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Control of Total Suspended Solids and Phosphorous from Stormwater in Lake Wickaboag

A Major Qualifying Project

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of

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1. Lake Wickaboag, West Brookfield
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Abstract

This project evaluated stormwater inputs to Lake Wickaboag, a 320 acre recreational lake in West Brookfield, Massachusetts. Total suspended solids and phosphorous in runoff were measured at three sites around the lake and the most problematic site identified. Best management practices for reducing these contaminant inputs were compared based on effectiveness, applicability and cost. An infiltration system was designed to control stormwater at the site of concern.

Acknowledgements

We would like to take this time to thank all of the individuals who have helped our group throughout this project. First we would like to thank our advisor Jeanine Plummer for her guidance and support since the beginning of this project. Secondly we would like to thank the president of the Lake Wickaboag Preservation Association, Al Collings, for guiding our group in our site selection and for providing previous study data. Third we would like to thank WPI laboratory manager Don Pellegrino, for helping our group with laboratory testing, and Professor Suzanne LePage for providing us with all the necessary rainfall data. We would also like to thank Ryan Gauvin of New England Environmental Design for his guidance on the AutoCAD drawings. Lastly we would like to thank West Brookfield resident Bill Jenkins for taking to time to meet and provide the group with a history of Lake Wickaboag.

Capstone Design Statement

This Major Qualifying Project evaluated stormwater inputs of phosphorous and total suspended solids to Lake Wickaboag in West Brookfield, MA. The town has taken action previously to improve the lake water quality by installing an infiltrator system at a site on the eastern part of the lake. The town is looking to do more by installing a Best Management Practice (BMP) at another site around the lake that is contributing to the contaminant loads.

The first objective of this MQP was to determine where pollutants were entering the lake. In order to determine sampling sites, locations around the lake were ranked based on drainage area, approximate runoff, soil group, and phosphorous load. Then, water was collected at the priority sites during storm events in the fall of 2010. The site with the highest phosphorus concentration was chosen as a potential site for a BMP application. BMPs were ranked based on four criteria, including pollutant removal efficiencies, design considerations, and maintenance concerns. An infiltration system was the most suitable BMP for this site. A preliminary design was completed for this system.

The infiltration system can be fit on the site and can be tailored to connect to an existing drainage pipe. The system when fully operational should be able to reduce the concentrations of total suspended solids and phosphorus flowing through the pipe by 60 to 80 percent. Additional work that is needed prior to final design is to determine the total runoff storage needs and conduct a survey of the land area.

This project fulfilled the requirements of a major capstone design experience. First, the project included environmental components as well as health and safety concerns, as the primary topic was identification and control of stormwater pollutants in a surface water body used for recreational activities. Second, this project considered sustainability as part of the design by selecting a low maintenance infiltration system that will reduce pollutants in the lake. Lastly, manufacturability and economics were taken into consideration by developing materials and cost estimation tables for the town to apply when implementing the final BMP.

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1 Introduction

Lake Wickaboag, located in West Brookfield, Massachusetts, is home to many residents and is an asset to the town. It has been a summer staple for boating and fishing, but recently there have been issues with the water quality in the lake. In particular, there have been increasing phosphorous concentrations, which promote algal growth, and sediment loadings which have caused a decrease in depth. The town has already taken action by installing an infiltration system at a site near the lake, but the town is looking to do more to improve the quality of the lake by means of additional stormwater control options.

The purpose of this Major Qualifying Project was to identify locations where stormwater was contributing phosphorus and total suspended solids to the lake, and design a Best Management Practice (BMP) that would help improve the lake water quality by reducing these inputs.

Three sites around the lake were selected and water samples were collected from these sites during storm events in the fall of 2010. The samples were tested for phosphorous and total suspended solids. The site that contained the highest level of phosphorous was the proposed site for a BMP installation. Several different BMPs were researched and were compared through a BMP criteria matrix that included design considerations and pollutant efficiency removal. Finally, a BMP was selected for the site and a preliminary design completed.

The following chapters describe issues surrounding the lake, methods used to investigate the concerns, and a final design recommendation.

2 Background

This section of the report contains background research on water quality characteristics and constituents of concern in Lake Wickaboag. A brief history and overview of the lake and people involved in the restoration of the lake's quality is also provided. Projects that have taken place in the lake area are discussed as well as Best Management Practices (BMPs) that can be implemented in the area of Lake Wickaboag. All the research conducted was required to meet the project goals, which are outlined in this report section.

2.1 Lake Wickaboag

The following sections provide background information on Lake Wickaboag, a 320 acre recreational lake located in West Brookfield, MA. Figure 1 provides a map of the lake.

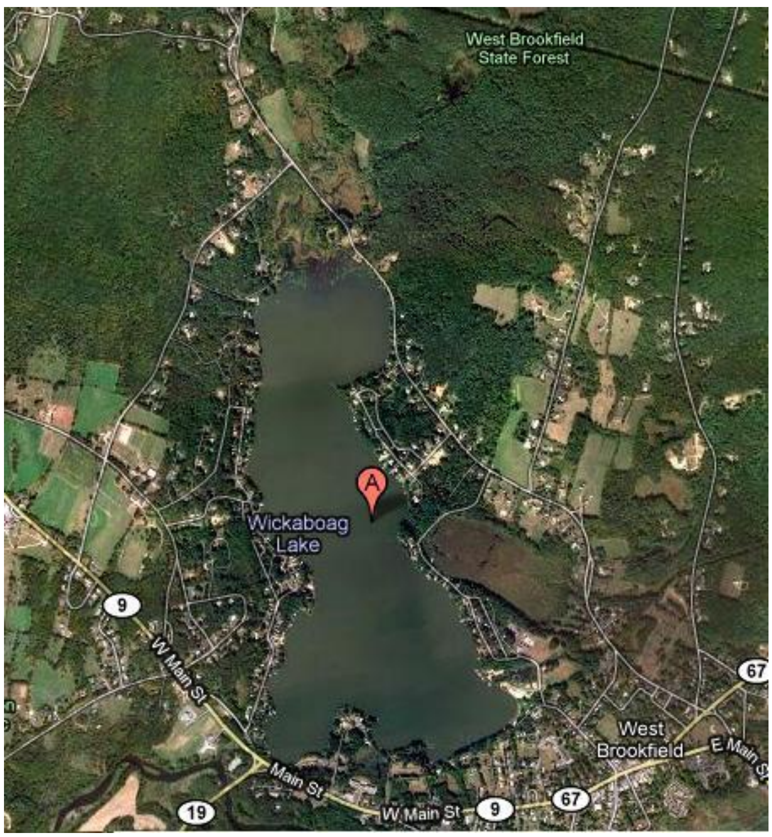

Figure 1: Map of Lake Wickaboag, West Brookfield, MA (Google Maps, 2010)

2.1.1 <u>History and Characteristics of Lake Wickaboag</u>

Lake Wickaboag is a dammed lake located in West Brookfield, Massachusetts. The lake is an asset to the town of West Brookfield and is full of history. Over the past 50 years, the lake has expanded to over 300 acres and today the lake has an area of 320 acres. Prior to 1900, Lake Wickaboag was used as a source for ice harvesting for refrigeration. The ice was shaved from the lake and was shipped to Boston. During the Civil War, 1861 to 1865, it was rumored that the area surrounding Lake Wickaboag was used to mine iron and the iron that was discovered was used to make cannonballs which were forged at a housing unit located near Sucker Brook, northeast of the pond. From 1900 to 1910, there were about six to eight seasonal cottages on the lake. A trolley lot was housed on the western part of the lake from 1904 - 1906. This area was converted to year round and seasonal housing, about 200 housing lots, around 1920. The southeast corner of the lake used to be a swampy area, but was developed around 1948. The depth of the lake has decreased, especially in the north side of the lake, over a time frame of 30 years due to sediment inflows from storm water. One possible cause of the sediment buildup could be from runoff of road sand that is applied during the winter (Jenkins, 2010).

Today, the lake is comprised of around 90% year round housing and is primarily used for recreation including fishing, swimming and most popular, boating. The lake has a maximum depth of 11 feet with an average depth of seven feet. A town beach located near the southeast perimeter of the lake allows boat access to the lake. A public boat ramp in the center of town near the lake provides parking for seven boat trailers (Lake Wickaboag Preservation Association, 2010). As of the 2000 Census, the town of West Brookfield's population was 3,804 with 1,534 total housing units. Approximately 220 of these housing units are located on Lake Wickaboag. The lake has the first million dollar property in West Brookfield and around one third of the town's taxes are generated from residents living on the lake.

2.1.2 Sediment Buildup

The depth of Lake Wickaboag has decreased due to sediments from various sources. The loss of depth has been an issue since 1975 (Apex Companies, LLC, 2010). Shallow water has a negative impact on recreational activities practiced on Lake Wickaboag. Fishing, boating, and swimming have become practically impossible in the north end of the lake where the sediment has decreased the lake depth to less than a foot in some places. It was estimated that the lake has been filled by 4 feet of material across more than 75 acres of the north cove (Apex Companies, LLC, 2010). This amounts to more than 500,000 cubic yards of sediment. ESS Group Inc. conducted stormwater testing for sediment at Lake Wickaboag from 2004-2007. They concluded that the sediments enter the lake from non-point source pollution (ESS Group Inc., 2004).

2.1.3 Dredging Project

In June 2011, the town of West Brookfield will begin their plan to deepen the north end of Lake Wickaboag in order to improve the water quality. Sediment buildup along the bottom of the lake not only decreases the lake depth but also contributes to high phosphorous levels (Apex Companies, LLC, 2010). Hydraulic dredging will be used to complete the ultimate goal of removing 200,000 to 500,000 cubic yards of sediment. Re-contouring of the lake bottom will also take place after the dredging.

The Town of West Brookfield along with the Lake Wickaboag Preservation Association, formed in 1990, raised $23,000 from private sources toward the conceptual design of the project. West Brookfield continues to reach out for private funds and has begun to look into grants and donations to back the construction costs to cover the $2.5 to $4.0 million needed (Apex Companies, LLC, 2010). The grants and specific funding sources for the project are not known at this time. According to the dredging prospectus, the conceptual design of the project, including sampling, surveying and design, concluded October 2010. The permitting portion is

projected to finish in April 2011 while the construction or actual dredging will occur from June 2011 to June 2012 (Apex Companies, LLC, 2010).
Dredging is the first step in the process of restoring Lake Wickaboag. Preventing future sediment inflows is also necessary. Therefore, a forebay settling basin will be constructed at the north end of the lake. The basin will trap sediment in stormwater runoff coming from Mill Brook before it reaches the lake, thus reducing sediment loading in the north end of the lake (Department of Conservation and Recreation, 2010). The dredging project and forebay installation are expected to result in the following benefits:

- Improved water quality;
- Improved water clarity;
- Removal of nutrient-rich sediments;
- Re-establishment of habitat;
- Eradication of nuisance weeds and removal of invasive species; and
- Reversal of eutrophic conditions (Apex Companies, LLC, 2010).

The town of West Brookfield is hopeful that the project will enhance recreational opportunities, improve the fish and wildlife populations, and reduce the weed growth to create a sustainable aquatic system. The project is expected to increase property values, in turn creating better tax revenues for the town (Apex Companies, LLC, 2010).

2.1.4 Parties Involved with Lake Wickaboag

The Town of West Brookfield is collaborating with multiple groups in the effort to improve Lake Wickaboag. These groups are the Board of Health (BOH), Massachusetts Department of Environmental Protection (DEP) and the Stormwater Authority. The BOH began efforts to improve water quality in the lake in 1975 when they collaborated with the West Brookfield Board of Selectmen to encourage lake weed and algae awareness. The Board of Health is an elected board and has been active in communicating with residents of the lake and enforcing the Massachusetts Title V septic requirements, to prevent leaching of pollutants from household wastewater into the lake. The Lake Wickaboag Preservation Association compiles a newsletter twice a year to inform residents and interested parties about the lake and its condition.

In the winter of 2009, the West Brookfield Board of Health was notified about the availability of federal stimulus money for remediating Lake Wickaboag (Collings, 2010). The BOH identified a dredging project at Lake Wickaboag and applied for federal funds. Dredging would help manage weed and algae growth (Collings, 2010). The West Brookfield Board of Selectmen put the Board of Health in charge of completing a dredging plan (Collings, 2010). The BOH, Lake Wickaboag Preservation Society, the West Brookfield Planning Board, and the West Brookfield Conservation Commission started the West Brookfield Dredging Committee. This committee was started in order to meet strict deadlines set by the government for the dredging project preparation (Apex Companies, LLC, 2010). The Stormwater Authority was also incorporated in this committee. Their role is to locate non-point pollution sources and recommend options for reducing these pollutant inputs. The Board of Health maintains authority to make decisions that affect the lake, yet it is ultimately the residents' vote that matters on this topic (Collings, 2010).

The dredging project in West Brookfield had three firms respond to the West Brookfield Dredging Committees' request for proposal (RFP) in order to help with the dredging plan (Collings, 2010). APEX Companies was chosen by the BOH to help the Dredging Committee with the dredging plan.

The Department of Environmental Protection plays an important role to Lake Wickaboag. The DEP sets criteria that specify the maximum levels for certain contaminants in order for the lake to be safe for human recreational use. The specified contaminant levels are measured when entering the lake as well as the concentration of these chemicals in the lake. Some of the chemicals found in Lake Wickaboag include nickel, zinc and extractable petroleum hydrocarbons (Apex Companies, LLC, 2010). In many areas of the lake, borings with these chemicals exceeded the DEP limits, making it crucial for action to be taken considering the human presence around the lake.

2.2 Project Goals

The objective of this MQP was to identify potential pollutant sources to Lake Wickaboag and develop strategies to mitigate these inputs. Specific tasks included:

- Determining high priority sites for potential stormwater pollutant loadings based on previously compiled data.
- Sampling stormwater flows and testing for phosphorus and total suspended solids at priority sites around Lake Wickaboag.
- Evaluating Best Management Practices (BMPs) for priority sites considering location, cost, type and potential to reduce sediment and phosphorus inflows.

