weights and a vacuum for suction. To operate this test, all dish plates were labeled corresponding to the labels of samples and weighted. Each filter paper was weighted and put in a dish plate after weighted. Every dish plate with filter paper was weighted together to obtain the total original weight. In order to obtain the weight of the total suspended solids, it requires drying the solids in the oven of 104 ^{o}C. To preheat the oven, it was turned on before operating the filtration process and set to 104 ^{o}C. After the preparation, the stopper was put on top of the Erlenmeyer flask so that the Erlenmeyer flask is sealed. And the filter paper in the labeled dish plate was put inside the stopper. To start the filtration process, 200ml of the corresponding labeled sample was measured and poured into stopper. The vacuum was connected with the Erlenmeyer flask and turned on for suction. After all water was filtered into Erlenmeyer flask, the cup was rinsed with distilled water by using a squeeze bottle. Since the distilled water does not contain any suspended solids, the volume of the distilled water that was rinsed into stopper was not recorded for determinations. After the all water was filtered, the decision about whether the amount of suspended solids on the filter paper was enough for calculations was determined by observations. For those samples that did not contain lots of solids, it was decided to add another 200ml of sample to filter. After the filter paper obtained enough solids for calculations, it was taken out and put back into the labeled dish plate. The filtration process was repeated for each sample. After obtained the suspended solids from all samples, the labeled dish plates and filter paper with suspended solids were put into the oven which was preheated to 104^{o}C for one hour. After the dish plates and filter paper with solids were taken out from the oven, they were placed in the plastic container and cooled down to room-temperature level. After the cooling period, each dish plate with filter paper inside was weighted as the total weight of those three items in the plate. For accuracy, it was decided to also weight each filter paper with solids. To confirm the result of the weight of suspended solids from each measured amount of sample, comparisons were conducted by using the equations:

$$W_{ss} = W_{d+f+ss} – W_{d+f}$$

$$W_{ss} = W_{f+ss} – W_{f}$$

Where W_{ss} = weight of suspended solids from the measured sample

W_{d+f+ss} = total weight of dish plate and filter paper and solids

W_{d+f} = total weight of dish plate and filter paper

W_{f+ss} = weight of filter paper and solids

W_f = weight of filter paper

After confirmed the weight of the suspended solids from the measure amount of sample, the concentration of suspended solids in each sample was calculated by using the equations:

$$C_{ss} = W_{ss} / V$$

Where C_{ss} = concentration of suspended solids in the sample

V = volume of sample that is used for the test

Bacteria Test

This test is to determine the amount of the bacteria in the samples by using the LaMotte ColiQuant EZ. Due to the test can cause danger to health and there were factors from the surrounding environment that could influence the results of the test, so it was required to put extra care while the test was conducted. To prepare the test, it required to set the incubator to be 35 ^oC and defreeze the Coliscan Easygel to liquid because they were stored in the freezer. One Petri dish, one sterile dropper and one bottle of Coliscan Easygel were prepared for each sample. Both sides of the Petri dish were taped, and one side of the tapes was used as a hinge and the other as a latch. The sterile dropper was unwrapped and ensured the tip of the dropper did not touch anything except the water sample. After the dropper was ready, the water sample was shaken and swirled to make it well mixed. The bulb of the dropper was squeezed and immersed into the sample water and slowly released to obtain 1 ml of water sample. The cap of the Coliscan Easygel bottle was removed and ensured the inside of the cap was not touched or put down to where it could possibly get contaminated. The water sample that was obtained was dropped into the Coliscan Easygel. The bottle was then capped and swirled without creating any bubbles. After the Coliscan Easygel was well mixed with the sample, the mixture was poured into the dish by lifting up only one side of the dish lid. The lid was taped back onto the dish and the dish was slowly swirled until the bottom was completely covered. The dish with mixture was placed in the incubator. The steps were repeated for each sample and all dishes were placed in the 35^{o}C incubator for 30 hours because it the best time to count colonies. After the number of colonies were obtained by observations. The concentrations of E. coli and total Coliform were calculated by using equations:

E.coli (colonies per ml) CFU/ml = [# colonies (Type 1-4 only)] / (1 ml)

Total Coliform Colonies per ml = [# colonies (All Types)] / (1 ml)

Appendix V: Laboratory Equipment

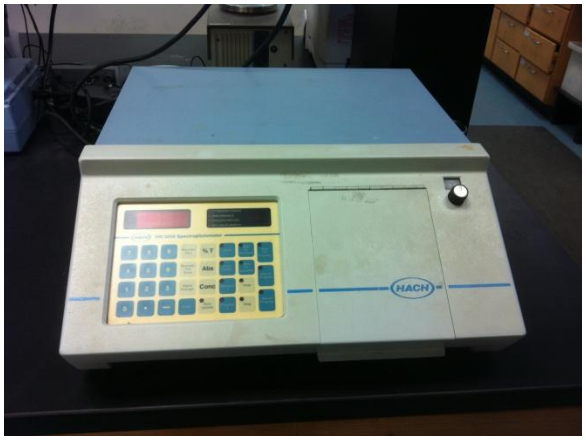


Figure 37: Hach DR/3000 Color Spectrometer (Total Phosphorus and Ammonia Test)

Figure 38: Hood or Smoke Protection (Total Phosphorus Test)

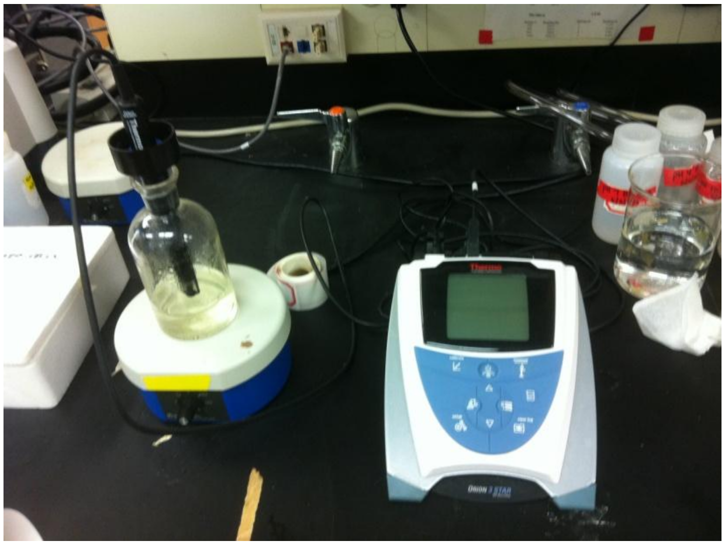


Figure 39: DO Meter (Dissolved Oxygen Test)

Figure 40: Vacuum, Graduate Cylinder, Filter, Tweezers (Total Suspended Solid Test)

Figure 41: Dryer Machine (Total Suspended Solid Test)

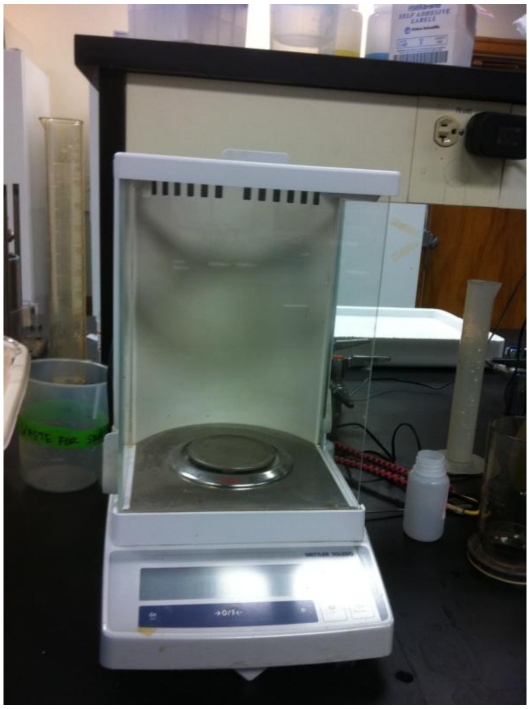


Figure 42: Weight Scale (Total Suspended Solids Test)

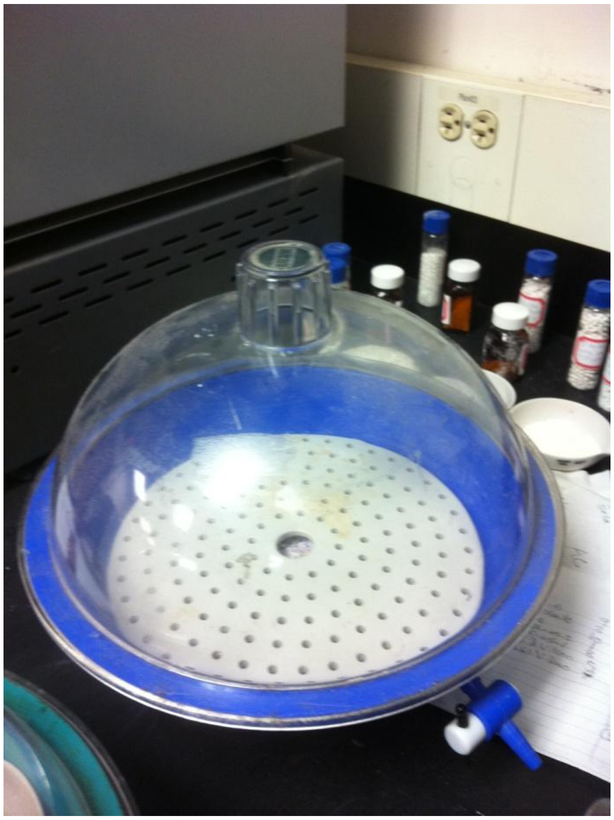


Figure 43: Cooler Plastic (Total Suspended Solids Test)

Figure 44: Ion Chromatography Set (Dissolved Ions Test)

