PPM1232

Designing a Stormwater Runoff Control System to Help Prevent Pollution of Flint Pond

A Major Qualifying Project Report submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract

The Lake Quinsigamond Watershed Association was concerned with water quality in Flint Pond in Shrewsbury, MA. The objectives of this project were to understand current conditions in Flint Pond; identify potential pollution inputs; and recommend alternatives for mitigating inputs. Water samples were collected from the pond and analyzed for solids, nutrients, and dissolved oxygen. Results showed a correlation between 12-hour rainfall and solids. Best management practices to reduce nutrients and solids were evaluated and weighted by effectiveness, cost, and size. Recommended BMPs were landscaping and lawn care management, on-lot treatment, and grassed swales. Two grassed swales were designed and the team recommended strategies for educating homeowners on reducing runoff pollutants.

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Finally, we would like to thank Mr. Castagna and the Department of Engineering for the Town of Shrewsbury for providing us with maps and information on the location of catch basins and piping of the public water system.

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Acronym Glossary

ABET - Accreditation Board for Engineering and Technology
LQWA - Lake Quinsigamond Water Association
USEPA – United States Environmental Protection Agency
MADEP - Massachusetts Department of Environmental Protection
TMDL - Total Maximum Daily Load
GIS – Geographic Information Systems
DO - Dissolved Oxygen
NPDES - National Pollutant Discharge Elimination System
CWA/FCWA - Clean Water Act
BMPs - Best Management Practices
TSS - Total Suspended Solids
BOD - Biochemical oxygen demand
ICS - Ion Chromatography System
TKN - Total Kjeldhal Nitrogen
ASCE - American Society of Civil Engineers
WPA - Massachusetts Wetlands Protection Act

Capstone Design Statement

Every Major Qualifying Project must meet the requirements of the capstone design experience. The Accreditation Board for Engineering and Technology (ABET) defines the capstone design experience as an "experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political" (Cryer, 2011). Our team designed a stormwater runoff water quality control system to recommend to the Lake Quinsigamond Water Association (LQWA) in order to prevent pollution of Flint Pond. Through the design of our treatment system, we aspired to include as many of the above considerations as possible, as follows:

- Economic: Our team designed a stormwater runoff water quality control system to be used by the Lake Quinsigamond Water Association (LQWA) and the Town of Shrewsbury in order to improve the water quality in Flint Pond. The LQWA is a non-profit organization consisting of around 150 volunteers. Therefore, we made it a priority to design an inexpensive but effective water quality control system.
- Environmental: The purpose of our project was to assess the current quality of the water in Flint Pond and design a water quality system that can help treat the stormwater runoff that enters the Pond. By improving the quality of the runoff that enters Flint Pond, our project aimed to enhance the overall water quality of Flint Pond and preserve the pond's ecosystem and surrounding environment.
- Sustainability: The design of the stormwater runoff water quality control system is a pair of grassed swales. The swales require minimal maintenance and are a long-term solution, as they will continue to work for years to come.
- Manufacturability: The design of the water quality control system included suggested materials and details for implementation. Flint Pond is surrounded by high-density residential, commercial, and recreational areas which was important to consider throughout the designing process in order to ensure that the system does not interfere with the activities in these areas.
- Ethical: This project was completed keeping in mind that the goal of our sponsor, the LQWA, was to improve the current condition of Flint Pond. The design was completed such that it would create the most effective stormwater runoff water quality control system in order preserve the quality of the water in Flint Pond so that it may be enjoyed for future generations.
- Health and Safety: The water quality control system was designed in a way that would preserve the health and safety of the community. The design strives to prevent further stormwater-runoff-contamination of Flint Pond that could be potentially harmful to humans or aquatic wildlife. Flint Pond is used mainly for recreational purposes, so by designing such system, we would be contributing to the efforts to keep the water quality safe for public use. The proposed locations of the swales were set at a distance from buildings so that flooding of the swales would not risk a building's integrity. Also the proposed swales avoided sudden radical changes to the ground surface in order to minimize risk of injury. This was accomplished through the combination of a modest side slope and small minimum depth of the swales.

Executive Summary

This project assisted the Lake Quinsigamond Watershed Association in understanding the current water quality conditions in Flint Pond, identifying the potential sources of pollution, and designing a stormwater runoff control system to mitigate pollution. Lake Quinsigamond and Flint Pond, connected via the Route 20 culvert, are located in Shrewsbury, Massachusetts. One challenge of controlling what enters Lake Quinsigamond and Flint Pond is that the entire boarder of the lake is developed. Most of the development is private residences or beaches; however, there are also parks, marinas, and a few commercial buildings. Lake Quinsigamond is also crossed by three major highways: Route 9, Route 20 (the location of the culvert), and Interstate 290.

The goal of this project was to address concerns of possible sediment inputs due to stormwater runoff at the western-most point of Lake Quinsigamond, where it drains into Flint Pond. This was accomplished through two major objectives: (1) identifying pollution issues in Flint Pond and (2) designing best management practices to alleviate those issues. First, water samples from Flint Pond were collected and analyzed for water quality. Samples were collected from five locations: (1) Lake Quinsigamond side of the culvert, (2) Flint Pond side of the culvert, (3) at the shoreline, (4) approximately 150 feet from the shore, and (5) at the tree line. Samples were analyzed for temperature, pH, dissolved oxygen (DO), total suspended solids (TSS), turbidity, nutrients, and total phosphorus. Rainfall data, including 12-, 24-, and 48-hour totals were obtained from Worcester airport.

Second, statistical analyses were conducted on the data. Correlation analysis was conducted to determine relationships between different water quality parameters. Nitrate was correlated to both turbidity and total suspended solids at the 99% confidence level. Total phosphorus was correlated with total suspended solids and turbidity at 95% and 99% confidence levels, respectively. Total phosphorus and nitrate were correlated at a 95% confidence level. Lastly, there were significant correlations between several water quality parameters and 12-hour rainfall. Single factor analyses of variance were used to test water quality by location and by sampling date. A number of water quality parameters experienced elevated concentrations, warranting concern, in response to the 12-hour rainfall. Parameters that were of concern include: turbidity, total suspended solids, nitrate, and total phosphorus. Thus, it is reasonable to conclude that the quality of the storm water runoff in the area is of concern. The highest rainfall amount in this study was a 12-hour rainfall volume of 0.39 inches.

Theoretical initial abstraction, runoff area, and land use were used to estimate the amount of rainfall that would be required before significant runoff would be expected to flow into the area. A land elevation layer found in the MassGIS database was retrieved to delineate an approximate contributing runoff area. Data on land use and soil type layers were also retrieved and overlain to analyze combinations of land use and soil type within the area of interest. It was determined that the commercial area adjacent to the area of interest in Flint Pond might be generating significant runoff after rainfall of only 0.25 inches; while the average expected initial abstraction within the whole contributing area would be 0.56 inches.

Best management practices are a USEPA-approved method for improving stormwater runoff water quality before introduction to natural water bodies. Therefore, BMPs were evaluated to mitigate stormwater runoff into Flint Pond, with particular interest in mitigation of nitrate and phosphorous levels, as well as reducing turbidity and concentration of total suspended solids. BMPs were ranked based on seven criteria, including cost, longevity, size requirements,

and maintenance. The three highest ranked options were landscaping and lawn care, on-lot treatment, and grassed swales.

The team suggested the implementation of landscaping and lawn care management as a BMP because lawns can produce large amounts of stormwater runoff. The stormwater resulting from poor landscaping and lawn care practices can cause nutrient loading of nearby streams, lakes, and other bodies of water. In order to assist the LQWA in their outreach efforts, the team developed an educational brochure to raise public awareness about the LQWA, the current water quality conditions in Flint Pond, and explain a few simple steps homeowners could take in order to make their landscaping and lawn care practices more environmentally friendly.

Another BMP the team investigated was on-lot treatment. On-lot treatment includes a range of practices designed to treat runoff from individual residential lots. The main purpose of on-lot practices is to manage runoff from rooftops, driveways, and sidewalks. By managing rooftop runoff effectively, the impervious surface becomes disconnected, which reduces a watershed's overall imperviousness. On-lot treatment depends on constraints and preferences specific to each homeowner.

The BMP specifically designed for implementation near Flint Pond was a system of two grassed swales. The drainage area, land use, soil type, swale slope, and a number of preset variables were used in determining the required length of the grassed swales. The cost of a grassed swale is unique to each design, but ranges from approximately $0.60 - $1.95 per sq. ft. The swales were designed to treat reduce nutrient and solid content in runoff resulting from a 2 year, 1 hour storm.) The first swale (required size: 143 feet by 8 feet) would be placed between Sears Plaza and Route 20 and the second swale (required size: 114 feet by 6 feet) would be placed between Sears Plaza and Pineland Avenue. Because these swales may exceed the readily available space, they could be modified by changing the slope or desired hydraulic residence time.

The team recommends that the LQWA investigate water quality-rainfall correlations over an extended period of time to better identify the contributing pollutant sources. Sediment testing could also provide valuable information about whether runoff treatment would be effective at treating the water quality problems in Flint Pond, or if more extreme measures, such as dredging would be required. To best utilize the data provided by this project, a site visit is recommended to pinpoint the best, and most feasible, locations for implementation of grassed swales.

1 Introduction

Lakes and reservoirs are a major water resource in the United States, covering 1.7% of the total land area. Freshwater inland lakes and reservoirs provide 70% of the nation's drinking water and water for industry, irrigation, and hydropower. Lakes contain ecosystems that support complex and integral food chains and provide habitat for many threatened and endangered species. Lakes are also the foundation of the 19 billion dollar freshwater fishing industry in the United States, are the reason for many tourist visits, and provide numerous recreational opportunities (USEPA, 2012b).

Massachusetts has over 3,000 lakes and ponds that provide recreational opportunities and also provide habitat for plants and animals. However, the water quality of many lakes in Massachusetts is at risk. Issues that threaten the health of lakes include aquatic nuisance species, pollution, shoreline and watershed development, and issues related to stormwater. Stormwater is a concern because of the volume and timing of runoff as well as the contaminants that the runoff contains (Robinson, 2004).

Stormwater pollution was the focus of this project. Precipitation including rain, hail, and snow travels over highways, parking lots, streets, and lawns. This runoff can pick up pollutants and carry them into nearby water bodies, which can negatively affect the water quality (Robinson, 2004). Types of pollutants that are collected and can be found in stormwater runoff include nutrients, oil, toxins, and sediments.

Stormwater pollution is a threat to water quality in lakes and ponds as well as to the health of the aquatic environment. Stormwater poses a greater threat to water quality in urban areas because there are significantly more impervious surfaces. In forested areas, the water leaches into the soil via infiltration, allowing the subsurface to filter out pollutants. Urbanization has significantly impacted the ability of nature to filter stormwater runoff. When the amount of impervious surfaces increases, the speed of runoff also increases. This causes the stormwater to carry significant pollutants to nearby water bodies. Examples of pollutants generated in urban areas include sediment, oil, grease, toxic chemicals, nutrients and pesticides, viruses and bacteria, road salts and heavy metals (USEPA, 2012c). The runoff travels from the highest to the lowest point, which is typically a detention pond, catch basin, or naturally-occurring body of water.

Both the Massachusetts Department of Environmental Protection (MADEP) and the United States Environmental Protection Agency (USEPA) manage stormwater discharges in Massachusetts. The Department of Environmental Protection is the state agency responsible for "ensuring clean air and water, the safe management of toxics and hazards, the recycling of solid and hazardous wastes, the timely cleanup of hazardous waste sites and spills, and the preservation of wetlands and coastal resources" (MADEP, 2012). Governing agencies such as the Massachusetts DEP have developed regulations in order to preserve the integrity of the Massachusetts lakes.

According to the USEPA, an impaired water body is defined as a water body with continuing or recurring monitored violations of numeric and/or narrative water quality criteria. The Massachusetts DEP identifies impaired bodies of water and creates plans to remediate the problems. For example, the MADEP can set Total Maximum Daily Loads (TMDLs) to improve or maintain water quality in a particular water body. A TMDL is the maximum amount of a pollutant that a water body can receive and still meet water quality standards. Once a TMDL is set, the load is distribution among the different point and nonpoint sources of that pollutant.

The focus of this project was Lake Quinsigamond and Flint Pond. These surface waters are located between the city of Worcester and the town of Shrewsbury. Three major highways cross Lake Quinsigamond: Interstate 290, Route 9, and Route 20. Lake Quinsigamond drains into Flint Pond underneath a bridge on Route 20. The scope of this project concentrates around the area of this Route 20 Bridge. Located in a highly urbanized area, the lake is used for recreational activities including fishing, boating, water skiing, and swimming. The perimeter of the lake is densely settled with private homes and commercial establishments as well as two state parks, several private beaches, and marinas. A map of the area is show in Figure 1.

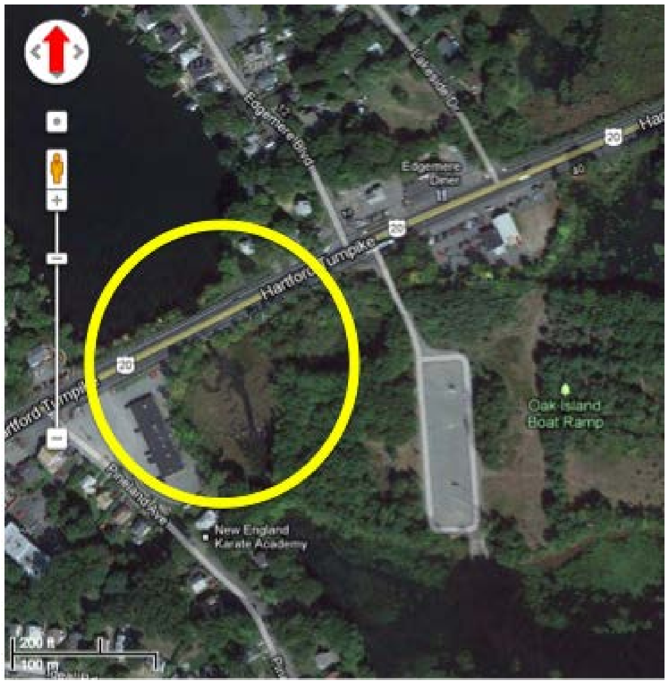

Figure 1: Project area of interest encircled in yellow (Google Maps, 2013).

Flint Pond is listed on the impaired water bodies list for turbidity due to high phosphorus loading (MADEP, 2002). According to the Total Maximum Daily Load of Phosphorus for Lake Quinsigamond and Flint Pond report, Flint Pond has been negatively impacted by stormwater pollution (MADEP, 2002). The concerns include eutrophication and sediment buildup, suspected to come from runoff coming from Route 20. Therefore, the goals of this project were to (1) identify water quality pollution problems in Flint Pond and probable sources of pollutants and (2) design a water quality control system that addresses the identified problems. To achieve these goals, water samples were collected during dry and wet weather conditions near where Lake Quinsigamond flows into Flint Pond. Water samples were analyzed for temperature, dissolved oxygen, pH, turbidity, nutrient concentrations, and total suspended solids. Using GIS, the contributing runoff area around Flint Pond was estimated. Using the collected data, pollution issues in Flint Pond were analyzed and best management practices were evaluated to improve the water quality.

The following chapters provide background information about Lake Quinsigamond and Flint Pond, discuss the procedures for collecting and analyzing water samples from Flint Pond, and summarize the results. Recommendations are then provided to help improve and preserve water quality in Flint Pond.

2 Background

The Lake Quinsigamond Watershed Association (LQWA) is concerned with potential sediment inputs caused by stormwater runoff near the Route 20 Bridge culvert separating Lake Quinsigamond and Flint Pond. To address this problem, it is important to understand lake water quality and how stormwater affects the quality. The following sections provide background on lake water quality, pollution sources, pollution control, and Lake Quinsigamond.

2.1 Lake Water Quality

A number of natural and human factors can affect the water quality and use of surface waters such as streams, lakes, and rivers. Land use within a watershed is one of the most important factors that can affect that quality of surface water. A number of studies have shown that the amount of urbanization can affect the concentration of chloride, nitrate, and pesticides in lakes and streams (Water Encyclopedia, 2012). In areas with good vegetation cover and little disturbance from humans, such as forests, most rainfall percolates into the soil rather than running over the ground. In developed areas with a lot of pavement and buildings, little rainfall is able to soak into the ground, causing higher volumes of runoff (Purdue University, 2012). Nutrient deposition into lakes is a result of changing landscapes and urbanization (Nielsen *et al.,* 2012).

When determining which remediation efforts will be most effective to improve water quality of a lake, the watershed as a whole must be considered because the entire watershed contributes to the water quality problem. Ideally, the development of land within a fragile watershed should be limited as much as possible in order to effectively preserve the water quality of the lake (Nielsen *et al.,* 2012). There are many issues that can impact the water quality of a lake such as eutrophication, organic matter, pathogenic organisms, solids, chemicals, and heavy metals. The following discussion focuses on a few of these issues.

2.1.1 Water Quality Monitoring

Water quality monitoring can be used to identify whether waters are meeting designated uses, to identify specific pollutants and sources of pollution, to determine trends, and to screen for impairment. The first step in determining a water quality-monitoring program is to determine the purpose of the monitoring (USEPA, 1997).

The State of Massachusetts is required by the US Environmental Protection Agency to monitor bodies of water and to report those that are considered impaired. The State of Massachusetts publishes a list of impaired waters and includes the reason for which they are considered impaired. Flint Pond appears on this list due to high levels of turbidity (MADEP, 2002).

Table 1 provides a summary of water quality impacts that are commonly associated with specific land uses. In the area of Flint Pond that the LQWA is concerned with, the primary use is for recreational activities. This area also receives suburban and urban runoff from multiple sources such as driveways, lawns, rooftops, parking lots, and roadways. The two rows that are highlighted in yellow in this table to show the land use areas associated with the land around Flint Pond. Therefore, pollutants and factors such as fecal bacteria, nutrients, turbidity, total solids, thermal impacts, conductivity, dissolved oxygen, bacteria, metals, and petroleum hydrocarbon have the potential to impact water quality in the area under the section of Route 20 where Lake Quinsigamond drains into Flint Pond. A further discussion of specific pollutants and factors that affect water quality is provided in sections 2.1.2 through 2.1.6, 2.2, and 2.3.

Table 1: Common Water Quality Impacts Potentially Associated with Selected Land Uses (USEPA, 1997)

Source	Common Pollutants or Impacts
Construction	Sediment, turbidity, total suspended and dissolved solids, thermal impacts, dissolved oxygen/biochemical oxygen demand
Cropland	Sediment, turbidity, total solids, nutrients, thermal impacts, pesticides
Grazing land	Sediment, fecal bacteria, turbidity, nutrients, thermal impacts
Forestry	Sediment, turbidity, total solids, thermal impacts
Lawns/Golf courses	Nutrients, turbidity, total solids, bacteria
Marinas/Boat usage	Nutrients, bacteria, petroleum hydrocarbons
Mining	Sediment, alkalinity, pH, total dissolved solids, leached metals
Recreation	Fecal bacteria, nutrients, turbidity, total solids
Septic systems	Fecal bacteria, nutrients, dissolved oxygen/biochemical oxygen demand, conductivity, thermal impacts
Sewage treatment plants	Dissolved oxygen/biochemical oxygen demand, turbidity, total solids, conductivity, nutrients, fecal bacteria, thermal impacts, pH, manufactured chemicals
Suburban/Urban runoff	Turbidity, nutrients, thermal impacts, conductivity, dissolved oxygen/biochemical oxygen demand, bacteria, metals, petroleum hydrocarbons

2.1.2 Nutrients and Eutrophication

Nutrients are critical to the growth of all living things (Davis and Masten, 2009). However, when nutrients reach excessive levels in a body of water, the results are potentially harmful. The limiting nutrient in a body of water is defined as a nutrient that, when its concentration is increased, can result in an upward shift of aquatic growth. Nitrogen tends to be the limiting nutrient in water bodies connected to the sea, while phosphorus tends to limit aquatic growth in freshwater systems (Davis and Masten, 2009). Excess nutrient levels can cause eutrophication. Eutrophication is defined as an increase in the rate of supply of organic matter in an ecosystem (Nixon, 1995). Eutrophication traditionally begins with an algal bloom in response to high nutrient levels. After the algae die, dissolved oxygen is consumed during the decay process, which results in low dissolved oxygen levels. Many life forms in the aquatic ecosystem require dissolved oxygen to survive. Thus, oxygen dependent species in the water cannot survive when this shift in ecosystem balance occurs (Nielsen *et al.,* 2012).

2.1.3 Organic Matter

In aquatic systems, organic matter is produced in surface waters by the primary production of phytoplankton, and passed along the food chain. Some forms of organic matter are capable of being biodegraded aerobically by decomposers. Biodegradable matter is both produced in a lake and introduced from outside sources. Biodegradable matter includes human or animal waste, dead plant or animal life from inside or outside of the lake ecosystem, and food waste (Davis and Masten, 2009). If the rate of nonliving organic matter entering the lake is high relative to the re-aeration rate of the water, oxygen levels can become a serious problem. Wastes high in organic matter directly increase the chemical and biological oxygen demand in receiving waters which results in areas of oxygen depletion within the lake. In industrial areas, factories are sometimes connected directly to the sewers and discharge metal and organic chemical pollutants into the sewage treatment system (Thomas, 1996).

2.1.4 Pathogenic Organisms

Pathogenic organisms include viruses, bacteria, and protozoa. The source of most pathogens is fecal material from an infected warm-blooded animal. In urban areas the major sources of pathogens are pet wastes, wildlife that may exists in high numbers, septic systems in areas without sewers, and sewage treatment plant discharges (Purdue University, 2012). If a person or animal has a disease, they are capable of passing the disease on in their excrement. Waterborne diseases include typhoid, viral jaundice, dysentery and various parasitic diseases (Thomas, 1996). Since surface waters are the major discharge point for waste streams, this poses a direct risk to the spread of disease through the consumption of or direct contact with the contaminated water (Nielsen *et al.,* 2012).

2.1.5 Solids

Erosion near bodies of water such as lakes, streams, and ponds is caused by storm water being transported quickly to nearby waterways during storm events. After the water has been carried through pipes or directly from impervious surfaces in the form of runoff, it enters water bodies at an accelerated speed resulting in streambeds being washed away and causing stream banks to erode. Erosion can, over time, trigger instability in the aquatic system (Nielsen *et al.,* 2012). This erosion causes sediments in the water to stir up, which can have negative effects on the ecosystems within that water body. Sediment buries aquatic insect life, suffocates fish, and carries harmful pollutants, such as phosphorus, that further diminish living conditions for fish and other aquatic wildlife.

2.1.6 Toxic Chemicals

The introduction of foreign chemicals can prove dangerous to many aquatic species. Two of the main chemical categories that pose a particular threat to aquatic life are pharmaceuticals and pesticides. These chemicals can prove beneficial when used as intended, such as pesticides for protecting crops or a prescription to help reduce cholesterol. However, these same chemicals can also end up in the environment, ingested by organisms, including people, for which they were not intended. The results can be harmful to the wide-reaching demographic of aquatic life (Nielsen *et al.,* 2012). Oil leaks, pesticides, road salts and other toxic compounds that are spilled or disposed of incorrectly are carried via storm runoff into lakes and other water bodies. These compounds can reduce oxygen levels in lakes and can kill fish or sensitive organisms. Many of these chemicals contaminate groundwater and other drinking water supplies as well (Robinson, 2004).

2.2 Water Quality Parameters

There are many different parameters to test when assessing the water quality in lakes. The following sections discuss dissolved oxygen, total suspended solids, turbidity, nutrients, and total phosphorus.

2.2.1 Dissolved Oxygen

A lake or pond system produces and consumes oxygen. The system receives oxygen from the surrounding atmosphere and plants within the ecosystem due to photosynthesis.

Running water has a faster rate of transfer of oxygen from the atmosphere than stagnant water because of its constant mixing. Oxygen is consumed due to respiration of aquatic animals, decomposition, and various chemical reactions. Sewage treatment plants discharge wastewater, which can contain organic materials that are decomposed by microorganisms. This process requires oxygen. Storm water runoff from farmland or roadways, feedlots, and failing septic systems are other sources of oxygen-consuming waste (USEPA, 1997).

If more oxygen is consumed than is produced, dissolved oxygen (DO) levels decrease and some aquatic animals may leave the area, become weak, or die. DO levels vary depending on the season and over a 24-hour period. They also vary with temperature and altitude of the water. Aquatic animals are most susceptible to the effects of low DO values during the early morning on hot days when streams flows are low, water temperatures are high, and plants have not been producing oxygen since sunset (USEPA, 1997).

2.2.2 Total Suspended Solids

Total suspended solids are particles that are not able to pass through a filter with a 2 micron pore size. In lake water, suspended solids may include slit particles, clay particles, plankton, algae, fine organic debris, and other similar particulate matter, which will not pass through a filter of the same size (USEPA, 1997).

High concentrations of suspended solids can carry toxins, which cling to suspended particles. This can pose a problem where pesticides are being used on irrigated crops. Where there is a high concentration of solids, pesticide concentrations may increase to more than the intended use. Total solids also affect the clarity of water. Higher solids hinder the passage of light, which slows photosynthesis by aquatic plants. Suspended solids have the ability to absorb heat from the sun, causing water temperature to increase. This increase in temperature may have negative effects on the aquatic life that has adapted to a lower temperature. Sources of total solids include industrial discharges, sewage, fertilizers, road runoff, and soil erosion. Total solids are measured in milligrams per liter (mg/L) (USEPA, 1997).

2.2.3 Turbidity

Turbidity is a measure of water clarity. It measures the amount of light that is scattered due to suspended material in the water. These suspended materials are the same as described in section 2.2.2 and include soil particles (clay, silt, sand), algae, plankton, microbes, and other substances. These materials usually range between 0.004 mm, which is representative of clay, to 1.0 mm, representative of sand particles. Turbidity can also affect the color of the water (USEPA, 1997).

When the turbidity is higher, the water temperatures increase because the suspended particles absorb more heat. Higher temperatures result in a reduction of dissolved oxygen because warm water has a lower DO saturation level than cold water. Additionally, higher turbidity reduces the amount of light passing through the water, thus reducing photosynthesis and the producing dissolved oxygen. Suspended materials can also be harmful to fish as they can clog fish gills, reduce resistance to disease, lower growth rates, and affect the development of egg and larvae. When the particles settle, they can cover the bottom of the lake and smother fish eggs. This is especially prevalent in slower moving waters (USEPA, 1997).