In order to accomplish these tasks, background info on non-point source pollution and BMPs was compiled, as discussed in the following sections.

2.3 Non-Point Source Pollution

Non-point source pollution is pollution that affects a water body from a variety of sources such as runoff, groundwater plumes, debris carried in the wind, or any other source that is not concentrated or identified. Excess sediment and pollutants can cause changes in hydrology and water quality which can result in erosion, increased sediment buildup, flooding, and disruption of aquatic habitats (U.S. EPA, 2006). It is difficult to establish solutions to non-point source pollution because the actual source of the pollution cannot be established. Contaminated stormwater washed off parking lots, roads, highways, and lawns is called urban runoff and is often considered non-point source pollution even if it drains into a single pipe that drains into a water body. This runoff is believed to be a part of the sedimentation problems at Lake Wickaboag as well as the rivers and streams that enter the lake carrying potential pollutants (ESS Group Inc., 2004).

In Lake Wickaboag, the contaminants that are of concern include sediment and phosphorus from non-point source pollution, algal growth as a result of excess phosphorus and copper, which is applied to the lake to control algae. The amount of phosphorus and copper present in the lake exceeds Environmental Protection Agency (EPA) standards.

2.3.1 Phosphorus

Phosphorus is an element that is an essential mineral for many forms of life. Phosphorus is usually a limiting factor to the growth of many organisms, especially plants in aquatic ecosystems. There are two forms of phosphorus: total and dissolved. Total phosphorus includes dissolved and particulate forms of the nutrient, while dissolved phosphorus is the measure of phosphorus remaining in the water after it has passed through a filter of a chosen diameter pore size. Dissolved phosphorus is immediately available for use by plants and algae, while particulate phosphorus may slowly release dissolved phosphorus, or could settle and be retained by sediment (ESS Group Inc., 2004).

Phosphorus typically enters into water bodies through non-point source pollution, but it can also enter into larger water bodies through rivers or streams. In some cases, point source pollution may occur that transmits phosphorus to a water body such as a leaking sewer pipe. Phosphorus is a common contaminant transported in stormwater runoff, from lawns where fertilizers have been applied.

The Massachusetts DEP specifies a Total Maximum Daily Load (TMDL) of phosphorous for every lake in Massachusetts. The TMDL is a regulatory term in the U.S. Clean Water Act (CWA), describing the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. The TMDL for phosphorous in Lake Wickaboag is 729 kg/yr (MA DEP, 2002), however the actual loading is 1983 kg/yr. In a 2005 study by ESS Group, it was estimated that 98% of the phosphorus enters the lake from stormwater runoff (ESS Group Inc, 2004). High levels of dissolved phosphorus are available to algae and other vegetation. These high levels of phosphorus contribute to recurring algae blooms in the lake. Algae blooms in Lake Wickaboag have been an issue due to the excessive amounts of total and dissolved phosphorus that exceed the 0.02 mg/L acceptable and the 0.05 mg/L critical EPA recommended criteria for the concentration in the lake. Actual phosphorus values ranged from 0.07-0.15 mg/L at the sites tested (ESS Group Inc, 2004). It was recommended by ESS Group Inc. in 2007 that further phosphorus testing at stormwater runoff sites be conducted to determine where phosphorus in the lake is coming from.

2.3.2 Algae

An excess of phosphorus in water bodies can lead to rapid growth of aquatic species such as algae and phytoplankton. This rapid growth can cause several problems in a water body. Oxygen needed by fish and other species in the lake may be reduced and the water could become cloudy. The value of the lake for recreational activities such as swimming, boating, and fishing is diminished. The high levels of phosphorus have led to algae blooms in the lake that are treated with copper sulfate ($CuSO_4$). The amount of algae in the lake is determined by secchi disk measurements and visual observations. Secchi disk transparency is commonly 1.2 meters during the summer which is below the 1.22 meters safety level determined by the DEP (MA DEP, 2002). Water studies done by Lycott Environmental Group found blue green algae in Lake Wickaboag (Collins, 2010). The algae problem tends to be an issue during late July or early August. During warmer years the algae problem becomes an issue earlier in the year, and excess rain can also bring on algae issues earlier in the year.

2.3.3 Copper

Copper has been introduced into Lake Wickaboag through the application of copper sulfate to control algae blooms. Copper sulfate is toxic to algae blooms, but needs to be administered correctly because an overdose can be toxic to fish. At Lake Wickaboag, applications of copper sulfate of about 5 pounds per surface acre have been used to treat the algae problem which is about 1,600 pounds of copper sulfate (ESS Group Inc, 2004). Lycott Environmental reports that they usually apply 1,750 pounds of copper sulfate to the lake per treatment and perform one treatment yearly at a cost of $3,700. Lycott Environmental applied two treatments of copper sulfate in 2010. Because of a heavy rain season the algae were not controlled by the first application. One application was on July 21 and the second on August 11 (Collings, 2010).

Copper has become an issue in Lake Wickaboag and exceeds the upper threshold of U.S. EPA Great Lake Sediment Quality Criteria (the criteria that is followed by the Massachusetts DEP), which is 25-75 mg/kg DW. One mg/kg DW means one milligram of substance per kilogram of dry weight of the total sediment in the water tested. The use of copper sulfate has resulted in an accumulation of copper in the lake.

2.4 Best Management Practices (BMPs)

One objective of this MQP was to design a stormwater Best Management Practice (BMP) to reduce stormwater pollutant loadings to Lake Wickaboag and improve water quality.
BMPs are implemented strategies that are designed to reduce sediment buildup and monitor pollutant control from stormwater runoff. BMPs can be structural or non-structural. An example of a structural BMP that exists in Lake Wickaboag is at the northeast region of the lake where a stormwater drain was modified with a sediment trap so no excess sediment would enter the lake. An example of a non-structural BMP would be not applying road sand and/or salt to a certain road that contributes to stormwater runoff.

The advantage to BMPs is they not only treat the problem at hand, they also prevent further pollution and sediment buildup from occurring in the future. This step is both environmentally and economically sound. If done properly, BMPs can also prevent illness if the water body of concern is of public use. One important preliminary step is that the proposed BMPs must follow regulations from both the Massachusetts Stormwater Handbook and the Environmental Protection Agency. The Massachusetts Stormwater Handbook notes that the BMP must be designed to remove 80% of total suspended solids that enter the water body over the course of one year, and the peak discharge rate from the BMP must be less than or equal to the peak discharge rate before the BMP. The 10 handbook regulations that were taken into consideration can be found in Appendix A.

3 Methods

The methodology for the project is provided in this chapter. The methods include site selection, sampling procedures, analysis of data, and BMP selection.

3.1 Site Selection

In order to choose locations to collect and stormwater, a site selection matrix was created. The information used to create the matrix came from a report by ESS Group (ESS Group Inc., 2004). This report outlined the main stormwater inflows to Lake Wickaboag and issues that the lake faced. Nine sites that were recommended by ESS Group were used in the matrix (ESS Group Inc, 2004). In order to select three sites to study, the following criteria were used:

- Drainage Area
- Runoff
- Soil Group
- Phosphorous Load
- Total Phosphorous
- Estimated Cost of Phosphorous Load Reduction
- BMP Cost

The first three data categories were considered important to the final site decision because the drainage area, runoff, and soil group all contribute to the amount of stormwater that will flow into the lake. The more flow into the lake from a specific site, the greater the chances are that the site is a significant contributor of non-point source pollution. Other data that were used in selecting sampling sites were; phosphorous load (%), total phosphorous (Kg/Yr), and estimated cost of phosphorous load reduction. Phosphorous levels are high in the lake and therefore this pollutant was of primary concern. Because the majority of the sediment problem is in the northern section of the lake, it was important to keep in mind where each site was located. Also significant was whether the site was public or private and if the land was farm land, residential or forest. The last piece of information that was included in the matrix was the BMP cost. This was not considered to be extremely important because it was an estimated number, yet it was included because it gives an idea of how feasible it is to reduce stormwater impacts at each site.

Data were compiled for the nine sites from the report. Each criterion was ranked as Good, Neutral or Bad for each site. A rank of Good meant that the data did not indicate that the site was a contributing factor to the non-point source (NPS) pollution in the lake. A rank of Bad meant that the data indicated the site was potentially contributing to stormwater pollution inputs. A number was given to each rank (Good=1, Bad=3) and a final total score was found. Based on the scores and personal comments by Al Collings, test sites were selected (Collings, 2010).

3.2 Sampling Procedures

Consistent procedures were followed to ensure that stormwater sampling and testing of phosphorous and total suspended solids would yield accurate results. The methods followed are described in the following sections.

3.2.1 Collecting Stormwater Samples

After sampling sites were selected, samples of stormwater were collected from each site. The equipment necessary for collecting samples included a cooler, ice-packs, plastic sample bottles (four 1 L bottles and four 250 mL bottles for each site), tape and a pen for labeling. Once all of the supplies were gathered, each group member was assigned a site to sample. According to the MA DEP Standard Operating Procedure for Stormwater Gathering as of December 2005, the common minimum criteria for gathering stormwater are a 48-72 hour minimum dry period prior to the sampling as well as a 0.25 inch minimum total amount of rainfall per storm event or in 24 hours (MA DEP, 2008).

After each member was at their designated site, the group designated a time to collect a sample so the samples could be collected at the same time. This step ensured more consistent results in determining the amount of solids or phosphorous entering the lake over a period of time. In addition, notes were recorded for each site which included the total rainfall and intensity data through the NOAA website (NOAA, 2010).

To collect a sample, the sample bottle (1 L or 250 mL) was held under the pipe or edge where the stormwater was flowing into the lake until the bottle was full. Once the bottle was full, the bottle was then sealed and labeled with the site number, time collected and date and was then put into the cooler containing ice-packs. This process was repeated four times with 30 minute intervals until all the bottles were full. The samples were then taken back to the Environmental Engineering Laboratory at WPI and were stored in a refrigerator for no later than 14 days. Within this time period, the samples were tested for phosphorous and total suspended solids (TSS). The stormwater collected in the 1 L sample bottles was used to test for TSS and the samples in the 250 mL sample bottles were used to test for phosphorous.

3.2.2 Total Suspended Solids

Total suspended solids (TSS) were determined by a gravimetric method. A VWR filter with a 1.2 micrometer retention was obtained and placed onto the filtration apparatus. The vacuum pump was turned on and the filter disk was rinsed three times with 20 mL of Epure water. The prewashed filter disk was removed from the filtration apparatus with tweezers and placed into a porcelain dish. The dish and filter disk were placed into an oven at 103°-105° C for one hour. Once removed, the two items were then placed into a dessicator to be stored and cooled until they were ready to be used. Both the dish and filter disk were then weighed and recorded. The filter disk was then removed from the dish and placed back onto the filter apparatus in order to collect the solids from the sample. This was done by choosing a sample volume that would leave a residue between 10 and 200 mg. The chosen water volume was then pulled through the filter, leaving behind solids on the filter. After washing down the filter apparatus with Epure water in order to collect all solids, the filter disk was removed and placed back onto the dish. The dish and filter disk were then placed back into the oven at 103°-105° C for one hour. After being removed from the oven, the sample was placed into the dessicator until cool (about 30 minutes). Once cooled, the dish and filter disk with residue were weighed and recorded.

The total suspended solids were calculated using Equation 1. The weight of the dish and filter disk (B) are subtracted from the weight of the dish, filter disk, and residue (A). This value is divided by the volume of sample filtered through the disk.

$$TSS\ \left(\frac{mg}{L}\right) = \frac{A - B\ (mg)}{Sample\ Volume\ (L)}$$

Equation 1

3.2.3 <u>Total Phosphorus</u>

Four major steps were taken to test for total phosphorus in the stormwater samples. These included the preparation of standards, digestion of the aqueous samples, analysis using a DR/3000 Color Spectrophotometer, and the calculation of sample concentrations.

3.2.3.1 Preparation of Standards

In order to calibrate the color spectrophotometer, a set of standards with known concentrations of phosphorus were prepared. The analysis of these standards was used to create a calibration curve and the unknown stormwater samples were compared to the curve. The samples were prepared using a stock solution with a phosphorus concentration of 0.1 mg/mL. Six standards were created for the calibration. These included a 0.0 blank, 0.2, 0.5, 1.0, 3.0, and 5.0 mg/L standards. These six different standards were made by adding 0, 0.2, 0.5, 1, 3, and 5 mL of 0.1 mg/mL stock solution to each of six 100 mL volumetric flasks. The flasks were then filled to the 100 mL mark with Epure water. After these mixtures were completed, the digestion step was started.

3.2.3.2 Digestion of Aqueous Samples

All of the aqueous stormwater samples, standards, and the blank were digested in the following way. First, 25 mL of sample or standard (or Epure water for the blank) was poured into a clean beaker. 5 mL concentrated HNO_3 (nitric acid) and 1 mL concentrated H_2SO_4 (sulfuric acid) were then added to the beaker in that order. The beaker was covered with a watch cover making sure there was a gap for evaporated gases. The beaker was then gently heated on a hot plate under the hood until white fumes were visible in the beaker, and the sample was reduced to a volume of about 1 mL. This process was repeated for all samples and standards. After digestion, the beakers were removed from the hot plate to let them cool.

3.2.3.3 Analysis Using a DR/3000 Color Spectrometer

The spectrophotometer was turned on 2 hours before using it to ensure that the lamp had warmed up sufficiently. The "Manual Program" button was pressed and the wavelength selector was set at 400 nm. The instrument was zeroed with a blank. This was done by first transferring the digested blank from the beaker into a clean sample cell. 1 drop of phenolphthalein indicator solution was added to the cell, followed by as much 5N NaOH (sodium hydroxide) solution as required to produce a faint pink tinge. Epure water was added up to the 25 mL mark and 1 mL Molybdovanadate was added to the sample cell. The buttons "3" and "timer" were then pressed to time 3 minutes as the contents in the sample cell reacted. When the timer beeped, the sample was placed in the cell holder and the compartment door was closed. The instrument was zeroed by pressing the "Zero Abs" button and the display then read 0.000 Abs. The sample cell was the emptied and rinsed. The same sample cell was used for each successive standard and unknown. The process for getting readings for each sample and standard was the same as for the blank until the part when the "Zero Abs" button was pressed. For the samples and standards, instead of pressing the "Zero Abs" button, the "Abs" button was pressed to read the absorbance from the display. The sample cell was then rinsed and the same task was performed for each standard and unknown sample. Once all the data were collected, the laboratory area was thoroughly cleaned.