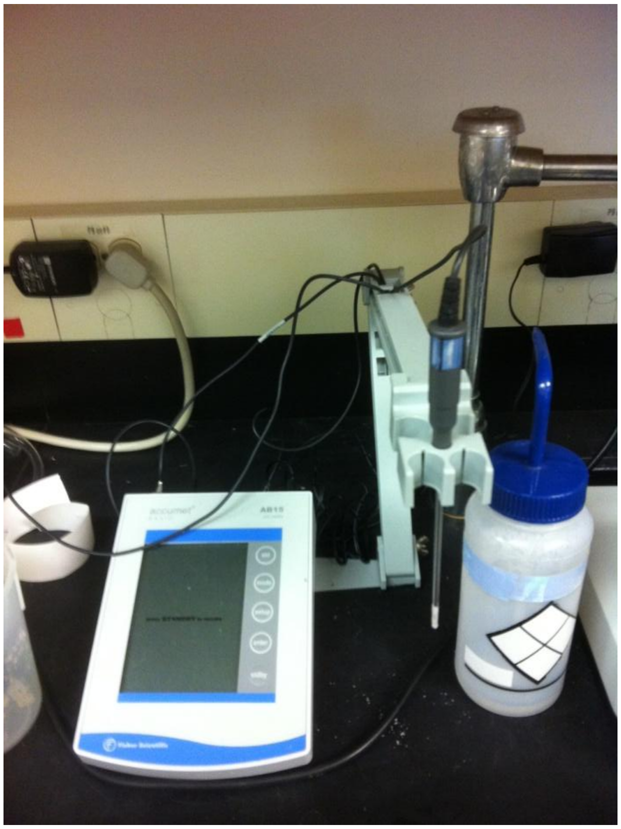


Figure 45: pH meter (pH Values Test)

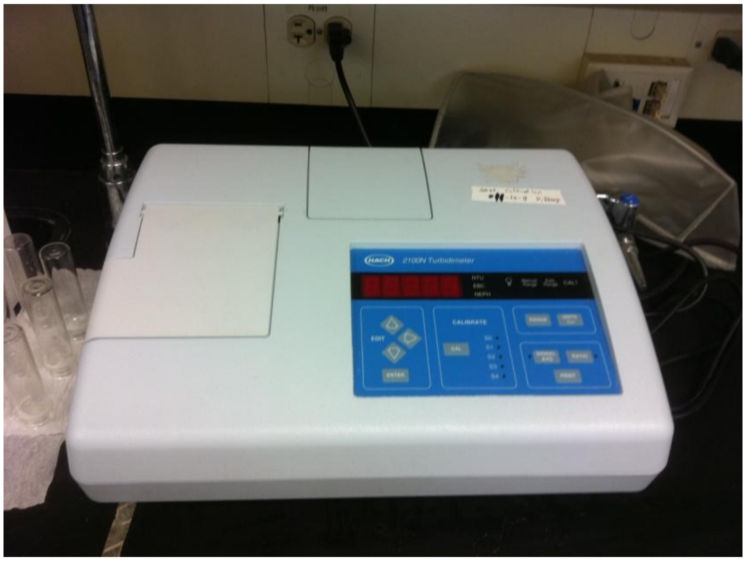


Figure 46: Turbidimeter (Turbidity Test)

Appendix VI: Pollutant Sources Analysis

In this section, there are two equations for determining the amount of stormwater runoff and ground water in the Green Hill Pond

Stormwater Runoff Analysis-NRCS Method

Pollutants in stormwater runoff are generally considered as the major source of pollution. Generally, the quantity of runoff is calculated by following Natural Resources Conservation Service (NCRS) – curve number method:

$$R = P - S$$

Where R = rainfall excess

P = rainfall volume

S = storage volume on and within the soil (initial abstraction plus infiltration) (Wanielista, Hydrology: Water Quantity and Quality Control, 1997)

However, the rate of rainfall excess is equal to the intensity of precipitation at saturation. Thus, a proportional relationship can be developed as

$$\frac{S}{S'} = \frac{R}{P}$$

Where S = storage at any time (mm, in)

S’ = storage at saturation (mm, in)

R = rainfall excess at any time (mm, in)

P = precipitation at any time (mm, in) (Wanielista, Hydrology: Water Quantity and Quality Control, 1997)

Moreover, the NRCS developed runoff curve number (CN) to estimate S’ and rainfall excess in the previous equations. The maximum storage of water can be calculated by following equation;

$$S' = \frac{25400}{CN} - 254\ (mm)$$

$$S' = \frac{1000}{CN} - 10\ (in)$$

Where S’ = storage at saturation (mm, in)

CN = runoff curve number (Wanielista, Hydrology: Water Quantity and Quality Control, 1997)

Also, rainfall excess can be determined by

$$R = \frac{(P - 0.2S')^2}{P + 0.8S'}\ (if\ P > 0.2S')$$

$$R = 0\ (if\ P \leq 0.2S')$$

Runoff curve number can be estimated if the soil classification and the land use are known which tables are also provided in this section.

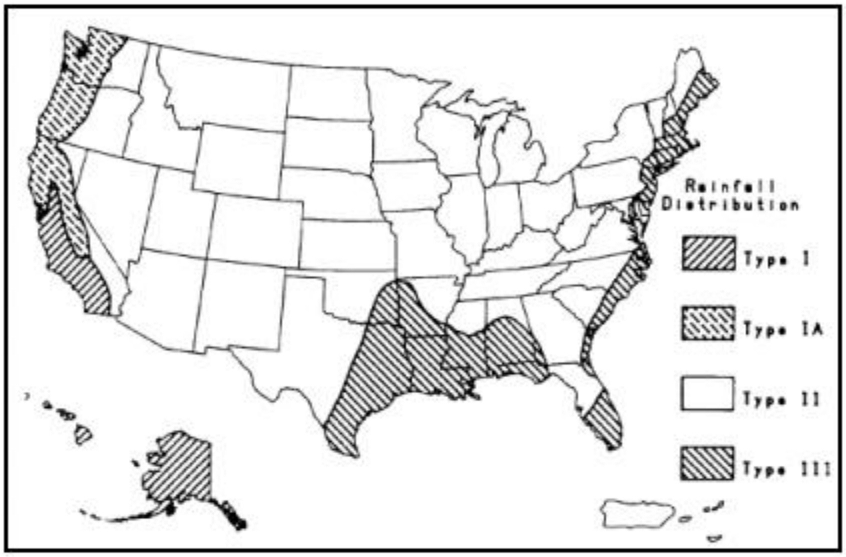


Figure 47: Geographic boundaries for the NRCS rainfall distributions (Iowa Storm Management, 2008)

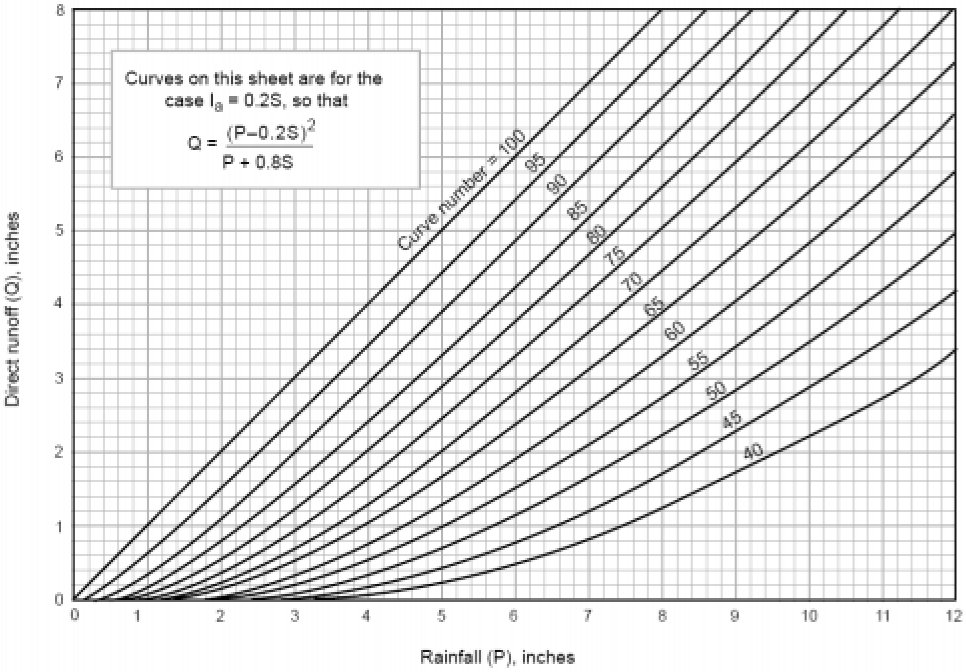
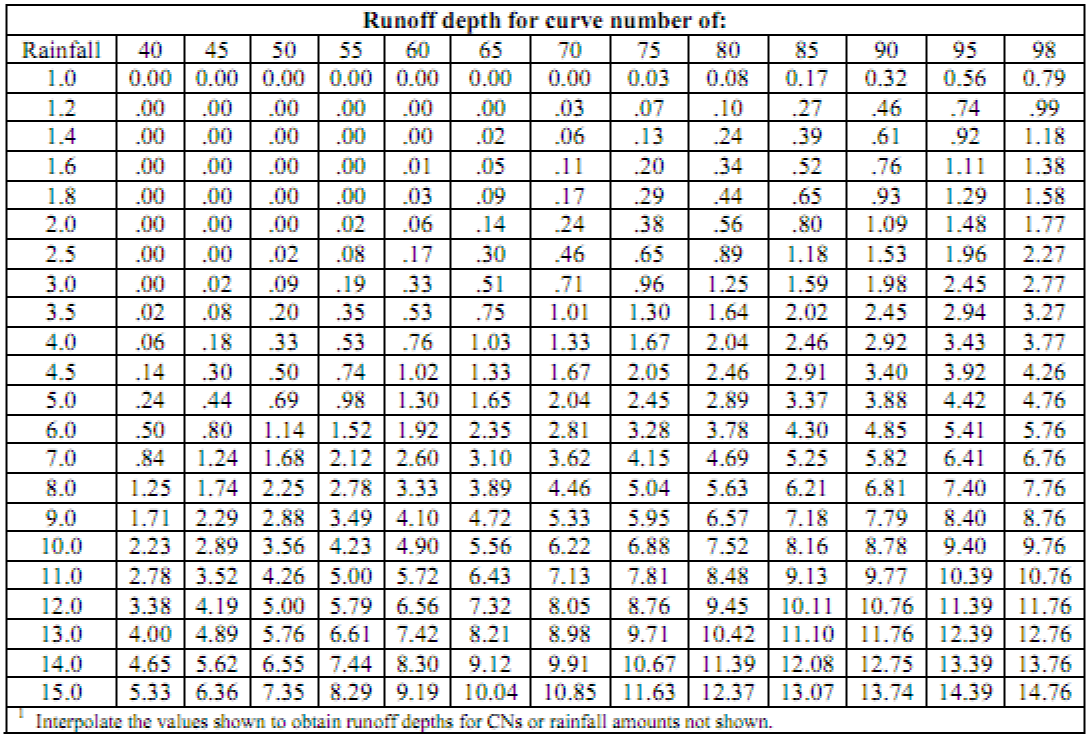