According to the USEPA, turbidity often increases greatly during a rainfall, especially in watersheds that are developed. Watersheds with a lot of development usually have high proportions of impervious surfaces. The flow of stormwater runoff from these impervious surfaces quickly increases a lakes flow rate, which increases the erosion rates of the stream banks and swales. It is important to realize that turbidity is not a measurement of the amount of suspended solids present or the rate of sedimentation in a lake. Instead, turbidity measures the amount of light that is scattered by suspended particles (USEPA, 1997).

2.2.4 Nutrients

Nutrients are chemicals that plants and animals require in order to grow and survive. However, excess amounts of nutrients can be harmful to aquatic environments. The use of fertilizers and manures increase the amount of nutrients that can reach a lake. The most noticeable effect of high nutrient levels is reduction in water clarity because of increased growth of plants and algae (USEPA, 1997). Lake Quinsigamond, which feeds into Flint Pond, is listed as an impaired water body because of Noxious Aquatic Plants (MADEP, 2002).

2.2.5 Total Phosphorus

Phosphorus and nitrogen are both important nutrients for the plants and animals that make up the aquatic food web. Since phosphorus is usually low in most fresh waters, even a slight increase in phosphorus can, under the right conditions, bring about negative events in a water body. Events such as plant growth, algae blooms, low dissolved oxygen, and the death of certain aquatic animals can occur. Sources of phosphorus include soils and rocks, runoff from fertilized lawns and cropland, wastewater treatment plants failing septic systems, runoff from manure storage areas, disturbed land areas, drained wetlands, water treatment, and commercial cleaning preparations (USEPA, 1997).

2.3 Pollution Sources

Point and non-point sources of pollution can cause deterioration of the water quality of lakes and their ecosystems (Nielsen *et al.,* 2012). Advancements in technology have successfully reduced the impacts of point source pollution (Nielsen *et al.,* 2012), however, despite current efforts, the nutrient loading that results from stormwater runoff from a watershed typically still "exceeds the loading threshold for sustaining a clean-water status in many water bodies" (Nielsen *et al.,* 2012).

2.3.1 Point Sources

Point source pollution is pollution that comes from a single distinct point where liquid waste is discharged. Water pollution from point sources occurs primarily when such a point source discharges directly into a water body. Point sources of pollution include industrial, commercial, and municipal systems. Point discharges can be traced back to the facility that produced them. Because the origin of the pollution is known, point source pollution is usually relatively easy to control (Nielsen *et al.,* 2012). Section 2.4.1 discusses the National Pollutant Discharge Elimination System (NPDES) permitting system and how these permits control potential water pollution in the U.S. coming from point sources.

2.3.2 Non Point Sources

A non-point source is defined as pollution that is discharged over a wide land area rather than from one specific location. These are forms of dispersed pollution caused by sediment, nutrients, organic and toxic substances coming from certain land-use activities, which are carried to lakes and streams by surface runoff. Non-point source pollution is contamination that occurs when rainwater, snowmelt, or irrigation washes off of surfaces such as plowed fields, city streets, or suburban backyards. As this runoff moves across the land surface, if picks up solid particles and pollutants, such as nutrients and pesticides (U.S. Geological Survey, 2011). Examples of non-point source pollution include agricultural runoff, stormwater runoff, and urban runoff.

There are more than 330 million acres of agricultural land in the U.S., which produce a large supply of food and other products. When this land is managed improperly, farming and ranching activity can have negative effects on water quality. Data from the National Water Quality Inventory in 2000 shows that, according to the states, agricultural is the leading source of pollution in lakes (EPA, 2000). Agricultural pollution problems affect 18% of the lakes that were assessed and contribute to 41% of the reported water quality issues in impaired lakes (USEPA, 2000). Agricultural activities that cause nonpoint source pollution include animal feeding operations that are poorly located or managed; overgrazing; over plowing; and application of pesticides, irrigation water, and fertilizer that are improper, excessive, or poorly timed (USEPA, 1997).

According to the US Environmental Protection Agency, stormwater is defined as “water from precipitation and snowmelt events”. Stormwater runoff is formed when precipitation does not percolate into the ground and instead flows over land or impervious surfaces. Impervious surfaces are primarily man-made structures such as pavements, including roads, sidewalks, driveways, parking lots, and rooftops. Impervious structures are covered with impenetrable materials such as asphalt, concrete, brink, or stone. Soils that are compressed as a result of urban development are also highly impervious. While flowing over the land or impervious surfaces, debris, chemicals, sediment or other pollutants can accumulate in the stormwater. These pollutants can have an adverse effect on water quality if the runoff is discharged into streams or lakes prior to being treated (USEPA, 1997).

When impervious surfaces are created as a result of development, it prevents rainwater from infiltrating through the ground, forcing it to become runoff. As development continues and more natural spaces are converted into developed areas, more stormwater runoff is created.

Vehicles also contribute to the many different pollutants found in stormwater. Fluids such as oil and antifreeze sometimes leak from cars onto roads and parking lots or are spilled. Copper and other heavy metal dust that comes out of the automobile exhaust can settle onto surfaces and later get washed into a water body during a storm event. The metal dust and toxic fluids can become concentrated enough to disrupt the aquatic ecosystems in lakes (USEPA, 1997).

2.4 Pollution Control

Since pollutants may enter the environment through both point and non-point sources, there is no one solution to pollution control. For point source pollution, water quality can be tested at the point of discharge and necessary modifications can be made to the upstream treatment system so that the discharged water complies with regulations. Non-point sources, however, are not distinct. As a result, it is much more difficult to enforce regulations that mitigate pollution from such sources.

2.4.1 Point Source Control

The Clean Water Act (CWA), authorized in 1972, created the foundation for water quality regulation. Since 1972, the Clean Water Act has protected humans health and environmental by reducing pollution in streams, lakes, rivers, wetlands, and other water bodies. Under the Clean Water Act, the USEPA has implemented pollution control programs such as setting wastewater standards for industry. Water quality standards for all contaminants in surface waters have also been set. Under section 314 of the Clean Water Act is the Clean Lakes

Program, which was established to provide financial and technical assistance to states to restore publically owned lakes (USEPA, 2012e).

Most stormwater discharges are categorized as point sources and must be covered under a National Pollutant Discharge Elimination System (NPDES) permit, which is authorized by the Clean Water Act. The NPDES is a system that controls potential water pollution in the United States by regulating the discharge of pollutants from point sources, such as pipes, ditches, and drains. The goal of the NPDES permit program is to reduce the negative impacts to water quality and aquatic habitat. Homes that are connected to a community system, use a septic system, or do not have a surface discharge are exempt from needing a NPDES permit. However, it is necessary for industrial, municipal, and other facilities to obtain permits if their discharges go directly to surface waters (USEPA, 2012e).

2.4.2 Non-Point Source Control

Each state may have a different strategy to control nonpoint source pollution. The Massachusetts Nonpoint Source Management Plan introduces an integrated strategy and identifies programs and resources to prevent, control, and reduce pollution from nonpoint sources in order to protect and improve the quality of water in the state. Massachusetts also has a Clean Water Toolkit, which includes information about nonpoint source pollution, and includes a selector tool for choosing appropriate best management practices (USEPA, 2012e). A discussion of Best Management Practices is included in section 2.4.3.

2.4.3 Best Management Practices (BMPs)

The primary methods used to control stormwater discharges are best management practices (BMPs) (USEPA, 2012d). The main purpose of using BMPs is to protect valuable uses of water resources by reducing pollutant loads and concentrations as well as flow rates. It typically costs less to prevent negative impacts of runoff using source control rather than runoff treatment for pollutant removal (City of Highpoint, 2011).

There are a variety of best management practices that may be implemented. Depending on the area and the source of the stormwater pollution, some practices may be more efficient than others. The BMPs listed on the USEPA website are separated into six control measures. The control measures include public education and outreach on stormwater impacts; public involvement and participation; illicit discharge detection and elimination; construction site stormwater runoff control; post-construction stormwater management in new development and redevelopment; and pollution prevention/good housekeeping for municipal operations (USEPA, 2012d).

BMPs can be categorized as structural or non-structural. The goal of structural BMPs is to help alleviate stormwater-related impacts once they have already taken place. Structural BMPs are more specific to location and more physically explicit (SEMCOG, 2008). Using alleviating techniques does not take place of non-structural BMPs. Rather, the two are meant to work together to combine planning and design-based approaches in order to minimize unavoidable impacts (SEMCOG, 2008). Many structural BMPs are based on natural systems and rely on vegetation and soil mechanisms of the site in order to perform to their best ability. Some examples of structural BMPs include vegetated filter strips, infiltration trenches, and soil restoration.

Non-structural BMPs focus on averting stormwater runoff away from a site. They take broader planning and design approaches than structural plans do and are not specific to any one location. Most non-structural BMPs can be applied to an entire site or community, for example wetland protection through community wetland regulations. They do not involve fixed, permanent facilities and usually function by altering behavior through government regulation, persuasion, or economic means. Non-structural BMPs can be attained through efforts such as education, management and development practices. Some examples include regulations and practices connected with land use and comprehensive site planning (SEMCOG, 2008).

2.4.4 TMDLs

In accordance with section 303(d) of the Federal Clean Water Act (FCWA), the MADEP is the governing body that inspects and identifies bodies of water as impaired. A water body is considered impaired if it does not attain water quality standards. Causes of standard violation may include an individual pollutant, multiple pollutants, thermal pollution, or an unknown cause (Scorecard: The Pollutant Information Site, 2011). Once a water body is classified as impaired and a reason is assigned, the MADEP develops a plan to restore that body of water to clean-water status, meeting the Massachusetts Water Quality Standards. As required by the FCWA each state must: (1) "identify waters for which effluent limitations normally required are not stringent enough to attain water quality standards" and (2) "to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutant of concern" (MADEP, 2012).

When a body of water is identified as impaired, it is placed on the "303d list". This list is used to organize bodies of water and indicate the reason for their presence on the impaired-waters list. As a means for restoring the body of water to clean-water status, the MADEP establishes a "pollution budget" in which the MADEP identifies the source(s) of pollution and develops a TMDL, or "the maximum amount of the pollutant that can be discharged to a specific water body to meet water quality standards" (MADEP, 2012). Along with setting specific TMDLs, the MADEP also develops a plan for how to achieve them.

This project involved Lake Quinsigamond and Flint Pond, which both appear on the Massachusetts 303d list. Flint Pond is on the 303d list for "turbidity due to high phosphorus loadings" (MADEP, 2002) and Lake Quinsigamond is listed for "nuisance aquatic plants, organic enrichment and low dissolved oxygen due to high phosphorus loadings" (MADEP, 2002). Since the MADEP has determined that both bodies of water appear on the list as a result of "high phosphorus loading", they proposed that the phosphorus concentration be reduced from 0.016 mg/L, measured in 2002, to 0.012 mg/L (MADEP, 2002).

In 2002, the City of Worcester began initiatives to reduce the phosphorus loading into Lake Quinsigamond, Flint Pond, and other bodies of water within Worcester. These initiatives include: "a street sweeping program, a catch basin program, a program to find and remove illicit connections to storm sewers and a sewage/storm-drain dual manhole modification program to reduce cross flow between stormwater and sewage transport systems" (MADEP, 2002).

2.5 Lake Quinsigamond

Lake Quinsigamond is 475 acres and stretches into Worcester, Shrewsbury, and Grafton. The lake is approximately 5.0 miles long and 0.15 miles wide. Lake Quinsigamond has a maximum depth of 84.6 feet and an average depth of 33 feet. The lake has a volume of 688 million cubic feet (Fraser *et al*., 1971). The lake has a mean residence time of around half of a year. Since the shores of Lake Quinsigamond started being developed, urbanization has resulted in many pollution problems (Fraser *et al.*, 1971). Some notable sources of urban pollution include: "leaching from subsurface sewage disposal systems, landfill drainage, siltation, urban and rural stormwater runoff, and boat pollution". Due to these pollutants, the overall quality and usability of the lake has been impaired. Most notably, there have been significant decreases in fish population; occasional swimming bans due to bacterial contamination; increased growth of nuisance vegetation and algae blooms; and limitations on the use of the lake as a source of water supply for local communities (MDWPC, 1982).Based on the water quality and other data in the lake modeling analysis, the major pollution problems identified in the Lake Quinsigamond-Flint Pond drainage basin include hypolimnetic dissolved oxygen depletion, eutrophication, weed growth, and sedimentation, which are all symptoms of eutrophication (MDWPC, 1982). Most of the stormwater runoff that enters the lake is from the City of Worcester and the Town of Shrewsbury. However, there is drainage into the lake from parts of Worcester, Shrewsbury, Grafton, Millbury, Boylston, and West Boylston (MDWPC, 1982). Additionally, towards the northern end of the lake, the small inlets have become overgrown with "aquatic macrophytes" (MEOEA, 1995). In 1994, the Department of Environmental Protection reported that 20 of the 475 acres of the lake were considered non-supportive of primary and secondary contact recreation (MEOEA, 1995).Lake Quinsigamond is developing "anoxic conditions in the hypolimnetic waters". This is most likely caused by high concentrations of phosphorus which allows more algae to grow in the lake. Once the algae die, they decompose resulting in the consumption of oxygen in the hypolimnion. Lake Quinsigamond has a hypolimnetic oxygen supply ranging from 72-140 days, whereas a typical lake in similar temperatures should be around 200 days (MEOEA, 1995). These problems get significantly worse during the summer months.The increase of phosphorus and pollutants has resulted in the growth of five non-native plants. These plants include: *Myriophyllum spicatum, M. heterophyllum, Cabomba caroliniana, Potamogeton crispus,* and *Lytrum salicaria* (MEOEA, 1995). These non-native plants are invasive and if not treated could cause further damage to the lake. The MADEP states, "the overall goal is to restore the uses of the pond for primary and secondary contact recreation by reducing the nuisance aquatic plant growth." They suggest this can be accomplished through reduction of phosphorus loading and control of the aquatic macrophytes (MEOEA, 1995). One significant challenge to controlling what goes in and out of the lake is that the entirety of the border of the lake is developed. While most of the development is private residences or beaches, there are also parks, marinas, and a few commercial buildings. The lake is also crossed by three major highways: Route 9, Route 20 (the location of culvert), and Interstate 290 (MDWPC, 1982).

2.5.1 Lake Quinsigamond Water Association (LQWA)

The Lake Quinsigamond Water Association (LQWA) is a volunteer-based organization that was founded in 1984. The association currently has around 150 members. The mission of the LQWA is to "enhance the quality of life in and around Lake Quinsigamond for all of its natural and human residents". (LQWA, 2012) The members of the association strive to "restore, preserve, and maintain" the quality and usability of Lake Quinsigamond and the Blackstone Valley Watershed. (LQWA, 2012) The LQWA uses education and events to raise awareness of the water quality issues.

2.5.2 Flint Pond

Flint Pond occupies approximately 297 acres on the borders of Worcester, Shrewsbury, and Grafton (Fraser *et al.*, 1971). The pond has an average depth of 9 feet and a maximum depth of 15 feet (Fraser *et al.*, 1971). The pond is comprised of two basins, Flint Pond North and Flint Pond South. Flint Pond South makes up two-thirds of Flint Pond.

Stormwater runoff to Flint Pond is similar to that described for Lake Quinsigamond, with the addition of runoff from Massachusetts Highway Route 20 which crosses the pond. The lake has recreational uses including fishing, boating, water-skiing and swimming, but these uses are impaired by the shallow waters and the growth of macrophytes throughout much of the pond. A MADEP synoptic survey on July 19, 1994 noted transparency below safety criteria (4 ft. Secchi disk depth) and very dense macrophyte growth throughout the pond. The non-native plants *Cabomba caroliniana* and *Myriophyllum spicatum* were the predominant species of submergents (MADEP, 2012).

The lake was reassessed in a shoreline synoptic survey by MADEP staff on September 10, 1998. The north basin had dense macrophyte growth over approximately half of the lake area, particularly along the shores. The middle basin is mostly open water with dense macrophyte growth along the shore and in coves. The southeast basin is nearly completely covered with dense macrophyte growth. Thus, the macrophyte distribution apparently changed little in the four years between the surveys. Most of the impairment appears to be caused by emergent and floating species including *Pontedaria, Decadon* and *Nympea*, although many other species including the submergents *Ceratophyllum demersum* and *P. amphifolius* were noted. The non-natives *Lythrum salicaria* and *Cabomba caroliniana* were also noted. Based on the 1994 synoptic survey, Flint Pond was listed on the 1998 Massachusetts 303d list for turbidity (MADEP, 1998).

The overall goal of the MADEP studies is to restore the uses of the pond for primary and secondary contact recreation by reducing algae and the nuisance aquatic plant growth. A combination of reducing the phosphorus loading to the lake and directly controlling macrophytes will aid in reaching this goal.

3 Methodology

The goal of this project was to identify the causes of pollution in Flint Pond and to present the LQWA with suggestions for improving water quality in the pond. The specific objectives were:

- Determine of the current water quality in Flint Pond;
- Estimate the quantity of runoff going into Flint Pond and what the contributing areas are;
- Determine relationships between precipitation and water quality in Flint Pond; and
- Recommend best management practices (BMPs) to improve water quality in Flint Pond.

The following sections explain the steps taken in order to complete the analysis of the water quality in Flint Pond.

3.1 Land Use and Runoff Characteristics

The first objective was to determine land use around and runoff characteristics into Flint Pond. To meet this objective, data were gathered from the following sources:

- Contour maps created using GIS;
- Maps provided by LQWA;
- Maps provided by the Town of Shrewsbury; and
- Observations from site visits.

In order to approximate the runoff going into the pond, the team used maps of the surrounding area to delineate the watershed. Maps were obtained from the Engineering Department of the Town of Shrewsbury (generated from AutoCAD and imported into GIS) showing where runoff discharges from the site and into Lake Quinsigamond and Flint Pond.

To determine what other sources are contributing runoff to this small area of Flint Pond, some observations were made during site visits. The team walked around the site, taking photographs and recording observations about the topography and accessibility of the area around Flint Pond.

To better understand the runoff in the area, GIS was utilized to calculate a rough estimate of the area of the watershed contributing runoff to the area of interest. Analytical measures were taken to determine the total contributing area as well as the land use types. This analysis was conducted primarily through use of GIS software, specifically ArcMap 10.0 by ESRI. Data were retrieved from the MassGIS website for use in this GIS analysis. Specific goals of the runoff area analysis included: obtaining an estimate of the size of the runoff area, determining land use composition and soil type of the area to determine initial abstraction, and analyzing volumetric loadings of 2 and 10 year storms of one hour duration. Storm information was taken from the Hydrology Handbook for Conservation Commissioners by the Massachusetts Department of Environmental Protection (Nyman, 2002). Determination of initial abstraction and runoff volumes was completed using the SCS method.

3.1.1 Runoff Area Size and Shape

To determine the size and shape of the runoff area, contour elevation lines were imported into a base map in ArcMap. The approximate runoff area was delineated assuming that overland flow runs perpendicular to contour lines. The delineation was performed using the draw feature in ArcMap, which allows the user to draw a shape on top of the base map. After the approximate runoff area was drawn, it was measured using the area measurement feature in ArcMap.

3.1.2 Land Use Determination

The land use composition of the area was determined by importing a land use layer, from the MassGIS database, into the GIS program. The drawing of the runoff area was overlain on the land use layer. This allowed for both identification of the various land uses within the runoff area and measurement of the area which they each contribute to the total area.

3.1.3 Soil Type Determination

An alternate data layer was added to the GIS program which showed the local soil types. The primary data retrieved from this layer were the hydraulic groups (A-D) that each soil type was categorized under. The purpose of this was to combine the hydraulic group data with the land use data in order to calculate values necessary for theoretical runoff analysis.

3.1.4 Initial Abstraction and Runoff Analysis

An analysis of initial abstraction was conducted to determine the approximate amount of rainfall that would be expected to fall before significant amounts of runoff would be generated in the runoff area. In order to do this, the SCS method as described in Bedient *et al.* (2008) was used. This method utilizes Equations 1 and 2.

$$I_a = 0.2 * S \quad \text{(Equation 1)}$$

$$S = \frac{1000}{CN} - 10 \quad \text{(Equation 2)}$$

Where I_a represents initial abstraction in inches, S represents potential abstraction in inches, and CN represents the runoff curve number. The CN value is dependent on both land use and hydraulic group of the soil. CN values were determined from Bedient *et al.* (2008) using land use and soil hydraulic group information found in the GIS software.

The SCS method for direct runoff (Bedient *et al.*, 2008) was used to estimate the runoff volumes resulting from 2 and 10 year storms (Nyman, 2002). These storms were selected for their relevance to grassed swale design. Equation 3 was calculated to generate these estimates.

$$Q = \frac{(P - I_a)^2}{P + 0.8S} \quad \text{(Equation 3)}$$

Here, P represents the total storm rainfall in inches, Q represents direct runoff in inches, and S and I_a are the same as indicated in Equations 1 and 2. As appropriate, a volume conversion was conducted based on the area measurement of the point of focus. This information was then used to determine total volume of runoff moving into the water body or volume of runoff moving past a point of interest within the total runoff area. The purpose here was for the latter, providing runoff quantity information for two select swale locations. Since swale guidelines are generally based around 2 and 10 year storms, the quantities of rainfall resulting from these frequency storms were analyzed. The results were then incorporated into Equation 4, which in turn required Equations 5 and 6.

$$Q_p = \frac{2*Vol}{2.67T_R} \quad \text{(Equation 4)}$$

$$T_R = \frac{D}{2} + t_p \quad \text{(Equation 5)}$$

$$t_p = \frac{L^{0.8}(S+1)^{0.7}}{1900\sqrt{y}} \quad \text{(Equation 6)}$$

Here Q_p represents the peak flow in cfs, Vol represents volume in acre-inches, T_R represents time of rise in hours, D represents storm duration in hours, t_p represents lag time (hours), L represents maximum length of overland flow, S is as seen in Equation 2, and y is slope in percent (100*ft/ft or 100*m/m).

3.2 Water Quality Sampling

Water quality monitoring can be used to identify whether waters are meeting designated uses, to identify specific pollutants and sources of pollution, to determine trends, and to screen for impairment. The water sample testing completed for this project was shaped by the following:

- Types of water quality problems and pollution sources that will likely be encountered;
- Accessibility of available monitoring equipment;
- Precision and accuracy of available monitoring equipment;
- Duration of project;
- Time of year; and
- Weather.

To understand the current water quality of Flint Pond, the group collected samples in and around Flint Pond and tested for temperature, pH, dissolved oxygen (DO), total suspended solids (TSS), turbidity, nutrients, and total phosphorus. These water quality parameters provide data on ecosystem health and potential uses of the water body.

Land use is commonly associated with water quality problems. Flint Pond is primarily used for recreational activities. This area is also subjected to multiple sources of suburban and urban runoff coming from driveways, lawns, rooftops, parking lots, and roadways. Regulated by the USEPA, the State of Massachusetts publishes a list of impaired waters and includes the reason for which they are considered impaired. Flint Pond appears on this list due to high levels of turbidity.

3.2.1 Sampling Locations

Sampling locations were selected to be representative of the entire area of concern of Flint Pond and Lake Quinsigamond. The five sampling locations are shown in Figure 2 and are designated with yellow letters A through E. The northern most mark is the sampling location located furthest upstream. The further south the marks are, the further downstream the sampling locations are, as follows:

- *Location A:* Upstream of Rt. 20 Bridge;
- *Location B:* Downstream of Rt. 20 Bridge;
- *Location C:* At the end of the first bank on the west side of Flint Pond directly after the culvert;

- *Location D:* Halfway between bank and tree line which separates the smaller section of Flint Pond from the larger section and is located downstream in the southeast direction; and
- *Location E:* At the tree line, which separates the smaller section of Flint Pond from the larger section and is located downstream in the southeast direction.

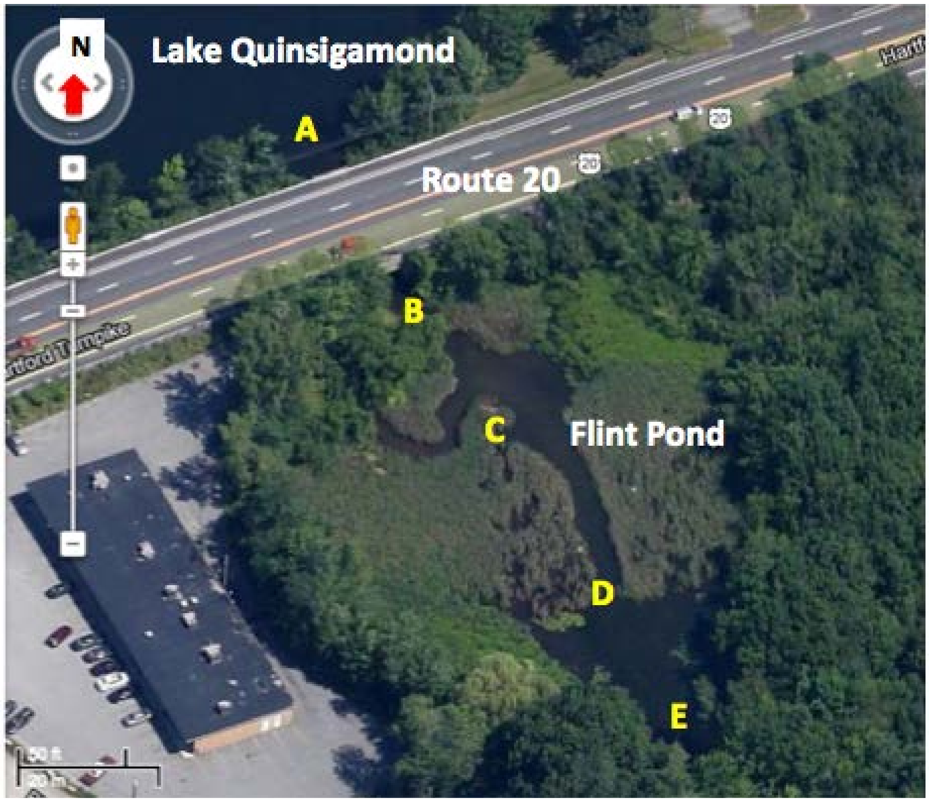

Figure 2: Flint Pond and Lake Quinsigamond sampling locations

3.2.2 Sampling

Samples were collected at five locations in and around Flint Pond. Samples were collected on six dates: September 14, 19, 28 and October 4, 14, and 30, 2012. Details are provided in Table 2. For the first two sampling dates, samples A and B were collected with a depth sampler and samples C, D, and E were collected by walking to the sample locations, which inherently resulted in some disturbance of the bottom sediments. To minimize this disruption, time was allotted for the disturbed particles to settle. Starting on September 28, all samples were collected using a kayak. For this method, the samples were collected by carefully reaching over the upstream side of the kayak. For all sampling methods, samples were taken from approximately 4 inches below the water surface and were taken with the bottle facing the upstream direction.