3.2.3.4 Calculation of Sample Concentrations

Once all the data were collected, the results were entered into Microsoft Excel. The data from the standards was plotted with absorbance on the y axis and total phosphorus (mg/L) on the x axis. A linear regression line was added to this calibration curve in the form y=mx+b (Abs=m (concentration)+b) where m is the slope and b is the y-intercept. This line was used to analyze the amount of total phosphorus from each sample by substituting the absorbance into the linear regression line equation and calculating the concentration in mg/L.

3.3 Analysis of Data

The field and laboratory data obtained were statistically analyzed to determine correlations and variance.

3.3.1 Correlation Analysis

A correlation analysis was conducted using Pearson's method in Microsoft Excel. The parameters used in the analysis were 24 hour rainfall, rainfall intensity, TSS, and total phosphorus. Correlation analysis establishes whether or not there is a relation between the concentration of pollutants and rainfall. If relationships were found they could then be used to make calculations about yearly amounts of TSS and total phosphorous at the different sample sites.

Correlation analysis was completed by organizing the sampling data in columns and running the correlation analysis package. The details about Pearson's Method can be found in Appendix C.

3.3.2 ANOVA Analysis of Variance

In order to determine if TSS and Phosphorous varied by site an analysis of variance (ANOVA) was conducted. This test is based on the hypothesis that there is no variation within the two groups of interest. The validity of the proposed hypothesis is based on a calculated P-value which was calculated using Microsoft Excel data analysis tool pack. According to statistical theory, if the calculated P-value is found to be greater than 0.05, then the hypothesis is correct, which means that there is no variation between the two groups. If the calculated P-value is found to be less than or equal to 0.05, then the two examined groups are statistically different.

The first step in conducting this test was entering the phosphorous and TSS data into Microsoft Excel separately by site location. The ANOVA: Single Factor test was then conducted in Excel by clicking the ANOVA: Single Factor tab under the Data Analysis Tab. The data of interest (phosphorous or TSS) was then selected along with site locations in the Input Range column. The alpha value, α, used in this test was 0.05. Alpha corresponds to the level of confidence. After clicking OK, summary and ANOVA tables were displayed revealing averages and variances of each site along with the degrees of freedom and a calculated P-value. The P-value was used to validate the proposed hypothesis. Details of the ANOVA method are provided in Appendix C.

3.4 BMP Matrix

In order to choose the best management practice for stormwater for the site selected, a BMP matrix was created (Appendix E). The information used in the matrix came from the Department of Environmental Protection Stormwater Handbook (MA DEP, 2001). This report outlined specifications for BMPs that are feasible in Massachusetts in four categories: structural, treatment, conveyance and other. Twenty two BMPs were considered in this matrix for stormwater management (MA DEP, 2001). In order to choose the best management practice for the selected site at Lake Wickaboag, the following criteria were used:

- Applicability
- Pollutant Removal Efficiencies (TSS, Nitrogen, Phosphorous, Metals, Pathogens)
- Design Considerations (Drainage Area, Size, Location)
- Maintenance (Inspection, Cleaning)

The first criterion considered was applicability. This criterion specified the conditions under which each BMP would perform to its maximum potential. The next criterion considered was pollutant removal efficiencies. This included the percent removal of total suspended solids, nitrogen, phosphorous, metals and pathogens. The five pollutants are ones that could cause potential risk in a body of water if the concentrations are high enough. Lake Wickaboag is threatened by high TSS and phosphorous levels therefore those two categories were the most important. The third criterion was design considerations. Drainage area, size and location are three aspects of design that can help distinguish a BMP. It is important to look into these three areas of design because every site is different and may include area limitations. The final criterion that was considered is maintenance. This is important to choosing a BMP because routine inspection and cleaning needs to be performed to keep the system performing at high level, and this cannot always be done.

As discussed in Chapter 4, site W-7 was selected as a potential threat to Lake Wickaboag. Therefore the BMP matrix was used to evaluate potential management strategies application for this site. Each criterion was ranked as Good, Neutral or Bad for each BMP. A rank of Good meant that the criterion fit the site specifications and would help manage the stormwater. A rank of Bad meant that the BMP could not be used to help manage stormwater at the site. A number was given to each rank (Good=1, Bad=3) and a final total score was found. Based on the scores, a best management practice was selected.

4 Results and Analysis

This section of the report contains all of the gathered results that were necessary in determining the proposed BMP of choice at the site of concern. Selected Sites and statistical results from the laboratory procedures are included as well as a preliminary list of BMPs. The site of most concern and the BMP of choice can also be found in this section. All of the results gathered were used to design a BMP.

4.1 Selected Sites

Sites were selected for sample testing based on the site selection matrix in Appendix B and input from Al Collings, president of the Lake Wickaboag Preservation Association. The most critical factor in choosing the sites was whether or not a pipe was present to allow collection of samples for water quality testing. Only sites W-2, W-3 and W-7 could be used for this project because there was no discernable flow available for collection at any of the other sites.

The three sites selected for sampling were W-2, W-3, and W-7. Appendix B shows that site W-2 had a criterion rank of 20/21 while site W-7 had a ranking of 18/21. Therefore, both sites have a high potential of contributing to stormwater contamination. Site W-3 was not included in the table because it does not contribute runoff directly into Lake Wickaboag. This site was selected as a sampling site due to input from Al Collings. These sites are shown in Figure 2 and described below.

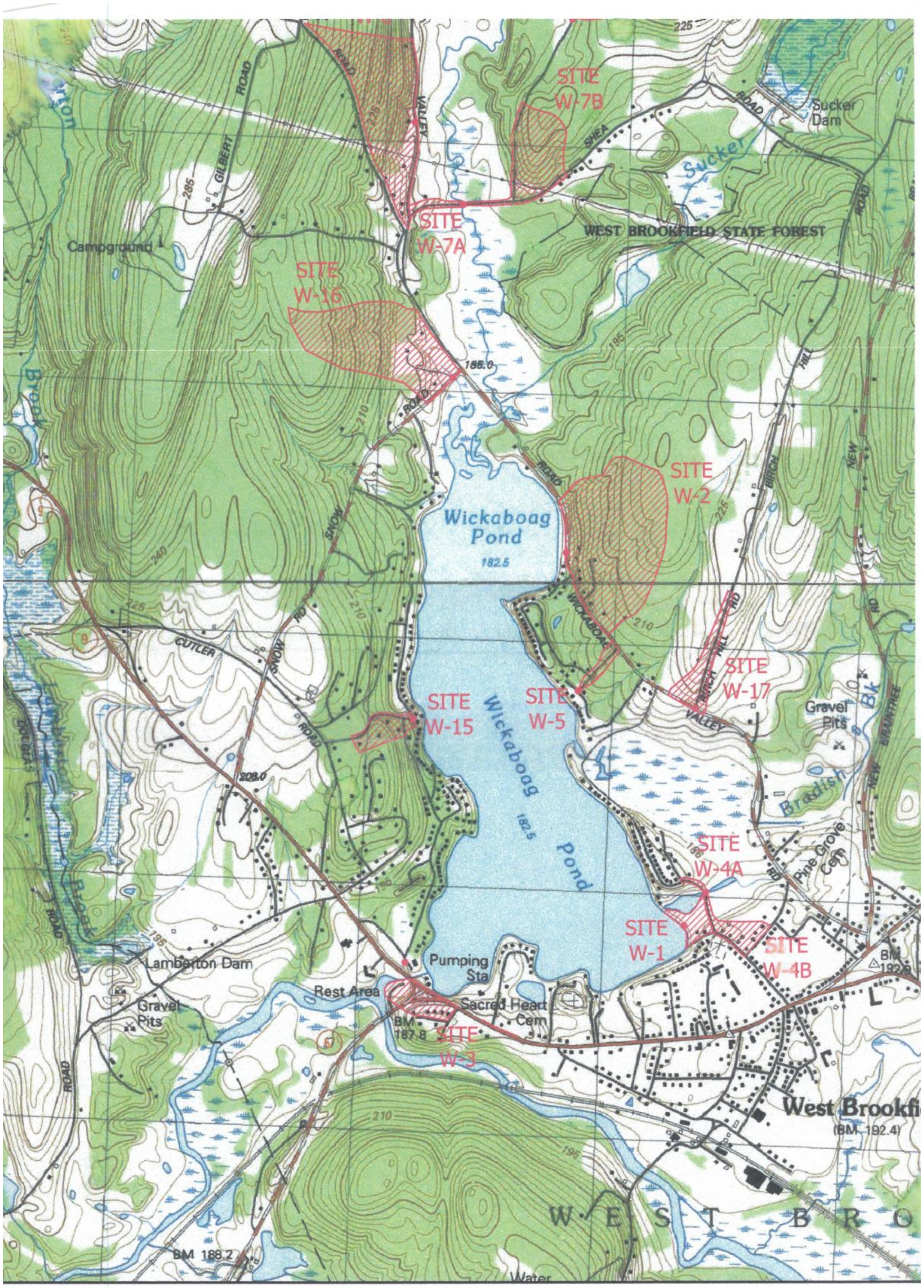

Figure 2: Lake Wickaboag Map

4.1.1 Site W-2

This site is located on Wickaboag Valley Road which is bordered by Lake Wickaboag on the west. A series of catch basins at the site lead to an infiltrator system designed to allow the stormwater to seep into the ground while being filtered. At the end of the infiltrator system is a dual chambered catch basin that has a twelve inch outflow pipe into Lake Wickaboag. The total land area that drains into the catch basins at W-2 is fifty-five acres. This site was renovated in 2007, and no testing has been done to see how the system in place has affected the amount of sediment and phosphorus entering Lake Wickaboag from the site. This site was chosen because of the easy pipe access, and also because Al Collings expressed that the sampling data could be useful to determine the effectiveness of the BMP that was implemented at the site.

4.1.2 Site W-3

This site is located near the intersection of Route 9 and Route 67. Stormwater from a seven acre area is carried by existing catch basins and drainage pipes to an outflow pipe in a bridge on Route 67 that pours directly into the Quaboag River. This site does not directly affect Lake Wickaboag, but the site that contributes to the outflow pipe is similar to many areas around Lake Wickaboag. The site was chosen because of easy pipe access and similarities to other areas near Lake Wickaboag.

4.1.3 Site W-7

This site is a combination of site 7a and 7b which receive runoff from a land area totaling 20 acres. The site is located at an outflow pipe near a bridge on Shea Road. Stormwater enters a catch basin at the beginning of Shea Road and is combined with road runoff at the outflow pipe. The pipe flows directly into Sucker Brook, which then flows into Mill Brook and subsequently into Lake Wickaboag. This site was chosen due to easy pipe access, as well as its direct effect on Lake Wickaboag. Al Collings also expressed that this site could offer insight to the effects of runoff on Lake Wickaboag, as this site is similar to many other sites along the rivers that lead to Lake Wickaboag, and into Lake Wickaboag itself.

4.2 Analysis of Stormwater Quality

4.2.1 Sampling Data

Stormwater samples were collected on four days over the course of three months. The samples were analyzed for total suspended solids and phosphorous. In addition, rainfall intensity and cumulative rainfall during the day of sampling were obtained from the NOAA website (NOAA, 2010). The raw data calibration curve for phosphorous and calculated concentration of TSS and phosphorous were shown in Appendix F and Appendix G. The summary data are shown in Table 1, Figure 3 and Figure 4. As shown in the figures, the highest pollutant levels were observed on November 4th, which was the storm with the highest rainfall intensity. For phosphorous, site W-7 consistently had the highest concentrations.

Table 1: Stormwater Sampling Data

Date	Cumulative Storm Rainfall (in)	Rain Intensity (in/hr)	Total Suspended Solids (mg/L)			Phosphorous (mg/L)		
			W-2	W-3	W-7	W-2	W-3	W-7
30-Sep	0.27	0.02	No Flow	3.40	5.53	No Flow	0.07	0.27
6-Oct	1.42	0.05	No Flow	3.60	5.66	No Flow	0.05	0.20
4-Nov	0.46	0.08	27.63	3.65	0.04	0.26	0.04	0.58
5-Nov	0.46	0.00	No Flow	No Flow	2.18	No Flow	No Flow	0.07

Note: Values found for W-2 were not from flow going into the lake. Samples were taken from inside the catch basin to determine the quality of the water entering the infiltration BMP.