Figure 48: Solution of the NRCS runoff equation (Iowa Storm Management, 2008)

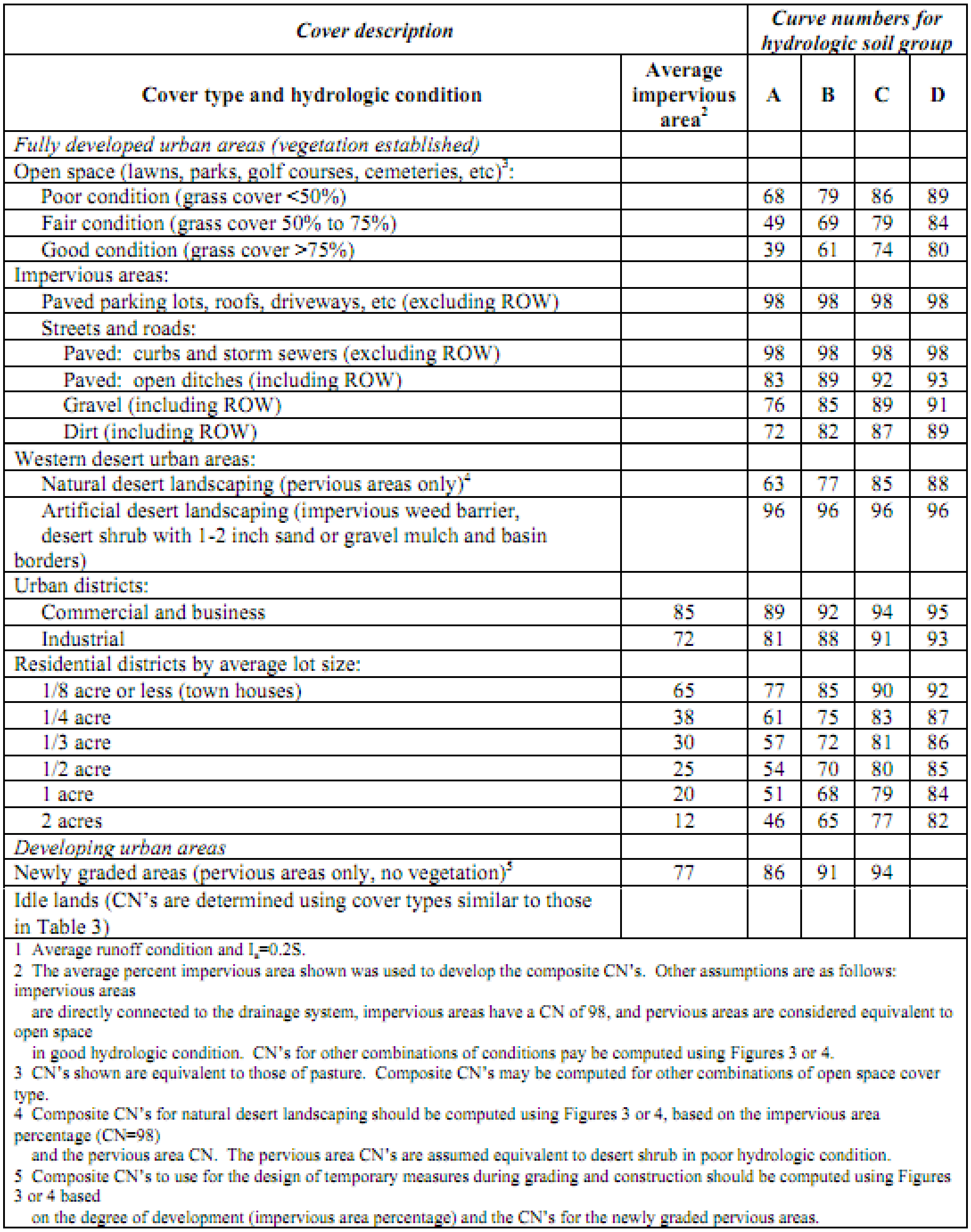
Table 22: Runoff Depth for Selected CN's and Rainfall Amounts (Iowa Storm Management, 2008)



	Runoff depth for curve number of:												
Rainfall	40	45	50	55	60	65	70	75	80	85	90	95	98
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.10	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1] Interpolate the values shown to obtain runoff depths for CNs or rainfall amounts not shown.

Table 23: NRCS Runoff Curve Numbers (CN) for Selected Urban Land Use (Iowa Storm Management, 2008)



Cover description		*Curve numbers for hydrologic soil group*			
Cover type and hydrologic condition	**Average impervious area[2]**	**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc)[3]:					
Poor condition (grass cover <50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover >75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc (excluding ROW)		98	98	98	98
Streets and roads:					
Paved: curbs and storm sewers (excluding ROW)		98	98	98	98
Paved: open ditches (including ROW)		83	89	92	93
Gravel (including ROW)		76	85	89	91
Dirt (including ROW)		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 1-2 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 3)					

1 Average runoff condition and I_a=0.2S.

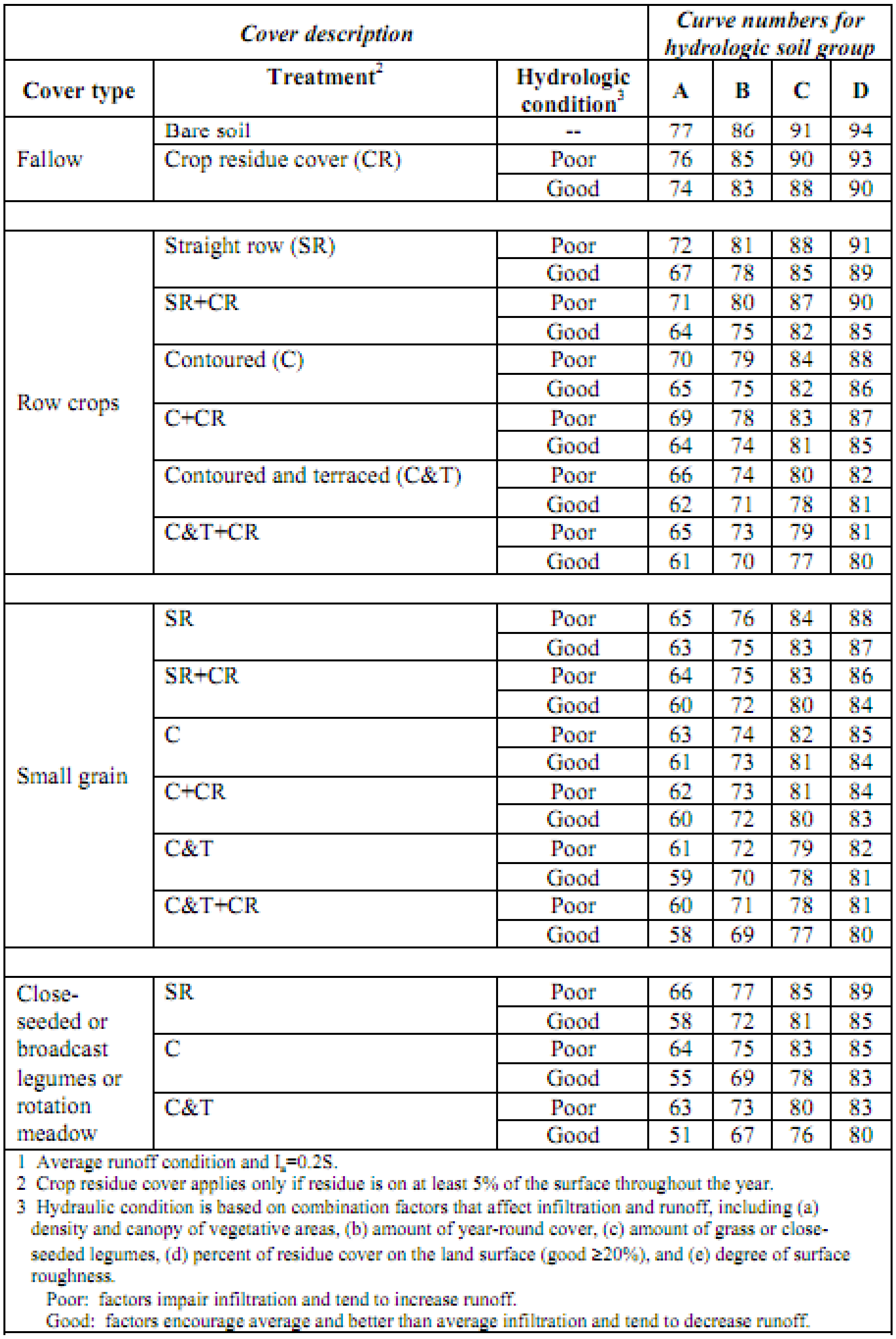
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions pay be computed using Figures 3 or 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 3 or 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 Figures 3 or 4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