Water samples were collected in accordance with Standard Methods (APHA *et al*., 1995). Sample containers were washed with soap and water, rinsed three times with tap water, and finally, rinsed three times with distilled water. At each of the five locations, five sample bottles were used as follows:

- 1 liter Nalgene bottle (HDPE, Thermo Scientific, Billerica, MA) for testing total suspended solids;

- 250 mL Nalgene bottle for the turbidity and pH tests;
- (2) 60 mL Nalgene bottle for the ion chromatography test; and
- 300 mL BOD bottle, filled headspace free, for the DO test.

To collect samples, first each bottle was labeled with the site number, date, and time and a field data sheet was prepared. All bottles were filled with a 1-inch air space, except for DO and BOD samples which were filled headspace free. Samples to be analyzed in the laboratory were placed in the cooler for transport to the laboratory (USEPA, 1997).

Table 1: Sampling method by site

Date: (2012)	Sampling Method by Site				
	Before Bridge (A)	After Bridge (B)	At Bank (C)	Halfway between bank and tree line (D)	At tree line (E)
9/14	Depth Sampler (conducted from bridge)	Depth Sampler (conducted from bridge)	wading	wading	wading
9/19	Depth Sampler (conducted from bridge)	Depth Sampler (conducted from bridge)	wading	wading	wading
9/28	Kayak	Kayak	Kayak	Kayak	Kayak
10/4	Kayak	Kayak	Kayak	Kayak	Kayak
10/14	Kayak	Kayak	Kayak	Kayak	Kayak
10/30	Kayak	Kayak	Kayak	Kayak	Kayak

3.2.3 Sample Analysis

Once the samples were collected, they were either analyzed in the field or in the water quality laboratory. The following sections discuss the methods used to analyze the samples that were collected. Table 3 shows a summary of the testing parameters and the corresponding methods used.

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Table 2: Summary of testing parameters

Parameter	Location	Standard Method	Instrument
Temperature	On-site measurement. Test completed in field	2550 B	DO Probe
pH	Samples collected, test completed in the laboratory	Titration Method 2310 B	pH meter
Dissolved Oxygen (DO)	On-site measurement. Test completed in field	Membrane Electrode Method 4500-O G	DO Probe
Total Suspended Solids (TSS)	Samples collected, test completed in the laboratory	2540 D	Desiccator, vacuum, oven
Turbidity	Samples collected, test completed in the laboratory	Nephelometric Method 2130 B	Turbidimeter
Anions	Samples collected, test completed in the laboratory	Ion Chromatography with Chemical Suppression of Eluent Conductivity 4110 B	Ion Chromatography System
Total Phosphorus	Samples collected, test completed in the laboratory	Persulfate Digestion Method 4500-P B	Ion Chromatography System, Spectrometer

3.2.3.1 Temperature

Temperature was measured because temperature changes affect reaction rates and dissolved oxygen saturation. Temperature was measured using a field probe (YSI Model 85 Handheld Dissolved Oxygen, Conductivity, Salinity and Temperature System, YSI Incorporated, Yellow Springs, Ohio) placed 4 inches below the surface of the water at the sampling locations.

3.2.3.2 pH

pH is a reading of the intensity of the acid or alkaline condition of a solution. The commonly accepted range for pH of water is between 6.5 and 8.5 with 9.5 as the upper limit. pH affects many chemical and biological processes in the water. Low pH can cause toxic elements and compounds to become mobile and "available" for aquatic plants and animals to uptake. pH was analyzed in the Water Quality Laboratory within two hours of the sample collection to minimize changes due to carbon dioxide dissolution.

Upon returning to the laboratory, the samples collected in the 50 mL Nalgene bottles were poured into separate, clean 50 mL beakers. The pH meter (Fisher Scientific, AB15, Waltham, MA) was calibrated with buffers of pH 4, 7, and 10 based on the instruction manual. The electrode was rinsed with reagent grade water and placed into the sample. When the meter read "stable" the pH was recorded. This was repeated for each sample.

3.2.3.3 Dissolved Oxygen

A lake or pond system gains oxygen from the surrounding atmosphere and from plants within the ecosystem as a result of photosynthesis. Oxygen is consumed due to respiration of aquatic animals, decomposition, and various chemical reactions. Storm water runoff from farmland or roadways, feedlots, and failing septic systems are sources of oxygen-consuming waste. DO was measured in milligrams per liter (mg/L). A dissolved oxygen field probe (YSI Model 85 Handheld Dissolved Oxygen, Conductivity, Salinity and Temperature System, YSI Incorporated, Yellow Springs, Ohio) was used to collect the data on site.

This probe also measured temperature so both readings were recorded at the same time. The probe is filled with a salt solution and has a selectively permeable membrane that allows DO to pass from the stream water into the salt solution. The DO that has diffused into the salt solution changes the electric potential of the salt solution, which is then sent by electric cable to the meter. This converts the signal to milligrams per liter on a scale that can then be read and recorded. The probe was calibrated according to the manual before each sample run. Once ready to measure the dissolved oxygen, the DO probe was immersed directly into the water body below the surface and allowed to equilibrate to the water temperature. If the water velocity at the sampling location was less than about 1 ft/s, the probe was stirred by hand to increase the velocity. Once the instrument has stabilized to within +/- 0.2 mg/L, the DO concentration was recorded. This process was repeated at each of the five locations.

3.2.3.4 Total Suspended Solids

Total solids include dissolved solids as well as suspended and settleable solids in a water body. Sources of total solids include industrial discharges, sewage, fertilizers, road runoff, and soil erosion. Total solids are measured in milligrams per liter (mg/L). By monitoring total solids regularly, it can help detect trends that might be indicative of increasing erosion in developing watersheds.

Suspended solids were measured by weighing the amount of solids in a known volume of sample. Total suspended solids (mg/L) are measured using the Equation 7.

$$Total\ suspended\ solids\ (mg/L)\ = \frac{(A-B)*1000}{sample\ volume,mL} \qquad \text{(Equation 7)}$$

Where:
A= weight of filter + dried residue, mg and
B=weight of filter, mg

Samples that were brought to the laboratory for suspended solids analysis were tested within seven days of collection and were kept refrigerated. To measure the total suspended solids, the following steps were performed using the 1 L samples. Glass fiber filters (934 AH, Whatman, Miami, Florida) were prepared by first soaking them in distilled water, drying them at 103°C, cooling them in a desiccator, then weighing and recording their weights. The dried, weighed glass fiber filter was then placed onto a filtering flask. The sample bottle was gently shaken to evenly distribute the solids. 100 mL of water was poured into the flask and the pump was turned on. Less volume was used if the filter began to get clogged too quickly and more water was added if the water filtered very fast. Next, the volume of water filtered was recorded. The filter was then dried at 103-105°C, allowed to cool to room temperature, and weighed. The weight was recorded and steps 3-7 were repeated for each of the water samples. The residue is very light and thus, requires a balance (Discovery Analytical Balance, Ohaus Pinebrook, NJ) that is sensitive to weights in the range of 0.0001 gram.

3.2.3.5 Turbidity

Turbidity measures the extent to which the water scatters light. Some sources of turbidity include: soil erosion, waste discharge, urban runoff, eroding stream banks, large number of bottom feeders (which stir up bottom sediments), and excessive algal growth.

Turbidity was measured with a turbidimeter (Hach Model 2100N, Loveland, CO). A turbidimeter consists of a light source that illuminates a water sample and a photoelectric cell that measures the intensity of light scattered at a 90-degree angle by the particles in the sample. Meters can measure turbidity over a wide range from 0 to 4000 NTUs (nephlometric turbidity units). Samples being tested for turbidity were done so within two days of the samples being taken (USEPA 1997). The following procedure was used to analyze the turbidity of each water sample:

1. Use the turbidity standards provided with the meter to calibrate it (every 3 months).
2. Gently invert the 250 mL sample container and pour sample into turbidity vial to the white line.
3. Pour the sample water into the vial. Wipe off any drops on the outside of the vial.
4. Use a lint-free cloth to wipe the outside of vial. Do not to handle the vial below the line where the light will pass when the tube is placed in the meter.
5. Place the vial in the meter, wait for about 10 seconds for the signal to average, and then read the turbidity measurement directly from the meter display.
6. Record the result on the field or laboratory sheet.
7. Repeat steps 3-7 for each sample.

3.2.3.6 Anions

The most noticeable effect of high nutrient levels includes reduction in water clarity because of increased growth of plants and algae. Lake Quinsigamond, which feeds into Flint Pond, is listed as an impaired water body because of Noxious Aquatic Plants (MADEP, 2002).

The “Ion Chromatography with Chemical Suppression of Eluent Conductivity” method was used to measure the nutrient levels of the samples. The samples were stored while awaiting testing. Don Pellegrino, Laboratory Manager for the Water Quality Laboratory, performed the test using the Ion Chromatography System (ICS) and sent the data to the group. The ICS measured fluoride, chloride, nitrite, sulfate, bromide, nitrate, and phosphate.

3.2.3.7 Total Phosphorus

An increase in phosphorus levels can cause noxious plant growth, algae blooms, low dissolved oxygen, and the death of certain aquatic animals. Sources of phosphorus include: soils and rocks, wastewater treatment plants, runoff from fertilized lawns and cropland, failing septic systems, runoff from manure storage areas, disturbed land areas, drained wetlands, water treatment, and commercial cleaning preparations. The team chose to test for total phosphorus due to concerns expressed by the LQWA.

The Total Phosphorus test was used to confirm the presence of phosphorus because the ICS values obtained were inconclusive. By using a digestion method to determine total phosphorus, it allows organic matter to oxidize effectively in order to release the phosphorus as orthophosphate. To measure total phosphorus in the samples the following method was used:

1. Digest sample. The simplest method is the persulfate oxidation technique. The samples were digested in accordance with Standard Method 4500-P B (APHA *et al.,* 1995).
    a. Use 50 mL portion of thoroughly mixed sample in a beaker.
    b. Add 0.05 mL of phenolphthalein indicator solution.
    c. If a red color develops, add H_2SO_4 solution drop-wise to just discharge the color.
    d. Then add 1 mL H_2SO_4 solution and either 0.4 g solid $(NH_4)_2S_2O_8$ or 0.5 g solid $K_2S_2O_8$.
    e. Boil gently on a preheated hot plate for 30-40 min or until a final volume of 10 mL is reached.
    f. Cool, then dilute to 30 mL with distilled water.
    g. Add 0.05 mL (1 drop) phenolphthalein indicator solution, and neutralize to a faint pink color with NaOH.
2. Complete steps 3-11 with a blank to calibrate the spectrometer (Hach DR3000).
3. Carefully pour digested sample from its beaker into a clean 25 mL volumetric flask. It is very important that the same flask is used for every sample.
4. Pour deionized water into beaker, swirl around, and pour into the volumetric again in order to get the entire sample out.
5. Add one drop of phenolphthalein indicator.
6. Add NaOH one drop at a time until sample turns pink.
7. Bring the rest of the sample to 25 mL with deionized water.
8. Add 1 mL of molybdovanadate reagent to sample and swirl around until sample is no longer pink.
9. Set spectrometer to three minutes.
10. Once the three minutes is up, place the sample into the spectrometer (Hach DR3000).
11. Read and record the absorbance.
12. Complete steps 3-11 with different standards.

Since the phosphate concentration is measured as a function of absorbance, a plot of the standard curve of absorbance versus known phosphate concentrations was prepared. Six standard phosphorus concentrations and a blank were used during the test. The various concentrations were prepared with varying amounts of distilled water. The values were then used to plot absorbance vs. phosphate concentration to develop a straight line on the graph passing through the origin. With each new batch of samples, another standard phosphate concentration was included to check the calibration curve. The wavelength on the spectrometer was 400 nm and the six standard concentrations were 0.1, 0.2, 0.5, 1.0, 3.0, and 5.0 mg/L.

The values read on the spectrometer are absorbance values, not concentration. To convert values from absorption to concentration (mg/L), the absorption value was divided by the slope from the curve. This gives a value of concentration of phosphorus in mg/L. These values were then compared to the water quality goal for Flint Pond.

3.3 Rainfall Data

Rainfall data was acquired from the Worcester Regional Airport gage on the National Climatic Data Center website (National Climatic Data Center, 2012). Rainfall data were collected to evaluate the relationship, if any, between precipitation and water quality in Lake

Quinsigamond and Flint Pond. The data were collected by hour and in inches. This allowed the data to be organized into categories of 12, 24, and 48 hours prior to sampling as well as daily rainfall. Data were recorded for each hour within the sampling period, which lasted from September 14 to October 30.

3.4 Statistical Analysis

Statistical analysis of the rainfall and water quality parameter data consisted of two tests: correlation analysis and analysis of variance. The objective of the correlation test was to examine linear relationships between variables. The objective of the analysis of variance tests were to determine whether the variance between select groups of data outweighed the variance within the groups so that they may be statistically distinguished as separate groups.

3.4.1. Correlation Analysis

Pearson's method for correlation is intended to determine the strength of linear association between two variables. This method utilizes standardized data. This means that for each data pair, instead of directly comparing the magnitudes, the standardized values are compared. Data are standardized using Equation 8 (Petruccelli *et al.*, 1999).

$$X'_i = \frac{X_i - \bar{X}}{S_X} \qquad \text{(Equation 8)}$$

Where X'_i is the standardized value, X_i is the original value of the data, $\bar{X}$ is the mean value of the parameter, and S_X represents the standard deviation. When all data for the two variables of interest have been standardized, Equation 9 is used to calculate a correlation coefficient.

$$r = \frac{1}{n-1} * \sum_{i=1}^{n} X'_i Y'_i \qquad \text{(Equation 9)}$$

Where r represents the correlation coefficient, n represents the number of data pairs, and X'_i and Y'_i represent the standardized values for both variables of a data pair. Correlation coefficients range from -1 to 1. The absolute value of the correlation coefficient determines the confidence level of correlation. In order to be statistically significant, a correlation coefficient should match or exceed the critical value for a confidence level of 95%. Different critical coefficient values exist for varying numbers of data pairs and confidence levels. Negative coefficients indicate variables that are inversely related: as one variable increases, the other tends to decrease (Petruccelli *et al.*, 1999).

Correlation analysis was conducted using the Data Analysis Tool-pack of Microsoft Excel. Selecting the Data Analysis Tool-pack brings up a menu of statistical tests that can be conducted. Correlation was selected, followed by the input and output ranges for the test. The output comes in the form of a table with the data parameter labels across the left side and the top. The value found at the point at which the row and column for the data parameters of interest intersect is the correlation coefficient for that relationship. To determine whether a correlation was present, the correlation coefficients were compared to the critical values found in Appendix B. The correlation tests were conducted for all water quality parameters that were tested for and 12, 24, and 48-hour rainfall values.

3.4.2 Analysis of Variance

Analysis of variance (ANOVA) was used to determine if groupings of data for a single parameter were statistically distinguishable from the other groups by comparing the sum of squares within each group and between groups. Analysis of variance centers on the idea that each group has received a different treatment. The baseline for the analysis is the null hypothesis that the groups have had no response to the varying treatments. Thus, determining the groups to be statistically different is a matter of disproving the null hypothesis. Equations 10-17 were used to conduct this test (Petruccelli *et al.*, 1999). Equation 10 was used to find the total sum of squares for a data set.

$$SS_T = \sum_{i=1}^{N}(X_i - \bar{X})^2 \qquad \text{(Equation 10)}$$

Where SS_T represents the total sum of squares, N represents the total number of data points, $\overline{X}$ represents the average of all data points, and X_i represents an individual data point. Equation 11 shows that the total sum of squares equivalent to the combination of the sum of squares within groups and the sum of squares between groups.

$$SS_T = SS_W + SS_B \qquad \text{(Equation 11)}$$

Here SS_W and SS_B represent the sum of squares within the groups and sum of squares between the groups, respectively. Equation 12 was used to solve for the sum of squares between groups.

$$SS_B = \sum_{i=1}^{g}\left(\left(\bar{X}_g - \bar{X}\right)^2 * n\right) \qquad \text{(Equation 12)}$$

Here, g represents that total number of groups, $\bar{X}_g$ represents the average for a group, and n represents the number of data points within that specific group. After solving for SS_B, Equation 11 was rearranged to solve for SS_W. Degrees of freedom were also determined. Total degrees of freedom is equivalent to the sum of degrees of freedom within groups and degrees of freedom between groups, as seen in Equation 13.

$$df_T = df_W + df_B \qquad \text{(Equation 13)}$$

Where, df_T represents the total degrees of freedom while df_W and df_B represent the degrees of freedom within and between groups, respectively. The degrees of freedom between groups was solved for using Equation 14 while degrees of freedom within groups was solved for using Equation 15.

$$df_B = g - 1 \qquad \text{(Equation 14)}$$

$$df_W = \sum_{i=1}^{g}(n - 1) \qquad \text{(Equation 15)}$$

Where g again represents the total number of groups and n represents the number of values within a single group. Once sum of squares and degrees of freedom have been determined for both within group and between group categories, the calculations in Equations 16-17 were performed to determine the mean squares and F-value as shown in Equation 16 and Equation 17, respectively.

$$MS = \frac{SS}{df} \qquad \text{(Equation 16)}$$

Here MS is the mean square. The mean square between groups, MS_B, was solved for using Equation 16 with SS_B and df_B. Similarly, the mean square within groups was solved for using SS_W and df_W with Equation 16. The F-value was then solved for using Equation 17.

$$F = \frac{MS_B}{MS_W} \qquad \text{(Equation 17)}$$

Once calculated, the F-value was compared to a generated F-critical value. The F-critical value is dependent on the number of data points and the desired level of confidence. If the F-value is in excess of the F-critical value, the groups are statistically different according the selected level of confidence. The p-value generated in the ANOVA test indicates the probability that the calculated F-value was achieved by coincidence. The p-value serves as a different manner of viewing the F-critical value. For example, if a confidence level of 0.05 was selected and the calculated F-value was equivalent to the F-critical value, p would be equivalent to 0.05, or 5% probably of a chance occurrence. If the F-value were higher than the F-critical value, p would decrease to even smaller probabilities (Petruccelli *et al.*, 1999).

Analysis of variance was carried out using the Data Analysis Tool-pack in Microsoft Excel. For this project, the ANOVA: Single Factor analysis tool was used. Analysis of variance tests were conducted for turbidity, total suspended solids, nitrate, and total phosphorus. Two different groupings were tested. Grouping by sampling date was the first of these two. A number of factors may have affected water quality results on individual dates; one of these factors was rainfall prior to sampling. Thus the goal of this test was to see if differing rainfall treatments may cause different parameter concentrations; however the large number of potential factors that could affect these values may cause significant interference. The second grouping method was by sample site: A, B, C, D, and E. If this grouping method was statistically significant, it may provide an indication to pollutant input points.

3.5 BMP Ranking System and Selection

The national menu of stormwater best management practices listed on the USEPA website includes over 150 measures that one may choose to use when solving stormwater problems. The site lists options in categories such as public education, public involvement, illicit discharge detection and elimination, construction, post-construction, and pollution prevention/good housekeeping. To begin the process of choosing appropriate BMPs for Flint Pond, a ranking system was utilized. First, the list of all possible BMPs was researched to narrow the options down to seventeen. BMPs were eliminated as not relevant to the project based on applicability and effectiveness. Next, seven criteria were chosen to rank the BMPs—effectiveness, cost, land area, maintenance, applicability, general feasibility, and longevity.

These criteria were chosen because they are all important factors to consider when designing a BMP for the specific site characteristics around Flint Pond. The BMP that is chosen needs to be effective in removing total suspended solids because Flint Pond is currently on the list of impaired water bodies for turbidity due to suspended solids. Cost is an essential consideration because depending on who pays for the implementation, the LQWA or the Town of Shrewsbury, there is an associated budget with both associations and the design must be affordable. When visiting the site, it was observed that there is not an abundant amount of land area available for implementation. Therefore, land area needs to be taken into account when choosing a BMP. Maintenance was included in the ranking because a person hired by the town of Shrewsbury will be responsible for the maintenance of the BMP. Applicability is necessary in the BMP ranking. The BMP chosen must be applicable to the problem in which it aims to resolves. Generally feasibility was included because if the LQWA is responsible for implementing the BMP, it has to be attainable for the volunteers to implement. Finally, longevity was included because the BMP must be durable to ensure that the implementation is worthwhile.

Each BMP was ranked on a scale from 1 to 5 in each of the criteria, with one being the lowest ranking and five being the highest. The BMPs were ranked separately by each member of the group and then averaged. The sponsors did not participate in this section of the evaluation.

The next part of the evaluation was the ordering of each criterion. The same seven criteria were ordered, this time from 1 to 7, with 1 being the least important and 7 being the most important. For this ordering, each criterion must have a different number and no numbers were repeated. This ordering was completed one time by each of the three group members and once by each of the two sponsors. Once the criteria were ordered, the ordering assigned by the MQP team were added for each criterion and divided by 21 since 21 was the maximum total that each criterion could have received with three people ordering it. The same thing was done with the MQP team and sponsors orderings—the orderings given by each member of the MQP team and each of the two sponsors were added together for each criterion and divided by 35 since that was the maximum total each criterion could have received with all five people ordering it. The result was the "multiplier". As a result, there were two multipliers—one only considering the MQP teams orderings and once considering both the MQP team and the sponsor's orderings.

The multiplier was then multiplied by the original ranking to get a "weighted total" for each criterion for each BMP. The criterion was added together to get two weighted totals for each BMP—one from the sponsors and one from the MQP team. These weighted totals were then divided by the maximum weighted total they could have received in order to get a percentage. This was done to allow consistency in the ranking in order to accurately compare the values.

4 Results

The purpose of this project was to address concerns of water quality and possible sediment inflow occurring due to stormwater runoff at the western most point where Lake Quinsigamond drains into Flint Pond. This was accomplished by completing the following objectives: collecting and analyzing water quality samples in the area of interest; evaluating correlations among and variances between water quality, site location and rainfall; and designing best management practices to mitigate any pollution problems. The full data sets can be found in Appendix A.

4.1 Rainfall Data

In order to determine if there was a relationship between water quality and storm events, rainfall data were obtained through the National Climatic Data Center. The data were organized by date and by hour relative to a sampling event. Figure 3 illustrates daily rainfall throughout the sampling period and also indicates dates on which samples were taken.

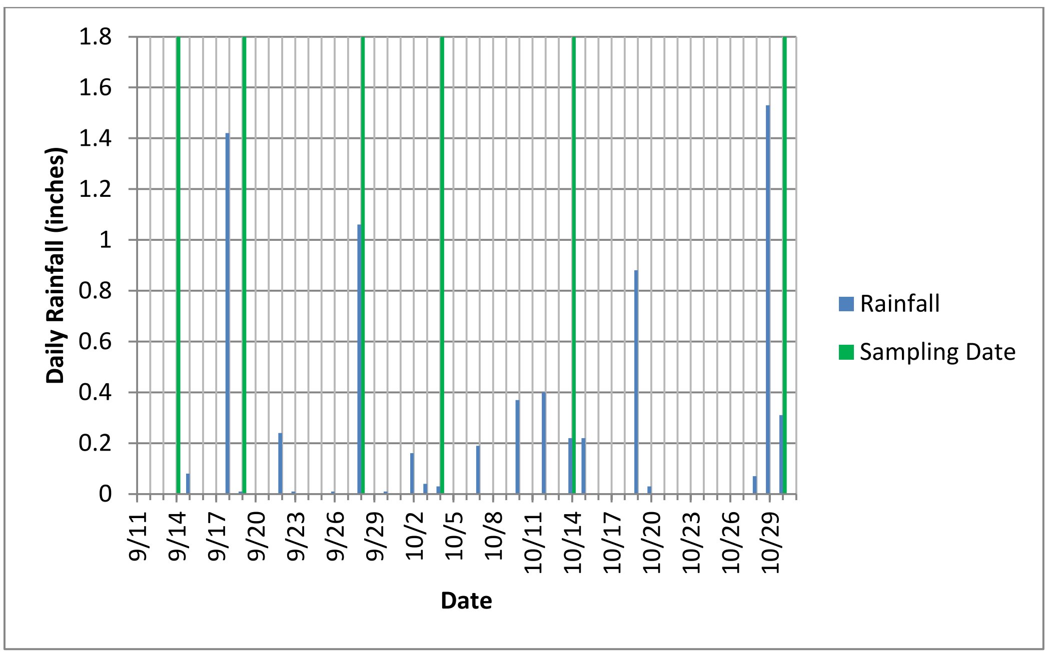

Figure 3: Daily rainfall

For the September 19 and October 30 sampling dates, there were relatively large amounts of rain, in excess of 1 inch, on the day prior to sampling. In contrast, there was no rain in the three days before sample date of September 14 and no rain for five days before sample date of September 29. Finally, the days before sample dates of October 4 and October 14 had rainfall quantities totaling less than 1 inch. For the days of sampling, no rainfall occurred on September 14 and September 19. Rainfall quantities on September 28, October 4, October 14, and October 30 were 1.06 inches, 0.03 inches, 0.22 inches, and 0.31 inches, respectively.

Rainfall data were organized into categories based on time prior to a sampling event. These categories included rainfall within the 12, 24, or 48 hours prior to water sample collection.

The purpose of this was to provide quantitative values for statistical analysis. Additionally, the hourly rainfall data take into account that only rainfall occurring prior to the time of sampling may be related to runoff quantity and quality. The data for hourly rainfall can be found in Appendix A.

4.2 Area analysis

An analysis of the runoff area was conducted primarily based on data from the Massachusetts GIS website that was pooled into an ArcMap document. Table 4 shows the percent composition of the runoff area for each soil type and land use combination, CN values, and the calculated initial abstraction. The map output from this analysis can be seen in Figures 4 and 5, which show the areas land uses and soil types, respectively.