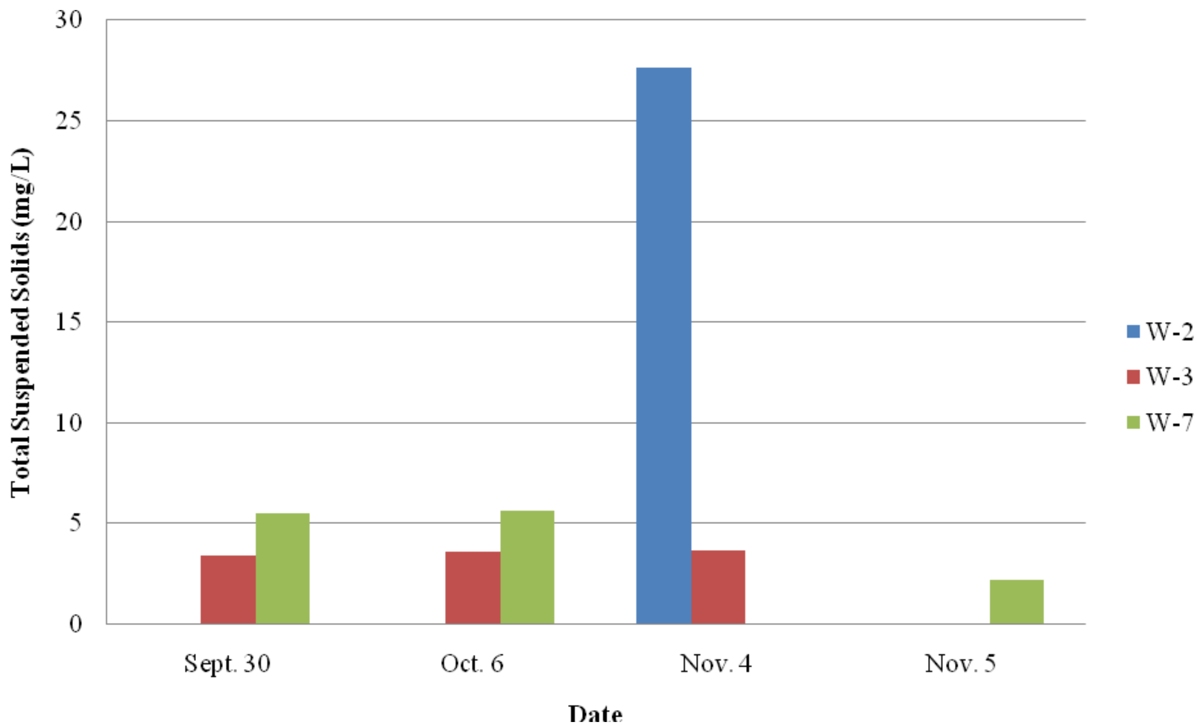

Figure 3: TSS Concentrations in Stormwater Flows

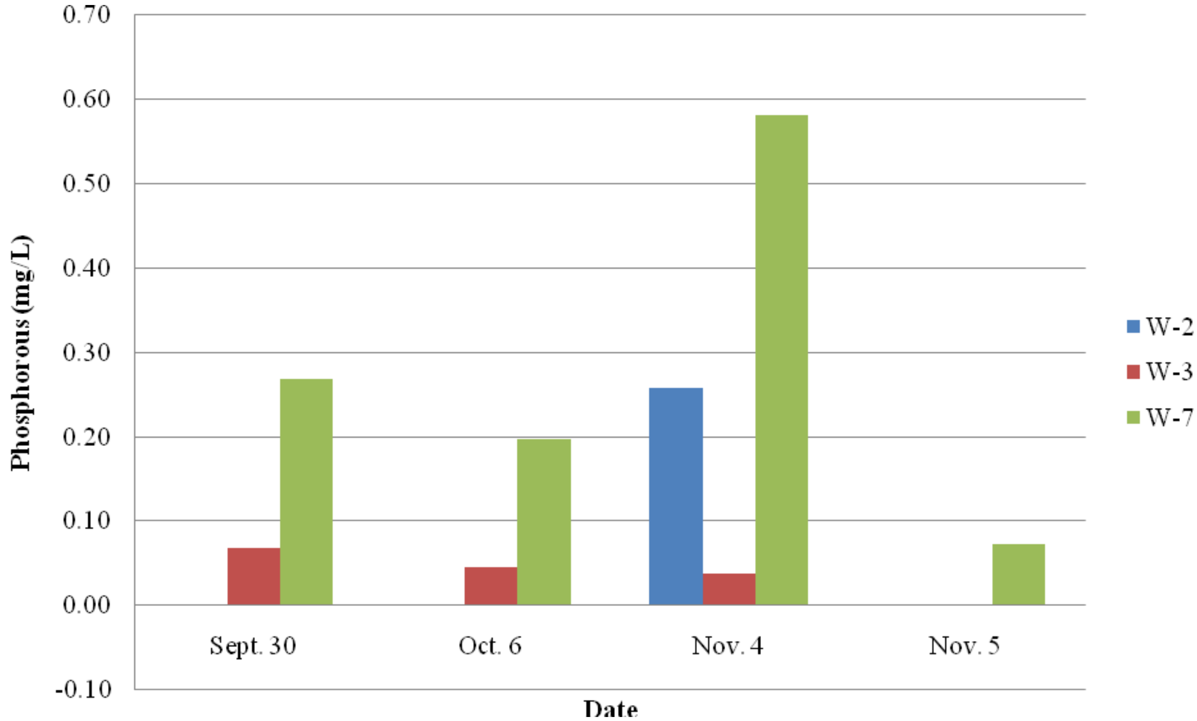

Figure 4: Phosphorous Concentrations in Stormwater Flows

4.2.2 Statistical Analyses

Two statistical analyses described in Chapter 3 were performed on the data: correlation analysis and analysis of variance. The results for the correlation analysis are shown in Tables 2 and 3.

Table 2: Correlation Analysis Excel Data

	TSS	**Phosphorus**	**Rain Intensity (in/hr)**	**Cumulative Storm Rainfall (in)**
TSS	1			
Phosphorus	0.656	1		
Rain Intensity (in/hr)	0.474	0.403	1	
Cumulative Storm Rainfall (in)	-0.230	-0.193	0.088	1

Table 3: Correlation Analysis Results (Correlation Coefficient Table vs Excel)

Rainfall Measure	Water Quality Measure	# Paired Data Points	Critical Value (Based on Table)	Correlation Coefficient (Based on Excel Output)	Significant Correlation
Cumulative 24-hr rain	Phosphorous	24	0.4056	-0.193	NO
	Total Suspended Solids	22	0.4248	-0.253	NO
Intensity (in/hr)	Phosphorous	24	0.4056	0.402	NO
	Total Suspended Solids	22	0.4248	0.473	YES

Table 2 illustrates Microsoft Excel correlation coefficients based on parameters of interest. Parameters in the columns are compared with parameters in the rows to see if there is a correlation between the two. For example, if a correlation between TSS and phosphorous was of interest, the reader would look at row 2 (phosphorous) and column 1 (TSS) to find the value. The coefficients can range from -1 to +1. Absolute values are used if negative findings are displayed. The correlation coefficient values from Microsoft Excel are compared with the critical correlation coefficients (see Appendix C). The critical values are based on the number of paired data points and an alpha value of 0.05. If the absolute value from Microsoft Excel is larger, then the two parameters are correlated.

The correlation analysis was conducted to determine if there was a statistical relationship between rainfall amounts and water quality as measured by phosphorous and total suspended solids. As shown in Table 3, there is no significant correlation between cumulative rainfall and TSS/phosphorous, or between intensity and phosphorous. A statistically significant correlation was found between intensity and TSS. Also of note is that TSS and phosphorous were correlated (coefficient of 0.656 compared to critical value of 0.425).

Analysis of variance was used to determine if there were differences in water quality by site. Appendix C has the full ANOVA output while Table 4 presents a summary of the p-values. For both TSS and phosphorous, the p-values were less than 0.05. Therefore, both measures of water quality were statistically different by site at the 95% confidence level.

Table 4: ANOVA Results for Site Differences

Parameter	Average Concentration (mg/L)			P-Value	Critical P-Value	Statistical Difference By Site
	W-2	W-3	W-7			
TSS	27.63	3.59	10.98	0.013	0.05	YES
Phosphorous	0.26	0.05	0.28	0.019	0.05	YES

4.2.3 Site of Most Concern

Based on location and water quality analysis, site W-7 is the site of most concern. The laboratory testing showed the highest concentration of phosphorus at this site compared to W-2 and W-3. A pipe at W-7 enters Sucker Brook which then flows into Lake Wickaboag through Mill Brook. Therefore, contaminants from this area are of great concern.

Pollutant inflows at site W-3 are considered less important because of the site's location. At site W-3, a drainage pipe drains into the Quaboag River which does not flow into Lake Wickaboag. In addition the pipe in the bridge at the site would be difficult to reconstruct due to a lack of land area. Also the concentration of phosphorus and TSS at site W-3 were the lowest among the three sites that were examined. Site W-2 is not considered a site of concern because the sampling done at this site was done to determine if the phosphorus and TSS levels at the previously renovated site W-2 were less than the other sites. Site W-2 had no stormwater runoff leaving the outflow pipe during any of the storms that were witnessed, however stormwater that collected in a basin before it enters the infiltrator system was tested to see what contaminants were in the runoff. The TSS and phosphorus in the basin were at levels higher than W-3, the contaminants do not enter Lake Wickaboag due to the infiltrator system at site W-2. This means that the site was contributing no TSS or phosphorus to Lake Wickaboag, and since the site had already been modified with a BMP, it was not considered the site of most concern.

4.3 Preliminary List of BMP's

Appendix E provides the criteria matrix for developing a preliminary list of BMPs. The comprehensive list includes BMPs in multiple categories, including structural pretreatment, treatment, conveyance, infiltration, and other. The potential for each BMP to provide useful stormwater management at site W-7 was evaluated based on three criteria, including pollutant removal efficiency (phosphorous & total suspended solids), design considerations and maintenance. Each criterion was ranked from 1 (best) to 3 (worst) and thus each BMP could have a total ranking from 4 (best) to 12 (worst).

As shown in Appendix E, the BMPs with the best rankings were bioretention areas/rain gardens, rain barrels/cisterns and infiltration basins/trenches. Bioretention areas/rain gardens and rain barrels/cisterns had a criterion rank of 6/12. In particular, these BMPs ranked very well in drainage area and maintenance. Infiltration basins/trenches both scored 5/12. These BMPs had the best rank due to high pollutant removal efficiencies, large drainage areas and minimal maintenance requirements. Each of the highly ranked BMPs are described below.

4.3.1 Infiltration Basins or Trenches

An infiltration basin/trench is an impoundment that is designed to infiltrate stormwater into the soil which can help recharge the groundwater. Infiltration systems are comprised of an equalization tank and a leach field which are sized according to expected flows (United States Environmental Protection Agency, 2006). For the systems to work, stormwater has to be collected from the streets through catch basins and then piped to the equalization tank. A leach field may be used to get stormwater runoff to infiltrate into the ground while being treated for certain contaminants.

A typical leach field is comprised of a distribution box (d-box), and several trenches of stone, gravel, or other media with perforated pipes above the trenches to allow the leachate (stormwater runoff) to be distributed over the media. Two things happen in the leach field that help to create a higher quality effluent. First, the leachate percolates through the media and is filtered. Secondly, there may be a breakdown of organics and other nutrients through aerobic processes. Microbial degradation may be limited and may occur in some systems and not others depending upon the properties of the media. For example, stone media has much more air in it than clay such that aerobic processes will occur more with a stone leach field. Several configurations of the leach field exist. All of these different designs act as infiltration trenches to reduce the amount of total suspended solids and phosphorus in the effluent.

The average pollutant removals for a simple infiltration trench are as follows in cold climates similar to that of Wisconsin, Massachusetts or Maine:

- TSS: 75%
- Phosphorus: 60-70%
- Nitrogen: 55-60%
- Metals: 85-90%
- Bacteria: 90%

These removal efficiencies assume that the infiltration basin is well designed and maintained. Warmer climates are likely to see higher pollutant removals (Shueler, 1987). Many newer designs such as the Presby and Infiltrator systems are expected to have the same treatment efficiency or better (Watershed Management Institute (WMI), 2008).

It is estimated the total construction of an infiltration basin/trench costs about $2 per ft^3 of storage for a 0 – 3 acre basin/trench. Infiltration basins/trenches typically consume about 1 to 2 percent of the site draining to them, and newer designs have been able to reduce this percentage. Maintenance costs are estimated at 3 to 5 percent of construction costs bi-annually for cleaning of the equalization basin and other inspections (SWRPC, 2005).

4.3.1.1 Stone Leach Field

In the stone leach field design, the stormwater collected at the d-box is dispersed to the leach field. The leach field is a rectangular bed of three quarter to one and a half inch stone approximately six inches in depth below the pipe and then filled to the level of the top of the pipe. Usually two or more perforated pipes (diameter depends on loading) are laid across the length of the leach field at a one-half percent pitch from the d-box depending on the designed flow. The leach field is then covered in two inches of pea stone to prevent backfill from getting into the leach field. A leach field is usually designed to work as a gravity system, but pumps can be installed for certain applications.

4.3.1.2 Trench or Step Leach Field

A trench or step leach field is a modification of a stone leach field. The trench or step system was designed to reduce the amount of material required to build a typical leach field, while maintaining the same effluent quality. For a trench or step system are built similar to the same way as a typical leach field, but aligned in multiple rows with space in between rather than as a a single rectangular trench. For example, instead of designing a 15' wide by 40' long leach field, three trenches would be built 3' wide, 40' long and 1' in depth with 1' in between each trench. The actual size of the system depends on the flow of stormwater being treated. The pea stone is not necessary on top to cover the stone and pipe, but could still help to protect the system from having dirt seep in. The reason that trenches reduce the total area is because the parameter that is used to size a leach field is surface area. For a stone leach field surface area is the top surface area. Because of the way the effluent leaches from the pipes, the side areas of the trench are also counted. This allows three 3' by 40' by1' stone trenches to replace a single 15' by 40' stone leach field, because the combined bottom and side surface areas of the trenches is equal to the surface area of the leach field. Thus trenches are a viable option that offer the same quality effluent, but with reduced area requirements.

4.3.1.3 Presby System

The Enviro-Septic was designed by Presby Systems in Whitefield, New Hampshire. This system is a infiltration trench leach field system. The leach field consists of a ten inch corrugated perforated pipe that is wrapped in a green plastic fiber mat and a non-woven black geo-textile. The pipes in the Enviro-Septic are all installed level as long as they are below the equalization tank outflow and can be offset from each other in series. In many applications including drainage or septic systems the pipes are set on top of six inches to one foot of gravel. Figure 5 shows the components of the Presby Enviro-Septic pipe system (Presby Environmental, 2009). Appendix D shows a detailed diagram of how the Enviro-Septic system works.