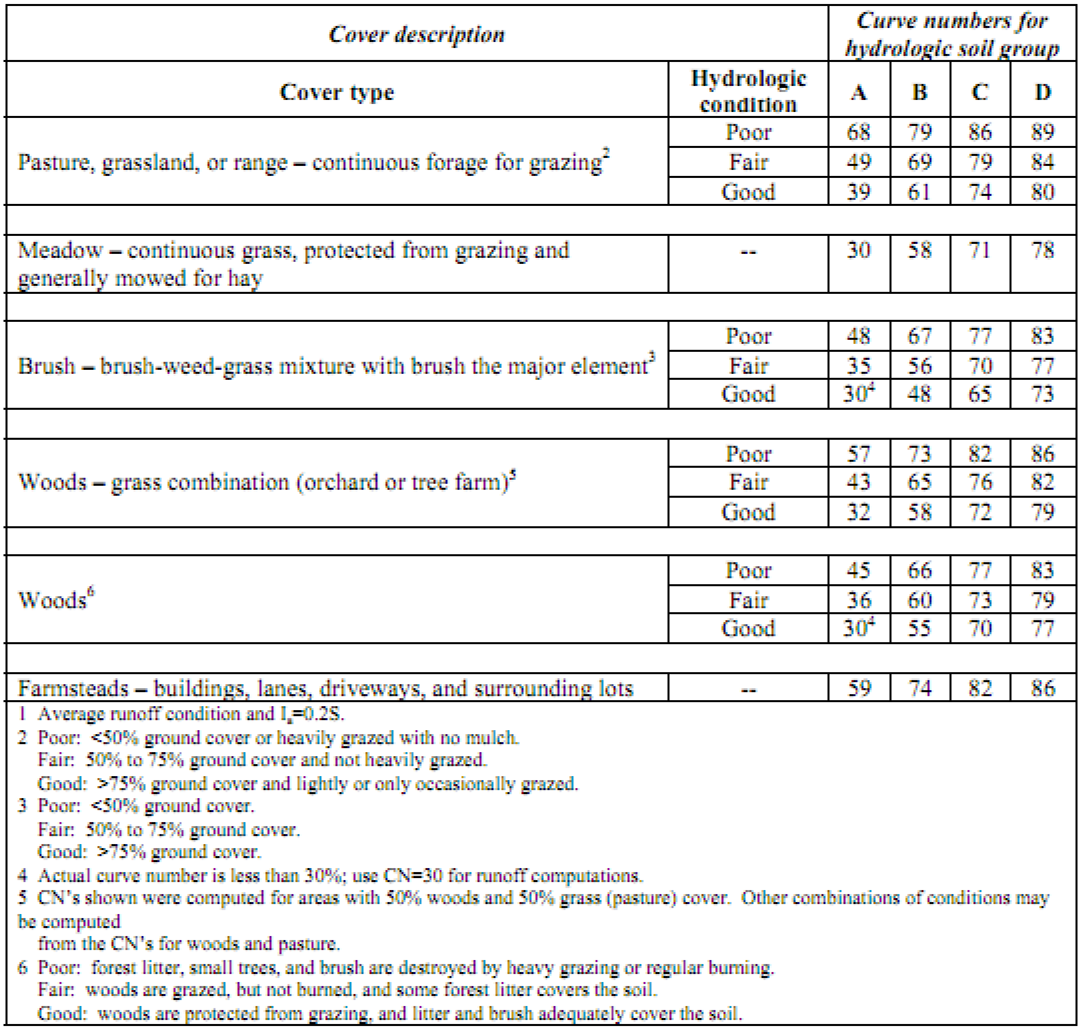
Table 24: NRCS Runoff Curve Numbers (CN) for Selected Cultivated Agricultural Land Use (Iowa Storm Management, 2008)



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 and 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.
Poor: factors impair infiltration and tend to increase runoff.
Good: factors encourage average and better than average infiltration and tend to decrease runoff.

Table 25: NRCS Runoff Curve Numbers (CN) for other Agricultural Land Use (Iowa Storm Management, 2008)



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.

Appendix VII: Pollutant Sources Calculation

Table 26: Runoff Analysis of Sub-area 1

Code	Name	Land Use	Soil Type	Area (Acre)	CN	CNxArea
305c	Paxton fine sandy loam	Forest	C	0.058384	73	4.262032
305c	Paxton fine sandy loam	Golf Course	C	5.483736	79	433.2151
305c	Paxton fine sandy loam	Forest	C	0.058533	73	4.272909
305b	Paxton fine sandy loam	Golf Course	C	1.091625	79	86.23838
305c	Paxton fine sandy loam	Forest	C	0.840024	73	61.32175
310b	Woodbridge fine sandy loam	Forest	C	0.303556	73	22.15959
102c	Chatfield-Hollis-Rock outcrop complex	Golf Course	B	0.244744	69	16.88734
102c	Chatfield-Hollis-Rock outcrop complex	Golf Course	B	3.400154	69	234.6106
102c	Chatfield-Hollis-Rock outcrop complex	Forest	B	0.077008	60	4.62048
102c	Chatfield-Hollis-Rock outcrop complex	Forest	B	0.078598	60	4.71588
102d	Chatfield-Hollis-Rock outcrop complex	Golf Course	B	0.124149	69	8.566281
102d	Chatfield-Hollis-Rock outcrop complex	Forest	B	0.33411	60	20.0466
102d	Chatfield-Hollis-Rock outcrop complex	Golf Course	B	0.003682	69	0.254058
102d	Chatfield-Hollis-Rock outcrop complex	Golf Course	B	0.003267	69	0.225423
1	Water	Wet land	N/A	0.073593	0	0
1	Water	Wet land	N/A	0.052753	0	0
			Total	12.227916		901.3965

CCN	73.71628035	
S'	3.565524402	in
R	0.006612924	in
V	0.080862283	in-acre
P-load	20.64662686	g

Table 27: Runoff Analysis of Sub-area 2

Code	Name	Land Use	Soil Type	Area (Acre)	CN	CNxArea
310b	Woodbridge fine sandy loam	Forest	C	0.162754	73	11.88104
1	Water	Wetland	N/A	0.043222	0	0
1	Water	Wetland	N/A	0.017341	0	0
305c	Paxton fine sandy loam	Golf Course	C	0.224085	79	17.70272
310b	Woodbridge fine sandy loam	Golf Course	C	2.950978	79	233.1273
305d	Paxton fine sandy loam	Golf Course	C	4.296588	79	339.4305
305b	Paxton fine sandy loam	Golf Course	C	3.911109	79	308.9776
305c	Paxton fine sandy loam	Golf Course	C	0.121617	79	9.607743
			Total	11.727694		920.7268

CCN	78.5087695	
S'	2.737430562	in
R	0.033992515	in
V	0.398653815	in-acre
P-load	31.75770761	g

Table 28: Runoff Analysis of Sub-area 3

Code	Name	Land Use	Soil Type	Area (Acre)	CN	CNxArea
310b	Woodbridge fine sandy loam	Golf Course	C	1.738563	79	137.3465
1	Water	Wetland	N/A	0.021865	0	0
1	Water	Wetland	N/A	0.008675	0	0
1	Water	Wetland	N/A	0.022165	0	0
305b	Paxton fine sandy loam	Golf Course	C	2.519841	79	199.0674
305c	Paxton fine sandy loam	Golf Course	C	1.189478	79	93.96876
305d	Paxton fine sandy loam	Golf Course	C	5.331099	79	421.1568
			Total	10.831686		851.5395

CCN	78.61560047	
S'	2.72012163	in
R	0.034884027	in
V	0.377852825	in-acre
P-load	59.9294261	g

Table 29: Runoff Analysis of Sub-area 4

Code	Name	Land Use	Soil Type	Area (Acre)	CN	CNxArea
305c	Paxton fine sandy loam	Golf Course	C	0.124291	79	9.818989
305b	Paxton fine sandy loam	Golf Course	C	2.377005	79	187.7834
310b	Woodbridge fine sandy loam	Golf Course	B	0.876359	69	60.46877
1	Water	Wetland	N/A	0.009135	0	0
1	Water	Wetland	N/A	0.000791	0	0
1	Water	Wetland	N/A	0.002957	0	0
1	Water	Wetland	N/A	0.006064	0	0
1	Water	Wetland	N/A	0.005024	0	0
1	Water	Wetland	N/A	0.022457	0	0
1	Water	Wetland	N/A	0.080566	0	0
70b	Ridgebury fine sandy loam	Golf Course	C	0.448974	79	35.46895
70b	Ridgebury fine sandy loam	Forest	C	0.318724	73	23.26685
305d	Paxton fine sandy loam	Forest	C	0.250732	73	18.30344
305d	Paxton fine sandy loam	Golf Course	C	3.792542	79	299.6108
			Total	8.315621		634.7212

CCN	76.32878014	
S'	3.101218154	in
R	0.018614956	in
V	0.154794921	in-acre
P-load	14.06567214	g

Table 30: Runoff Analysis of Sub-area 5

Code	Name	Land Use	Soil Type	Area (Acre)	CN	CNxArea
305b	Paxton fine sandy loam	Golf Course	C	1.047231	79	82.73125
305d	Paxton fine sandy loam	Golf Course	C	0.37703	79	29.78537
305d	Paxton fine sandy loam	Forest	C	3.059663	79	241.7134
70b	Ridgebury fine sandy loam	Forest	C	1.725669	79	136.3279
305d	Paxton fine sandy loam	Urban Public/ Institutional	C	0.463669	91	42.19388
305b	Paxton fine sandy loam	Urban Public/ Institutional	C	1.349471	91	122.8019
305b	Paxton fine sandy loam	Forest	C	0.348153	79	27.50409
305c	Paxton fine sandy loam	Forest	C	0.216316	79	17.08896
305c	Paxton fine sandy loam	Participation recreation	C	0.235047	98	23.03461
1	Water	Wetland	N/A	0.017682	0	0
1	Water	Wetland	N/A	0.001461	0	0
1	Water	Wetland	N/A	0.07717	0	0
1	Water	Wetland	N/A	0.008214	0	0
1	Water	Wetland	N/A	0.027464	0	0
1	Water	Wetland	N/A	0.00539	0	0
			Total	8.95963		723.1812

CCN	80.71552553	
S'	2.389190226	in
R	0.055293609	in
V	0.495410274	in-acre
P-load	69.35753278	g

Table 31: Runoff Analysis of Sub-area 6

Code	Name	Land Use	Soil Type	Area (Acre)	CN	CNxArea
102c	Chatfield-Hollis-Rock outcrop complex	Participation recreation	B	10.848107	98	1063.114
102c	Chatfield-Hollis-Rock outcrop complex	Forest	B	0.852899	63	53.73264
102c	Chatfield-Hollis-Rock outcrop complex	Forest	B	0.656585	63	41.36486
102c	Chatfield-Hollis-Rock outcrop complex	Forest	B	0.066496	63	4.189248
102d	Chatfield-Hollis-Rock outcrop complex	Participation recreation	B	0.242034	98	23.71933
102d	Chatfield-Hollis-Rock outcrop complex	Forest	B	1.773769	63	111.7474
1	Water	Wetland	N/A	0.058191	0	0
1	Water	Wetland	N/A	0.068295	0	0
1	Water	Wetland	N/A	0.007976	0	0
1	Water	Wetland	N/A	0.01304	0	0
1	Water	Wetland	N/A	0.053759	0	0
1	Water	Wetland	N/A	0.016333	0	0
1	Water	Wetland	N/A	0.011042	0	0
1	Water	Wetland	N/A	0.014764	0	0
1	Water	Wetland	N/A	0.049949	0	0
			Total	14.733239		1297.868