Table 3: Runoff area characteristics and initial abstraction analysis

Land Use	Soil Hydr Grp	Area (m^2)	% Area	CN Value	Initial Abstraction (inches)
Commercial	A	6,370	7.40	89	0.25
	B	5,920	6.88	92	0.17
Forest	A	60	0.07	45	2.44
	B	9,540	11.09	66	1.03
High Density Residential	A	46,680	54.24	77	0.60
	B	7,070	8.22	85	0.35
Industrial	A	6,330	7.36	81	0.47
Multi-Family Residential	A	3,380	3.93	77	0.60
Urban Public	A	710	0.83	89	0.25
Total		86,060	100.00	NA	NA
Average		NA	NA	79	0.56

4.2.1 Delineation

The approximate runoff area delineation was performed using contour elevation lines. It was assumed that runoff flows perpendicularly, or downhill, relative to contour lines. In both maps, contour lines of higher elevation are colored purple and shift through the red spectrum to yellow as elevation decreases. The results for the delineation process can be seen in both Figures 4 and 5.

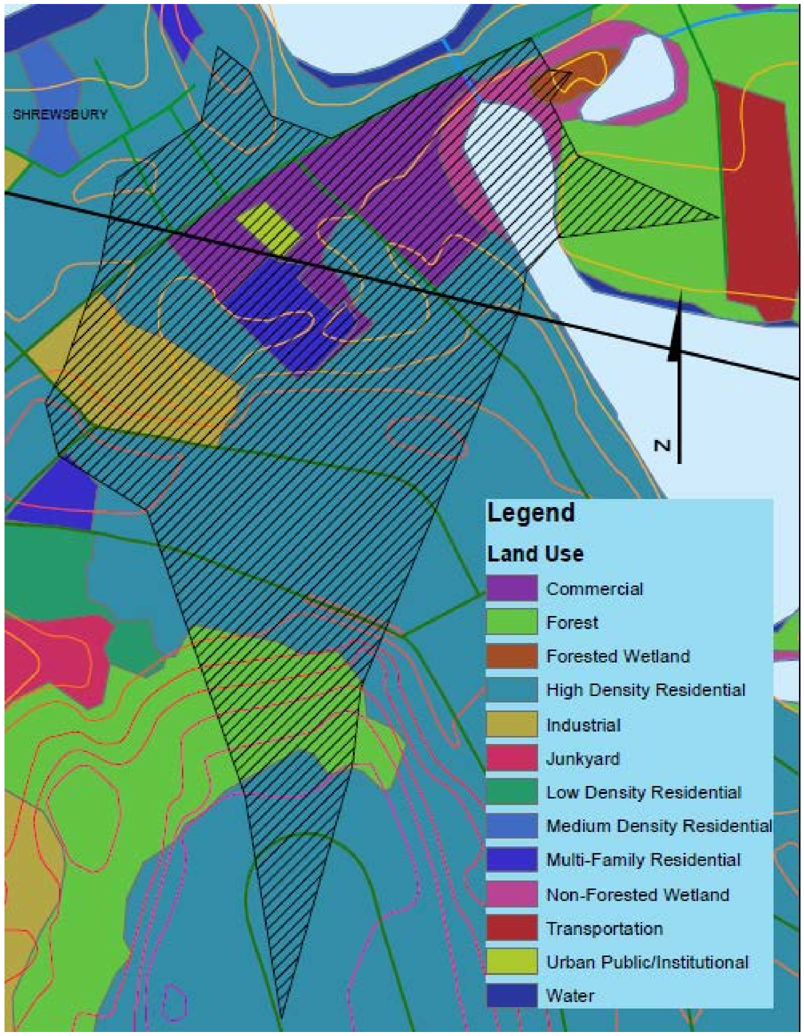

Figure 4: Approximate delineation with map of land use

Figure 4 shows the runoff area as well as the map of land uses in the area. Table 4 shows the percent composition of land uses in the runoff area. High density residential is the primary land use in the runoff area. It makes up 62.46% of the total area. Other land use types within the contributing area include industrial (7.36%), multi-family residential (3.93%), commercial (14.28%), urban public (0.83%), and forest (11.16%).

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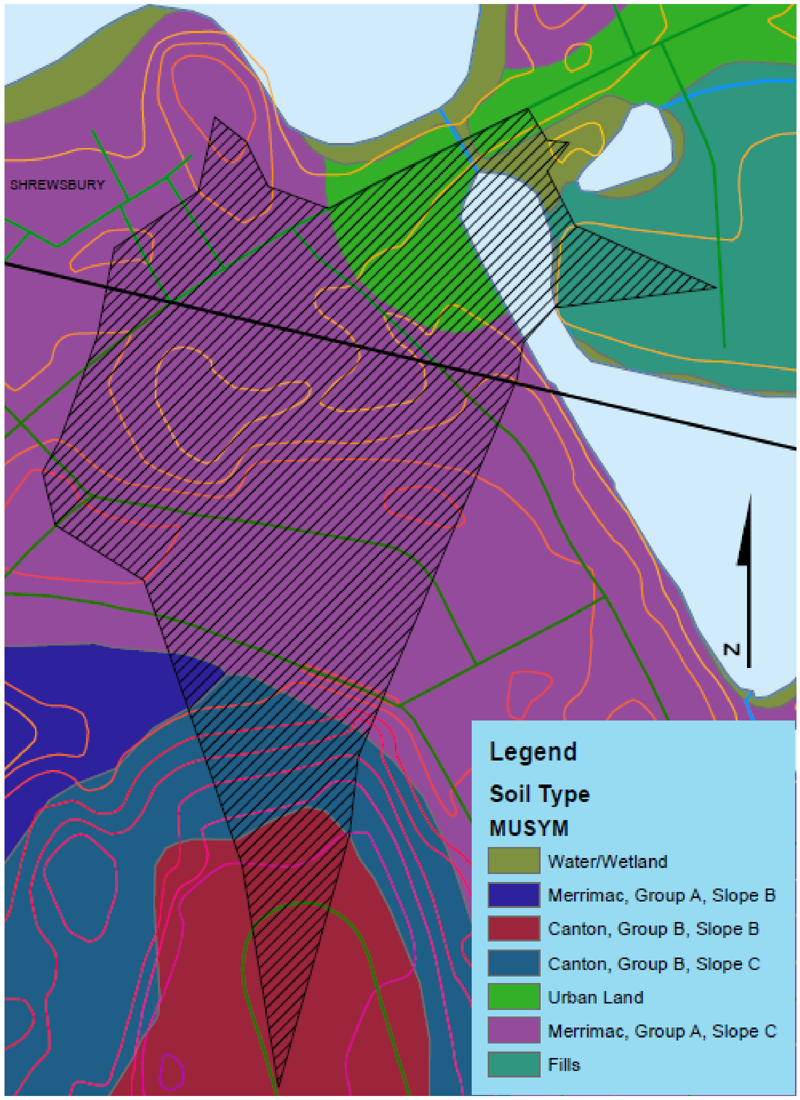

Figure 5: Approximate delineation with map of soil types

Figure 5 shows the soil type composition of the runoff area. Just less than 74% of the soil in the runoff area is hydraulic group A. The two southernmost soil types are from hydraulic group B. The two undocumented soil types, fills and urban land, were assumed to be hydraulic group B as well because hydraulic group B is an intermediate. Thus, it was selected in order to avoid the larger error that would result from inaccurately assuming the hydraulic group type to be one of the extremes. In total, about 26% of the soils in the runoff area were taken to be hydraulic group B.

4.2.2 Initial Abstraction

Theoretical initial abstraction was used to estimate the amount of rainfall that would be required before significant runoff would be expected to flow into the area of interest in Flint Pond. This required retrieval of data from the land use and soil type layers stored in the MassGIS database. A sample calculation of initial abstraction can be seen in Appendix D. The results for each combination of land use and soil type present within the runoff area are summarized in Table 4. CN values were taken based on the combination of land use and soil hydraulic group according to Bedient *et al.* (2008). The row labeled "Total" in Table 4 lists the approximate total runoff area. The "Average" row lists the average runoff curve number of the area and the average initial abstraction for land within the runoff area. The average CN and initial abstraction values were calculated by summing all components of the runoff area weighted by the fraction of the total area that the component makes up. The result for the average initial abstraction suggests that, on average, runoff will begin being generated after 0.56 inches of rainfall. The forest land use had the largest initial abstraction values of 2.44 inches and 1.03 inches for hydraulic groups A and B, respectively. The lowest initial abstraction value was for the commercial land use and hydraulic group B, 0.17 inches. The second lowest initial abstraction value, 0.25 inches, was calculated for commercial and urban public land uses on soil of hydraulic group A. Since the commercial area has the two lowest initial abstraction values and is adjacent to the water, runoff will likely begin flowing from it into the water from this area before the 0.56 inch average initial abstraction is reached. After only 0.25 inches of rain, over 14% (about 12,300 m^2) of the total runoff area, which is commercial, could generate significant amounts of runoff. At the same time, other areas, such as the forested areas, would not be expected to generate runoff until over an inch of rain has fallen.

4.3 Field Sampling Results

Field sampling was conducted at five locations in and around Flint Pond on six dates between September 14 and October 30. Samples were analyzed for a number of water quality parameters. The test results were then compared with rain data to determine if there were trends between rainfall and pond water quality.

The results of the field sampling analyses were also compared with the standard values of similar water bodies in the state of Massachusetts. The State classifies inland water bodies as Class A, B, or C. Class A water bodies are described as "excellent" sources of public water supply, habitats for fish, aquatic life, and wildlife, and areas of primary and secondary contact recreation. Class B water bodies are described as habitats for fish, aquatic life, and wildlife and areas for primary and secondary contact recreation. They may also be suitable as sources of water supply after certain treatment. Class C water bodies are described as habitats for fish, aquatic life, and wildlife, and areas for secondary contact recreation (MADEP, 2007). Primary contact recreation is defined as recreation which involves extensive contact with and potential ingestion of the water. Secondary contact recreation is defined as recreation in which contact with the water is minor or accidental. Both Flint Pond and Lake Quinsigamond are categorized as Class B water bodies.

4.3.1 Dissolved Oxygen

The concentration of dissolved oxygen in the pond water was determined using a field probe. Dissolved oxygen (DO) was measured because low levels are hazardous to oxygen-reliant species in the water, such as fish. Also, low dissolved oxygen levels are linked to nutrient pollution through the eutrophication process. Dissolved oxygen results are shown in Figure 6 along with dissolved oxygen saturation on each date.

The data show potential errors in the dissolved oxygen for the first three sampling dates (September 14, 18, and 28). The dissolved oxygen readings for multiple sites were in excess of the dissolved oxygen saturation point for the temperature. Because of this, it is expected that there was some error in calibration of or use of the DO field meter The dissolved oxygen levels for the last three sampling dates (October 4, 14, and 30) were all below the dissolved oxygen saturation points for each date. On October 4, the DO concentrations ranged from a low of 6.79

mg/L at Site B to a high of 7.71 mg/L at site E. Site A also had the second lowest DO value of 6.80 mg/L. The data from this date indicated that as the water moved from the Lake Quinsigamond side towards Flint Pond, it tended to reaerate. On October 14, a minimum of 4.04 mg/L was read at Site C and a maximum of 4.87 mg/L was read at Site E. This data set indicated increasing oxygen levels moving from the center of the area of interest towards the upstream and downstream sample sites. On October 30, the maximum of 7.99 mg/L was read at Site A while the minimum of 7.77 mg/L was read at site E. Site readings from this date tended to decrease moving from Site A through to Site E. Thus, the results from each of the last three sample dates indicate a different DO pattern relative to the samples sites.

The Massachusetts Surface Water Quality Standards (MADEP, 2007) indicate that Class B water bodies should have DO levels above 5.0 mg/L for warm water fisheries (water bodies that generally exceed 20°C in summer months) and above 6.0 mg/L for cold water fisheries (water bodies that generally remain under 20°C during the summer months). Of the three sample dates that appeared to have valid data based on DO saturation, DO on October 4 and October 30 remained above these recommended values. However, the readings taken on October 14 were below the suggested values. Further DO monitoring of the area would be able to provide additional information regarding how often DO values reach levels as low as those recorded on October 14.

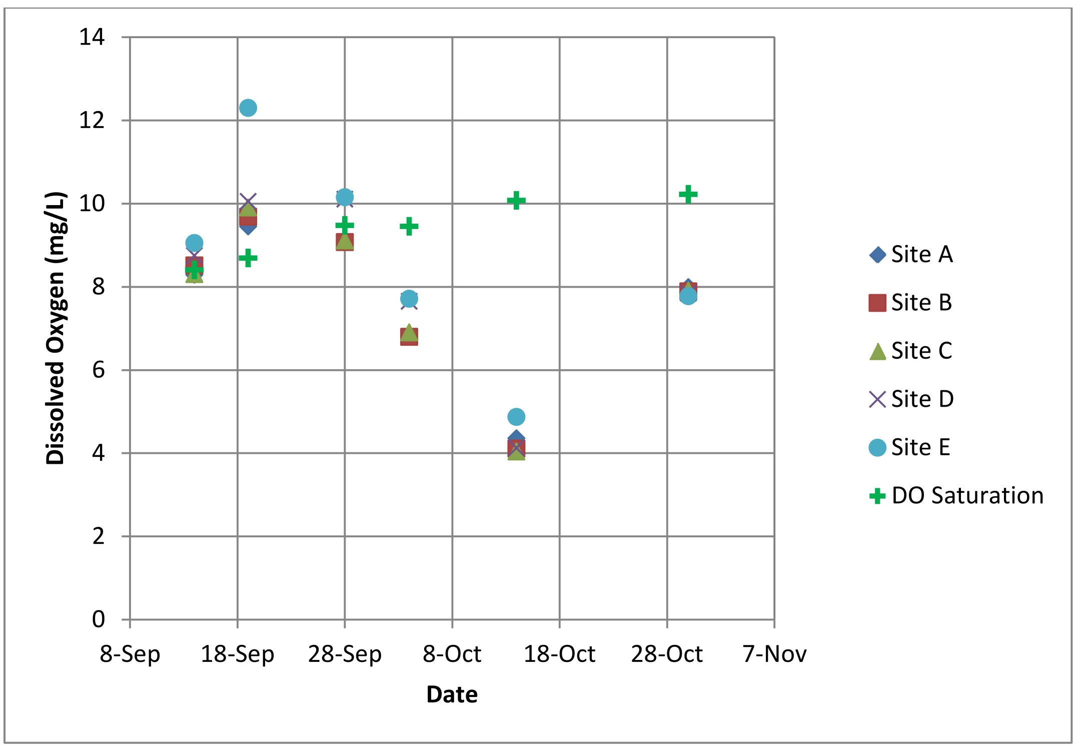

Figure 6: Dissolved oxygen by date

4.3.2 Temperature

Similar to DO, temperature readings were taken using a field probe. Regulations concerning the temperature of Class B bodies state that temperature should not exceed 28.3°C for warm water fisheries (MADEP, 2007). The temperature data are presented in Figure 7. The data demonstrate a decrease in temperature as the date moves forward. The temperature on September 14, the start of the sampling season, was about 24°C, and by the end has dropped to about 14.5°C. This was an expected occurrence as the local season shifts into winter. On September 28, Sites D and E deviated from the gradual temperature decrease seen in Figure 7. The temperature recorded on this date at site D was 17.1°C while the temperature recorded at site E was 15.8°C. Temperatures for sites A, B, and C were 19.1°C, 18.9°C, and 18.6°C. This is the only instance in which a temperature range greater than 1.0°C was recorded. September 28 had an elevated rainfall amount (0.39 inches in the 12 hours prior to sampling). No recorded temperatures exceeded the suggested limit of 28.3°C for warm water fisheries (MADEP, 2007).

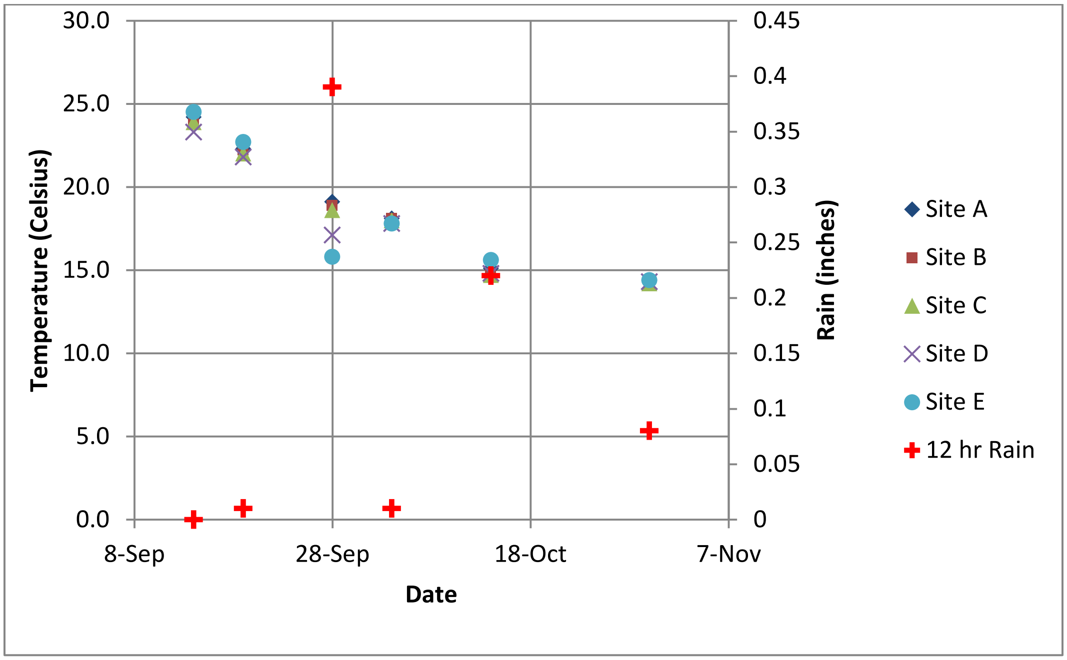

Figure 7: Temperature values by date

4.3.3 pH

pH was tested for because of the danger that can be presented to aquatic species, wildlife, and humans in contact with the water should the pH become too basic or acidic. The pH of the water from the five sampling sites in Lake Quinsigamond and Flint Pond was typically in the 6 to 8 range. The Massachusetts Water Quality Standards indicate that a class B water body should have pH values between 6.5 and 8.3 (MADEP, 2007). Four readings of pH fell outside of this range of acceptable values.

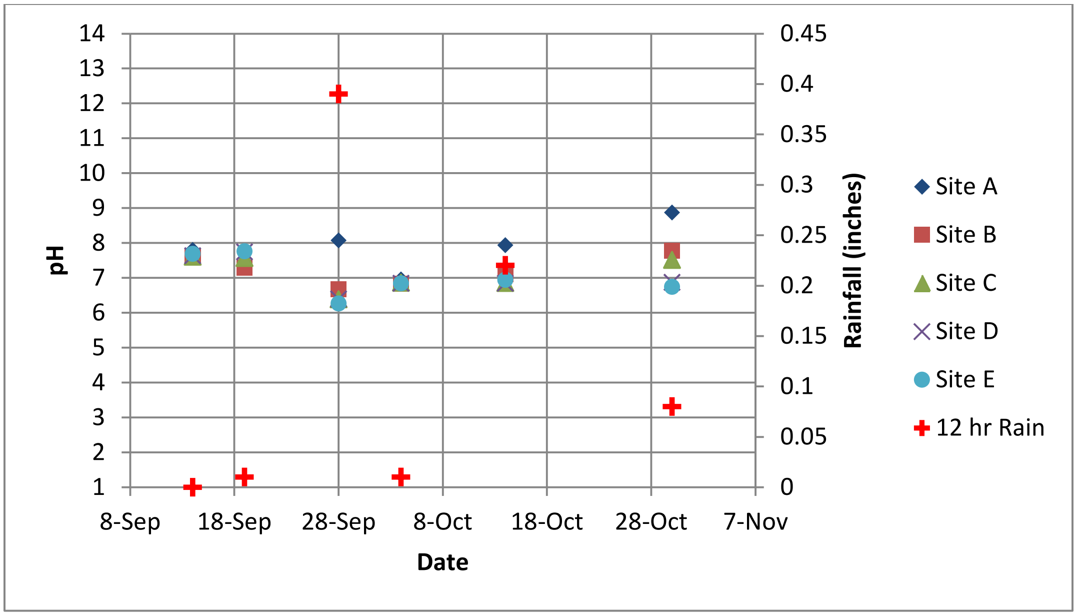

Figure 8: pH by date

Three samples were below the pH limit of 6.5 on September 28. Sites C, D, and E had pH values of 6.38, 6.39, and 6.26, respectively. The 12 hour rainfall quantity on September 28 was the greatest (0.39 inches), and may affect pH since September 28 was the only date on which the values were below the Class B water body standards. The highest pH was recorded at site A for five of the six sample sets (the exception being September 19). The only pH greater than the suggested range, 8.87, was recorded at site A on October 30. The biggest pH difference in adjacent sites was seen between sites A and B in all sample sets except the September 19 set. On September 19, the water samples still showed a drop in pH as water moves from site A to site B, however as the water moved across the latter 3 sites, the pH climbed. In three sample sets, September 14, September 19, and October 14, the pH recorded at site E climbed 0.06, 0.02, and 0.10 when compared to the reading at Site D, shown in Figure 8. Overall it appears that more basic water from Lake Quinsigamond moving through the area of focus tends to experience pH drops. The September 28 sample set indicates that this trend may be enhanced by increased quantities of rainfall.

A rainfall sample was collected on October 4 and tested for pH. The pH of this sample was 5.99. This reinforces the data from September 28 that indicates the rainfall is acidic and thus has a pH lowering effect on surface water. On September 28, October 14, and October 30, water became more acidic as it moved downstream through the area of interest. With the elevated rainfall on September 28, pH values were lower than the water body regulations. This acidification may prove to be detrimental to aquatic life in the area.

4.3.4 Turbidity

Turbidity measures the extent to which the water scatters light. This serves as a measure of solids content since particulates in the water are generally responsible for the light scattering. The Massachusetts Surface Water Quality Standards do not indicate specific limitations to class B water bodies with regard to turbidity (MADEP, 2007). The data for turbidity are shown in Figure 9. On the last three sample dates, October 4, October 14, and October 30, all recorded turbidity values were between 2.05 ntu and 3.15 ntu. On these dates there did not appear to be a significant difference between sites. The September 14 and September 19 sample sets also remained within this range except for the values recorded at site E. On September 14 and September 19 the recorded turbidity values at site E were 6.15 and 8.5 ntu, respectively. Site E is located at the downstream end of the area of interest, where the waterway narrows and the water velocity would increase. This velocity increase may stir up sediment from the floor of the waterway. A difference between the first two sample sets and the last four sample sets was the sampling method. The first two sample sets were collected by wading into the water body with a point of entrance near site C. The remaining sample sets were collected via kayak. It is possible that wading from upstream to downstream to collect a sample at site E would have stirred up sediment in the sampled water.

Samples taken on September 28 had turbidity values ranging from 2.6 ntu to 39.4 ntu. Sites A and B, the two most upstream sites, had the lowest turbidity values of 2.6 ntu and 4.0 ntu, respectively. Sites C, D, and E, located further into the area of interest, had turbidity values of 29.9 ntu, 25.6 ntu, and 39.4 ntu, respectively. These values are on the scale of 10 times the turbidity values of the other sample sets, with exception given to the values found at site E for the first two sample sets. These elevated turbidity values occurred after a rainfall of 0.39 inches in the 12 hours preceding sampling. Sites C, D, and E, being downstream from sites A and B, would be more subject to runoff pollutants, including solids, from the delineated contributing area. Runoff generated on September 28 may therefore be responsible for the elevated turbidity values for sites C, D, and E.

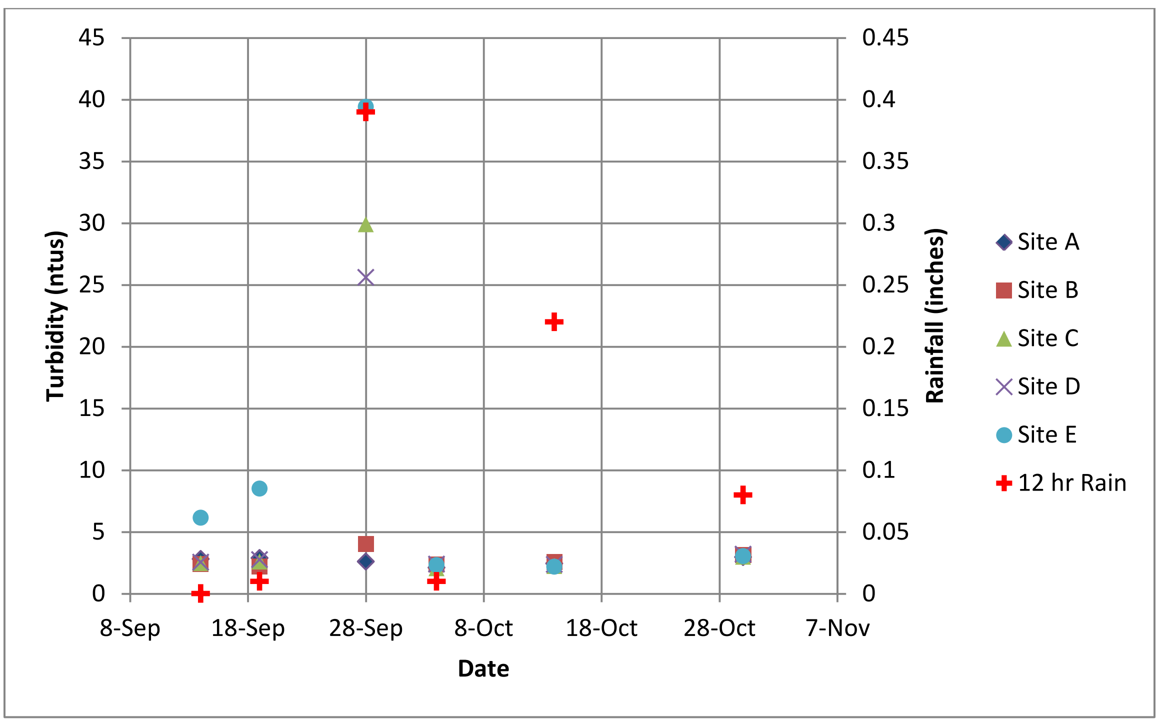

Figure 9: Turbidity by date

4.3.5 Total Suspended Solids

The total suspended solids test was conducted to directly measure the mass content of solids in the water through weighing. TSS data were collected for four sampling events

(September 19, September 28, October 4, and October 30) in order to supplement turbidity data on particulate matter.