Figure 5: Enviro-Septic Pipe System

Corrugated perforated pipe offer more surface area for bacterial growth along the pipe and block greases and large suspended solids from exiting the pipe. The green plastic fiber mat filters out suspended solids and creates a bacterial treatment area that helps to break down the suspended solids and other organic compounds. The non-woven black geo-textile surrounds the green plastic fiber mat and provides an additional protected bacterial treatment surface. This multi-bacterial layer system helps to provide oxygen for the aerobic digestion necessary to provide a high quality effluent from the system to the groundwater. The gravel part of the system provides an area of filtration and is an area where pathogens will get slowed down and inactivated prior to entering the groundwater. It was discovered by Presby Systems in 2009 that the addition of a vent to a new or existing system allows for oxygen to reach the aerobic bacteria more freely, and also allows for easier dispersion of gases created in the aerobic digestion process. This means that the addition of a vent allows the Enviro-Septic System to operate more efficiently (Presby Environmental, 2009).

4.3.1.4 Infiltrator System

The Infiltrator System was produced in 2001 as a means of drainage. The piping for this system, also known as chambers, is a half circle shaped pipe that is corrugated and perforated. The system is 34 inches wide by 12 inches high. It sits level on native soil. In Massachusetts, it is required by Massachusetts DEP to sit level on six inches of sand or stone and be filled to six inches over the top of the chamber with sand or stone as well. There can be one trench or more, as long as there is the required amount of feet of infiltrator chamber for the design flow (Infiltrator Systems Inc, 2010). Figure 6 shows a diagram of the Infiltrator System piping.

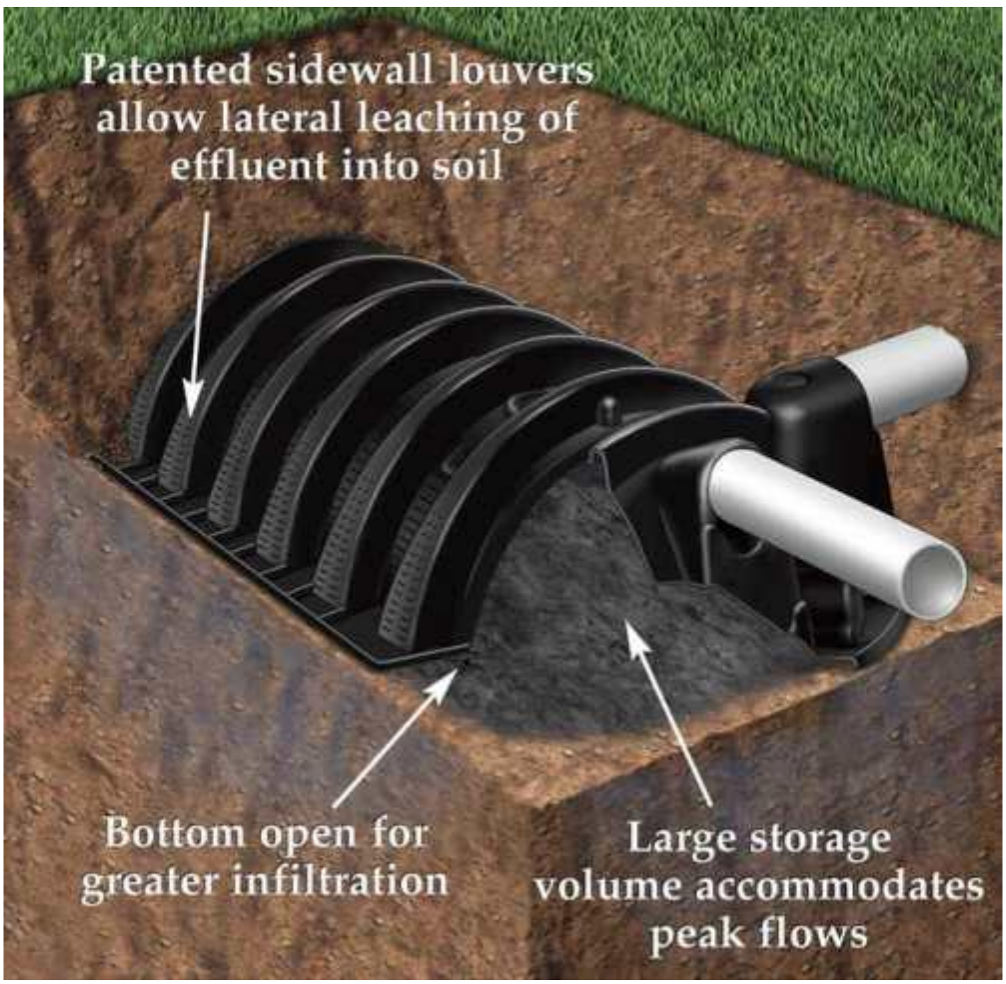

Figure 6: Infiltrator Chamber Diagram

The infiltrator chambers allow for bacteria to grow and form a biofilm on the sand surface. Inactivation of pathogens and the breakdown of organic material occurs in this biofilm and sand layer before it seeps down into the groundwater. The Infiltrator System can be used to reduce many contaminants such as TSS and phosphorus at the same or better efficiency than stone leach field systems. Also, since the Infiltrator is flexible, a single trench can be designed to reduce the construction area. The Infiltrator System can also be offset like the Presby and trench or step systems. A vent as with the Presby System has helped create a better exchange of oxygen into the system and helps it perform more efficiently.

The Infiltrator System was used at site W-2 and now none of the stormwater from the old catch basin system enters Lake Wickaboag. It is all trapped in the equalization basin and is treated as it leaches into the ground under an off street parking lot. Testing has shown that the water in the equalization basin during a storm event has TSS and phosphorus concentrations, but none of the water directly runs into the lake. The percent reduction of TSS and phosphorus at site W-2 is unknown as there is no feasible way to determine how much direct runoff comes off the street into Lake Wickaboag.

There exist many other systems that operate in the same way as the Infiltrator System. The StormTech infiltration system operates in the same way as the infiltrator, but it has larger sized chambers available than the Infiltrator System. Both systems can be used for an infiltration trench, but if the storage volumes are large, or the available area is limited it is likely that the larger StormTech infiltration chambers will be used.

4.3.1.5 Hydrodynamic Control Device

In addition to an infiltration basin or trench system, hydrodynamic source control devices may be used to pretreat influent stormwater. These systems can increase the life-span of infiltration systems and can improve the TSS removal efficiency of an infiltration system to 95% even in cold climates. These hydrodynamic control devices cost $10,000 and up depending on the flow of stormwater that the system is designed for. The units need to be maintained which includes an annually cleaning of sediment. There are a few companies that offer hydrodynamic control devices, but the most commonly used device used in Massachusetts is the Stormceptor which has a 50 year warranty (Infiltrator Systems Inc, 2010).

4.3.2 <u>Rain Barrels and Cisterns</u>

A rain barrel or cistern does not offer primary pollutant removal benefits, but can be used to manage stormwater on an individual basis for residents that live near the lake (MA DEP, 2001). Unlike most BMP’s which direct runoff into a treatment system, a rain barrel or cistern stores runoff from a rooftop and makes it accessible for future use (MA DEP, 2001). Rain water runs off a roof into a down spout which is directed into a barrel with a hole in the top. The water runs through a screen in order to remove large particles before entering the barrel.

Rain barrels or cisterns have two main benefits. The first is that they can reduce stormwater runoff volume by storing it instead of letting it run off a roof. Second, the stored water can be reused; decreasing private water bills (MA DEP, 2001).

Rain barrel systems can be modified depending on their use. A simple rain barrel collects water from a downspout and has a spout for accessing water when needed. A complex rain barrel may be insulated and placed underground in order to be used year round. In order to access the stored water in these systems, a pump is used to draw the water up. Rain barrels and cisterns are sized depending on the amount of runoff they are collecting. Most residential rain barrels used for one downspout are 55 gallons, yet when they are used for more than one downspout, they can range from 50-100 gallons (MA DEP, 2001).

Rain barrels and cisterns are a relatively inexpensive way of maintaining stormwater runoff from a private perspective and therefore seen as a successful BMP.

4.3.3 Bioretention Areas and Rain Gardens

Bioretention is a process which treats stormwater using soil, plants, and microbes. Stormwater is channeled into bioretention cells where the stormwater percolates through soil media and gets filtered. Bioretention cells are similar to regular outdoor gardening plants. They are comprised of native plants which are planted in small holes with sandy soil and are covered with a layer of mulch. The bioretention cells can have two operations which include groundwater recharge or organic filtration of bioretention areas. Bioretention cells that recharge groundwater are designed with an underdrain that helps enhance exfiltration of runoff into the groundwater (MA DEP, 2001). Bioretention cells that filter a bioretention area have an impermeable layer and underdrain that allows the stormwater to flow to another point of filtration such as a storm drain.

Designing a bioretention area requires five to seven percent of the area draining to it (MA DEP, 2001). In addition, the soil must be two to four feet deep. This range is based on the contaminants of interest that need to be removed. For example, if nitrogen is to be removed, then the depth needs to be at least 30 inches and if trees or shrubs are to be planted in the area then the soil media needs to be at least three feet deep. The typical soil mixture includes 40% sand, 20-30% topsoil, and 30-40% compost and must be stone free. In order for the microbes in the soil to function, the pH of the soil should range from 5.5-6.5.

When installed and maintained properly, bioretention areas and rain gardens can remove TSS, phosphorous, and metals such as lead and copper with 90% efficiency. To reach these efficiency levels, additional pretreatment steps are advised. These include vegetated filter strips and at least eight inches of gravel followed by three to five feet of sod added to the area/garden (MA DEP, 2001). Gardens/areas absorb noise, kill mosquitoes due to water drainage and impose little to no threat to animal health. The constraints of bioretention areas and rain gardens, however, are they require a lot of maintenance and space, and they are not effective in small drainage areas. The gardens/areas need to be mowed two to twelve times a year, mulched, fertilized and pruned annually as well. Since the area of concern is a cold climate, no snow can be stored in the area which may be a concern for snow plows in the winter.

4.4 BMP of Choice

After reviewing the list of potential BMP’s for site W-7, the recommended BMP is the infiltration system because it was the most desirable stormwater management option in the BMP Matrix in Appendix E. Installation of an infiltration system at site W-2 has prevented TSS and phosphorous from entering Lake Wickaboag through control of storm flows. The space around W-7 allows for a larger BMP implementation such as an infiltration system. An infiltration system will be able to reduce the amount of TSS and total phosphorus passing through the outlet pipe at site W-7 by 60 to 80 percent. Additional reduction can be achieved with the addition of a hydrodynamic control device.

4.5 Design of a Generic Infiltration Trench System at Site W-7

A preliminary design for an infiltrator system at site W-7 was completed. Figures 7 - 10 show a system using StormTech model SC-740 chambers. This model was chosen because it offers the largest storage volume while maintaining a minimal area footprint. This is important because the system that is designed at site W-7 has to use a minimal amount of area because the town will need to purchase the land required by the system from a private land owner.

The preliminary designs show the relative area that may be required at site W-7, and can be used as a model for other future projects around Lake Wickaboag as well. The designs show that the existing pipe can be used, but other options are possible, if the town wants to renovate the old drainage system in this area the old pipe may be replaced due to age, or to better fit a design for the land available. The designs for Figure 9 and Figure 10 were draw in AutoCAD with the use of the StormTech Design Manual (StormTech, 2003). Overall, these drawings demonstrate the feasibility of an infiltration system at site W-7.

The designs shown in Figure 7 and Figure 8 show the major components of the system. The existing pipe fed by the catch basin up the street will lead into an optional hydrodynamic control device if the town wants to spend the extra money for higher removal efficiency. The system then continues to a manhole which could be specially designed as a combined hydrodynamic control device/manhole avoiding the need for two separate structures. However, the existing pipe can feed directly into a manhole. From the manhole, the stormwater enters the infiltration chambers. In the case of a system failure such as a flow too high for the infiltration chambers to handle, the water will go out an emergency outflow pipe into an area of 50 pound riprap which is made up of large boulders along with a non-woven geotextile fabric. Together the riprap and fabric offer a 25-30% removal of TSS in the case of emergency overflow. When the system operates as designed, the water enters the infiltration chambers and seeps into the ground while recharging the ground water.