CCN	88.0911526	
S'	1.351877805	in
R	0.184242406	in
V	2.714487394	in-acre
P-load	891.7561623	g

Table 32: Runoff Analysis of Sub-area 7

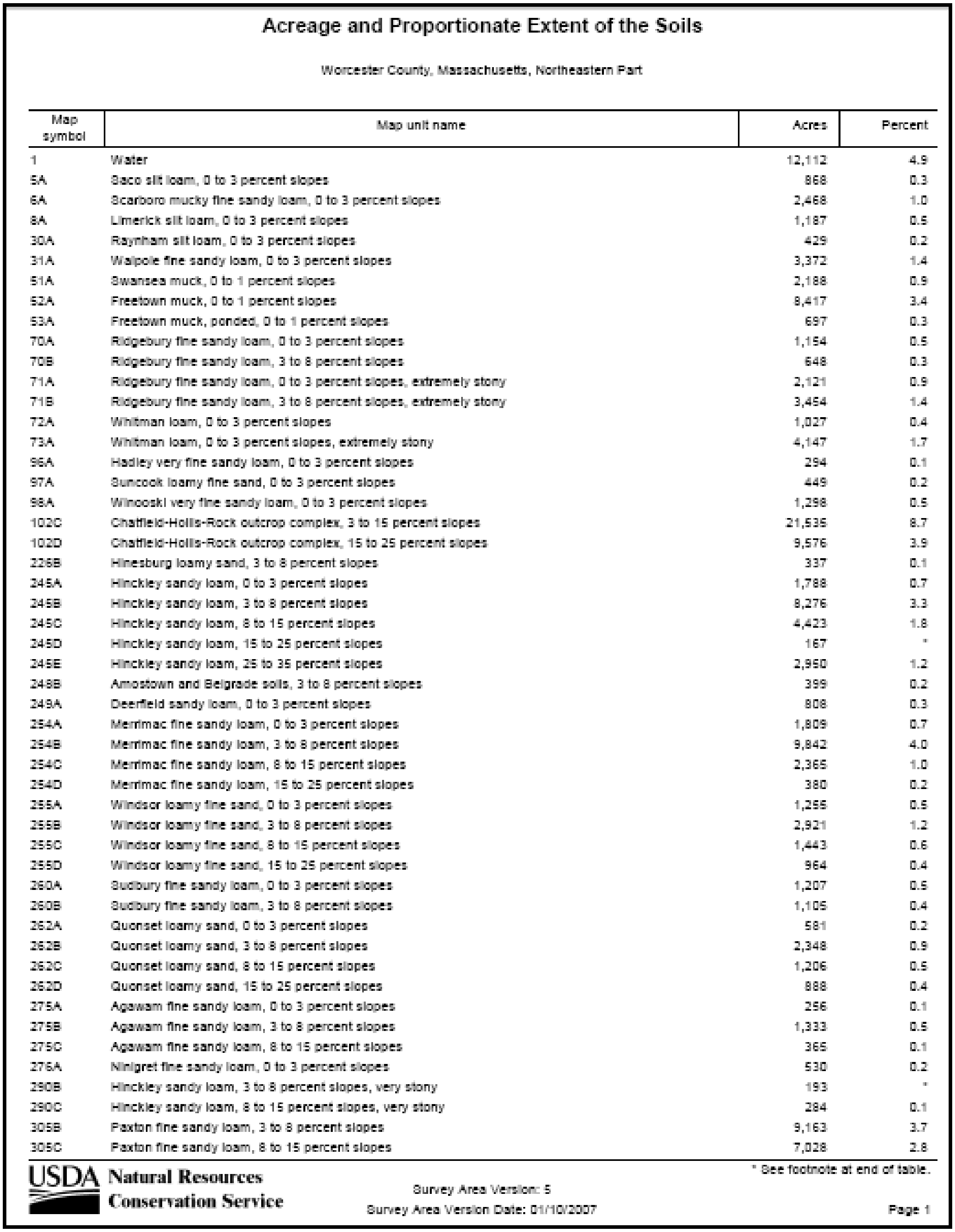
Code	Name	Land Use	Soil Type	Area (Acre)	CN	CNxArea
102d	Chatfield-Hollis-Rock outcrop complex	Forest	B	1.426765	63	89.8862
102c	Chatfield-Hollis-Rock outcrop complex	Forest	B	1.060376	63	66.80369
102c	Chatfield-Hollis-Rock outcrop complex	Forest	B	1.150819	63	72.5016
102c	Chatfield-Hollis-Rock outcrop complex	Forest	B	4.52499	63	285.0744
102c	Chatfield-Hollis-Rock outcrop complex	Participation Recreation	B	3.65707	98	358.3929
102d	Chatfield-Hollis-Rock outcrop complex	Participation recreation	B	0.50203	98	49.19894
102d	Chatfield-Hollis-Rock outcrop complex	Forest	B	0.896337	63	56.46923
102d	Chatfield-Hollis-Rock outcrop complex	Golf Course	B	0.065823	69	4.541787
102c	Chatfield-Hollis-Rock outcrop complex	Golf Course	B	1.583837	69	109.2848
102c	Chatfield-Hollis-Rock outcrop complex	Golf Course	B	0.00624	69	0.43056
1	Water	Wetland	N/A	0.276022	0	0
1	Water	Wetland	N/A	0.170115	0	0
			Total	15.320424		1092.584

CCN	71.31551849	
S'	4.022193503	in
R	0.001051502	in
V	0.016109463	in-acre
P-load	2.826611311	g

Table 33: Result of runoff analysis for entire sub-basin

Total Area	82.11621	
Total V	4.238170974	in-acre
Total P	1090.339739	grams

Table 34: Soil Identifications



Acreage and Proportionate Extent of the Soils

Worcester County, Massachusetts, Northeastern Part

Map symbol	Map unit name	Acres	Percent
1	Water	12,112	4.9
5A	Saco silt loam, 0 to 3 percent slopes	868	0.3
6A	Scarboro mucky fine sandy loam, 0 to 3 percent slopes	2,468	1.0
8A	Limerick silt loam, 0 to 3 percent slopes	1,187	0.5
30A	Raynham silt loam, 0 to 3 percent slopes	429	0.2
31A	Walpole fine sandy loam, 0 to 3 percent slopes	3,372	1.4
51A	Swansea muck, 0 to 1 percent slopes	2,188	0.9
52A	Freetown muck, 0 to 1 percent slopes	8,417	3.4
53A	Freetown muck, ponded, 0 to 1 percent slopes	697	0.3
70A	Ridgebury fine sandy loam, 0 to 3 percent slopes	1,154	0.5
70B	Ridgebury fine sandy loam, 3 to 8 percent slopes	648	0.3
71A	Ridgebury fine sandy loam, 0 to 3 percent slopes, extremely stony	2,121	0.9
71B	Ridgebury fine sandy loam, 3 to 8 percent slopes, extremely stony	3,454	1.4
72A	Whitman loam, 0 to 3 percent slopes	1,027	0.4
73A	Whitman loam, 0 to 3 percent slopes, extremely stony	4,147	1.7
96A	Hadley very fine sandy loam, 0 to 3 percent slopes	294	0.1
97A	Suncook loamy fine sand, 0 to 3 percent slopes	449	0.2
98A	Winooski very fine sandy loam, 0 to 3 percent slopes	1,298	0.5
102C	Chatfield-Hollis-Rock outcrop complex, 3 to 15 percent slopes	21,535	8.7
102D	Chatfield-Hollis-Rock outcrop complex, 15 to 25 percent slopes	9,576	3.9
226B	Hinesburg loamy sand, 3 to 8 percent slopes	337	0.1
245A	Hinckley sandy loam, 0 to 3 percent slopes	1,788	0.7
245B	Hinckley sandy loam, 3 to 8 percent slopes	8,276	3.3
245C	Hinckley sandy loam, 8 to 15 percent slopes	4,423	1.8
245D	Hinckley sandy loam, 15 to 25 percent slopes	167	*
245E	Hinckley sandy loam, 25 to 35 percent slopes	2,950	1.2
248B	Amostown and Belgrade soils, 3 to 8 percent slopes	399	0.2
249A	Deerfield sandy loam, 0 to 3 percent slopes	808	0.3
254A	Merrimac fine sandy loam, 0 to 3 percent slopes	1,809	0.7
254B	Merrimac fine sandy loam, 3 to 8 percent slopes	9,842	4.0
254C	Merrimac fine sandy loam, 8 to 15 percent slopes	2,365	1.0
254D	Merrimac fine sandy loam, 15 to 25 percent slopes	380	0.2
255A	Windsor loamy fine sand, 0 to 3 percent slopes	1,255	0.5
255B	Windsor loamy fine sand, 3 to 8 percent slopes	2,921	1.2
255C	Windsor loamy fine sand, 8 to 15 percent slopes	1,443	0.6
255D	Windsor loamy fine sand, 15 to 25 percent slopes	964	0.4
260A	Sudbury fine sandy loam, 0 to 3 percent slopes	1,207	0.5
260B	Sudbury fine sandy loam, 3 to 8 percent slopes	1,105	0.4
262A	Quonset loamy sand, 0 to 3 percent slopes	581	0.2
262B	Quonset loamy sand, 3 to 8 percent slopes	2,348	0.9
262C	Quonset loamy sand, 8 to 15 percent slopes	1,206	0.5
262D	Quonset loamy sand, 15 to 25 percent slopes	888	0.4
275A	Agawam fine sandy loam, 0 to 3 percent slopes	256	0.1
275B	Agawam fine sandy loam, 3 to 8 percent slopes	1,333	0.5
275C	Agawam fine sandy loam, 8 to 15 percent slopes	365	0.1
276A	Ninigret fine sandy loam, 0 to 3 percent slopes	530	0.2
290B	Hinckley sandy loam, 3 to 8 percent slopes, very stony	193	*
290C	Hinckley sandy loam, 8 to 15 percent slopes, very stony	284	0.1
305B	Paxton fine sandy loam, 3 to 8 percent slopes	9,163	3.7
305C	Paxton fine sandy loam, 8 to 15 percent slopes	7,028	2.8

* See footnote at end of table.