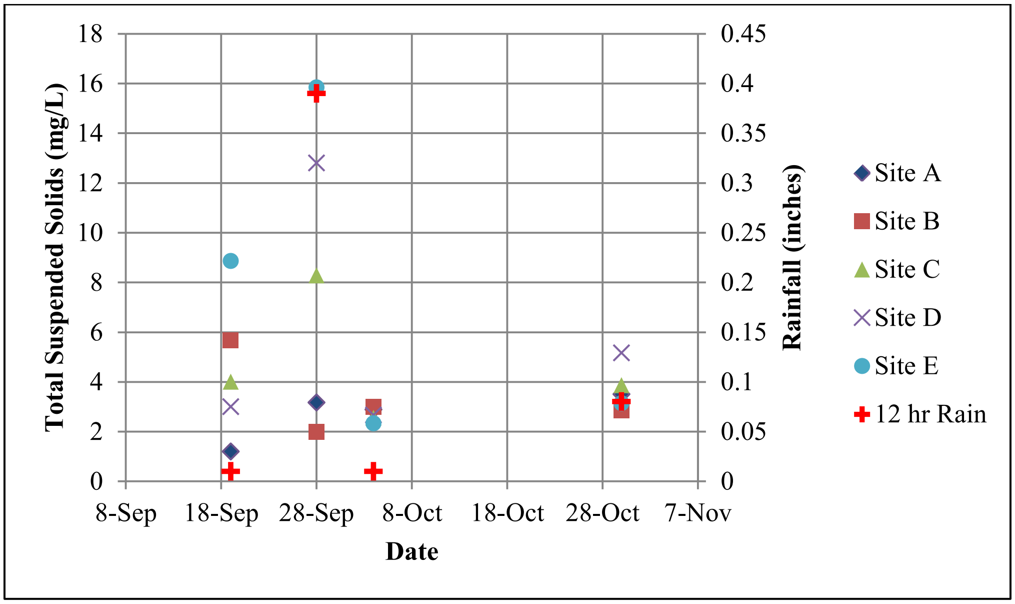

Figure 10: Total suspended solids by date

Figure 10 again demonstrates elevated TSS on September 28, which had the highest rainfall in the 12 hours prior to sampling (0.39 inches). Sites C, D, and E all had their highest TSS values for this sample date: 8.29 mg/L, 12.90 mg/L, and 15.83 mg/L, respectively. These maximum values exceeded the second highest values recorded during the sampling season at their respective sites by 4.29 mg/L, 7.63 mg/L, and 30.9 mg/L, respectively. Data from all other dates remained below 6 mg/L, with the exception of site E on September 19 (8.86 mg/L).

The Massachusetts Surface Water Quality Standards (MADEP, 2007) do not specify a limit for total suspended solids measurements for Class B water bodies. The majority of TSS results were below 5.70 mg/L with a minimum of 1.20 mg/L. TSS values were relatively tightly clustered for October 4 and October 30, with ranges of 0.67 mg/L and 2.31 mg/L. Sampling dates September 19 and September 28 had ranges of 6.3 mg/L and 13.83 mg/L. It is possible that the elevated TSS value for site E on September 19, 8.86 mg/L, may have been high at least in part due to the wading water sampling method and the downstream position of site E. Aside from site E, the results for September 19 remain relatively close to those values seen for October 4 and October 30, despite being more scattered. For the September 28 samples, the results at sites C, D, and E were elevated to 8.29 mg/L, 12.80 mg/L, and 15.83 mg/L. Similar to the turbidity results, sites A and B remained at levels similar to those seen in the results for the other three sampling dates: 3.17 mg/L and 2.00 mg/L, respectively. The total suspended solids data show the same trends as the turbidity data.

4.3.6 Anions and Total Phosphorus

Laboratory tests were conducted in order to provide insight on the nutrient content of the water. Specifically, this was intended to provide data regarding phosphorus and nitrate. Ion chromatography was conducted for five sampling dates: September 14, September 19, September 28, October 4, and October 30. The focus of the ion chromatography test was nitrate;

however additional chemicals were reported in the test. These chemicals included bromide, chloride, fluoride, and sulfate. The test also had the capability of reporting phosphate, however phosphate levels were too low to be detected. The data collected on these chemicals can be found in Appendix A. Total phosphorus tests were conducted for September 19, September 28, October 4, October 14, and October 30 sets.

The MADEP (2007) does not indicate any recommend values for these chemicals. However, the USEPA has drinking water regulations for chloride, fluoride, and sulfate that were used for points of reference. Chloride concentration generally ranged between 115 ppm and 130 ppm. The USEPA has a secondary drinking water regulation of chloride set at 250 ppm (USEPA, 2011b). Fluoride concentrations generally ranged from 0.057 ppm to 0.070 ppm. The USEPA Drinking Water Contaminants maximum contaminant level (MCL) for fluoride is 4.0 ppm (USEPA, 2011b). Sulfate concentrations generally ranged from 14.3 ppm to 17.6 ppm. The EPA secondary drinking water regulation for sulfate is 250 ppm (USEPA, 2011b). For all three of these chemicals, sites C, D, and E were lower than these general ranges on September 28. Data for bromide were highly variable. Sample sets from September 14 and September 19 remained between 0.08 ppm to 0.13 ppm. Bromide concentrations from sample sets from September 28, October 4, and October 13 remained between 0.04 ppm and 0.08 ppm. The bromide concentrations followed the pattern seen for the other three chemicals of dropping on September 28 relative to the remainder of the data.

The Massachusetts Surface Water Quality Standards (MADEP, 2007) do not specify limits for nitrate in Class B water bodies. The USEPA maximum contaminant level for nitrate in drinking water is 10 ppm (USEPA, 2011a). Mattson *et al.* (2004) states that lake ecology can be disrupted at nitrate levels as low as 0.5 ppm to 1.0 ppm. With the exception of four values, all nitrate values were below 0.65 ppm. Nitrate data can be seen in Figure 11. On September 14, site B had a nitrate concentration too low to be detected by ion chromatography. Site A on September 19 and sites C, D, and E on September 28 all had nitrate concentrations greater than 1.0 ppm. On September 28 (12 hour rainfall of 0.39 inches), nitrate concentrations at sites C, D, and E increased. These three values are the maximum recorded nitrate concentrations: 2.022 ppm, 1.335 ppm, and 5.027 ppm, respectively. On this same sampling event, site minimums of 0.041 ppm and 0.097 ppm were recorded for sites A and B, respectively. Sites A and B, being the closest to Lake Quinsigamond and having had similar trends for other water quality parameters, may be more influenced by dilution caused by inflow from the lake rather than by runoff. Data taken on October 30, the nitrate sampling event with the second highest 12 hour rainfall, 0.08 inches, indicate no corresponding increase in nitrate concentrations. The elevation of nitrate concentration at site A on September 19 was not noticeable in any other sites on the same date. On September 19, moving from upstream to downstream, nitrate concentrations decreased at each adjacent site. This indicates that nitrate might either be consumed as it moves through the area of focus or is settling out of the water.

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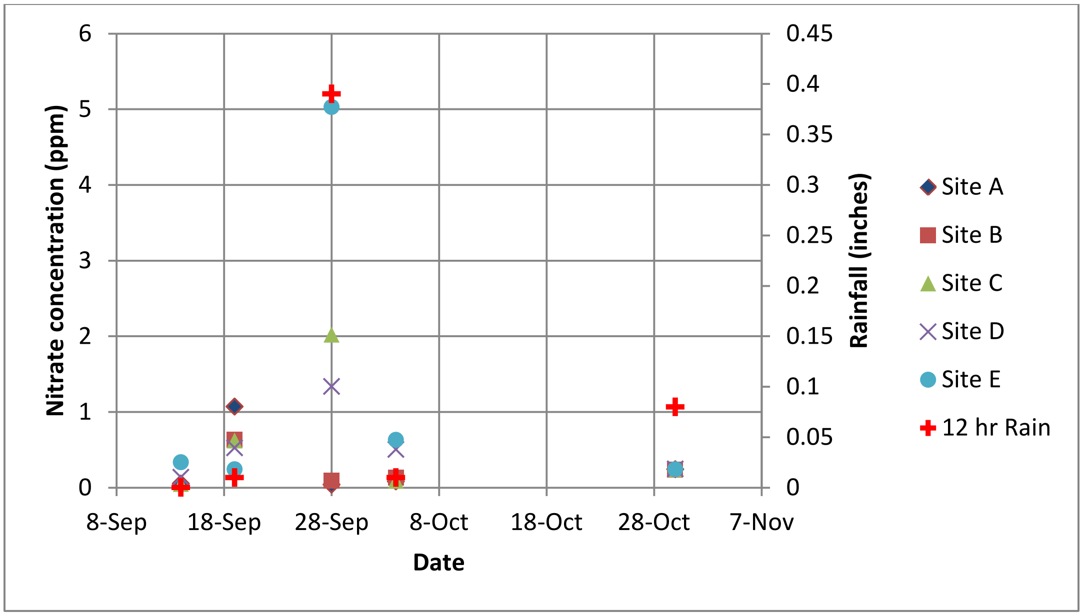

Figure 11: Nitrate by date

Total phosphorus data are shown in Figure 12. The goal for total phosphorus level in Lake Quinsigamond and Flint Pond is 0.012 mg/L, (MADEP, 2002) or 0.012 ppm. Total phosphorus concentrations only met this goal in four samples: site A on September 19, and Site E on October 14 and sites C and E on October 30. The majority of total phosphorus concentrations were below 0.07 ppm, however on September 28 all sites except for site B exceeded this value and on October 8, only site B exceeded 0.012 ppm. Site B on October 4 was also the maximum total phosphorus concentration recorded: 0.243 ppm. Sites A, C, D, and E all had maximum site concentrations of 0.091 ppm, 0.146 ppm, 0.080 ppm, and 0.189 ppm, respectively, on September 28. The second highest 12 hour rainfall event for the total phosphorus data was the October 14 sample set, with a 12 hour rainfall of 0.22 inches. No notable increases in total phosphorus concentrations were seen on this date. This concentration for site E on October 14, 0.004 ppm, was also the lowest recorded total phosphorus concentration.

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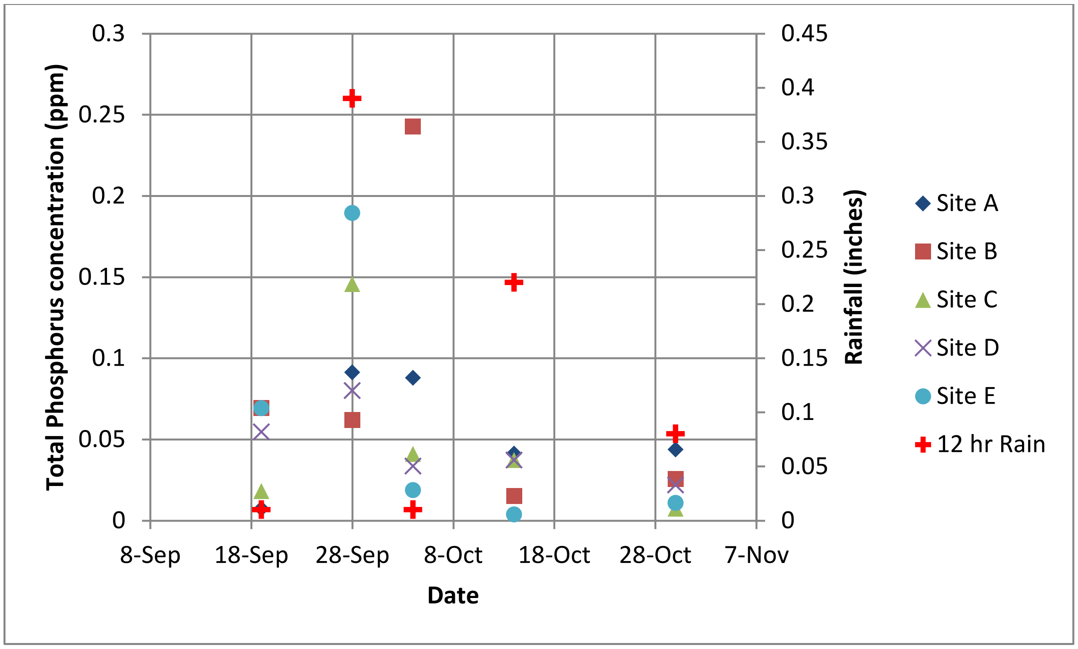

Figure 12: Total phosphorus by date

4.4 Water Quality Correlations

Correlation analysis was conducted to determine relationships between different water quality parameters. The full correlation tables are provided in Appendix B. Positive correlations were found between nitrate and both turbidity and total suspended solids at the 99% confidence level. Total phosphorus was correlated with total suspended solids and turbidity at 95% and 99% confidence levels, respectively. The analysis also revealed that total phosphorus and nitrate were correlated at a 95% confidence level. Thus, the elevated values of total suspended solids and turbidity seem to correspond with elevated values of nitrate and total phosphorus.

Statistical analyses were then conducted to determine the effect of rainfall on water quality. The rainfall parameter was divided into three categories: 12 hour rainfall, 24 hour rainfall, and 48 hour rainfall prior to sampling. The correlation test revealed significant correlations between several water quality parameters and rainfall only for the rainfall amount in the 12 hours prior to sampling. The correlation coefficients for all three rainfall categories are shown in Table 5. Correlation coefficients were compared to critical values of Spearman's rho to determine confidence levels (University of Sussex, 2012). This critical values for Spearman's rho depended on the number of data pairs present. In Table 5, the number of data points collected for each parameter is noted. At any intersection between a column and row, the coefficient of correlation was compared to the critical value of the lower n-value in determining the level of confidence. Statistically significant correlations are highlighted red and green for 95 and 99% confidence levels, respectively.

Table 4: Correlation table for rainfall categories

	48 hr rain (n=30)	*24 hr rain (n=30)*	*12 hr rain (n=30)*
48 hr rain (n=30)	1.000		
24 hr rain (n=30)	0.788	1.000	
12 hr rain (n=30)	-0.201	-0.120	1.000
DO (n=30)	0.358	0.525	-0.110
Temp (n=30)	-0.232	0.150	-0.440
pH (n=30)	0.276	0.214	-0.395
Turbidity (n=30)	-0.101	0.010	0.602
TSS (n=20)	-0.240	0.034	0.556
Bromide (n=25)	-0.193	0.249	-0.371
Chloride (n=25)	0.147	0.083	-0.706
Flouride (n=25)	-0.059	0.143	-0.676
Nitrate (n=24)	-0.085	0.076	0.525
Sulfate (n=25)	0.246	0.375	-0.258
Total Phos (n=25)	-0.340	-0.196	0.287

Inverse correlations were found between 12 hour rainfall and pH, chloride, and fluoride. For pH as rainfall amount increases, the pH value drops. The result of a one-time rainfall pH test yielded a value of 5.99. The USEPA (2012a) states that typical rain pH is approximately 5.6 and the National Atmospheric Deposition Program recorded that Massachusetts rainfall had an average pH of about 5.2 in 2011 (NADP, 2012). Although the one-time rainfall pH measurement was more basic than either of these predictions, it would still be expected to lower the pH of the pond water. The inverse correlations between 12 hour rainfall and fluoride and chloride indicate that instances of rainfall tended to dilute these chemicals in the water.

Positive correlations for 12 hour rain are with turbidity, total suspended solids, and nitrate. The correlations seen between 12 hour rainfall and turbidity and total suspended solids indicate that 12 hour rainfall tended to increase the solids content of the water. The cause of this is likely to be stormwater runoff because water falling directly into the water would contain no significant quantities of solids and the water velocity in a pond and lake is unlikely to cause significant uplift of sediments from the bed beneath the water. However, water running overland would carry solids with it into the water body. Thus, the increase in solids content in the water may indicate the presence of particles in the runoff. Depending on the concentration of the solids in the runoff, a system for mitigation may be necessary. Coulliette and Noble (2008) correlated 24 hour rainfall and 48 hour rainfall to turbidity at 95% and 99% confidence levels, respectively, in the Newport River Estuary in North Carolina. The goal of their research was to assess impacts on the Newport River Estuary of stormwater runoff after a recent increase in nearby impervious surface area.

The correlation between nitrate and 12 hour rainfall indicates that stormwater runoff may carry additional nitrate into the water body. It is unlikely that direct rainfall would cause a direct correlation between the two parameters.

4.5 Analysis of Variance

Single factor analyses of variance were used to test water quality by location in the area of interest for total suspended solids, turbidity, total phosphorus, and nitrate. All samples taken for a given location were grouped together for each of the parameters and tested to determine if the water quality was statistically different by location. Table 6 is a summary table of the results of the ANOVA test by location. The full tables can be found in Appendix B. None of the examined water quality parameters were found to have statistical differences by location, as all of the p-values were above the 0.05 threshold for a 95% confidence level.

Table 5: Summary table for ANOVA by location

Parameter	n (data pairs)	p-value	Statistically different by location?
Total Suspended Solids	20	0.4054	No
Turbidity	30	0.5818	No
Total Phosphorus	25	0.8904	No
Nitrate	24	0.5941	No

Single factor analyses of variance were also used to test total suspended solids, turbidity, total phosphorus, and nitrate for statistical difference by date. The objective of this was to determine if the different rainfall patterns preceeding and on the sampling date influenced the water quality parameters. However, it is likely that other factors such as temperature, sampling technique, and possible unknowns influenced parameter values as well. The summary table for the ANOVA tests by date is shown in Table 7.

Table 6: Summary table for ANOVA by date

Parameter	n (data pairs)	p-value	Statistically different by date?
Total Suspended Solids	20	0.0747	No
Turbidity	30	0.0017	Yes
Total Phosphorus	25	0.0375	Yes
Nitrate	24	0.1064	No

ANOVA results show that turbidity and total phosphorus were statistically different by date. Nitrate and total suspended solids, however, were not found to be statistically different by date. For turbidity, data were available for 5 sample sites on all 6 sampling dates (n=30). For total phosphorus, data were available for all 5 sites on 5 sampling dates (n=25). Table 8 shows the average values on each date for turbidity and total phosphorus.

Table 7: Average values for parameters statistically different by date

Sample Date	Turbidity (ntu)	Total Phosphorus (ppm)
14-Sep	3.28	-
19-Sep	3.79	0.044
28-Sep	20.3	0.11
4-Oct	2.24	0.085
14-Oct	2.37	0.027
30-Oct	3.07	0.022

For both parameters, the average value was greatest for the September 28 sample. This corresponds with the largest 12 hour rain quantity of 0.39 inches. The minimum value for turbidity was recorded on October 4 while the minimum value for total phosphorus was recorded on October 30. As previously mentioned, however, this does not eliminate potential impacts caused by additional factors that vary daily.

4.6 Implications of Data

The data indicate that a number of water quality parameters were elevated in response to the single 12 hour rainfall quantity that was expected to generate significant runoff volumes. The initial abstraction analysis indicated that runoff would likely begin generating from the commercial area after 0.25 inches of rain, though the average initial abstraction over the entire contributing area was 0.56 inches. The 12 hour rainfall for September 28 was 0.39 inches. A 12 hour rainfall in excess of the average initial abstraction of the contributing area was not witnessed. Parameters that were of concern included turbidity, total suspended solids, nitrate, and total phosphorus.

Turbidity appeared to have an elevated value caused by 12 hour rainfall. Although there is no established quantitative Massachusetts standard for turbidity of a surface water, readings on September 28 for sites C, D, and E were approximately 10 times the values recorded for the same sites on other sampling dates. Additionally, turbidity was correlated with 12 hour rainfall at the 99% confidence level. The analysis of variance also distinguished turbidity data to be statistically different by date.

Total suspended solids were correlated with 12 hour rainfall at the 95% confidence level. Sites C, D, and E had total suspended solids concentrations that were more than double the average values taken from the same sites on other sampling dates.

Nitrate was also correlated with 12 hour rainfall at a 95% confidence level. Mattson *et al.* (2004) states that nitrate concentrations can disrupt lake ecology at levels as low as 0.5 ppm to 1.0 ppm. While the majority of nitrate concentrations remained below 0.65 ppm, four data points exceeded this value. Three of these points were recorded on September 28 at sites C, D, and E. The maximum value recorded was over 5 ppm at site E on September 28.

The total phosphorus goal for Lake Quinsigamond and Flint Pond is 0.012 ppm (Durand, 2002). Of the 25 concentrations recorded, only 4 met this goal. While total phosphorus did not correlate with 12 hour rain, analysis of variance determined that the total phosphorus concentrations were statistically different by date. Furthermore, the total phosphorus concentration for September 28 was nearly double the second highest daily average total phosphorus concentration observed.

Based on the sampling data, it is reasonable to state that water quality in the area is of concern and that many of the concerning values observed correspond to a relatively high 12 hour rainfall volume of 0.39 inches, a volume suspected of generating significant volumes of runoff. As such, an appropriate step in addressing this issue was investigating a number of best management practices, or BMPs, that may help to treat runoff that is potentially causing or water quality issues. Specifically, low-cost BMPs capable of reducing solids and nutrients, the primary concerns of the statistical analysis, were the focus of the BMP investigation.

5 Best Management Practices (BMPs)

A USEPA-approved method for improving stormwater runoff water quality before introduction to natural water bodies is through the implementation of post-construction stormwater best management practices (BMPs). BMPs can be used in most settings, whether urban, suburban, or rural. Post-construction stormwater BMPs such as landscaping and lawn care, on-lot treatment, and grassed swales can significantly help to improve water quality. Many BMPs are “inexpensive and easy to implement given limited space and other constraints” (Iowa State University, 2008). The BMP systems that will best serve this project and the potential benefits they can provide in treating stormwater runoff are discussed briefly below. For the Flint Pond area, the contaminants of concern are nutrients and solids. This section includes the results from the BMP ranking system and selection process as well as an overview of and design criteria for the top three BMPs that are recommended to the LQWA.

5.1 BMP Ranking System and Selection

As noted in Chapter 3, a total of 17 BMPs were considered as potentially applicable for implementation near Flint Pond. The first part of the evaluation was to rank each BMP on a scale from one to five in each of the criterion, one being the lowest ranking and five being the highest. Only the MQP Team participated in this part of the evaluation. The result of the first part of the ranking can be found in Table 9.

The next part of the evaluation was the ordering of each criterion. Each criterion were ordered, from 1 to 7, with 1 being the least important and 7 being the most important and each number used only once. Each member of the MQP team as well as each sponsor participated in this part of the evaluation. Once the criteria were ordered, the orderings were divided by the maximum possible total to get a “multiplier”. The orderings and multipliers were calculated twice—once only considering the MQP teams orderings and once considering both the MQP team and the sponsor’s orderings. The results of the second part of ranking can be found in Table 10.

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Table 8: Part 1 of the ranking system: ranking BMPs on a scale of 1-5

E-Effectiveness C-Cost LA- Land Area M-Maintenance	A-Applicability GF-General Feasibility L-Longevity

BMP	Average Rankings for each BMP by the MQP Team						
	E	C	LA	M	A	GF	L
Landscaping/ Lawn Care	3.7	4.0	5.0	2.3	3.7	4.0	3.3
Trash/Debris Management	3.7	3.0	4.3	2.3	3.3	3.0	3.3
Volunteer Monitoring	3.0	3.7	5.0	2.0	3.0	2.3	2.7
Eliminating Curbs and Gutters	3.0	3.7	4.3	3.0	3.0	2.0	3.3
Green Parking	4.3	2.7	2.3	2.0	2.3	2.7	3.0
Grass Swales	4.0	4.3	3.0	2.3	4.0	2.3	3.3
Infiltration Basins	3.3	3.0	2.3	1.7	3.0	2.3	2.3
Infiltration Trench	4.7	2.3	3.7	2.3	3.3	2.7	3.0
Bioretention	4.0	3.0	3.0	2.3	3.7	4.0	3.0
Catch Basin Inserts	3.0	1.0	3.7	2.3	3.0	2.0	3.0
Sand/Organic Filters	3.7	2.7	3.7	2.0	3.7	2.7	3.3
Vegetated Filter Strips	3.3	2.0	1.7	3.3	3.7	2.7	3.3
Dry Detention Ponds	3.0	1.7	2.0	3.0	2.3	1.7	4.3
In-Line Storage	1.3	3.7	4.0	4.0	1.3	1.7	3.7
On-Lot Treatment	3.0	4.0	4.7	3.3	4.3	4.0	2.3
Stormwater Wetland	4.0	1.7	1.7	3.3	3.7	2.3	4.0
Manufactured Products	3.0	1.3	3.7	1.7	3.0	2.0	4.0

Table 9: Part 2 of the ranking system: ordering of criteria

Criteria	Ordering Results					MQP Team Only		MQP Team and Sponsors	
	Adam	Bianca	Sarah	Barbara	Linda	Total	Multiplier	Total	Multiplier
Effectiveness	4	6	5	7	4	15	0.71	26	0.74
Cost	5	4	7	6	7	16	0.76	29	0.83
Land Area	3	2	1	1	1	6	0.29	8	0.23
Maintenance	1	1	6	5	5	8	0.38	18	0.51
Applicability	7	7	4	3	2	18	0.86	23	0.66
General Feasibility	6	5	3	4	6	14	0.67	24	0.69
Longevity	2	3	2	2	3	7	0.33	12	0.34

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The BMPs were ranked in each criterion from 1 to 5 and the criterion was ordered from 1 to 7 to get a multiplier, the average BMP rankings were multiplied by the multiplier to yield a weighted ranking. The weighted rankings for all seven criteria were then added together to give a weighted total for each BMP. This total was then converted to a percentage out of 100. This procedure was completed twice—once with only the MQP teams ordering of the criterion and once with the MQP team and sponsors ordering. A full table of the results can be seen in Appendix F. The results for the weighted totals as well as the percentages for each BMP are shown in Table 11. The top three BMPs with the highest weighted totals were on-lot treatment; landscaping and lawn care; and grass swales, respectively. The top three BMPs remained the same when the weighted totals were calculated both ways—considering only the MQP team's orderings and considering the MQP team and the sponsor's orderings of the criterion.