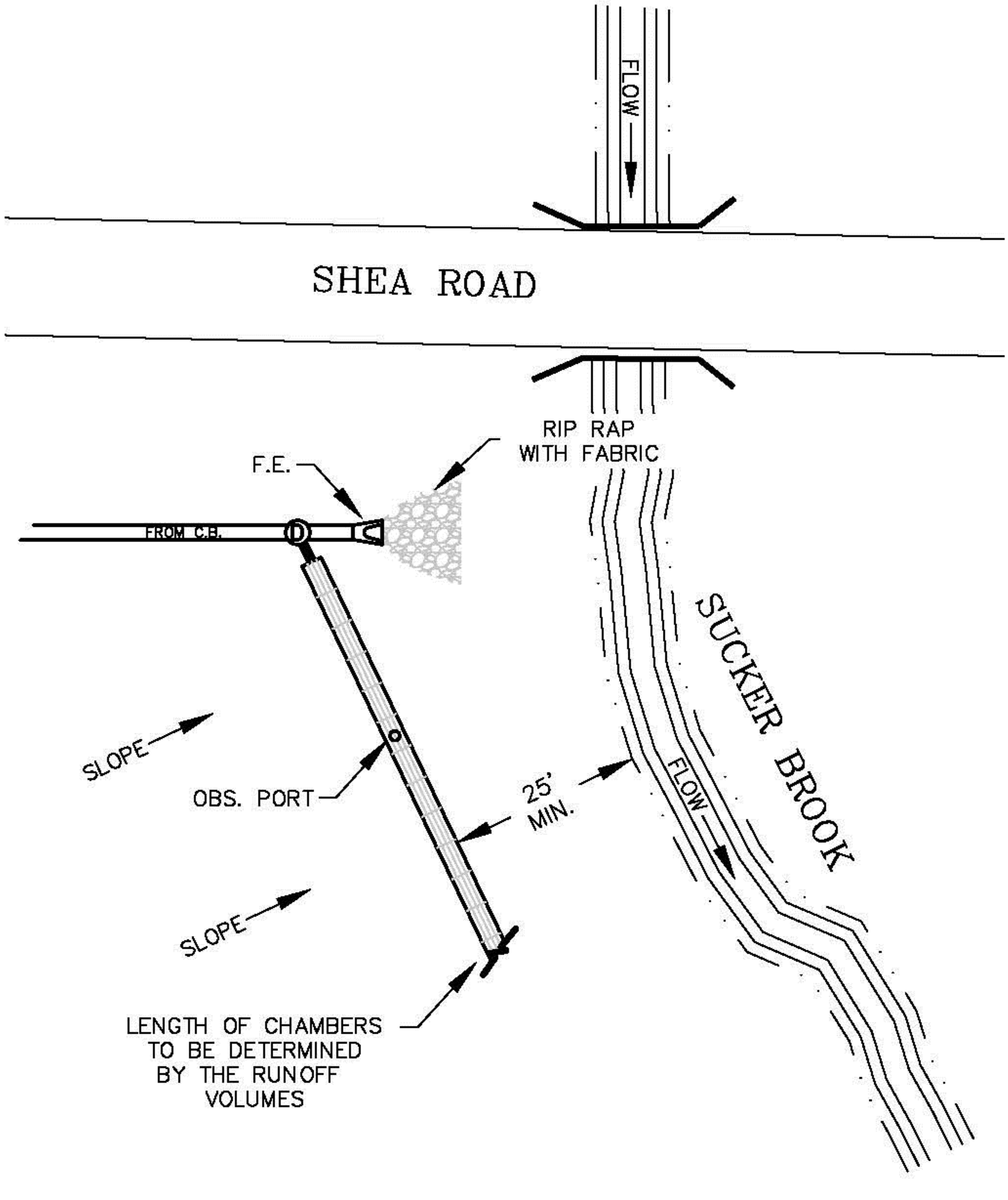

Figure 7: Site W-7 Infiltration Trench Design Plan View

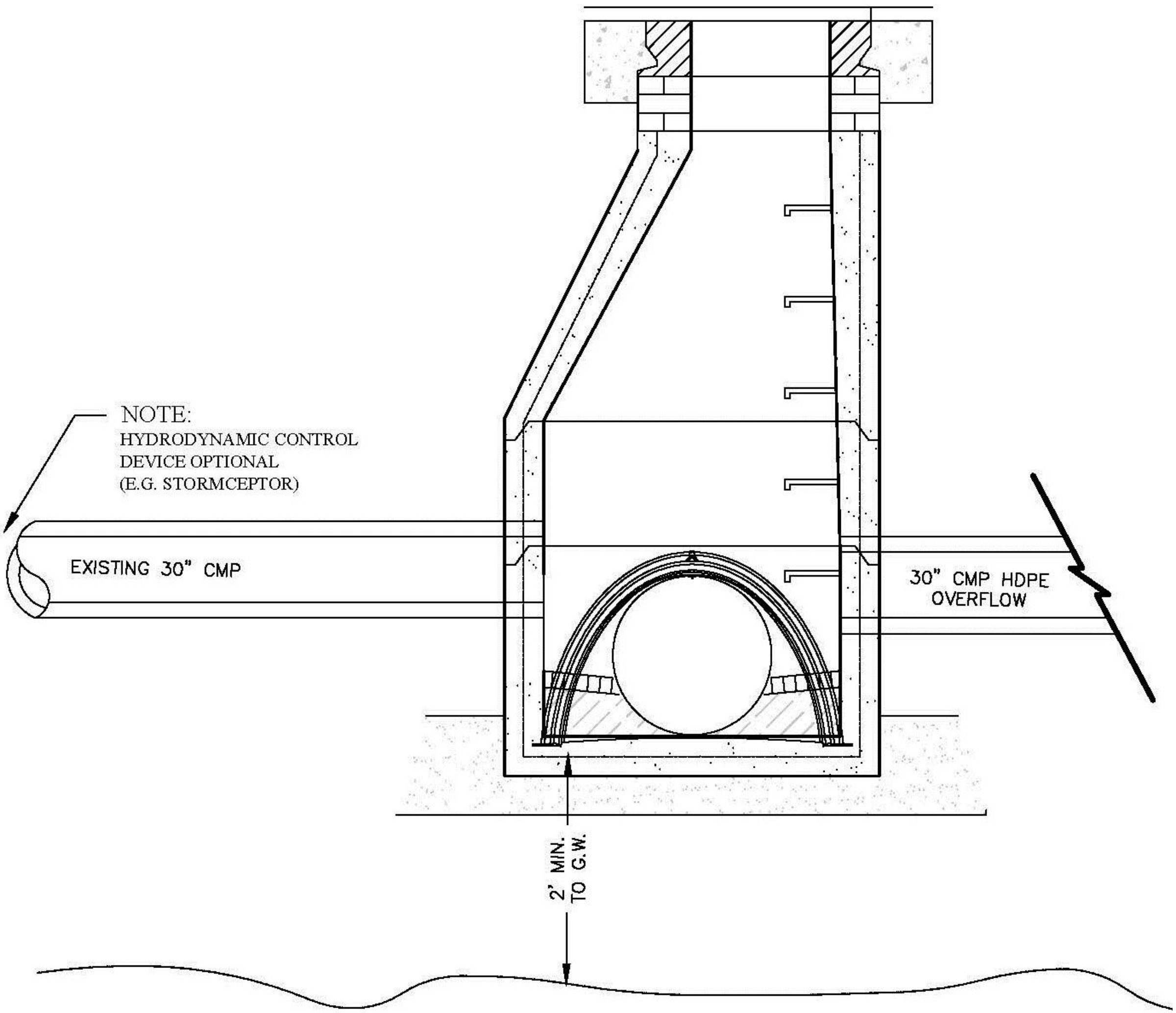

Figure 8: Site W-7 Man Hole Detail

Figure 9 and Figure 10 show the cross sectional views of the infiltration trenches. These trenches are composed of the infiltration chamber that sits on top of 6 inches of stone, and covered to the top with six inches of stone. All of the stone is surrounded by a non-woven geotextile fabric to reduce the amount of outside dirt from entering the stone. The system is then covered with four to 18 inches of acceptable fill materials.

Figure 10 shows a cross section view of a three chamber system which is a potential option to reduce the length of the system, and can minimize the area disturbed in construction. The plan view however shows that only a single trench is to be built which is the reason for the page break in the Figure 10 drawing.

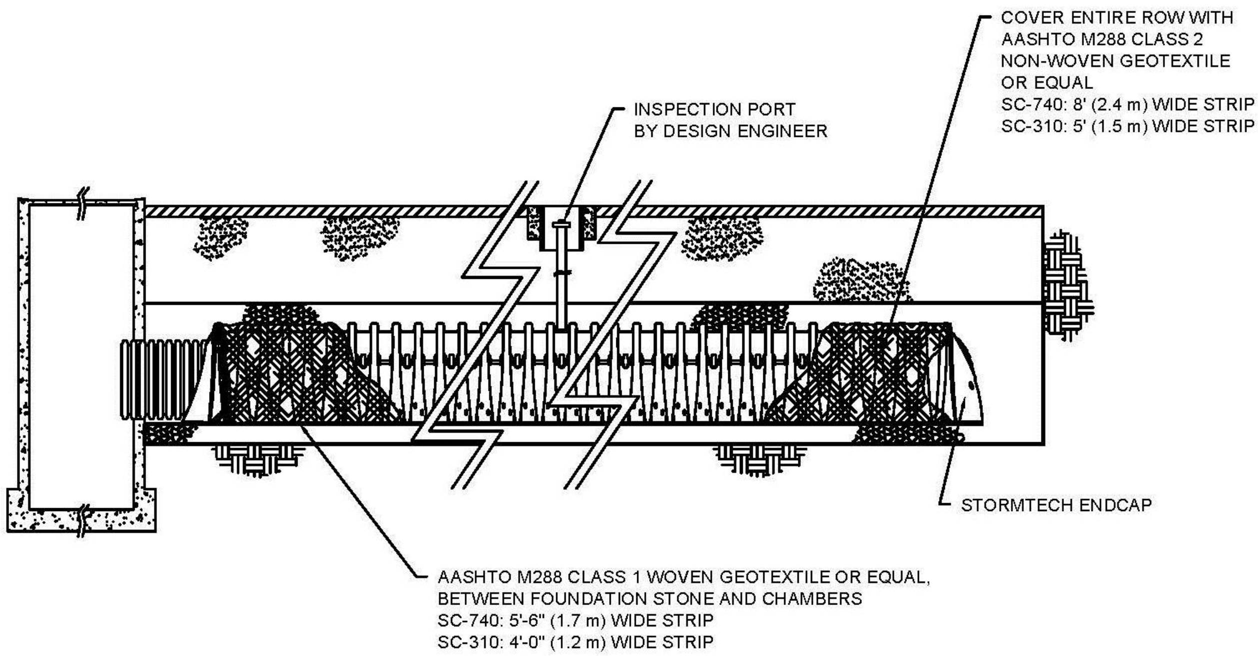

Figure 9: Cross Section of Chambers 1

Figure 10 shows a cross section view of a three chamber system which is a potential option to reduce the length of the system, and can minimize the area disturbed in construction. The plan view however shows that only a single trench is to be built which is the reason for the page break in the Figure 10 drawing.

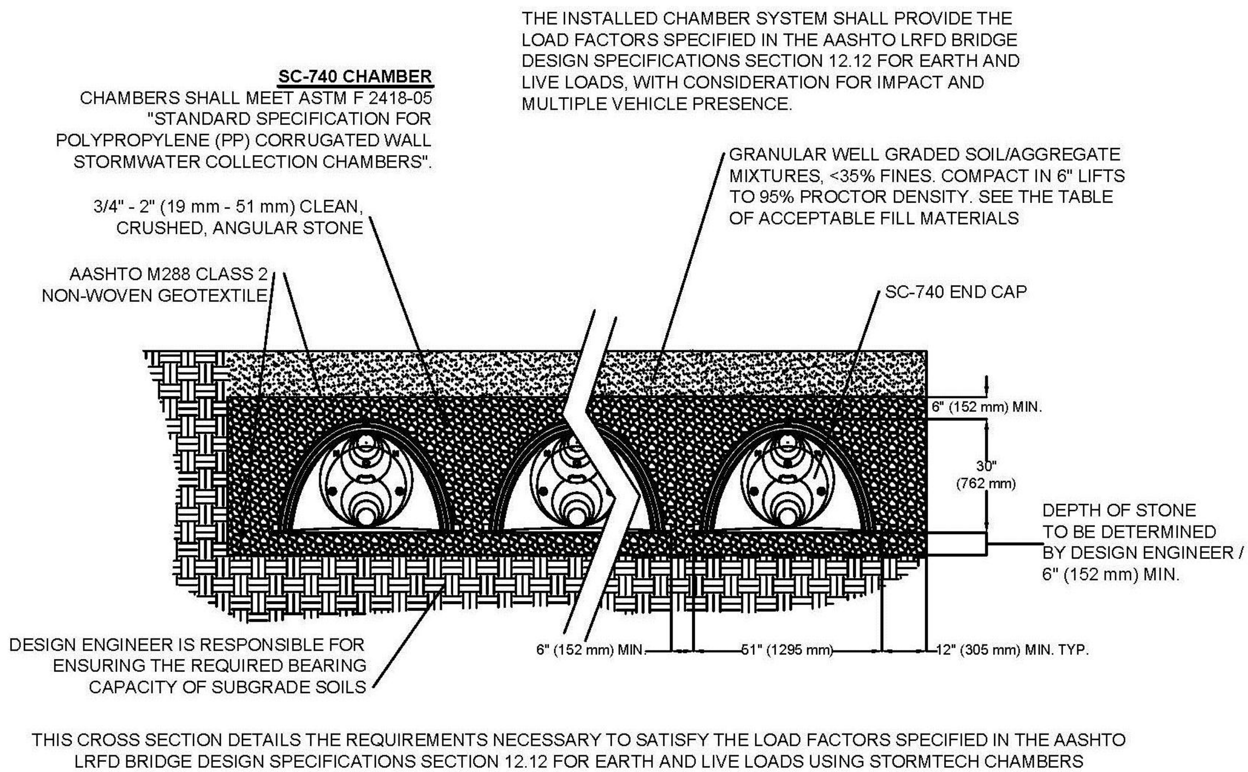

Figure 10: Cross Section of Chambers 2

Prior to final design, the site will have to be surveyed and the topography of the land will have to be mapped. In Figures 7 -10, no elevations were shown because at this point they are unknown. In order to determine where cuts and fills are necessary, a topographical land survey must be completed. Percolation tests will be necessary because in Massachusetts it is required by the DEP that all of the structures in the design must be 2’ above high ground water. Also, the rate at which water will infiltrate into the ground will be better determined if a percolation test is completed. Surveying and engineering are still needed for the final design of an infiltration system to be completed by a professional engineer.

Obtaining access to the private land at site W-7 will be required in order to perform a land survey and percolation test. If the town decides that an infiltration system would be beneficial to the water quality in Lake Wickaboag, the land will have to be obtained from the owner through purchase or easement. This may increase the cost of the project.

As seen in Figure 7, the length of the infiltration chambers has not been determined. The length of these chambers will have to be determined in the final design depending on the required amount of storage needed for the stormwater contributing to the flow in the pipe at W-7. This storage is usually based on rainfalls from a 10 or 100 year storm and can be estimated using certain formulas or programs that take into account the soil type, land use, slopes, area and the length of the area contributing to the outflow pipe. Once the engineer determines the necessary storage volume, the length of the chamber can be determined. The length of the chamber will be 85.4” for every 45.9 feet cubed of storage volume required.

Costs can be estimated for the project once the final design is completed. Table 5 has the information necessary to estimate the amount of materials that will be needed to build the infiltration trench if using StormTech SC-740 Chambers (StormTech, 2003). Table 6 can be used to make a cost estimation of the project. The costs will have to be negotiated with the suppliers of materials and services, and Table 6 can be filled in to determine an estimated cost of the project. Yearly costs will be incurred for cleaning out of the hydrodynamic control device/catch basins. This is usually done by the town Department of Public Works and these costs will be negligible because they will become a part of road maintenance costs that are incurred yearly by the town.