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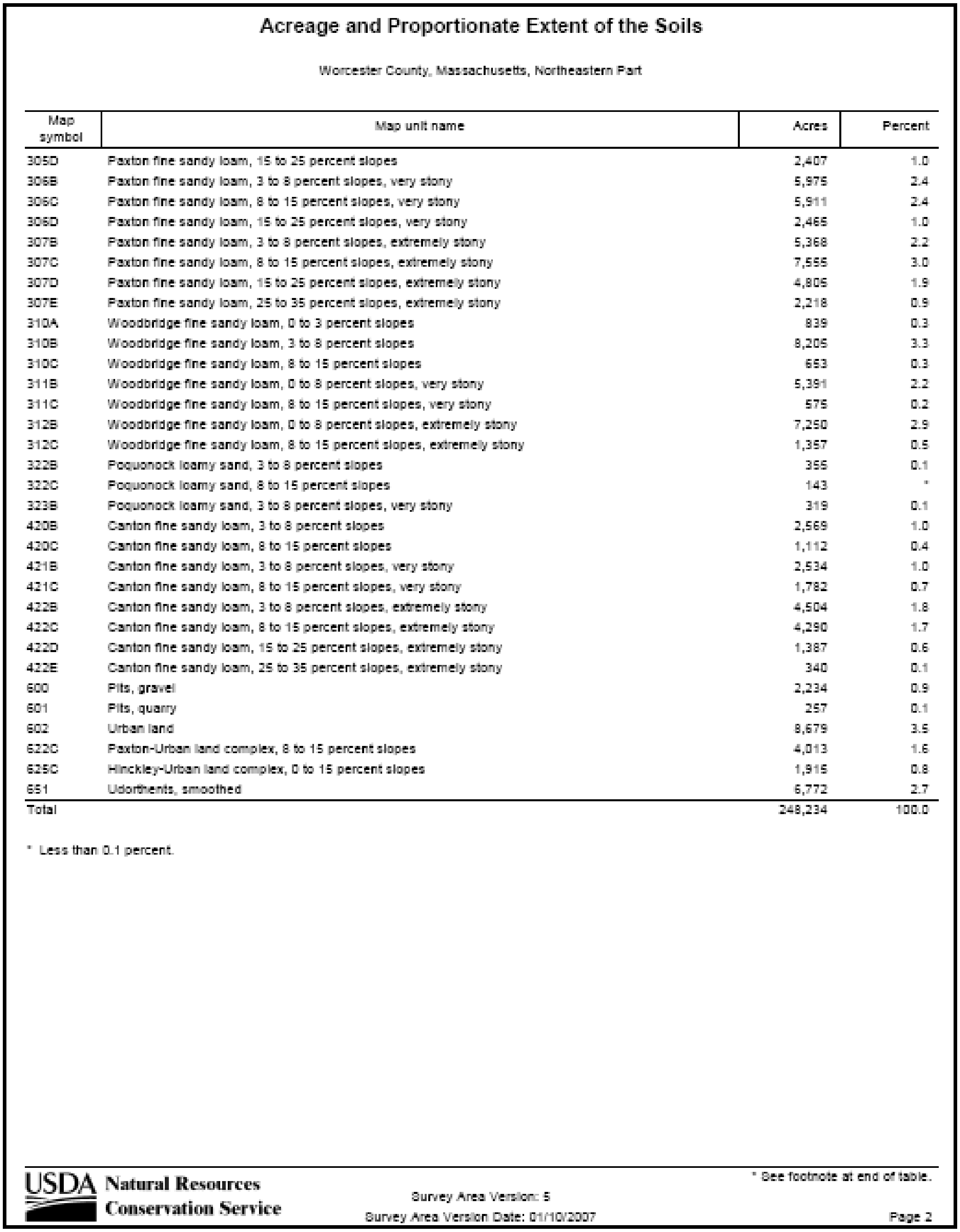

Acreage and Proportionate Extent of the Soils

Worcester County, Massachusetts, Northeastern Part

Map symbol	Map unit name	Acres	Percent
305D	Paxton fine sandy loam, 15 to 25 percent slopes	2,407	1.0
306B	Paxton fine sandy loam, 3 to 8 percent slopes, very stony	5,975	2.4
306C	Paxton fine sandy loam, 8 to 15 percent slopes, very stony	5,911	2.4
306D	Paxton fine sandy loam, 15 to 25 percent slopes, very stony	2,465	1.0
307B	Paxton fine sandy loam, 3 to 8 percent slopes, extremely stony	5,368	2.2
307C	Paxton fine sandy loam, 8 to 15 percent slopes, extremely stony	7,555	3.0
307D	Paxton fine sandy loam, 15 to 25 percent slopes, extremely stony	4,806	1.9
307E	Paxton fine sandy loam, 25 to 35 percent slopes, extremely stony	2,218	0.9
310A	Woodbridge fine sandy loam, 0 to 3 percent slopes	839	0.3
310B	Woodbridge fine sandy loam, 3 to 8 percent slopes	8,205	3.3
310C	Woodbridge fine sandy loam, 8 to 15 percent slopes	653	0.3
311B	Woodbridge fine sandy loam, 0 to 8 percent slopes, very stony	5,391	2.2
311C	Woodbridge fine sandy loam, 8 to 15 percent slopes, very stony	575	0.2
312B	Woodbridge fine sandy loam, 0 to 8 percent slopes, extremely stony	7,250	2.9
312C	Woodbridge fine sandy loam, 8 to 15 percent slopes, extremely stony	1,357	0.5
322B	Poquonock loamy sand, 3 to 8 percent slopes	355	0.1
322C	Poquonock loamy sand, 8 to 15 percent slopes	143	*
323B	Poquonock loamy sand, 3 to 8 percent slopes, very stony	319	0.1
420B	Canton fine sandy loam, 3 to 8 percent slopes	2,569	1.0
420C	Canton fine sandy loam, 8 to 15 percent slopes	1,112	0.4
421B	Canton fine sandy loam, 3 to 8 percent slopes, very stony	2,534	1.0
421C	Canton fine sandy loam, 8 to 15 percent slopes, very stony	1,782	0.7
422B	Canton fine sandy loam, 3 to 8 percent slopes, extremely stony	4,504	1.8
422C	Canton fine sandy loam, 8 to 15 percent slopes, extremely stony	4,290	1.7
422D	Canton fine sandy loam, 15 to 25 percent slopes, extremely stony	1,387	0.6
422E	Canton fine sandy loam, 25 to 35 percent slopes, extremely stony	340	0.1
600	Pits, gravel	2,234	0.9
601	Pits, quarry	257	0.1
602	Urban land	8,679	3.5
622C	Paxton-Urban land complex, 8 to 15 percent slopes	4,013	1.6
625C	Hinckley-Urban land complex, 0 to 15 percent slopes	1,915	0.8
651	Udorthents, smoothed	6,772	2.7
Total		248,234	100.0

* Less than 0.1 percent.

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* See footnote at end of table.

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Table 35: Massachusetts Hydrologic Soil Group List

Soil Series/Map Unit Phase	Hydrologic Group
Acton	B
Agawam	B
Agawam, silty subsoil variant	C
Agawam, silty substratum	C
Amenia	C
Amenia variant	B
Amostown	C
Au Gres	B
Bayboro	D
Beaches	Unclassified
Belgrade	B
Berkshire	B
Berkshire, dark subsoil	B
Bernardston	C
Berryland	D
Berryland variant	D
Biddeford	D
Birchwood	C
Birdsall	D
Borrow pit	Unclassified
Borrow land, loamy material	Unclassified
Borrow land, sandy and gravelly materials	Unclassified

Borrow pit, glacial till	Unclassified
Brimfield	C/D*
Broadbrook	C
Brockton	D
Brookfield	B
Boxford	C
Buckland	C
Burdick	A
Buxton	C
Buxton variant	C
Cabot	D
Cabot, black surface	D
Canton	B
Carver	A
Charlton	B
Chatfield	B
Cheshire	B
Chilmark	C
Coastal beach	Unclassified
Colrain	B
Copake	B
Cranberry bog	D
Deerfield	B
Dukes	A

Dumps	Unclassified
Dune land	A
Dune land and Coastal beach	A
Dune sand	A
Dunes, stabilized	A
Dutchess	B
Eldridge	C
Elmwood	C
Elmridge	C
Enfield	B
Enosburg	D
Essex	C
Evesboro	A
Fredon	C
Fredon, silty subsoil variant	C
Freetown	D
Freetown, ponded	D
Fresh water marsh	D
Galestown	A
Gloucester	A
Gravel pit	A
Groton	A
Hadley	B
Halsey	D
Halsey, silty subsoil variant	D

Hartland	B
Haven	B
Hero	B
Hero, silty subsoil variant	C
Hinckley	A
Hinesburg	C
Hollis	C/D*
Holyoke	C/D*
Ipswich	D
Katama	B
Kendaia	C
Klej	B
Leicester	C
Lenox	B
Limerick	C
Lincroft	A
Ludlow	C
Lyman	C/D*
Lyons	D
Made land	Unclassified
Marlow	C
Marlow, dark subsoil	C
Matawan	C
Matunuck	D
Maybid	D

Meckesville	C
Medisaprists	D
Medisaprists, deep	D
Medisaprists, sandy surface	D
Medisaprists, shallow	D
Melrose	C
Merrimac	A
Montauk	C
Muck	D
Muck, deep	D
Muck, shallow	D
Nantucket	C
Narragansett	B
Nassau	C/D*
Newport	C
Ninigret	B
Ninigret, silty subsoil variant	C
Ninigret, silty substratum	C
Norwell	C
Oakville	A
Occum	B
Ondawa	B
Pawcatuck	D
Paxton	C