Table 10: Results of weighted totals

Best Management Practice	**MQP Team**		**MQP Team and Sponsor**	
	Weighted Total	**Percentage**	**Weighted Total**	**Percentage**
On-Lot Treatment	*14.97*	*75*	*14.73*	*74*
Landscaping/ Lawn Care	*14.91*	*74*	*14.69*	*73*
Grass Swales	*13.99*	*70*	*13.82*	*69*
Bioretention	13.70	68	13.53	68
Trash Debris/ Management	13.00	65	12.79	64
Infiltration Trench	12.68	63	12.48	62
Eliminating Curbs and Gutters	12.57	63	12.53	63
Sand/Organic Filters	12.49	62	12.18	61
Volunteer Monitoring	12.15	61	11.93	60
Stormwater Wetland	11.89	59	11.82	59
Vegetated Filter Strips	11.68	58	11.60	58
Green Parking	11.32	56	11.38	57
Infiltration Basins	10.87	54	10.73	54
Manufactured Products	10.08	50	9.74	49
In-Line Storage	9.89	49	10.27	51
Catch Basin Inserts	9.75	49	9.46	47
Dry Detention Ponds	9.67	48	9.76	49

The criteria that were the most influential when calculating the weighted total were effectiveness, cost, applicability, and general feasibility. On-lot treatment ranked highest in the applicability category out of all other BMPs with a 4.33 out of 5. On-lot treatment also tied for highest ranking in general feasibility with a 4 out of 5. On-lot treatment and landscaping and lawn care tied for second highest ranking in cost and also ranked high in applicability with a 3.76

out of 5. Grass swales ranked highest out of all other BMPs in cost with 4.33 out of 5. Swales also ranked second highest for effectiveness with 4 out of 5 and second highest in applicability with 4 out of 5.

The following sections in this chapter discuss the top three BMPs in detail. Information about effectiveness, implementation, planning, limitations, and cost will be presented on landscape and lawn care management and on-lot treatment. For grassed swales, information on application, benefits and limitations, maintenance requirements, design considerations and determining locations are discussed.

5.2 Landscaping and Lawn Care Management

Landscaping and lawn care is a potentially useful best management practice (BMP) that could be implemented in the area surrounding Flint Pond. This is best achieved through homeowner education and outreach. Lawns can produce large amounts of stormwater runoff causing nutrient loading of nearby streams, lakes, and other bodies of water. The runoff from lawns can contain fertilizers and pesticides which can result in the contamination of drinking water sources, which could become a public health concern. In the United States, homeowners maintain approximately 40 million acres of lawn (USEPA, 2013). In urban neighborhoods, it is estimated that "five to seven pounds of pesticide" are used per acre each year (USEPA, 2013). In a survey of Minnesota residents conducted in 1997, only 21 percent of homeowners acknowledged that their lawn and lawn care practices contribute to water quality problems, while at least twice as many noted that their neighbor's lawns and lawn care practices do (USEPA, 2013).

Landscaping and lawn care is a BMP that is applicable in most areas. Lawns and landscaping exist in urban, suburban, and rural settings as well as in various climates and different parts of the country. In a survey conducted in 1999 of the Chesapeake Bay area, approximately 50 percent of homeowners treated their lawns with fertilizer each year (USEPA, 2013). Because fertilizing and other methods of lawn care are common practices across the United States, education of homeowners is an effective way of improving water quality conditions.

5.2.1 Implementation

Targeting the Lawn Care Industry could be useful in educating homeowners and lawn care providers. According to the Environmental Protection Agency, across the United States, 7 – 50 % of homeowners hire lawn care companies to maintain their landscaping and lawns (USEPA, 2013). The EPA suggests investigation into common lawn care practices and educating workers on improvements they can make as a primary tool for the success of BMPs. Lawn care professionals can then make changes to their customers' practices, thereby compounding the effects. The LQWA distributes newsletters, informing the local community about what is going on within the watershed association. The LQWA could reach out to local lawn care companies and offer advertisement space in their newsletter in exchange for that company, or companies, practicing more environmentally-conscious lawn care, which could be regulated by the Massachusetts Department of Environmental Protection.

5.2.2 Planning and Design

When planning and designing landscapes and lawns, important things to consider are sunlight, soil type, and where the area will drain to. The desired amount of maintenance required by the vegetation should also be taken into consideration when determining size and type. It is important to determine which existing plants will remain on the property and which ones will be removed and/or replaced (USEPA, 2013).

5.2.3 Limitations

The biggest limitation is gaining public interest in green lawns care and environmentally friendly practices. Annually, American homeowners spend upwards of $36 million dollars on landscaping and lawn care (USEPA, 2013). Reversing the belief that chemicals are needed in order to achieve beautiful, healthy, green lawns is difficult because current practices are considered faster, easier, and more effective (USEPA, 2013).

5.2.4 Cost

The cost of implementing educational and outreach programs depends on the methods selected to convey the information. Brochures and flyers can range from $0.10 to $0.50 per brochure (USEPA, 2013). However, other methods such as radio or TV could be more expensive endeavors.

5.2.5 Recommendations

The team suggests that the LQWA reaches out to professionals and homeowners through educational workshops. The LQWA could hold workshops that educate the public about the impacts of current lawn care maintenance practices, what changes can be made, and the approximate impacts of these changes. Lawn care professionals could be one of the targeted audiences. An incentive, the team suggests providing a LQWA-issued certificate of completion.

Typical recommendations to homeowners could be encouraging homeowners to be more conscious about the runoff their lawn produces, reduced lawn area, using plants native to that region, and not using chemical fertilizers (USEPA, 2013). Seven basic steps to reducing water used in lawn care are as follows: planning and design, soil improvement, appropriate plant selection, practical lawns, efficient irrigation, effective use of mulches, and appropriate maintenance.

A brochure that can be used by the LQWA for outreach was developed. The purpose of the brochure is to spread awareness of the LQWA and what they do, the current conditions of Lake Quinsigamond and Flint Pond, and what residents of the community can do to help. The brochure that was designed for the LQWA, included in Appendix E).

5.3 On Lot Treatment

On-lot treatment includes a range of practices designed to treat runoff from individual residential lots. The main purpose of on-lot practices is to manage runoff from rooftops, but it can also be used for driveways and sidewalks (USEPA, 2013). Runoff from rooftops in residential areas generally has low concentrations of pollutants when compared to other urban sources, yet is still important in the overall runoff contribution (USEPA, 2013). By managing rooftop runoff effectively, the impervious surface becomes disconnected, which reduces a watershed's overall imperviousness (USEPA, 2013). This is significant because many harmful effects of urbanization on water quality are caused by changes in the hydrological cycle caused by increases in impervious surfaces such as rooftops, which cover the landscape (USEPA, 2013). Most residential lots are able to incorporate on-lot treatment, but options for each site depend on design constraints and preferences of the homeowner. Some of the on-lot treatment BMPs may not be suitable for small lots. Even if on-lot treatment practices were utilized in every household within a watershed, these practices would still only be able to treat a small portion of the water coming off of impervious surfaces (USEPA, 2013).

5.3.1 Application

All forms of on-lot treatment can be applied to most sites with a few exceptions such as very small lots or lots with no landscaping. On-site treatment of residential stormwater has been encouraged by the USEPA but has generally not been a common option that people choose to utilize to meet stormwater requirements. In Denver, Colorado, sites designed with on-lot treatment methods to reduce the “directly connected impervious cover” are allowed to report a lower site impervious area when calculating the storage requirement of stormwater services. Also, in Maryland, there are regulations that allow designers to deduct rooftops that are not connected to the total site impervious cover when they are calculating the required stormwater storage (USEPA, 2013).

5.3.2 Effectiveness

Practices used for on-lot applications can have high pollutant removals (USEPA, 2013). However, there are some data suggesting that there may be an “irreducible concentration” for runoff entering BMPs, specifically infiltration basins and trenches and bioretention areas which are common types of on-lot treatment (Clayton and Schueler, 1996). There was a study done on the water quality that is discharged from these types of BMPs. The study showed that once the pollutant is reduced to a certain concentration, no further removal could be achieved. The limits for natural filtering systems such as a grassed swale were set at 20 mg/L for total suspended solids, 2.0 mg/L for total nitrogen, and 0.15 mg/L for total phosphorus. This “irreducible concentration” may be attributed to pollutants that become trapped in the natural filters over time (Clayton and Schueler, 1996). Additionally, on-lot practices generally help with groundwater recharge, obtained directly though infiltration or by directing runoff to pervious areas (USEPA, 2013).

5.3.3 Cost Consideration

Compared to other stormwater treatment options such as grassed swales and landscape and lawn care, on-lot practices are quite expensive based on cost per unit-area treated. It is somewhat difficult to make this comparison since on-lot practices are usually paid for directly by the homeowner. The cost of some on-lot practices can be reduced or eliminated if homeowners choose to make their own BMP instead of buying a commercial product. Some of the treatment practices, such as rain barrels and on-lot bioretention, may offer additional benefits to the homeowner that could cancel out the cost of applying the practice. Watering plants and lawns is a good example of this (USEPA, 2013).

5.3.4 Types of On-Lot Treatment

There are many different on-lot treatment practices, which can be placed in one of the following categories: practices that infiltrate rooftop runoff; practices that divert runoff to a pervious area; and practices that store runoff for later use. Types of on-lot treatment that will be discussed in this section include infiltration basins and trenches, bioretention areas, and cisterns and barrels. Table 13 shows the different on-lot treatments and their corresponding siting and design considerations, maintenance considerations, effectiveness, and cost considerations.

Table 11: Types of on-lot treatment

On-Lot Treatment	Siting/Design Considerations	Maintenance	Effectiveness	Cost
Infiltration Basin/Trench	Soil Infiltration Rate=0.5 in/hr.; $\leq$20% Clay; $\leq$40% Silt/Clay	Removing sediment and debris; replacing clogged media; removing settlement; oil and grease	TSS 75%; Phosphorus 60-70%; Nitrogen 55-60%; Metals 85-90%; Bacteria 90%	Basins \$2/ft^3; Trenches \$5/ft^3
Bioretention Areas	$\leq$ acre site; 5% Slope; Any type of soil	Mulching; treating trees/shrubs; mowing turf area; watering plants; inspecting and repairing; removing litter, debris, and dead vegetation	Phosphorus 65-87%; Nitrogen 52-67%; Total Phosphorus 49%	Cost=730*(Volume of treated water)$^{0.99}$
Cisterns and Rain Barrels	n/a	Cleaning barrels; checking that barrels are properly sealed	Homeowners must have a use for the water collected	\$300-\$2,500/ barrel

5.3.5 Infiltration Basins and Trenches

An infiltration basin is a shallow trench that is built with very permeable soils and stores stormwater runoff. This practice has high pollutant removal efficiencies and can also assist in recharging the groundwater. An infiltration trench is similar to an infiltration basin but is filled with stone. This practice also collects stormwater runoff and allows the runoff to percolate into the soil. If practices such as infiltration basins and infiltration trenches are used as a form of on-lot treatment, there are certain soil requirements including infiltration rate and soil type. Soils must be permeable enough to ensure that the stormwater can quickly infiltrate in order to reduce the potential for clogging, but not too permeable that stormwater infiltrates too quickly. If the stormwater infiltrates the soil too quickly, the soil may not have time to treat the water sufficiently, creating the potential for groundwater contamination. The infiltration rate of the soil should be between 0.5 and 3 inches per hour. Soils should also have no more than 20 percent clay content, and less than 40 percent silt/clay content. Infiltration areas should be at least ten feet away from the house to prevent the foundation from becoming weakened or a basement from flooding (USEPA, 2013).

Infiltration practices require maintenance such as regular removal of sediment and debris that settle in the pretreatment area. The media may also need to be replaced if it becomes clogged. Settled particles, oil, and grease must be removed from the pretreatment devices and overflow structures must be removed. After five years, it is possible to regain infiltration by providing an extended dry period (USEPA, 2013).

5.3.6 Bioretention Areas

Bioretention areas (or rain gardens) are built into the landscape to allow on-site treatment of runoff. They are shallow depressions that are usually located in parking lot medians or other small areas of vegetation. These types of practices naturally filter the stormwater runoff through the soil. If bioretention areas are used, some considerations include the drainage area the BMP needs to treat, the slopes at the location of the BMP as well as at the drainage area, soil and subsurface conditions, and the depth of the groundwater table. Bioretention areas may be applied on many sites, although they must be applied on small sites consisting of five acres or less. The bioretention area is used to catch and retain most of the stormwater runoff. If rain gardens are used to treat larger areas, the possibility of the garden clogging is higher. It is also challenging to direct flow from a large area to a bioretention area. Relatively shallow slopes, about five percent, work best for bioretention areas. At the site of the bioretention BMP, a sufficient slope is needed to ensure that the water that enters can be connected to the storm drain system. Bioretention areas can be applied to essentially any type of soil. Grassed swales and bioretention cells, such as rain gardens, can be designed to absorb a large amount of water. In other cases, flows sometimes go untreated over the BMPs because the BMP cannot handle the amount of flow (USEPA, 2013).

Maintenance requirements for bioretention areas include mulching void areas, treating trees and shrubs that are unhealthy and mowing turf areas as needed. Once the bioretention area is implemented, the plants must be watered daily for two weeks. Monthly inspections of soil and repairing of eroded areas must be completed as well as the removal of litter and debris. Twice per year, dead and unhealthy vegetation must be removed. Once a year, mulch must be added and tree stakes and wires must be replaced (USEPA, 2013).

5.3.7 Cisterns and Rain Barrels

Cisterns and rain barrels are tanks that catch runoff from a catchment area and store it. Cisterns are used to catch rainwater for commercial and industrial purposes because they can hold significantly more water whereas rain barrels are smaller and are used to catch rainwater in homeowner's yards. Of all the on-lot BMPs, the use of cisterns and rain barrels would have the least amount of site constraints. However, to ensure that the practice is effective, homeowners must have a use for the water collected. The design must also accommodate overflow as well as conditions that would cause the water to freeze. If the homeowner does not perform a lot of landscaping, it may be difficult for them to find uses for the water that is collected in the rain barrels or cisterns (USEPA, 2013).

Maintenance requirements for rain barrels and cisterns are minimal, however, the homeowner must ensure that the hose remains elevated during the winter in order to prevent freezing and cracking. The tank must also be cleaned out at least once a year to prevent further contamination of the rainwater. Finally, rain barrels and cisterns should be checked occasionally to ensure that they are properly sealed to prevent mosquitoes from breeding. Rain barrels are typically around $100 (USEPA, 2013).

5.4 Grassed Swales

Based on the BMP ranking system, grassed swales were one of the three most feasible and effective practices to treat stormwater runoff flowing into Flint Pond. The following sections describe swales and their applicability to the project and also outline the major components that were taken into consideration when proposing a design for a swale.

5.4.1 Description

Grassed swales, also known as grassed swales, are open swales that include vegetation and are designed to manage stormwater runoff by reducing the depth of flow and velocity through the swale and improving its water quality by using infiltration, sedimentation, and filtration (Iowa State University, 2008). The runoff enters the swale through the outside perimeter of the swale where it receives pretreatment from the vegetation along the perimeter. As the stormwater runoff flows along the swale, it is treated by the vegetation, which covers the side slope and swale bottom. The swale then slows the water and allows sedimentation to occur before the water is conveyed to a downstream discharge location (USEPA, 2013). In many sites, grassed swales can be blended into the landscape and drainage infrastructure design (West Virginia DEP, 2002). Figure 13 shows two examples of grassed swales.

Figure 13: Examples of grassed swales

5.4.2 Application

Typically, grassed swales are used to manage runoff from residential sites, parking areas, and along perimeters of paved roadways. Traditionally, grassed swales have been used for stormwater conveyance purposes only. The swale design is capable of conveying a larger storm such as a 10-year or 100-year storm as well as protecting against erosion for smaller, more frequent storms (Iowa State University, 2008). The swales are most effective for low- to moderate-density residential areas with impervious area in the range of 16 – 21 % (City of Roanoke, 2007).

5.4.3 Benefits and Limitations

Some advantages of grassed swales include the management of runoff from impervious surfaces and the removal of sediment and pollutants in order to improve water quality. Swales can also reduce the rate and volume of runoff in areas that are highly impervious, therefore reducing the runoff velocity. The linear design of grassed swales is most efficient when situated next to highways or residential areas. The effectiveness of swales to control large storms is limited. The high loads of sediment can be too much for the system and may cause the swale to become clogged. Therefore, it is suggested by the USEPA that swales be paired with other BMPs for maximum effectiveness. It is common that grass swales are used as a pre-treatment measure for other BMPs that are downstream (Iowa State University, 2008). Lastly, swales are limited to treating runoff from small areas of no more than five acres (USEPA, 2013).

5.4.4 Maintenance Requirements

Grassed swales must be routinely landscaped to maintain a grass height between four and six inches. Swales also need to be inspected annually for erosion problems. Accumulated trash and debris should also be removed during annual inspections. If necessary, maintenance may also include the removal of sediment from the swale (Iowa State University, 2008).

5.4.5 Design Considerations

The two primary considerations when designing a grassed swale include swale capacity and erosion minimization. Runoff velocity should be 1 fps or less during the peak discharge associated with the storm event. Additionally, the total length of a grassed swale should provide a residence time of at least five minutes. To improve water quality treatment, swales should have larger bottoms, lesser slopes, and denser vegetation than basic drainage swales (Iowa State University, 2008).

There are three sets of criteria for designing grassed swales for stormwater treatment, taking larger storms such as 10-year or 100-year into consideration as well as 2-year storms. First, the swale should be designed based on the "treatment principles of small storm hydrology for the water quality storm." Next, the swale design must be checked against a 2-year storm to ensure the conditions in the swale are non-erosive. Finally, the capacity for transportation of the 10-year storm runoff is checked. The design procedure is based on flow rate to determine sizing and uses Manning's equation to calculate velocities and depths, based on the specific geometry and slope of the swale (Iowa State University, 2008).

5.4.6 General Design Criteria

The following design criteria are taken from Iowa's Stormwater Management Manual (2008):

- Grassed swales are used to treat small drainage areas of less than 5 acres. If the practices are applied to areas with larger drainage areas, the flows and volumes of runoff through the swale become too large for filtering and infiltration.
- Grassed swales should be designed on moderately flat slopes of less than 4%. Swale slopes of 1-2% are best.
- Grassed swales can be used on most soils except for impermeable soils. Swales should not be used on soils that have infiltration rates less than 0.3 inches per hour.
- A grass swale should be able to accommodate the peak flow for the water quality design storm (Q_{wq}).
- Velocity of runoff must not be erosive. For the Q_{wq}, the velocity should be less than 1 fps.
- A residence time of 5 minutes is recommended for the water quality peak flow. Reducing the swale slope, increasing the wetted perimeter, or planting denser vegetation, therefore raising the Manning's "n" value, can increase residence time.

- The depth from the bottom of the swale to the groundwater should be at least 2 ft to prevent a moist swale bottom or contamination of groundwater.
- To maximize retention time, check dams may be added within the swale.
- The grass selected should be able to withstand relatively high-velocity flows at the entrances

5.4.7 Shape and Size

It is recommended by the USEPA that the grassed swale should be in the shape of a trapezoid or a parabola, but rectangular and triangular designs may also be used (West Virginia EPA, 2012). It is common that the swale takes the shape of a parabola after the first year of construction due to sedimentation and erosion. It is easier to construct the trapezoidal cross section. Using a trapezoidal shape will also give the swale "more efficient hydraulic configuration" (Iowa State University, 2008).

The length of a grassed swale is usually a function of site drainage constraints; therefore a required length is unnecessary. For treating stormwater however, a minimum residence time of ten minutes is recommended to enable filtering. The minimum length required for water quality treatment grass swales is expressed in Equation 18:

$$L = V * 600 \qquad \text{(Equation 18)}$$

Where, V= Velocity (fps) and 600 is the minimum residence time in seconds (Iowa State University, 2008).

The drainage area, land use, and swale slope are used in determining the length of the grassed swale. Table 14 is a table proving the specific sizing for grassed swales for a one-acre drainage area. The minimum length of a grassed swale is 20 ft.

Table 12: Grassed swale sizing table (Iowa State University, 2008)

Parameter	Upstream Imperviousness					
	≤33%		34-66%		≥67%	
Slope (max=4%)	<2%	>2%	<2%	>2%	<2%	>2%
Grass swale minimum length (ft.)	25	40	30	45	35	50

References such as the Iowa Stormwater Management Manual and the Massachusetts BMP Handbook recommend that the bottom width of a swale using the trapezoidal design should be between two and eight feet (MADEP, 2002). Allowing the width to be two feet leaves room for construction and ensures that there is a filtering surface for the stormwater to be treated. There is an 8-foot maximum to allow maximum filtration by vegetation and therefore preventing flows from eroding the swale (Iowa State University, 2008).

Side slopes should be made as flat as possible to help with pre-treatment of incoming flows and in order to "maximize the swale filtering surface." If the swale is designed with steep slide slopes, there is a potential for erosion from flows being received. A maximum slope of 3:1, or 33%, is recommended (Iowa State University, 2008). Designing a swale with flatter slide slopes also increases the wetted perimeter. The wetted perimeter is the length along the edge of the swale where runoff flowing through the swale contacts the vegetated sides and bottom.

Increasing the wetted perimeter slows down the runoff velocity and also provides more contact time with vegetation to maximize sorption, filtering, and infiltration (USEPA, 2013).

The removal of sediment and pollutants from stormwater is contingent upon the proper design of slope. The slope of the swale itself should not be steeper than 4%. The recommended minimum slope is 1%. The slope must be gradual enough in order for the contact time between the runoff and vegetation to be effective in treating the stormwater (Iowa State University, 2008).

5.4.8 Flow

The roughness coefficient, "n", changes depending on the vegetative cover type and flow depth. If the depth is shallow, and the vegetation height is equal to or greater than the flow depth, the "n" value should be about 0.15. This value is acceptable to use for flow depths four inches or less (Iowa State University, 2008).

When implementing a swale for water quality treatment purposes, the maximum flow depth should be about the same height as the grass. It is likely that higher grass will flatten once runoff begins to flow through it, therefore four inches is recommended as the maximum flow depth. The flow depth for the 2-year and 10-year storms depends on the flow rate and geometry of the swale (Iowa State University, 2008).

To treat stormwater, the maximum flow velocity through the swale should be low to allow enough residence time with the swale. The recommended maximum flow velocity is 1 fps. For the 2-year storm, the maximum flow velocity should be non-erosive and is usually between 4 and 5 fps. The velocity for 10-year storms may be higher because of their low frequency occurrence. For 10-year storms, 7 fps is recommended (West Virginia DEP, 2002).

5.4.9 Cost Considerations

The cost of a grassed swale is unique to each design. Hathaway *et al.* (2007) estimated the cost of constructing grassed swales from approximately \$0.60-\$1.95 per ft^2. These costs are significantly lower than most other BMPs; however, this estimation does not include design costs. Table 12 shows a comparison between the typical costs of grassed swales compared to other BMPs (Hathaway *et al.*, 2007).

5.4.10 Determining Locations

Grassed swales are used to enhance water quality; however, they are not effective for large flows. Grassed swales can serve as an alternative to curbing or installation of a gutter drainage system (Hathaway *et al.*, 2007).

The best location for implementation of grassed swales is in the pathway of runoff from the contributing area. An alternative location for installing the swale could be within drainage catchments along the side or rear of a lot.

When selecting possible locations for the grassed swales, the team considered the following:

- **Soils –** For best results, grassed swales should be used with soils that have moderate to high infiltration rates. The best soil type is silt loam. The soil should also be nutrient rich and hearty, able to support vegetative cover with minimal chemical treatment and maintenance (NVPDC and ESI, 1992). Soil types A and B are located near the swale sites in Figure 14.
- **Topography –** It is important to ensure the selected location is relatively flat. Locations too close to the steep banks of Flint Pond were avoided for this reason. The swale should

be constructed with a slope no greater than 3%. The reduction of slope helps to reduce flow velocities promoting pooling and infiltration instead of runoff.

- **Depth to water table –** One of the greatest challenges of selecting the locations for the grassed swales was ensuring that the swale was at least two feet above the groundwater table. The locations directly around Flint Pond do not meet this requirement, thus locations closer to residential neighborhood and greater depths between the ground surface and the groundwater table were selected. This is important because a high or low water table will hinder the amount of infiltration.
- **Surroundings –** Swales should not be located too close to a building and it is fairly unrealistic to expect private property to be a reasonable location for a grass swale.

This approach seems highly relevant to the Flint Pond area, therefore a more detailed design is developed in section 5.5.

5.5 Grassed Swale Design

Grassed swale design was conducted by combining Manning's equation with a number of recommended and standard characteristics of a grassed swale. Recommended values included hydraulic residence time, width, and shape. The standard value used was for the Manning's coefficient.

5.5.1 Location

The most prominent limitation for potential swale locations within the contributing area was the surroundings. The area is primarily high density residential and is therefore composed primarily of houses, yards, and impervious surfaces such as parking lots or roads. No ideal locations were found for a grassed swale. However, two locations with potential for future consideration were found near the commercial area that is adjacent to Flint Pond. These locations are shown in Figure 14 and labeled as 1 and 2. Swale 1 is a grassy area located between two impervious areas: Route 20 and the Sears Plaza parking lot. The area is about 137 feet long and 13 feet wide. Runoff from the northern side of Route 20 may not flow into to the swale because reworking of roadways is not recommended. Rather, these runoff areas are conservative estimates. Perhaps only runoff coming directly from Route 20 as well as Sears Plaza will be treated via swale 1. The swale 2 location is between Pineland Ave the Sears Plaza parking lot. The available length is only about 90 feet between electrical poles. The average width is about 6 feet. Pineland road is a dirt road and it was observed that runoff flows over the road and therefore, it is estimated that runoff would flow into swale 2.