Table 5: Materials Estimation

System Requirements	**STORMTECH SC-740**
1. Required Storage Volume (V_S)	______ Ft^3
2. Number of Chambers (C) Required:	______ (V_S) / Chamber Storage
3. Required Bed Size (S):	______ [(C) x 33.8 ft^2] + (1 ft. x Bed Perimeter)
4. Tons of Stone (V_{ST}) Required:	______ 3.8 x (C)
5. Volume of Excavation (E_X):	______ 5.5 x (C)
6. Area of Filter Fabric (F) Required =	______ Yd^2
7. Quantity of End Caps Required [2 X Number of Rows (E_C)]:	______ End Caps

Table 6: Cost Estimation of System

	Quantity	Cost ($)	Total (Quantity x Cost)
Chambers (C)	__________(Chambers)	$______________ / Chamber	$___________
Stone (T_{ST})	__________(Tons)	$______________ / Ton	$___________
Excavation (E_X)	__________(Yd^3)	$______________ / Yd^3	$___________
Filter Fabric (F)	__________(Yd^2)	$______________ / Yd^2	$___________
End Caps (E_C)	__________(# of End Caps)	$______________ / End Cap	$___________
Hydrodynamic Control Device/Manhole	__________(# of Structures)	$______________ / Structure	$___________
Stone Riprap	__________(Tons)	$______________ / Ton	$___________
Site Work	__________(Hours)	$______________ / Hour	$___________
Engineering/Design	To Be Determined by Engineer/Designer	$_______________	$___________

SUBTOTAL:	$___________
COST PER FT^3 of Required Storage(subtotal ÷ required storage (V_S):	$___________

5 Conclusions and Recommendations

This section of the report contains the final recommendation for control of stormwater phosphorus and solids in Lake Wickaboag. In addition, it contains information and future recommendations for citizens of the community and other engineers to help preserve the quality of the lake and other sites surrounding Lake Wickaboag.

5.1 Conclusions

Stormwater samples were collected at three sites around Lake Wickaboag on four dates in 2010. The highest contaminant levels were observed at site W-7, an outflow pipe near a bridge on Shea Road that receives stormwater runoff from an area of approximately 20 acres. Average total suspended solids were 11.0 mg/L and average total phosphorus was 0.28 mg/L at this site. The TSS inputs were correlated to rainfall intensity, and water quality statistically differed by site. Based on pollution removal efficiency, design concentrations and maintenance, several BMPs were considered for this site: bioretention areas, rain barrels and infiltration basins. An infiltration system is recommended for this site based on successful application at site W-2. The system requires a possible renovation of some of the roadways leading to the major catch basin at the end of Shea Road, an equalization chamber, and approximately 85.5" of infiltration piping per 45.9 square feet of storage required for the drainage area. The cost of the system can be estimated once the storage required for the drainage area is calculated by a professional engineer.

5.2 Recommendations

It is recommended that stormwater quality at site W-7 be analyzed by a state certified laboratory. The testing in this project showed high concentration of TSS and total phosphorus during rain events. Certified data can be used by the town of West Brookfield or the Lake Wickaboag Preservation Association to make future decisions regarding contaminant concerns in Lake Wickaboag.

In order to install an infiltration system at site W-7, the town of West Brookfield will have to purchase a parcel of land or get an easement from the property owner. The parcel of interest is located along Shea Road and Wickaboag Valley Road near the outflow pipe.

In addition to installation of a BMP at site W-7, other projects could be initiated to decrease stormwater inputs entering Lake Wickaboag. The project team recommends that the town of West Brookfield invest in drainage systems along the roadways around Lake Wickaboag. Many of the roads around the lake do not have proper drainage systems and stormwater is able to run across the roads into Lake Wickaboag. Curbs and catch basins can be installed on the downhill sides of the roads, along the lake, to catch and treat large amounts of stormwater that would otherwise run directly into Lake Wickaboag. The roads around Lake Wickaboag should be assessed and ranked from most critical to least critical in order to prioritize areas for improvements.

In addition, programs to encourage lake residents to install rain gardens and barrels can provide an additional means for stormwater control around Lake Wickaboag.

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Appendix A: Massachusetts Stormwater Handbook Regulations

The Massachusetts Stormwater Handbook has ten management standards for BMP's as follows (MSS, 2010):

1. No new stormwater conveyances (e.g. outfalls) may discharge untreated stormwater directly to or cause erosion in wetlands or waters of the Commonwealth.

2. Stormwater management systems shall be designed so that post-development peak discharge rates do not exceed pre-development peak discharge rates.

3. Loss of annual recharge to groundwater shall be eliminated or minimized through the use of infiltration measures including environmentally sensitive site design, low impact development techniques, stormwater best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume as determined in accordance with the Massachusetts Stormwater Handbook.

4. Stormwater management systems shall be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS)

5. For land uses with higher potential pollutant loads, source control and pollution prevention shall be implemented in accordance with the Massachusetts Stormwater Handbook to eliminate or reduce the discharge of stormwater runoff from such land uses to the maximum extent practicable.

6. Stormwater discharges within the Zone II or Interim Wellhead Protection Area of a public water supply, and stormwater discharges near or to any other critical area, require the use of the specific source control and pollution prevention measures and the specific structural stormwater best management practices determined by the Department to be suitable for managing discharges to such areas, as provided in the Massachusetts Stormwater Handbook

7. A redevelopment project is required to meet the following Stormwater Management Standards only to the maximum extent practicable: Standard 2, Standard 3, and the pretreatment and structural best management practice requirements of Standards 4, 5, and 6. Existing stormwater discharges shall comply with Standard 1 only to the maximum extent practicable. A redevelopment project shall also comply with all other requirements of the Stormwater Management Standards and improve existing conditions.

8. A plan to control construction-related impacts including erosion, sedimentation and other pollutant sources during construction and land disturbance activities (construction period erosion, sedimentation, and pollution prevention plan) shall be developed and implemented.

9. A long-term operation and maintenance plan shall be developed and implemented to ensure that stormwater management systems function as designed.

10. All illicit discharges to the stormwater management system are prohibited

Appendix B: Matrix Used For Site Selection

Table B-1: Site Selection Matrix

Site	Approximate Drainage Area (Acres)	Phosphorous Load (Kg/Yr)	BMP Cost Basis ($)	Total Phosphorous (%)	Estimated Cost of Phosphorous Load Reduction ($ Per kg removed)	Total Approximate Runoff (CF/Yr)	Soil Group	Rank
W-2	55	5.76	4760	65	28,758	4065188	A	20
W-4B	6	0.77	360	30	27,622	542025	D	12
W-5	3	0.35	2860	65	39,072	246375	A	13
W-7A	2	0.28	360	30	759,602	197100	D	10
W-7B	18	1.88	3810	65	8,011	1330425	NA	18
W-10A	1	0.18	9520	65	133,674	126144	A	17
W-10B	7	0.98	9520	65	122,217	689850	A	18
W-11	3	0.35	860	30	27,327	246375	NA	11
W-14	6	0.77	1720	30	16,156	542025	NA	15

Key	Rank
Good	1
Neutral	2
Bad	3

Appendix C: Statistical Analysis

Correlation Analysis

Pearson's method of correlation analyses is a statistical test to determine the linear association between two pairs of the data. The analysis is not dependent on the units of the data, meaning the data must be standardized before running the analysis. The data pairs can be standardized using equation C-1 and C-2.

$$X'_i = \frac{(X_i - \bar{X})}{S_X}$$

Equation C-1

$$Y'_i = \frac{(Y_i - \bar{Y})}{S_Y}$$

Equation C-2

The correlation coefficient, R, is a value of the linear relationship between the data pairs. Correlation coefficient values range from –1.00 to +1.00, where the negative sign indicates a negative correlation and zero indicates no correlation. The statistical significance of the analysis is determined using a correlation coefficient table (see Table C-1). This table takes two variables into consideration when determining that the correlation coefficient was not calculated based on pure chance. The two variables are the desired confidence level and number of data pairs. The P-value is a measure how reliable the data are. The P-value commonly used on research is 0.05, which is borderline significant. A "statistically" significant correlation would have a P-value of ≤ 0.01 and a highly significant correlation would be ≤ 0.005.

Table C-1: Correlation Coefficient Table

α					
	0.20	0.10	0.05	0.02	0.01
3	0.951	0.988	0.997	1.000	1.000
4	0.800	0.900	0.950	0.980	0.990
5	0.687	0.805	0.878	0.934	0.959
6	0.608	0.729	0.811	0.882	0.917
7	0.551	0.669	0.754	0.833	0.875
8	0.507	0.621	0.707	0.789	0.834
9	0.472	0.582	0.666	0.751	0.798
10	0.443	0.549	0.632	0.715	0.765
11	0.419	0.521	0.602	0.685	0.735
12	0.398	0.497	0.576	0.658	0.708
13	0.380	0.476	0.553	0.634	0.684
14	0.365	0.458	0.532	0.612	0.661
15	0.351	0.441	0.514	0.592	0.641
16	0.338	0.426	0.497	0.574	0.623
17	0.327	0.412	0.482	0.558	0.606
18	0.317	0.400	0.468	0.543	0.590
19	0.308	0.389	0.456	0.529	0.575
20	0.299	0.378	0.444	0.516	0.561
25	0.265	0.337	0.396	0.462	0.505
30	0.241	0.306	0.361	0.423	0.463
35	0.222	0.283	0.334	0.392	0.430
40	0.207	0.264	0.312	0.367	0.403
45	0.195	0.248	0.294	0.346	0.380
50	0.184	0.235	0.279	0.328	0.361
100	0.129	0.166	0.197	0.233	0.257
200	0.091	0.116	0.138	0.163	0.180

Using the data analysis tool pack in Microsoft Excel, correlation analyses were performed on the data from the three sites of concern. The correlation analysis was chosen from the Data Analysis Tools as seen in Figure C-1. The data were input in a worksheet where the data for each of the water quality constituents was arranged in columns, as shown in Figure C-2.

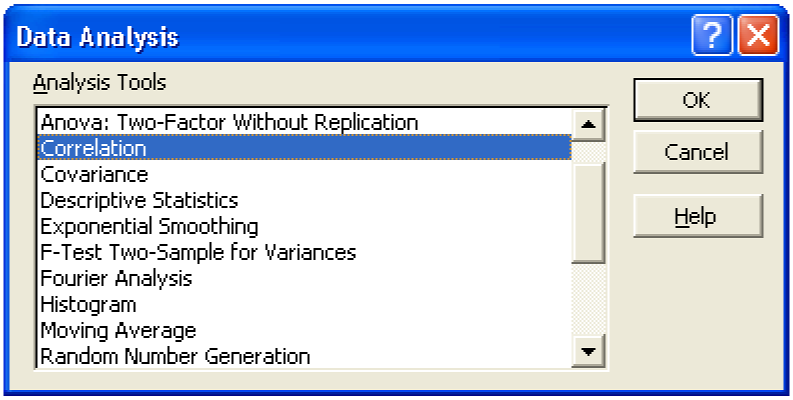


Figure C-1: Statistical analyses available on Microsoft data analysis tool pack.

The correlation analysis output was directed to another excel sheet where a table was generated giving the correlation coefficients for the pairs of constituents measured. As shown in Figure C-3, only one half of the table is filled because the same parameter that is being observed in a row, for example TSS, is the same parameter that is being observed in a column. For example the TSS in the first row is the same TSS that is in the first column. Thus, when observing the correlation between TSS and phosphorous, the correlation is the same for the TSS in the first column and the phosphorous second row as well as the TSS in first row and the phosphorous in the second column. Otherwise the data would repeat itself. The correlation between the same two constituents is always 1. The correlation coefficients from Excel were compared to R-values in the correlation coefficient table (see Table C-1) to determine if the relationships were significant at the 95% confidence level.

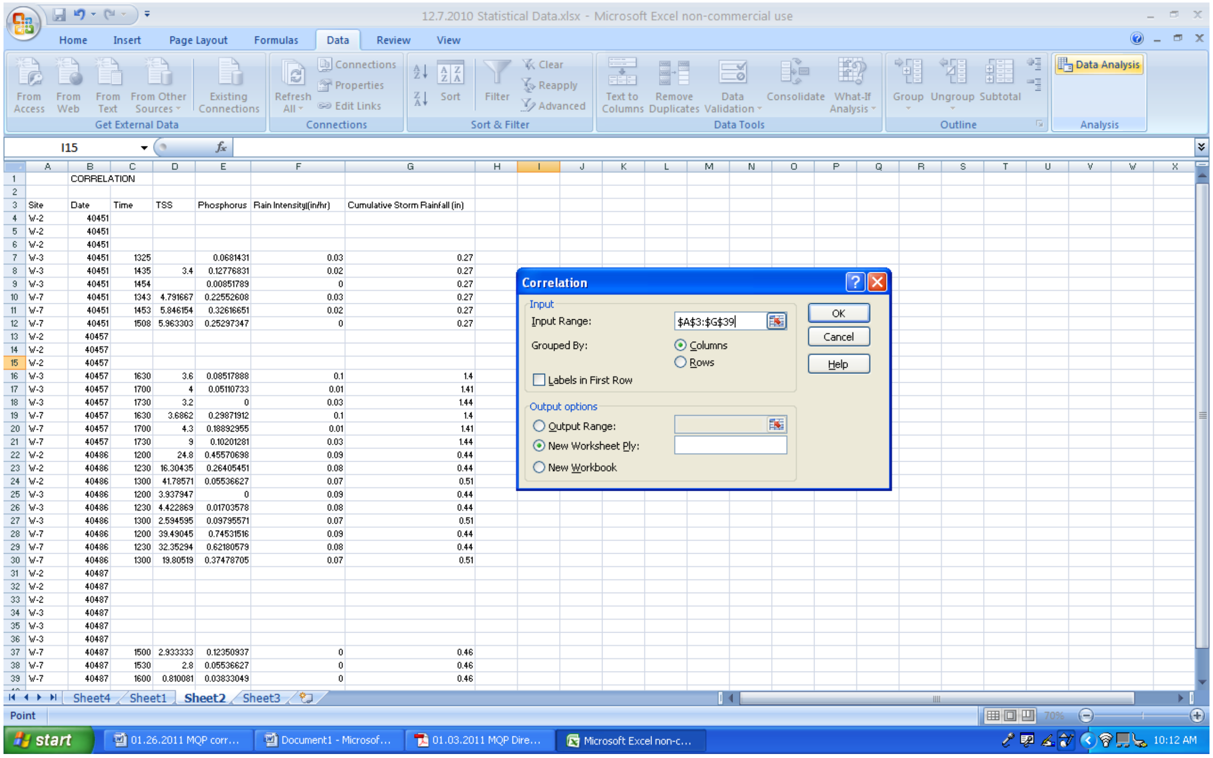


Figure C-2: Input for correlation analysis.