Peacham	D
Peat	D
Peru	C
Pipestone	C
Pits	A
Pits, gravel	A
Pits, quarry	Unclassified
Pits - Udorthents, gravelly	A
Pittsfield	B
Pittstown	C
Plymouth	A
Podunk	B
Pollux	C
Pompton	B
Pootatuck	B
Poquonock	C
Quarries	Unclassified
Quonset	A
Rainbow	C
Raynham	C
Ridgebury	C
Ridgebury variant (Nantucket)	C
Rippowam	C
Riverhead	B

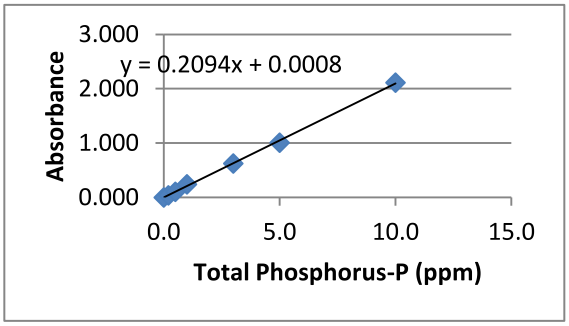
Riverwash	Unclassified
Rock land	D
Rock outcrop	D
Rumney	C
Saco	D
Saco variant	D
Sanded muck	D
Saugatuck	C
Scantic	D
Scantic variant	D
Scarboro	D
Scarboro, brownish subsoil variant	D
Scarboro, silty subsoil variant	D
Scio	B
Scitico	D
Scituate	C
Shaker	D
Shapleigh	C/D*
Shelburne	C
Stissing	C
Stockbridge	C
Sudbury	B
Suffield	C

Suncook	A
Sunderland	C/D*
Sutton	B
Swansea	D
Swanton	D
Terrace escarpments	B
Terric Medisaprists	D
Tidal marsh	D
Tisbury	B
Tisbury, SBA variant	B
Udipsamments, rolling	A
Udipsamments, hilly	A
Udorthents	Unclassified
Udorthents, smoothed	Unclassified
Unadilla	B
Urban land	Unclassified
Walpole	C
Walpole, silty subsoil variant	C
Walpole variant	C
Wareham	C
Warwick	A
Westbrook	D
Westminster	C/D*
Wethersfield	C

Whately	D
Whately variant	D
Whitman	D
Wilbrahma	C
Windsor	A
Winooski	B
Woodbridge	C
Woodbridge variant	C

Appendix VIII: Total Phosphorus Spreadsheet

Standard (PPM)	**Absorbance**	
0.0	**0.000**	
0.2	0.039	20-Jul
0.5	0.104	21-Oct
1.0	0.242	20-Jul
3.0	0.625	21-Oct
5.0	1.008	1-Nov
10.0	2.113	22-Jun

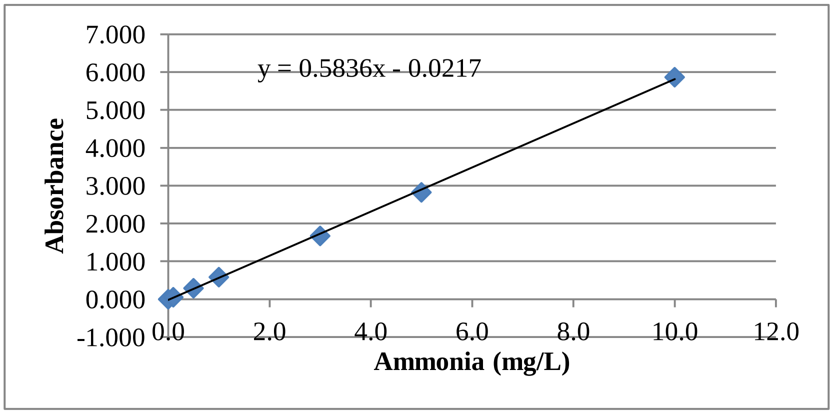


	Location P1-		Location 1-		Runoff-
Sample Name	dry	**Sample Name**	wet	**Sample Name**	1
Absorbance	0.114	**Absorbance**	0.122	**Absorbance**	0.521
Total Phos-P	0.541	**Total Phos-P**	0.579	**Total Phos-P**	2.484
Total Phos-PO$_4^{-3}$	1.657	**Total Phos-PO$_4^{-3}$**	1.774	**Total Phos-PO$_4^{-3}$**	7.613
	Location P2-		Location 2-		Runoff-
Sample Name	dry	**Sample Name**	wet	**Sample Name**	2
Absorbance	0.140	**Absorbance**	0.137	**Absorbance**	0.163
Total Phos-P	0.665	**Total Phos-P**	0.650	**Total Phos-P**	0.775
Total Phos-PO$_4^{-3}$	2.037	**Total Phos-PO$_4^{-3}$**	1.993	**Total Phos-PO$_4^{-3}$**	2.374
	Location P3-		Location 3-		Runoff-
Sample Name	dry	**Sample Name**	wet	**Sample Name**	3
Absorbance	0.131	**Absorbance**	0.118	**Absorbance**	0.324

Total Phos-P	0.622	**Total Phos-P**	0.560	**Total Phos-P**	1.543
Total Phos-PO_4^{-3}	1.905	**Total Phos-PO_4^{-3}**	1.715	**Total Phos-PO_4^{-3}**	4.730
Sample Name	Location P4-dry	**Sample Name**	Location 4-wet	**Sample Name**	Runoff-4
Absorbance	0.131	**Absorbance**	0.122	**Absorbance**	0.186
Total Phos-P	0.622	**Total Phos-P**	0.579	**Total Phos-P**	0.884
Total Phos-PO_4^{-3}	1.905	**Total Phos-PO_4^{-3}**	1.774	**Total Phos-PO_4^{-3}**	2.710
Sample Name	In pond-Middle			**Sample Name**	Runoff-5
Absorbance	0.113			**Absorbance**	0.286
Total Phos-P	0.536			**Total Phos-P**	1.362
Total Phos-PO_4^{-3}	1.642			**Total Phos-PO_4^{-3}**	4.174
Sample Name	In pond-North			**Sample Name**	Runoff-6
Absorbance	0.109			**Absorbance**	0.670
Total Phos-P	0.517			**Total Phos-P**	3.196
Total Phos-PO_4^{-3}	1.583			**Total Phos-PO_4^{-3}**	9.794

Appendix IX: Ammonia Spreadsheet

Standard (mg/L)	**Absorbance**
0.0	**0.000**
0.1	0.053
0.5	0.290
1.0	0.584
3.0	1.672
5.0	2.823
10.0	5.865



Sample Name	Runoff 5	Sample Name	Location 1-dry	Sample Name	Location 1-wet
Absorbance	2.934	Absorbance	0.224	Absorbance	0.154
Ammonia	4.999	Ammonia	0.377	Ammonia	0.258

Sample Name	Runoff 6	Sample Name	Location 4-dry	Sample Name	Location 4-wet
Absorbance	1.752	Absorbance	0.225	Absorbance	0.250
Ammonia	2.983	Ammonia	0.379	Ammonia	0.422

Sample Name	Runoff 2	Sample Name	Location 2-dry	Sample Name	Location 2-wet

Absorbance	0.463	Absorbance	0.198	Absorbance	0.256
Ammonia	0.785	Ammonia	0.333	Ammonia	0.432

Sample Name	Runoff 3	Sample Name	Location 3-dry	Sample Name	Location 3-wet
Absorbance	0.443	Absorbance	0.216	Absorbance	0.285
Ammonia	0.751	Ammonia	0.364	Ammonia	0.481

Sample Name	Runoff 1	Sample Name	in pond-middle
Absorbance	0.243	Absorbance	0.209
Ammonia	0.410	Ammonia	0.352

Sample Name	Runoff 4	Sample Name	in pond-north outlet
Absorbance	0.463	Absorbance	0.227
Ammonia	0.785	Ammonia	0.382

Appendix X: Total Suspended Solid Spreadsheet and Result Pictures


Location 1-Wet
Location 2-Wet
Location 3-Wet
Location 4-Wet
Location 1-Dry
Location 2-Dry
Location 3-Dry
Location 4-Dry
Location 5-Dry
Location 6-Dry