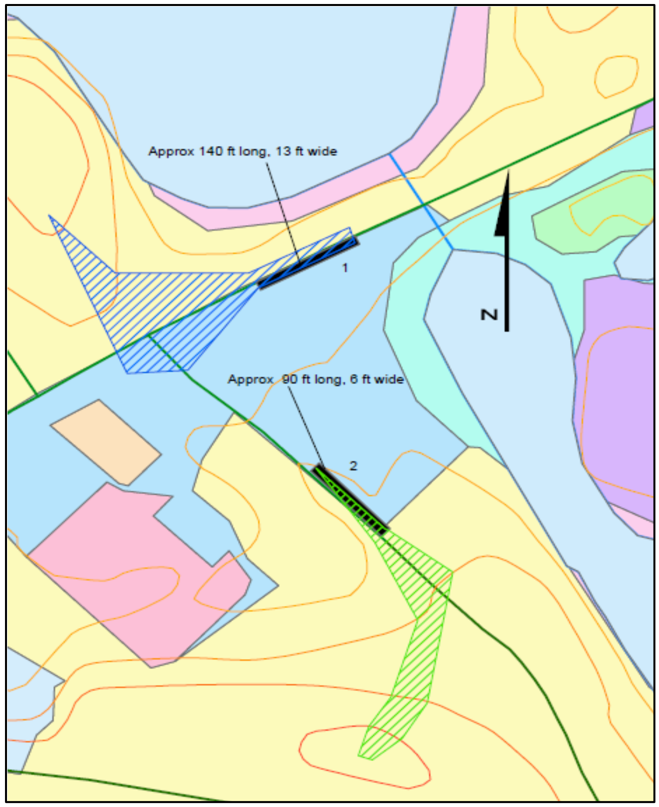

Figure 14: Potential swale locations

5.5.2 Methodology

Manning's equation was used in conjunction with standard grass swale parameters to determine the most effective design for a swale. The version of Manning's equation used in this design is expressed in Equation 19:

$$Q = \frac{1.49}{n} * A * \left(\frac{A}{P}\right)^{\frac{2}{3}} * S^{1/2} \qquad \text{(Equation 19)}$$

Here, Q is equivalent to the volumetric flow rate of water through the grass swale, in cubic feet per second. n represents the Manning coefficient of the swale. A and P represent cross sectional area of flow (ft^2) and wetted perimeter (ft), respectively. S represents the slope of the swale (ft/ft). Some general parameter guidelines for swale design are shown in Table 15.

Table 13: Recommended and standard values for swale parameters (Iowa State University, 2008)

Parameter	Unit	Recommended/Standard Value
Flow Velocity, V	fps	<1
Manning's value, n		0.15 - 0.2
Flow Depth, D	Ft.	0.25 - 0.333
Swale Slope, S	%	1- 3
Bottom width, W	Ft.	2 – 8

Length, L	Ft.	≥20
Residence Time, T_r	Sec.	600
Side Slope, z		3:1

The peak flows expected for each swale after a 1-hr 2 year storm were used to select design parameters. The shape of a trapezoid for the swale was chosen because according to the West Virginia Stormwater Management and Design Guidance Manual, the trapezoidal shape provides the most effective treatment (West Virginia DEP, 2002). Next, Manning's equation was rearranged as seen in Equation 20:

$$\frac{Q*n}{1.49*\sqrt{S}} = A*(\frac{A}{P})^{2/3} \quad \text{(Equation 20)}$$

Next, area and wetted perimeter were expressed in terms of depth. This was done knowing that the swale shape would be trapezoidal and the side slopes would have a 3:1 horizontal-to-vertical ratio. This is shown in Equation 20 and 21.

$$A = D*\left(W+\left(\frac{D}{\tan(0.322)}\right)\right) \quad \text{(Equation 21)}$$

$$P = W+\left(2*\left(\frac{D}{\sin(0.322)}\right)\right) \quad \text{(Equation 22)}$$

Where D represents flow depth (ft), W is the width of the bottom of the swale, A represents the cross sectional area of flow, and P is the wetted perimeter. The value 0.322 is the angle of the side slope in radians for a horizontal-to-vertical of 3:1. Equations 20-22 were programmed into Microsoft Excel. An iterative method was used adjusting D until the left and right sides of Equation 20 were approximately equivalent. The depth that satisfied this equivalency test was the expected flow depth for the design parameters that were input.

The velocity of the flow through the swale was solved using Equation 23, an alternate form of the Manning Equation.

$$V = \frac{1.49}{n}*\left(\frac{A}{P}\right)^{\frac{2}{3}}*\sqrt{S} \quad \text{(Equation 23)}$$

To determine the required length of a swale, the desired hydraulic residence time and the estimated peak flow rate were combined to solve for the required total volume within the swale in Equation 24.

$$Vol = HRT*Q \quad \text{(Equation 24)}$$

Where HRT is the hydraulic residence time and Vol is the total volume of water within the swale at peak flow. The volume was then divided by the cross sectional area to determine the necessary length of the swale. This is shown in Equation 25.

$$L = \frac{Vol}{A} \quad \text{(Equation 25)}$$

Here L is the required length of the swale to satisfy the desired hydraulic residence time. These calculations were repeated for each of the two sites.

5.5.3 Results

Similar to the runoff analysis conducted for the entire land area contributing runoff to the area of interest in Flint Pond, a land and soil analysis was conducted for each swale. The results are shown in Table 16.

The CN values and the land use areas were then used to determine that peak flow of runoff in response to 2 and 10 year storms. The estimated peak flow values for each swale can be found in Table 17.

Table 14: Land use composition for potential swales contributing areas

	Land Use	Soil Type	Area (ft^2)	% Area	CN
Swale1	Commercial	A	6211	24.6	89
		B	2917	11.6	92
	High Density Residential	A	12615	50.0	77
		B	3509	13.9	85
	Total		25252	100.00	
Swale 2	High Density Residential	A	15069	100.00	77
	Total		15069	100.00	

Table 15: 2 and 10 year peak flow rates for swale locations

Swale	2 Year Peak Flow (cfs)	10 Year Peak Flow (cfs)
1	0.22	0.46
2	0.05	0.16

Design parameters then were developed for the two different swales at the selected locations. A summary of these results can be found in Table 18.

Table 16: Summary of Swales and Corresponding Parameters

Swale	Slope (ft/ft)	Width (ft.)	HRT (mins)	Required Length (ft.)	Depth (ft, 2 yr.)	Depth (10 yr)
1	0.020	8	10	143	0.11	0.17
2	0.044	6	10	114	0.043	0.086

For both of the proposed grassed swale locations: the n-value was assumed to be 0.2, desired hydraulic residence time was set to 10 minutes, and the side slope of the swale was set to a 3:1 horizontal-to-vertical ratio. The slopes shown in Table 18 are approximately equivalent to the current surface slopes at the proposed swale locations. This could be modified, however, in the swales. Lower slopes of about 0.01 (or 1%) would result in greater flow depths for a given flow rate and thus decreased length requirements to achieve set hydraulic residence times. Swale 1 was analyzed for the widest recommended swale bottom because the area selected has a width of 13 feet. Swale 2 was analyzed for a 6 foot width because of the limitation caused by the narrower selected area.

Swale 1 had a required length of about 143 feet and a depth of flow caused by a 2 year storm of about 0.11 inches. The natural slope determined from ArcGIS was about 0.02, which is roughly ideal. The calculated required length of the swale exceeds the available area by about 6 feet. Reducing the desired level of treatment by using a hydraulic residence time of 9 minutes would reduce the required length to 128 feet. This would allow the proposed swale to fit within the available area. Additionally, the minimum swale depth would be 0.17 feet to prevent overflow in the case of a 10 year storm.

Swale 2 had a required length of 114 feet and was analyzed for a 6 foot width. The required length is about 24 feet longer than the space available between electrical poles. However, the measured slope of the area is about 0.044 ft/ft. Artificial alteration of this slope when constructing the swale would slow down flowrate and result in a smaller required length. A slope of 0.02 would result in a required length of 90 feet. However, the "exact fit" prediction of a swale 90 feet long and 6 feet wide in an area with the same measurements is unlikely, so compromises might be necessary to reduce the length and width of the swale. The simplest is accepting a lower degree of treatment via a decreased hydraulic residence time. An alternative and costlier solution is to make the area wider by digging up some of the perimeter of the parking lot. The required depth of the swale, in order to satisfy the requirement of not overflowing in response to a 10 year storm, is 0.086 feet. This does not warrant a significant concern. In the case of a 15 or 25 year storm, it is not expected for flooding to occur in either swale because the runoff area delineated is a conservative estimate and it is expected that less runoff will flow through the swales.

These swales would serve the function of providing treatment to runoff from and around Sears Plaza. The swales would be particularly useful for alleviating contaminant loading in runoff resulting from rainfall between 0.25 inches and 0.56 inches, as the primary source of runoff in these cases would be Sears Plaza and the adjacent roads. The locations of the swales were selected specifically with this in mind. Factors to be considered before installation include the implications of property lines and potential downstream impacts of discharges during higher rainfall events.

6 Conclusions and Recommendations

6.1 Conclusions

This project provided assistance for the Lake Quinsigamond Watershed Association (LQWA) by assessing the current water quality conditions of Flint Pond, identifying possible pollutant sources, and suggesting solutions for treating water quality problems. Lake Quinsigamond and Flint Pond are surrounded by residential and commercial development in Shrewsbury, MA. Both water bodies are assets to the community because of their high recreational use. However, both water bodies have been on the Massachusetts DEP list of impaired bodies of water. Flint Pond specifically appears on the list for high turbidity levels. The objectives for this project were to identify potential contaminants and suggest BMPs that could be implemented to address the issue.

The team collected water samples from Flint Pond and tested them for solids, nutrients, and dissolved oxygen. Then, statistical analyses were done to determine correlations between the selected water quality parameters and rainfall. Results showed a correlation between 12-hour rainfall and the following water quality parameters in and near Flint Pond: turbidity, suspended solids, and nutrient levels. Results from the analysis of variances tests indicate statistically significant correlations for turbidity and total phosphorus based on date.

Analysis of the runoff area was also conducted. Land uses within this area included commercial (14.28%), forest (11.16%), high density residential (62.46%), industrial (7.36%), multi-family residential (3.93%) and urban public (0.83%). Additionally, soil types of hydraulic group A (74%) and hydraulic group B (26%) were found within the area. The average initial abstraction of the runoff area was 0.56 inches. All of the recorded 12 hour rainfalls remained below this threshold. However, the commercial land use located adjacent to the area of interest in Flint Pond had initial abstractions of 0.25 inches and 0.17 inches with soils of hydraulic group A and B, respectively. The only 12 hour rainfall observed that exceeded the initial abstraction value (0.25 inches) was September 28. A number of water quality parameters were elevated on this date: turbidity, total suspended solids, nitrate, and total phosphorus. The conclusion is that even at low rainfall values (12 hour rainfall greater than 0.25 inches) significant runoff may be generated from the elevated commercial area adjacent to Flint Pond, which is composed of Sears Plaza as well as Route 20 and Pineland Ave. This runoff may be carrying nutrients and solids into the area of interest observed in Flint Pond.

In order to reduce the nutrient and sediment loadings into Flint Pond, various BMPs can be implemented in the runoff area. BMPs were evaluated based on criteria such as cost, maintenance requirements, space requirements, and longevity. It was determined that on-lot treatment, landscaping and lawn care management, and grassed swales would be the best options based on cost, maintenance requirements, and ease of implementation. Options for on-lot treatment were explored, such as infiltration basins, bioretention areas, and rain barrels. In order to assist homeowners in determining the best on-lot treatment system for their specific needs, the team investigated the cost, design considerations, maintenance, and overall effectiveness of four methods of on-lot treatment. An educational brochure was developed for the LQWA to utilize as a tool to spread awareness about their organization and to educate the public on the importance of responsible landscaping and lawn care. Then, designs for grassed swales at two potential locations near Flint Pond were completed. Potential locations for these swales can be found in Figure 14. The required lengths for 10 minute hydraulic residence times were calculated to be 143 feet for swale 1 located between Route 20 and Sears Plaza and 114 feet for swale 2, located between Sears Plaza and Pineland Avenue. Both of these lengths were in excess of the available areas; however, the lengths could be modified primarily by altering the slope and desired residence time. Before installation of the swales, implications of property lines and potential impacts of discharges during higher rainfall events must be considered.

The implementation of any of the three BMPs will reduce the amount of nutrients and solids that enter Lake Quinsigamond and Flint Pond. Whether through filtration provided by the grassed swale, or by reducing the runoff produced by the homes surrounding the lake through educating homeowners or implementation of on-lot treatment, the BMPs will reduce the nutrients and volume of runoff that enter Flint Pond.

6.2 Recommendations and Future Work

Water samples were collected during wet and dry weather conditions. This allowed the team to compare the results to determine if a correlation existed between the selected parameters and rainfall. Testing took place over two months, September and October. Of the six sampling periods, three were done during wet weather conditions with rainfall quantities over 0.01 inches. The team recommends five additions to this project to better identify the impacts of stormwater runoff around Flint Pond. They are as follows:

- **Year-round data collection:** Year-round data collection could provide a better representation of the impacts of storm events on runoff and the corresponding water quality conditions.
- **Add additional sampling locations:** Extending the sampling and testing into Lake Quinsigamond and the larger portions of Flint Pond could help determine if stormwater runoff affects certain areas more than others.
- **Test nutrients in the sediment:** Testing the nutrient contents in the sediment would help to determine if treatment of the runoff will fix the water quality problems. If during testing it is concluded that the sediment is saturated with nutrients, more aggressive treatment (i.e. dredging) may be required.
- **Investigate the impacts of draw down:** Investigating the impacts of drawing down the lake would help to identify if it is a harmful or helpful measure for weed control and how it impacts water quality. If it does not help with weed control and negatively impacts water quality by reducing flow, this practice should be discontinued.
- **Determine location of storm drain:** Storm drains collect and dispense water that collects on impervious surfaces. The LQWA informed the team that there is a storm drain located between the back of Sear's Plaza (1 Pineland Ave, Shrewsbury, MA 01545) and Flint Pond. Due to the adverse terrain and limited window of good weather, the team was not able to locate it. The town of Shrewsbury should have drawings to assist in locating the storm drain. The purpose of locating the storm drain is to test the quality of the effluent stream leaving the drain. Another benefit to locating the storm drain would be the ability to determine how much water flowing from the drain contributes runoff into Flint Pond.

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Appendix A – Water Quality Parameter Sample Data

Table 17: Rainfall and water quality parameter sampling data

Date	Site	48 hr rain	24 hr rain	12 hr rain	Dissolved Oxygen	Temperature	pH	Turbidity	Total Suspended Solids	Bromide	Chloride	Flouride	Nitrate	Sulfate	Total Phosphorus
14-Sep	A	0	0	0	8.29	24.2	7.80	2.8		0.098	118.856	0.064	0.054	14.676	
14-Sep	B	0	0	0	8.51	23.9	7.60	2.43		0.088	117.689	0.063		14.496	
14-Sep	C	0	0	0	8.30	23.9	7.60	2.46		0.089	116.787	0.062	0.048	14.445	
14-Sep	D	0	0	0	8.75	23.3	7.63	2.56		0.081	118.649	0.063	0.135	14.743	
14-Sep	E	0	0	0	9.05	24.5	7.69	6.15		0.103	125.320	0.065	0.333	16.267	
19-Sep	A	1.43	1.41	0.01	9.45	22.3	7.31	2.89	1.20	0.118	123.550	0.060	1.072	18.158	0.007
19-Sep	B	1.43	1.41	0.01	9.68	22.2	7.29	2.2	5.67	0.084	124.593	0.065	0.636	17.472	0.069
19-Sep	C	1.43	1.41	0.01	9.90	22.0	7.57	2.6	4.00	0.126	124.861	0.063	0.623	17.575	0.018
19-Sep	D	1.43	1.41	0.01	10.05	21.8	7.74	2.76	3.00	0.112	123.059	0.068	0.525	17.167	0.055
19-Sep	E	1.43	1.41	0.01	12.30	22.7	7.76	8.5	8.86	0.093	116.912	0.062	0.244	15.612	0.069
28-Sep	A	0.39	0.39	0.39	9.08	19.1	8.07	2.6	3.17	0.067	119.689	0.062	0.041	14.936	0.091
28-Sep	B	0.39	0.39	0.39	9.07	18.9	6.67	4	2.00	0.062	118.168	0.060	0.097	14.919	0.062
28-Sep	C	0.39	0.39	0.39	9.11	18.6	6.38	29.9	8.29	0.041	73.685	0.050	2.022	11.926	0.146
28-Sep	D	0.39	0.39	0.39	10.10	17.1	6.39	25.6	12.80	0.080	90.439	0.054	1.335	13.007	0.080
28-Sep	E	0.39	0.39	0.39	10.15	15.8	6.26	39.4	15.83		50.547	0.047	5.027	10.142	0.189
4-Oct	A	0.2	0.02	0.01	6.80	18.1	6.95	2.1	2.89	0.137	119.906	0.060	0.083	15.418	0.088
4-Oct	B	0.2	0.02	0.01	6.79	18.1	6.82	2.33	3.00	0.061	120.384	0.060	0.128	15.587	0.243
4-Oct	C	0.2	0.02	0.01	6.90	18.0	6.86	2.05	2.56	0.048	121.920	0.061	0.092	15.659	0.041
4-Oct	D	0.2	0.02	0.01	7.65	17.8	6.84	2.4	2.67	0.062	126.534	0.060	0.506	1.753	0.034
4-Oct	E	0.2	0.02	0.01	7.71	17.8	6.84	2.31	2.33	0.079	127.508	0.061	0.631	17.511	0.019
14-Oct	A	0.22	0.22	0.22	4.35	15.1	7.93	2.45							0.041
14-Oct	B	0.22	0.22	0.22	4.11	14.8	7.1	2.58							0.015
14-Oct	C	0.22	0.22	0.22	4.04	14.7	6.85	2.25							0.037
14-Oct	D	0.22	0.22	0.22	4.12	14.8	6.84	2.38							0.037
14-Oct	E	0.22	0.22	0.22	4.87	15.6	6.94	2.19							0.004
30-Oct	A	1.73	0.6	0.08	7.99	14.4	8.87	2.97	3.50	0.043	117.583	0.058	0.243	14.351	0.044
30-Oct	B	1.73	0.6	0.08	7.89	14.2	7.78	3.15	2.86	0.046	117.877	0.057	0.234	14.391	0.026
30-Oct	C	1.73	0.6	0.08	7.9	14.2	7.51	3	3.86	0.045	117.495	0.058	0.243	14.335	0.007
30-Oct	D	1.73	0.6	0.08	7.84	14.3	6.87	3.2	5.17	0.047	118.119	0.058	0.246	14.545	0.022
30-Oct	E	1.73	0.6	0.08	7.77	14.4	6.74	3.05	3.14	0.045	117.742	0.057	0.244	14.366	0.011

Appendix B – Statistical Analysis Results

Table 18: Critical values of Spearman's rho (University of Sussex, 2012)

n	0.05	0.01
5	1	-
6	0.886	1
7	0.786	0.929
8	0.738	0.881
9	0.683	0.833
10	0.648	0.794
12	0.591	0.777
14	0.544	0.715
16	0.506	0.665
18	0.475	0.625
20	0.45	0.591
22	0.428	0.562
24	0.409	0.537
26	0.392	0.515
28	0.377	0.496
30	0.364	0.478

Table 19: Water quality parameter and rainfall correlations

	48 hr rain (n=30)	*24 hr rain (n=30)*	*12 hr rain (n=30)*	*DO*	*Temp*	*pH*	*Turbidity*	*TSS*	*Bromide*	*Chloride*	*Flouride*	*Nitrate*	*Sulfate*	*Total Phoshorus*
48 hr rain (n=30)	1.000													
24 hr rain (n=30)	0.788	1.000												
12 hr rain (n=30)	-0.201	-0.120	1.000											
DO (n=30)	0.358	0.525	-0.110	1.000										
Temp (n=30)	-0.232	0.150	-0.440	0.571	1.000									
pH (n=30)	0.276	0.214	-0.395	0.128	0.284	1.000								
Turbidity (n=30)	-0.101	0.010	0.602	0.374	-0.098	-0.485	1.000							
TSS (n=20)	-0.240	0.034	0.556	0.586	0.035	-0.381	0.905	1.000						
Bromide (n=25)	-0.193	0.249	-0.371	0.352	0.689	0.151	-0.177	0.060	1.000					
Chloride (n=25)	0.147	0.083	-0.706	-0.305	0.263	0.497	-0.969	-0.853	0.308	1.000				
Flouride (n=25)	-0.059	0.143	-0.676	-0.006	0.646	0.534	-0.800	-0.617	0.590	0.842	1.000			
Nitrate (n=24)	-0.085	0.076	0.525	0.362	-0.178	-0.487	0.887	0.796	-0.003	-0.888	-0.710	1.000		
Sulfate (n=25)	0.246	0.375	-0.258	0.136	0.301	0.308	-0.339	-0.263	0.375	0.347	0.429	-0.303	1.000	
Total Phos (n=25)	-0.340	-0.196	0.287	0.241	0.160	-0.297	0.559	0.520	-0.063	-0.570	-0.373	0.467	-0.155	1

Table 20: Analysis of variance by date, turbidity

14-Sep	19-Sep	28-Sep	4-Oct	14-Oct	30-Oct
2.80	2.89	2.60	2.10	2.45	2.97
2.43	2.20	4.00	2.33	2.58	3.15
2.46	2.60	29.9	2.05	2.25	3.00
2.56	2.76	25.6	2.40	2.38	3.20
6.15	8.50	39.4	2.31	2.19	3.05

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
14-Sep	5	16.40	3.28	2.595
19-Sep	5	18.95	3.79	7.000
28-Sep	5	101.5	20.3	266.010
4-Oct	5	11.19	2.24	0.024
14-Oct	5	11.85	2.37	0.024
30-Oct	5	15.37	3.07	0.010

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1262.569	5	252.514	5.496	0.002	2.621
Within Groups	1102.650	24	45.944			
Total	2365.219	29				

Table 21: Analysis of variance by date, total suspended solids

19-Sep	28-Sep	4-Oct	30-Oct			
1.20	3.17	2.89	3.50			
5.67	2.00	3.00	2.86			
4.00	8.29	2.56	3.86			
3.00	12.8	2.67	5.17			
8.86	15.8	2.33	3.14			
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
19-Sep	5	22.72	4.54	8.431		
28-Sep	5	42.09	8.42	35.743		
4-Oct	5	13.44	2.69	0.070		
30-Oct	5	18.52	3.70	0.809		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	93.996	3	31.332	2.782	0.075	3.239
Within Groups	180.218	16	11.264			
Total	274.213	19				

Table 22: Analysis of variance by date, nitrate

14-Sep	19-Sep	28-Sep	4-Oct	30-Oct		
0.0542	1.07	0.0411	0.0828	0.243		
0.0475	0.636	0.097	0.128	0.234		
0.135	0.623	2.02	0.0921	0.243		
0.333	0.525	1.33	0.506	0.246		
	0.244	5.03	0.631	0.244		
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
14-Sep	4	0.570	0.142	0.018		
19-Sep	5	3.10	0.62	0.089		
28-Sep	5	8.52	1.70	4.157		
4-Oct	5	1.440	0.288	0.068		
30-Oct	5	1.209	0.242	0.000		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.056	4	2.014	2.211	0.106	2.895
Within Groups	17.306	19	0.911			
Total	25.362	23				

Table 23: Analysis of variance by date, total phosphorus

19-Sep	28-Sep	4-Oct	14-Oct	30-Oct		
0.0072	0.091	0.088	0.041	0.044		
0.069	0.062	0.24	0.015	0.026		
0.018	0.15	0.041	0.037	0.0073		
0.055	0.080	0.034	0.037	0.022		
0.069	0.19	0.019	0.0037	0.011		
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
19-Sep	5	0.218	0.044	0.00085		
28-Sep	5	0.57	0.11	0.00277		
4-Oct	5	0.42	0.08	0.00846		
14-Oct	5	0.134	0.027	0.00028		
30-Oct	5	0.109	0.022	0.00021		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.031	4	0.008	3.131	0.037	2.866
Within Groups	0.050	20	0.003			
Total	0.082	24				

Table 24: Analysis of variance by site, turbidity

A	B	C	D	E		
2.80	2.43	2.46	2.56	6.15		
2.89	2.20	2.60	2.76	8.50		
2.60	4.00	29.9	25.6	39.4		
2.10	2.33	2.05	2.40	2.31		
2.45	2.58	2.25	2.38	2.19		
2.97	3.15	3.00	3.20	3.05		
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
A	6	15.81	2.64	0.105		
B	6	16.69	2.78	0.465		
C	6	42.3	7.0	125		
D	6	38.9	6.5	87.8		
E	6	61.6	10.3	210		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	246.496	4	61.624	0.727	0.582	2.759
Within Groups	2118.723	25	84.749			
Total	2365.219	29				

Table 25: Analysis of variance by site, total suspended solids

A	B	C	D	E		
1.20	5.67	4.00	3.00	8.86		
3.17	2.00	8.29	12.8	15.8		
2.89	3.00	2.56	2.67	2.33		
3.50	2.86	3.86	5.17	3.14		
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
A	4	10.76	2.69	1.048		
B	4	13.52	3.38	2.517		
C	4	18.70	4.67	6.218		
D	4	23.6	5.9	22.34		
E	4	30.17	7.54	38.99		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	60.895	4	15.224	1.070	0.405	3.056
Within Groups	213.318	15	14.221			
Total	274.213	19				

Table 26: Analysis of variance by site, nitrate

A	B	C	D	E		
0.0542	0.636	0.0475	0.135	0.333		
1.07	0.0965	0.623	0.525	0.244		
0.0411	0.128	2.02	1.33	5.03		
0.0828	0.234	0.0921	0.506	0.631		
0.243		0.243	0.246	0.244		
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
A	5	1.49	0.30	0.193		
B	4	1.094	0.274	0.0617		
C	5	3.03	0.61	0.679		
D	5	2.75	0.55	0.221		
E	5	6.48	1.30	4.38		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.305	4	0.826	0.712	0.594	2.895
Within Groups	22.058	19	1.161			
Total	25.362	23				

Table 27: Analysis of variance by site, total phosphorus

A	B	C	D	E		
0.0072	0.069	0.018	0.055	0.069		
0.091	0.062	0.15	0.080	0.19		
0.088	0.24	0.041	0.034	0.019		
0.041	0.015	0.037	0.037	0.0037		
0.044	0.026	0.0073	0.022	0.011		
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
A	5	0.271	0.054	0.0012		
B	5	0.41	0.08	0.0085		
C	5	0.25	0.05	0.0031		
D	5	0.227	0.045	0.00051		
E	5	0.29	0.06	0.0060		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004	4	0.001	0.275	0.890	2.866
Within Groups	0.077	20	0.004			
Total	0.082	24				

Appendix C – Swale Parameter Results

Swale 1		2 yr storm							
W (ft)	S (ft/ft)	n	Side Angle	HRT (min)	Q (cfs)	A (ft^2)	P (ft)	D (ft)	Lreq (ft)
8	0.02	0.2	0.322	10	0.22	0.92	8.70	0.111	143
			(Q*n)/(1.49*sqrt(S))		=	A*(A/P)^(2/3)			
			0.209			0.208			
		V=(1.49/n)*((A/P)^(2/3))*sqrt(S)						Vol=HRT*Q	
		V (ft/s) =	0.56					132	