Figure 49: Total Suspended Solids Result Pictures- Wet &Dry

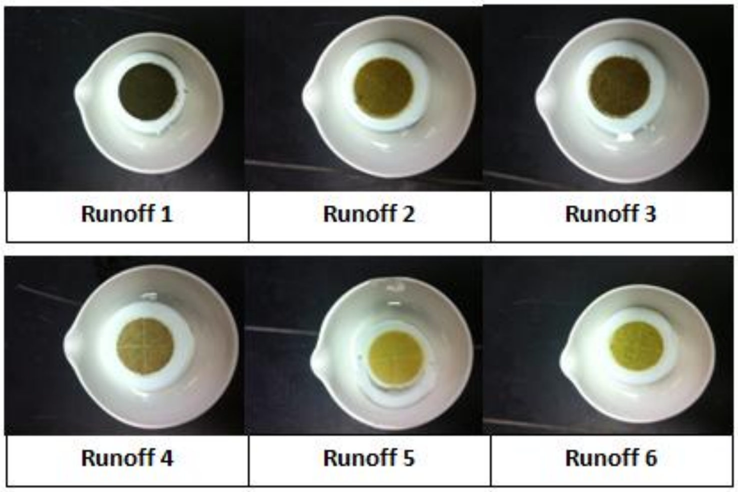
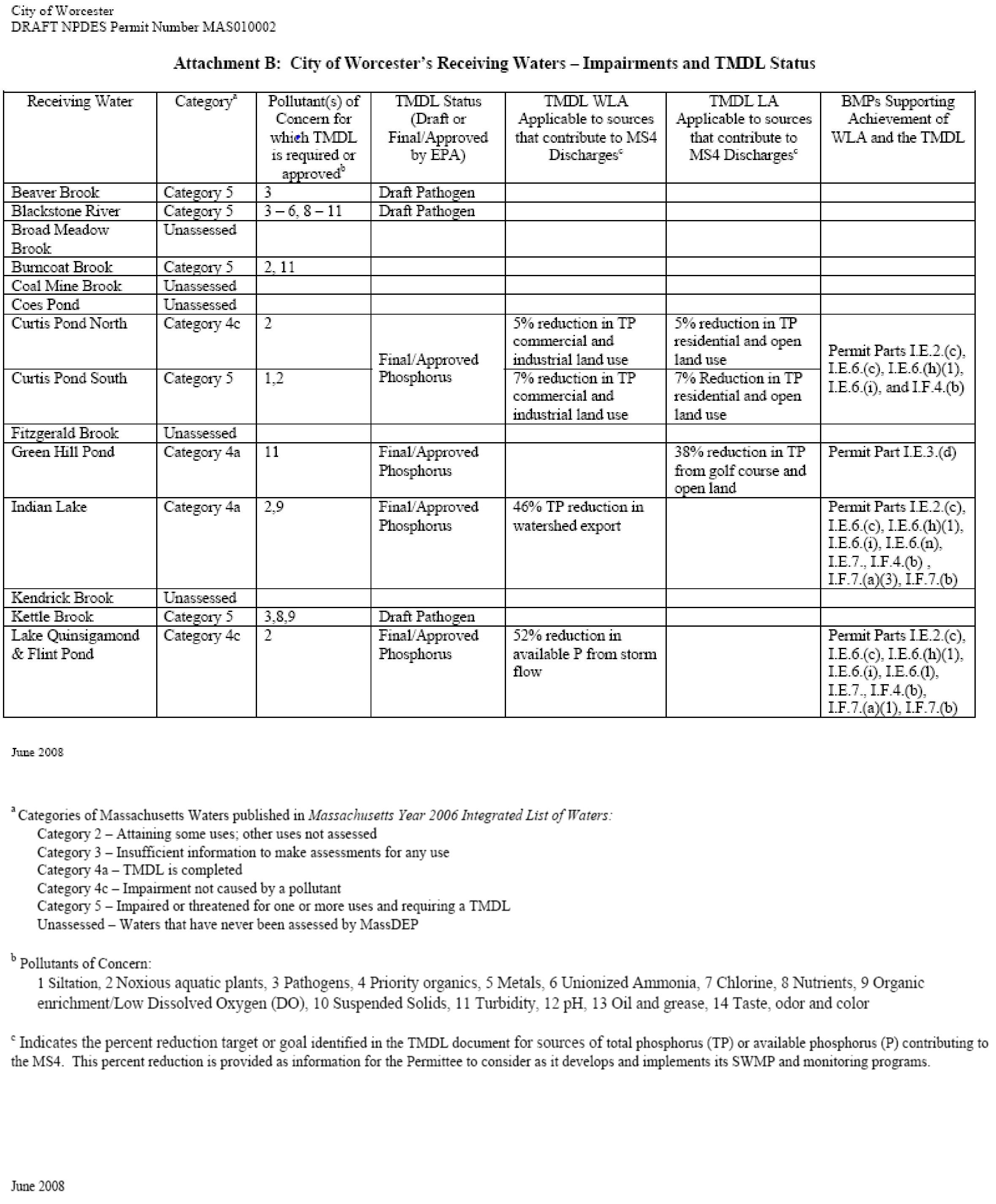


Figure 50: Total Suspended Solids Result Pictures-Runoff

Table 36: Total Suspended Solids Spreadsheet

Location	Volume (mL)	Filter Paper (g)	Filter paper + Suspended Solids(g)	Suspended Solid (g)	Concentration (mg/L)
1w	400	0.153	0.1724	0.0194	48.5
2w	400	0.1512	0.155	0.0038	9.5
3w	400	0.1518	0.1546	0.0028	7
4w	400	0.1532	0.1699	0.0167	41.75
1d	400	0.1528	0.1717	0.0189	47.25
2d	400	0.1506	0.1539	0.0033	8.25
3d	400	0.1515	0.1517	0.0002	0.5
4d	400	0.1529	0.157	0.0041	10.25
5d	400	0.1284	0.129	0.0006	1.5
6d	400	0.1289	0.13	0.0011	2.75
1r	200	0.1521	0.2631	0.111	555
2r	90	0.1527	0.1569	0.0042	46.7
3r	400	0.1521	0.1877	0.0356	89
4r	400	0.1517	0.1624	0.0107	26.75
5r	39	0.151	0.1515	0.0005	12.82
6r	87	0.1527	0.2813	0.1286	1478.16092

Appendix XI: City of Worcester's Receiving Waters



City of Worcester
DRAFT NPDES Permit Number MAS010002

Attachment B: City of Worcester's Receiving Waters – Impairments and TMDL Status

Receiving Water	Category[a]	Pollutant(s) of Concern for which TMDL is required or approved[b]	TMDL Status (Draft or Final/Approved by EPA)	TMDL WLA Applicable to sources that contribute to MS4 Discharges[c]	TMDL LA Applicable to sources that contribute to MS4 Discharges[c]	BMPs Supporting Achievement of WLA and the TMDL
Beaver Brook	Category 5	3	Draft Pathogen			
Blackstone River	Category 5	3 – 6, 8 – 11	Draft Pathogen			
Broad Meadow Brook	Unassessed					
Burncoat Brook	Category 5	2, 11				
Coal Mine Brook	Unassessed					
Coes Pond	Unassessed					
Curtis Pond North	Category 4c	2	Final/Approved Phosphorus	5% reduction in TP commercial and industrial land use	5% reduction in TP residential and open land use	Permit Parts I.E.2.(c), I.E.6.(c), I.E.6.(h)(1), I.E.6.(i), and I.F.4.(b)
Curtis Pond South	Category 5	1,2		7% reduction in TP commercial and industrial land use	7% Reduction in TP residential and open land use	
Fitzgerald Brook	Unassessed					
Green Hill Pond	Category 4a	11	Final/Approved Phosphorus		38% reduction in TP from golf course and open land	Permit Part I.E.3.(d)
Indian Lake	Category 4a	2,9	Final/Approved Phosphorus	46% TP reduction in watershed export		Permit Parts I.E.2.(c), I.E.6.(c), I.E.6.(h)(1), I.E.6.(i), I.E.6.(n), I.E.7., I.F.4.(b) , I.F.7.(a)(3), I.F.7.(b)
Kendrick Brook	Unassessed					
Kettle Brook	Category 5	3,8,9	Draft Pathogen			
Lake Quinsigamond & Flint Pond	Category 4c	2	Final/Approved Phosphorus	52% reduction in available P from storm flow		Permit Parts I.E.2.(c), I.E.6.(c), I.E.6.(h)(1), I.E.6.(i), I.E.6.(l), I.E.7., I.F.4.(b), I.F.7.(a)(1), I.F.7.(b)

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[a] Categories of Massachusetts Waters published in *Massachusetts Year 2006 Integrated List of Waters:*
Category 2 – Attaining some uses; other uses not assessed
Category 3 – Insufficient information to make assessments for any use
Category 4a – TMDL is completed
Category 4c – Impairment not caused by a pollutant
Category 5 – Impaired or threatened for one or more uses and requiring a TMDL
Unassessed – Waters that have never been assessed by MassDEP

[b] Pollutants of Concern:
1 Siltation, 2 Noxious aquatic plants, 3 Pathogens, 4 Priority organics, 5 Metals, 6 Unionized Ammonia, 7 Chlorine, 8 Nutrients, 9 Organic enrichment/Low Dissolved Oxygen (DO), 10 Suspended Solids, 11 Turbidity, 12 pH, 13 Oil and grease, 14 Taste, odor and color

[c] Indicates the percent reduction target or goal identified in the TMDL document for sources of total phosphorus (TP) or available phosphorus (P) contributing to the MS4. This percent reduction is provided as information for the Permittee to consider as it develops and implements its SWMP and monitoring programs.

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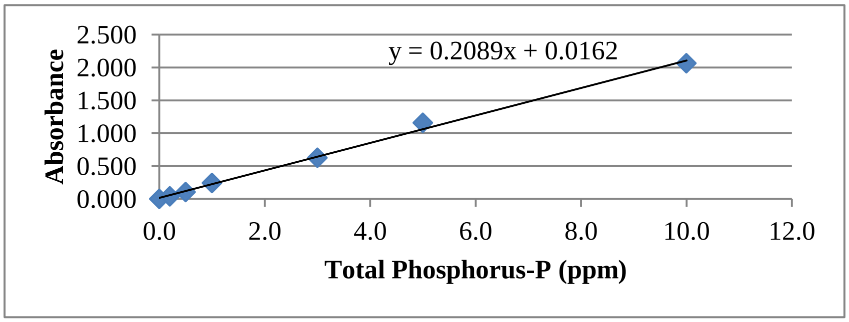
Appendix XII: Sediment Test Spreadsheet

Standard (PPM)	**Absorbance**
0.0	**0.000**
0.2	0.039
0.5	0.104
1.0	0.242
3.0	0.625
5.0	1.157
10.0	2.062



Sample Name	Sediment 1	**Sample Name**	Sediment 1-EI	**Sample Name**	Sediment 1-sample
Absorbance	0.358	**Absorbance**	0.044	**Absorbance**	0.015
Total Phos-P	1.706	**Total Phos-P**	0.206	**Total Phos-P**	0.068
Total Phos-PO_4^{-3}	5.228	**Total Phos-PO_4^{-3}**	0.632	**Total Phos-PO_4^{-3}**	0.208
Sample Name	Sediment 2	**Sample Name**	Sediment 2-EI	**Sample Name**	Sediment 2-sample
Absorbance	0.472	**Absorbance**	0.097	**Absorbance**	0.050
Total Phos-P	2.250	**Total Phos-P**	0.459	**Total Phos-P**	0.235
Total Phos-PO_4^{-3}	6.896	**Total Phos-PO_4^{-3}**	1.408	**Total Phos-PO_4^{-3}**	0.720

Since the sediment test was divided to 10 part; therefore, result of total phosphorus will multiplied by 10 as shown below

	Total Phosphorus (ppm)	**amount of sediment (g)**	**Total P in sediment(ppm/g)**
Sediment 1	17.060	1.0243	16.655
Sediment 2	22.500	1.0505	21.418

	Phosphate (ppm)	**phosphate in (ppm)**	**Phosphate release (ppm)**	**Total P releasing (ppm)**	**Amount of Sediment (g)**	**Total P Release (ppm/g)**
Sediment 1-EI	0.632	0	0.632	0.206	1.0356	0.199
Sediment 1-sample	0.208	0	0.208	0.068	1.0003	0.068
Sediment 2-EI	1.408	0	1.408	0.459	1.0306	0.445
Sediment 2-sample	0.720	0	0.720	0.235	1.0317	0.337