Figure 15: Parameters for swale 1, 2 year storm

Swale 1		10 yr storm							
W (ft)	S (ft/ft)	n	Side Angle	HRT (min)	Q (cfs)	A (ft^2)	P (ft)	D (ft)	Lreq (ft)
8	0.02	0.2	0.322	10	0.46	1.47	9.09	0.173	187
			(Q*n)/(1.49*sqrt(S))		=	A*(A/P)^(2/3)			
			0.437			0.438			
		V=(1.49/n)*((A/P)^(2/3))*sqrt(S)						Vol=HRT*Q	
		V (ft/s) =	0.92					276	

Figure 16: Parameters for swale 1, 10 year storm

Swale 2			2 yr storm						
W (ft)	S (ft/ft)	n	Side Angle	HRT (min)	Q (cfs)	A (ft^2)	P (ft)	D (ft)	Lreq (ft)
6	0.044	0.2	0.322	10	0.05	0.26	6.27	0.043	114
			(Q*n)/(1.49*sqrt(S))		=	A*(A/P)^(2/3)			
			0.032			0.032			
		V=(1.49/n)*((A/P)^(2/3))*sqrt(S)						Vol=HRT*Q	
		V (ft/s) =	0.19					30	

Figure 17: Parameters for swale 2, 2 year storm

Swale 2 Modified Slope			2 yr storm						
W (ft)	S (ft/ft)	n	Side Angle	HRT (min)	Q (cfs)	A (ft^2)	P (ft)	D (ft)	Lreq (ft)
6	0.02	0.2	0.322	10	0.05	0.33	6.34	0.054	90
			(Q*n)/(1.49*sqrt(S))		=	A*(A/P)^(2/3)			
			0.047			0.047			
		V=(1.49/n)*((A/P)^(2/3))*sqrt(S)						Vol=HRT*Q	
		V (ft/s) =	0.24					30	

Figure 18: Parameters for swale 2, 2 year storm, ideal slope

Swale 2		10 yr storm							
W (ft)	S (ft/ft)	n	Side Angle	HRT (min)	Q (cfs)	A (ft^2)	P (ft)	D (ft)	Lreq (ft)
6	0.044	0.2	0.322	10	0.16	0.54	6.54	0.086	179
			(Q*n)/(1.49*sqrt(S))		=	A*(A/P)^(2/3)			
			0.103			0.102			
		V=(1.49/n)*((A/P)^(2/3))*sqrt(S)						Vol=HRT*Q	
		V (ft/s) =	0.41					96	

Figure 19: Parameters for swale 2, 10 year storm

Swale 2 Modified Slope		10 yr storm							
W (ft)	S (ft/ft)	n	Side Angle	HRT (min)	Q (cfs)	A (ft^2)	P (ft)	D (ft)	Lreq (ft)
6	0.02	0.2	0.322	10	0.16	0.69	6.69	0.109	140
			(Q*n)/(1.49*sqrt(S))		=	A*(A/P)^(2/3)			
			0.152			0.152			
		V=(1.49/n)*((A/P)^(2/3))*sqrt(S)						Vol=HRT*Q	
		V (ft/s) =	0.54					96	

Figure 20: Parameters for swale 2, 10 year storm, ideal slope

Appendix D – Sample Calculations

Initial Abstraction

Here, the calculation for initial abstraction is shown for the commercial land use on soil that is hydraulic group B. Bedient *et al.* (2008) lists a CN value of 92 for these conditions. Potential abstraction (S) can be calculated from this.

$$S = \frac{1000}{CN} - 10 = \frac{1000}{92} - 10 = 0.87\ inches$$

Next, initial abstraction is calculated.

$$I_a = 0.87 * 0.2 = 0.17\ inches$$

Peak Runoff

The calculation for runoff is dependent on the storm being analyzed. The storms analyzed for grassed swale design were 2 and 10 year 1-hour storms, with rainfall volumes of 1.25 inches and 1.8 inches, respectively. Here, the calculation for the runoff volume resulting from a 2 year storm from the commercial land use over soil of hydraulic group B within the contributing area to **swale 1** is shown.

$$Q = \frac{(P - I_a)^2}{P + 0.8S} = \frac{(1.25 - 0.17)^2}{1.25 + (0.8 * 0.87)} = 0.60\ inches$$

The inches of runoff were then converted into workable volumes. In this case, the area contributing to **swale 1** that was commercial and hydraulic group B was roughly 2920 ft^2.

$$Volume = 0.60in * \frac{1\ ft}{12\ in} * 2920\ ft^2 = 146\ ft^3$$

Then, for use in the next equation, the cubic volume was converted into acre-inches.

$$Volume = 146\ ft^3 * \frac{1\ acre * in}{3630\ ft^3} = 0.04\ acre * inches$$

Runoff volumes for all contributing areas of the swale were calculated in this manner and summed to determine the total runoff volume. For swale 1**,** this result was 0.16 acre-inches. Next, peak runoff was calculated. This was done by combining this result with measurements taken of the swale contributing area on ArcMap. For swale 1, L was 400 ft and y was 4.75%. Additionally, S was taken as the average potential abstraction within the contributing area, based on area contribution of each S value seen.

$$t_p = \frac{L^{0.8}(S+1)^{0.7}}{1900\sqrt{y}} = \frac{400^{0.8}(2.08+1)^{0.7}}{1900 * \sqrt{4.75}} = 0.06\ hours$$

$$T_R = \frac{D}{2} + t_p = \frac{1}{2} + 0.06 = 0.56\ hours$$

$$Q_p = \frac{2 * Vol}{2.67 T_R} = \frac{2 * 0.16}{2.67 * 0.56} = 0.22\ cfs$$

Swale Length

The calculation for swale length was dependent on preset parameters and assumptions. The desired hydraulic residence time used was 10 minutes, the shape was trapezoidal with a 1:3 vertical:horizontal side slope. The Manning coefficient (n) was also assumed to be 0.2. The length was also dependent on the estimated peak flow for the design storm. The length calculation for swale 3 using a 2 year, 1 hour design storm is shown here, starting with a rearrangement of the Manning Equation.

$$Q_p = \frac{1.49}{n} * A * \left(\frac{A}{P}\right)^{\frac{2}{3}} \sqrt{S}$$

$$\frac{Q_p * n}{1.49 * \sqrt{S}} = A * \left(\frac{A}{P}\right)^{\frac{2}{3}}$$

For swale 3, the slope measured in ArcMap was about 0.02. The left side of the equation was then solved.

$$\frac{Q_p * n}{1.49 * \sqrt{S}} = \frac{0.22 * 0.2}{1.49 * \sqrt{0.02}} = 0.209$$

Cross sectional area (A) and wetted perimeter (P) were then put in terms of flow depth (D) based on the side slope and width of the swale bottom.

$$A = D * (W + \frac{D}{\sin\theta})$$

$$P = W + (2 * \frac{D}{\sin\theta})$$

Where W is the predetermined swale bottom width and θ is the selected side angle, leaving D as the only unknown on the right side of the equation. An iterative method was then used to determine the flow depth (D).

Try D= 0.10 ft

$$A = 0.10 * (8 + \frac{0.10}{\tan 0.322}) = 0.83\ ft^2$$

$$P = 8 + \left(2 * \frac{0.10}{\sin 0.322}\right) = 8.63\ ft$$

$$A * \left(\frac{A}{P}\right)^{\frac{2}{3}} = 0.83 * \left(\frac{0.83}{8.63}\right)^{\frac{2}{3}} = 0.174$$

$$0.174 < 0.209$$

Try D=0.12 ft

$$A = 0.12 * \left(8 + \frac{0.12}{\tan 0.322}\right) = 1.00\ ft^2$$

$$P = 8 + \left(2 * \frac{0.12}{\sin 0.322}\right) = 8.76\ ft$$

$$A * \left(\frac{A}{P}\right)^{\frac{2}{3}} = 1.00 * \left(\frac{1.00}{8.76}\right)^{\frac{2}{3}} = 0.235$$

$$0.235 > 0.209$$

Try D=0.11

$$A = 0.11 * (8 + \frac{0.11}{\tan 0.322}) = 0.92\ ft^2$$

$$P = 8 + \left(2 * \frac{0.11}{\sin 0.322}\right) = 8.68\ ft$$

$$A * \left(\frac{A}{P}\right)^{\frac{2}{3}} = 0.92 * \left(\frac{0.92}{8.68}\right)^{\frac{2}{3}} = 0.206$$

$$0.206 \approx 0.209$$

After determining the approximate flow depth, the desired hydraulic residence time was used to calculate the necessary total volume of water within the swale at peak flow conditions.

$$HRT = \frac{Vol}{Q}$$

$$Vol = HRT * Q = \left(10\ mins * \frac{60s}{1\ mins}\right) * 0.22\ cfs = 132\ ft^3$$

$$Vol = A * L_{req}$$

$$L_{req} = \frac{Vol}{A} = \frac{132ft^3}{0.92ft^2} = 143 \text{ ft}$$

Appendix E – Brochure

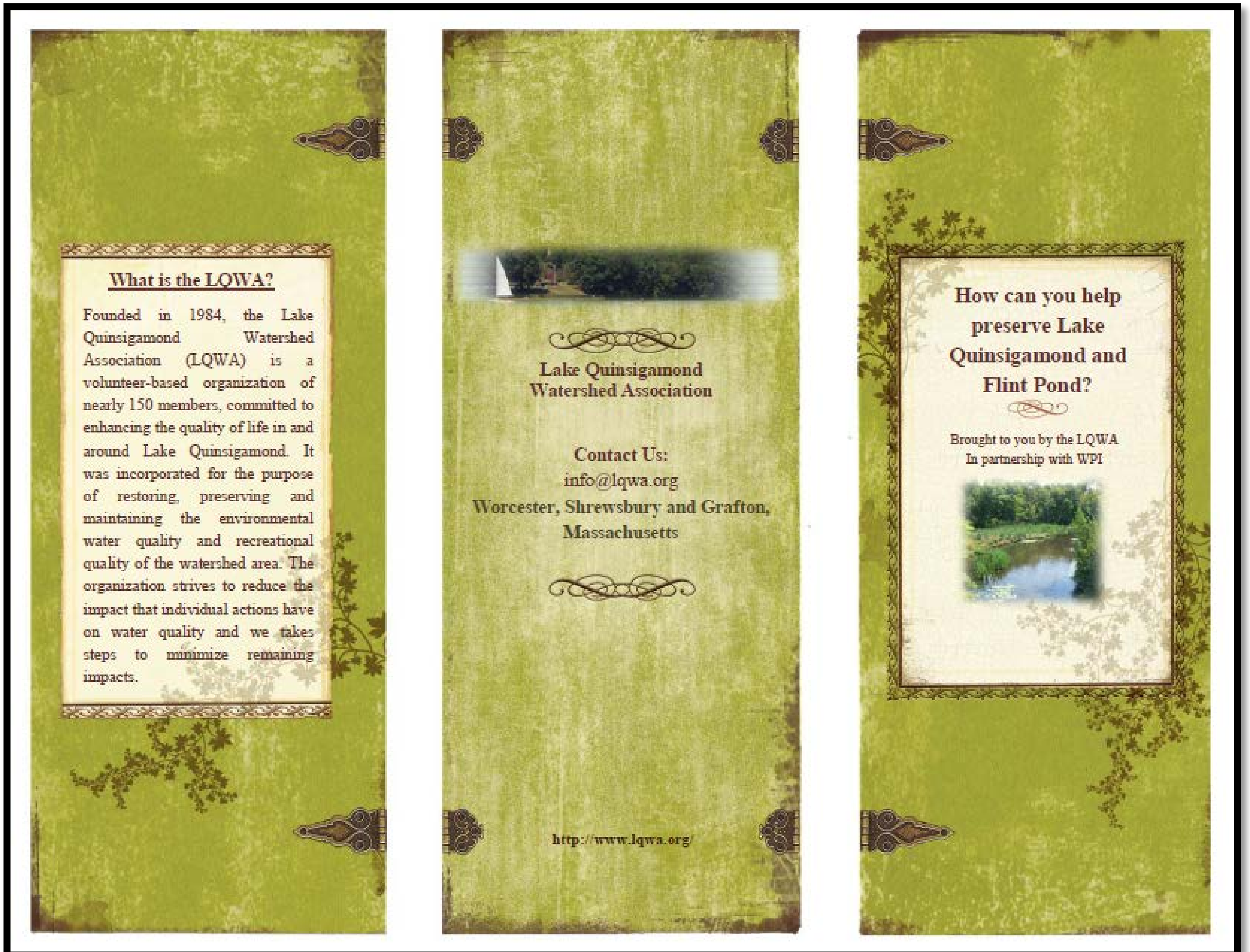
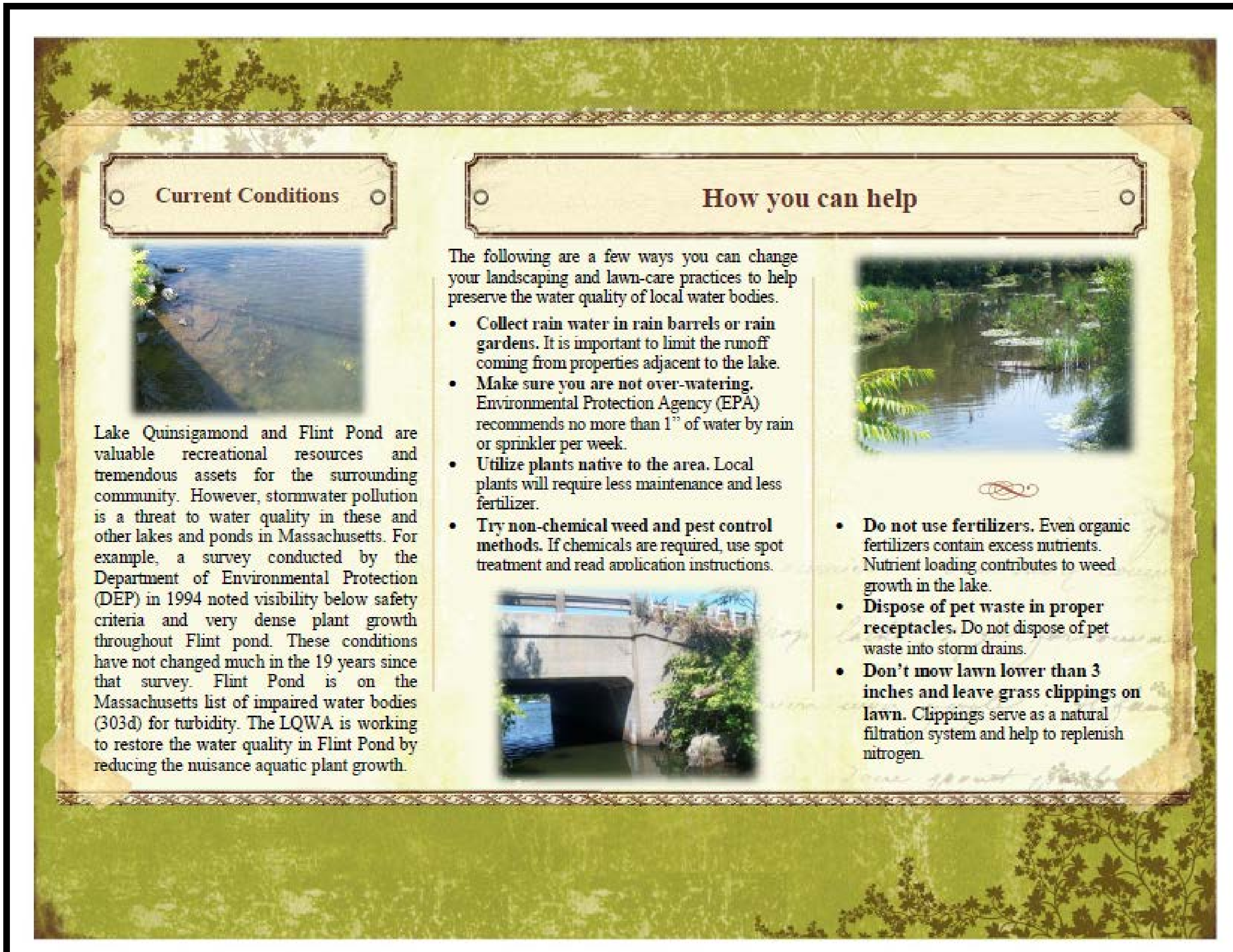


Figure 21: LQWA brochure front



Current Conditions

Lake Quinsigamond and Flint Pond are valuable recreational resources and tremendous assets for the surrounding community. However, stormwater pollution is a threat to water quality in these and other lakes and ponds in Massachusetts. For example, a survey conducted by the Department of Environmental Protection (DEP) in 1994 noted visibility below safety criteria and very dense plant growth throughout Flint pond. These conditions have not changed much in the 19 years since that survey. Flint Pond is on the Massachusetts list of impaired water bodies (303d) for turbidity. The LQWA is working to restore the water quality in Flint Pond by reducing the nuisance aquatic plant growth.

How you can help

The following are a few ways you can change your landscaping and lawn-care practices to help preserve the water quality of local water bodies.

- **Collect rain water in rain barrels or rain gardens.** It is important to limit the runoff coming from properties adjacent to the lake.
- **Make sure you are not over-watering.** Environmental Protection Agency (EPA) recommends no more than 1" of water by rain or sprinkler per week.
- **Utilize plants native to the area.** Local plants will require less maintenance and less fertilizer.
- **Try non-chemical weed and pest control methods.** If chemicals are required, use spot treatment and read application instructions.
- **Do not use fertilizers.** Even organic fertilizers contain excess nutrients. Nutrient loading contributes to weed growth in the lake.
- **Dispose of pet waste in proper receptacles.** Do not dispose of pet waste into storm drains.
- **Don't mow lawn lower than 3 inches and leave grass clippings on lawn.** Clippings serve as a natural filtration system and help to replenish nitrogen.

Figure 22: LQWA brochure back

Appendix F – BMP Ranking Results

Table 28: BMP ranking 1-5: Adam

	Effectiveness	Cost	Land Area	Maintenance	Applicability	General Feasibility	Longevity
Landscaping and Lawn Care	4	3	5	2	3	4	3
Trash and Debris Management	3	3	3	2	4	2	4
Volunteer Monitoring	4	2	5	2	4	2	3
Eliminating Curbs and Gutters	5	5	4	3	4	2	3
Green Parking	5	1	3	1	1	2	3
Grass Swales	5	5	4	3	4	2	3
Infiltration Basin	4	2	3	1	3	3	2
Infiltration Trench	5	2	5	2	2	3	3
Bioretention (Rain Gardens)	4	3	4	2	4	4	3
Catch Basin Inserts	3	1	3	2	3	2	4
Sand and Organic Filters	4	3	4	2	4	2	4
Vegitated Filter Strips	4	3	2	4	4	3	3
Dry Detention Ponds	3	2	2	2	3	2	4
In-Line Storage	1	3	4	4	1	1	4
On-Lot Treatment	3	3	5	3	4	3	3
Stormwater Wetland	4	2	1	3	4	2	3
actured Products for Stormwate	3	1	4	1	3	2	4

Table 29: BMP ranking 1-5: Bianca

	Effectiveness	Cost	Land Area	Maintenance	Applicability	General Feasibility	Longevity
Landscaping and Lawn Care	3	4	5	2	5	5	5
Trash and Debris Management	4	2	5	2	3	4	4
Volunteer Monitoring	2	5	5	1	2	3	3
Eliminating Curbs and Gutters	2	4	5	4	3	2	3
Green Parking	4	4	1	2	4	4	2
Grass Swales	4	4	2	2	5	3	4
Infiltration Basin	4	4	1	2	3	2	3
Infiltration Trench	5	2	3	2	4	2	3
Bioretention (Rain Gardens)	5	3	2	3	4	4	4
Catch Basin Inserts	3	1	5	4	3	2	4
Sand and Organic Filters	4	2	4	3	4	3	4
Vegitated Filter Strips	3	2	2	4	4	3	4
Dry Detention Ponds	3	2	2	3	2	2	5
In-Line Storage	2	4	4	4	2	2	4
On-Lot Treatment	3	5	5	4	5	5	3
Stormwater Wetland	5	2	2	3	4	2	5
ınufactured Products for Stormwater Inl	3	2	5	2	4	2	4

Table 30: BMP ranking 1-5: Sarah

	Effectiveness	Cost	Land Area	Maintenance	Applicability	General Feasibility	Longevity
Landscaping and Lawn Care	4	5	5	3	3	3	2
Trash and Debris Management	4	4	5	3	3	3	2
Volunteer Monitoring	3	4	5	3	3	2	2
Eliminating Curbs and Gutters	3	2	4	2	2	2	4
Green Parking	4	3	3	3	2	2	4
Grass Swales	3	4	3	2	3	2	3
Infiltration Basin	2	3	3	2	3	2	2
Infiltration Trench	4	3	3	3	4	3	3
Bioretention (Rain Gardens)	3	3	3	2	3	4	2
Catch Basin Inserts	3	1	3	1	3	2	1
Sand and Organic Filters	3	3	3	1	3	3	2
Vegitated Filter Strips	3	1	1	2	3	2	3
Dry Detention Ponds	3	1	2	4	2	1	4
In-Line Storage	1	4	4	4	1	2	3
On-Lot Treatment	3	4	4	3	4	4	1
Stormwater Wetland	3	1	2	4	3	3	4
ufactured Products for Stormwater Ir	3	1	2	2	2	2	4

Table 31: Criteria ordering and multipliers

Criteria	Adam	Bianca	Sarah	Barbara	Linda	Total (Team Only)	Multiplier (Team Only)	Total (Team+Sponsor)	Multiplier (Team+Sponsor)
Effectiveness	4	6	5	7	4	15	0.71	26	0.74
Cost	5	4	7	6	7	16	0.76	29	0.83
Land Area	3	2	1	1	1	6	0.29	8	0.23
Maintenance	1	1	6	5	5	8	0.38	18	0.51
Applicability	7	7	4	3	2	18	0.86	23	0.66
General Feasibility	6	5	3	4	6	14	0.67	24	0.69
Longevity	2	3	2	2	3	7	0.33	12	0.34

Table 32: Weighted total sand percentage: MQP team only

	Effectiveness	Cost	Land Area	Maintenance	Applicability	General Feasibility	Longevity	Total	%
Landscaping and Lawn Care	2.60	3.04	1.45	0.89	3.15	2.68	1.1	14.91	0.74
Trash and Debris Management	2.60	2.28	1.26	0.89	2.87	2.01	1.1	13.00	0.65
Volunteer Monitoring	2.13	2.79	1.45	0.76	2.58	1.56	0.88	12.15	0.61
Eliminating Curbs and Gutters	2.37	2.79	1.26	1.14	2.58	1.34	1.1	12.57	0.63
Green Parking	3.08	2.03	0.68	0.76	2.01	1.79	0.99	11.32	0.56
Grass Swales	2.84	3.29	0.87	0.89	3.44	1.56	1.1	13.99	0.70
Infiltration Basin	2.37	2.28	0.68	0.63	2.58	1.56	0.77	10.87	0.54
Infiltration Trench	3.31	1.77	1.06	0.89	2.87	1.79	0.99	12.68	0.63
Bioretention (Rain Gardens)	2.84	2.28	0.87	0.89	3.15	2.68	0.99	13.70	0.68
Catch Basin Inserts	2.13	0.76	1.06	0.89	2.58	1.34	0.99	9.75	0.49
Sand and Organic Filters	2.60	2.03	1.06	0.76	3.15	1.79	1.1	12.49	0.62
Vegitated Filter Strips	2.37	1.52	0.48	1.27	3.15	1.79	1.1	11.68	0.58
Dry Detention Ponds	2.13	1.27	0.58	1.14	2.01	1.12	1.43	9.67	0.48
In-Line Storage	0.95	2.79	1.16	1.52	1.15	1.12	1.21	9.89	0.49
On-Lot Treatment	2.13	3.04	1.35	1.27	3.73	2.68	0.77	14.97	0.75
Stormwater Wetland	2.84	1.27	0.48	1.27	3.15	1.56	1.32	11.89	0.59
Manufactured Products for Stormwater Inlet:	2.13	1.01	1.06	0.63	2.58	1.34	1.32	10.08	0.50

Table 33: Weighted totals and percentages: MQP team and sponsors

	Effectiveness	Cost	Land Area	Maintenance	Applicability	General Feasibility	Longevity	Total	%
Landscaping and Lawn Care	2.71	3.32	1.05	1.28	2.24	2.76	1.17	14.53	0.73
Trash and Debris Management	2.71	2.49	0.91	1.28	2.03	2.07	1.17	12.67	0.63
Volunteer Monitoring	2.22	3.04	1.05	1.10	1.83	1.61	0.93	11.79	0.59
Eliminating Curbs and Gutters	2.47	3.04	0.91	1.65	1.83	1.38	1.17	12.45	0.62
Green Parking	3.21	2.21	0.49	1.10	1.42	1.84	1.05	11.32	0.57
Grass Swales	2.96	3.60	0.63	1.28	2.44	1.61	1.17	13.69	0.68
Infiltration Basin	2.47	2.49	0.49	0.92	1.83	1.61	0.82	10.62	0.53
Infiltration Trench	3.45	1.94	0.77	1.28	2.03	1.84	1.05	12.37	0.62
Bioretention (Rain Gardens)	2.96	2.49	0.63	1.28	2.24	2.76	1.05	13.41	0.67
Catch Basin Inserts	2.22	0.83	0.77	1.28	1.83	1.38	1.05	9.36	0.47
Sand and Organic Filters	2.71	2.21	0.77	1.10	2.24	1.84	1.17	12.04	0.60
Vegitated Filter Strips	2.47	1.66	0.35	1.83	2.24	1.84	1.17	11.55	0.58
Dry Detention Ponds	2.22	1.38	0.42	1.65	1.42	1.15	1.52	9.76	0.49
In-Line Storage	0.99	3.04	0.84	2.20	0.81	1.15	1.28	10.32	0.52
On-Lot Treatment	2.22	3.32	0.98	1.83	2.64	2.76	0.82	14.57	0.73
Stormwater Wetland	2.96	1.38	0.35	1.83	2.24	1.61	1.40	11.77	0.59
Manufactured Products for Stormwater	2.22	1.11	0.77	0.92	1.83	1.38	1.40	9.62	0.48