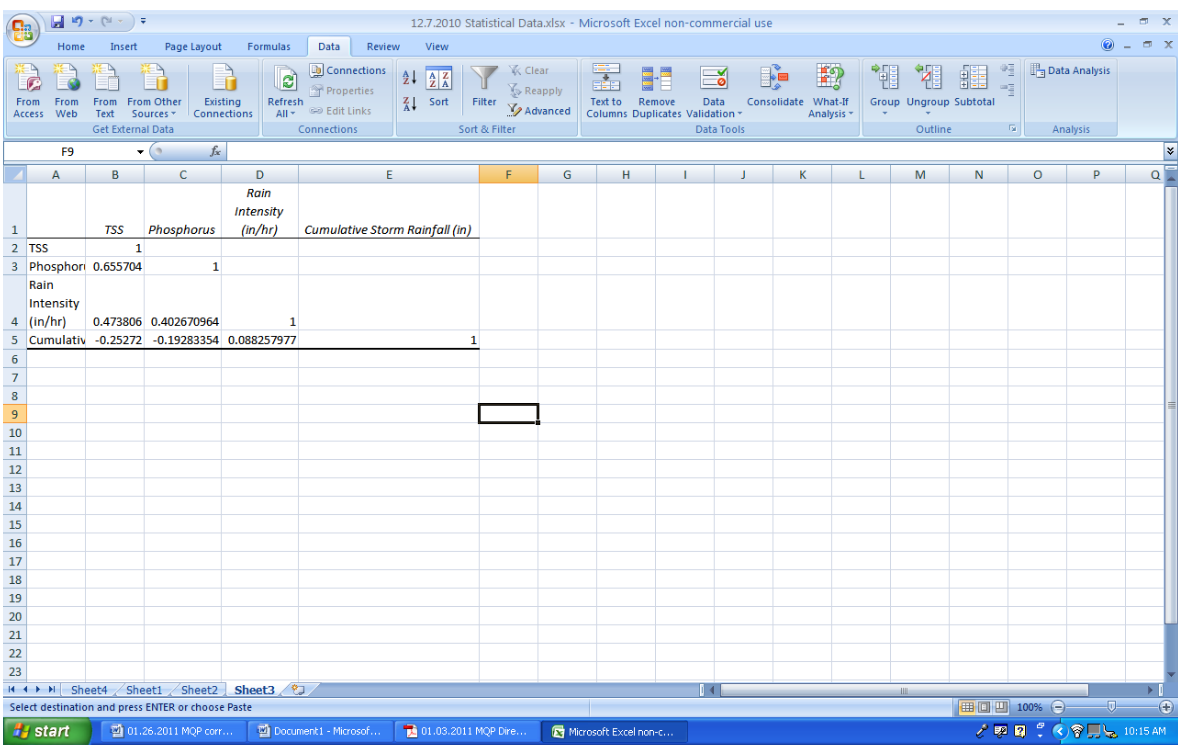


Figure C-3: Table output from correlation analysis.

ANOVA Analysis

The analysis of variance (ANOVA), also known as the F-test, is a method to determine the variation of the means of a group of data or variables to evaluate statistical significance. This method, when comparing two means, is similar to the t-test for independent samples. The single factor ANOVA test assumes a null hypothesis, H_0, which states there is no difference between the groups within the population, as shown in Equation C-3.

$$H_0: \beta_1 = \beta_2 = \cdots = \beta_q = 0$$

Equation C-3

If the analysis is found to be statistically significant, then the null hypothesis is rejected for the alternative hypothesis. The alternative hypothesis states that the means of the groups in the population are different. For this project, a P-value of ≤ 0.05 was used to determine statistical significance.

Microsoft Excel's data analysis tool pack was used to conduct the ANOVA analyses. The single factor test was chosen for analysis, as shown in Figure C-4. The data were arranged in two ways for analyses. The first was by sampling site and the second by TSS or phosphorous. The configuration for testing differences between sampling sites is shown in Figure C-5.

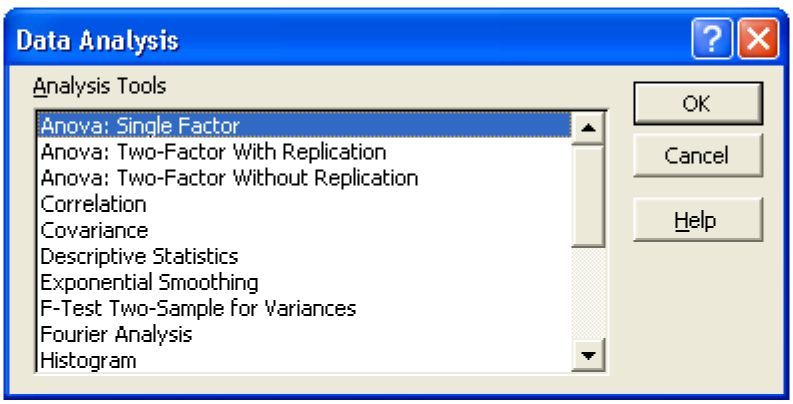


Figure C-4: Statistical analysis on Microsoft Excel used for ANOVA method.

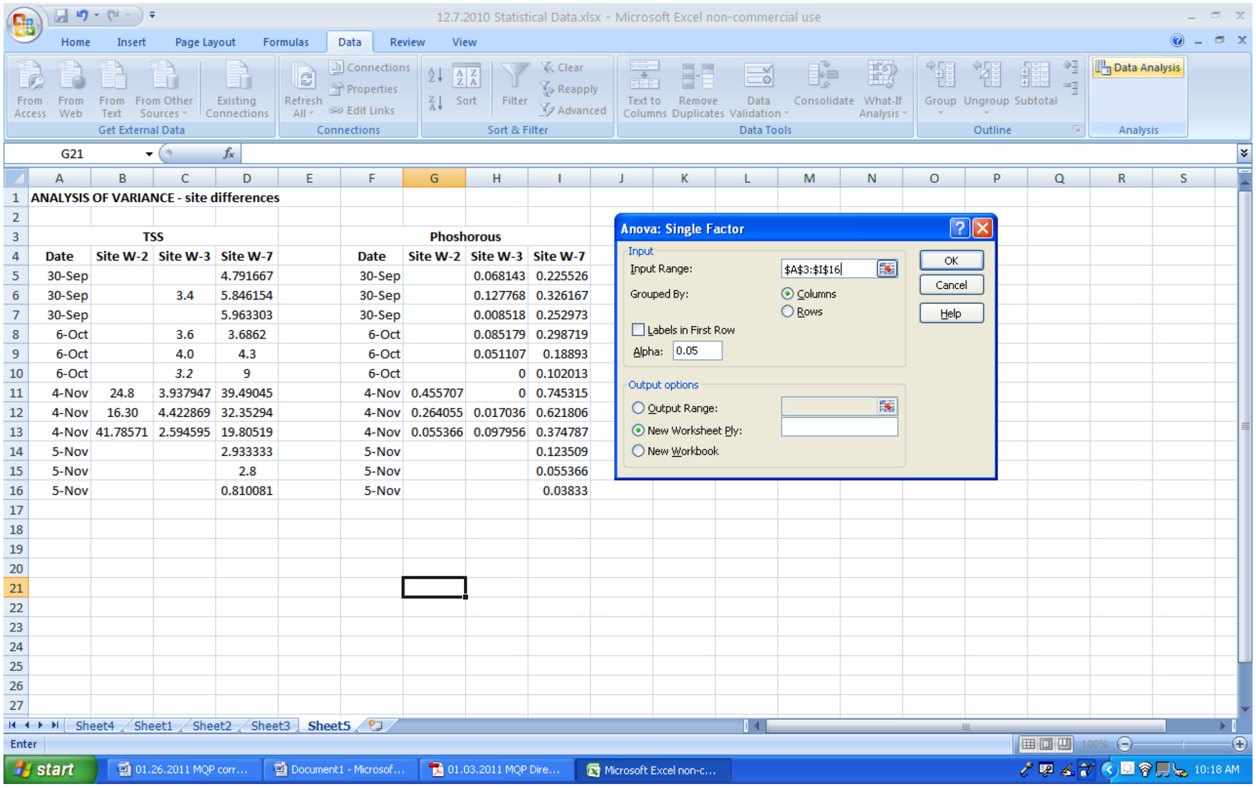
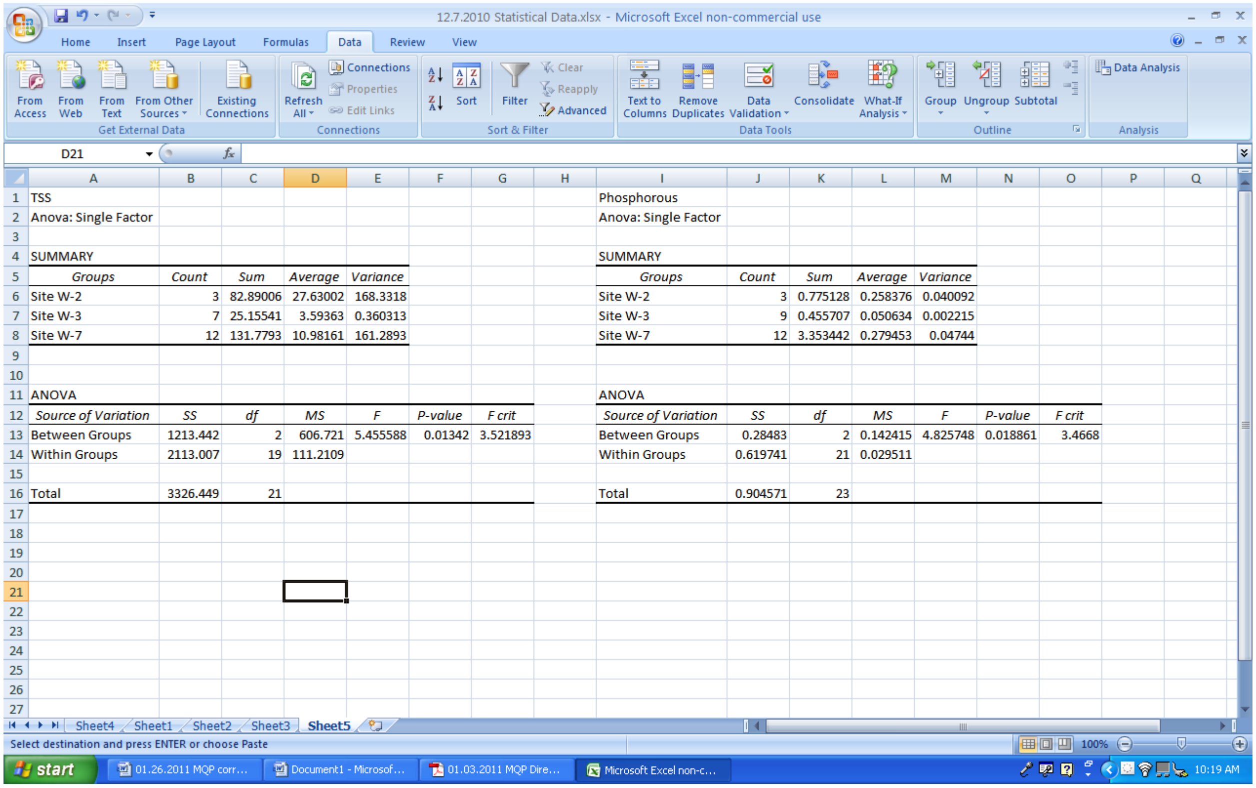


Figure C-5: Input data for ANOVA analysis based on each Lake Wickaboag sampling site.

The output from the analysis breaks down the sum, average, and variance from each sampling group. For example, Figure C-6 shows output for the TSS and phosphorous for each of the three sampling sites from Lake Wickaboag. The second table titled “ANOVA” gives statistical values between groups and within groups, including the sums of squares (SS), the degrees of freedom (df), the mean squares (MS), the variable under questioning (F), probability (P-value), and the critical value of F (F-critical). These values were computed by using the equations shown in Table C-2. The value of most importance was the P-value, which confirmed or rejected the initial hypotheses.



	A	B	C	D	E	F	G
1	TSS						
2	Anova: Single Factor						
4	SUMMARY						
5	Groups	Count	Sum	Average	Variance		
6	Site W-2	3	82.89006	27.63002	168.3318		
7	Site W-3	7	25.15541	3.59363	0.360313		
8	Site W-7	12	131.7793	10.98161	161.2893		
11	ANOVA						
12	Source of Variation	SS	df	MS	F	P-value	F crit
13	Between Groups	1213.442	2	606.721	5.455588	0.01342	3.521893
14	Within Groups	2113.007	19	111.2109			
16	Total	3326.449	21				

	I	J	K	L	M	N	O
1	Phosphorous						
2	Anova: Single Factor						
4	SUMMARY						
5	Groups	Count	Sum	Average	Variance		
6	Site W-2	3	0.775128	0.258376	0.040092		
7	Site W-3	9	0.455707	0.050634	0.002215		
8	Site W-7	12	3.353442	0.279453	0.04744		
11	ANOVA						
12	Source of Variation	SS	df	MS	F	P-value	F crit
13	Between Groups	0.28483	2	0.142415	4.825748	0.018861	3.4668
14	Within Groups	0.619741	21	0.029511			
16	Total	0.904571	23				

Figure C-6: Output from ANOVA analysis.

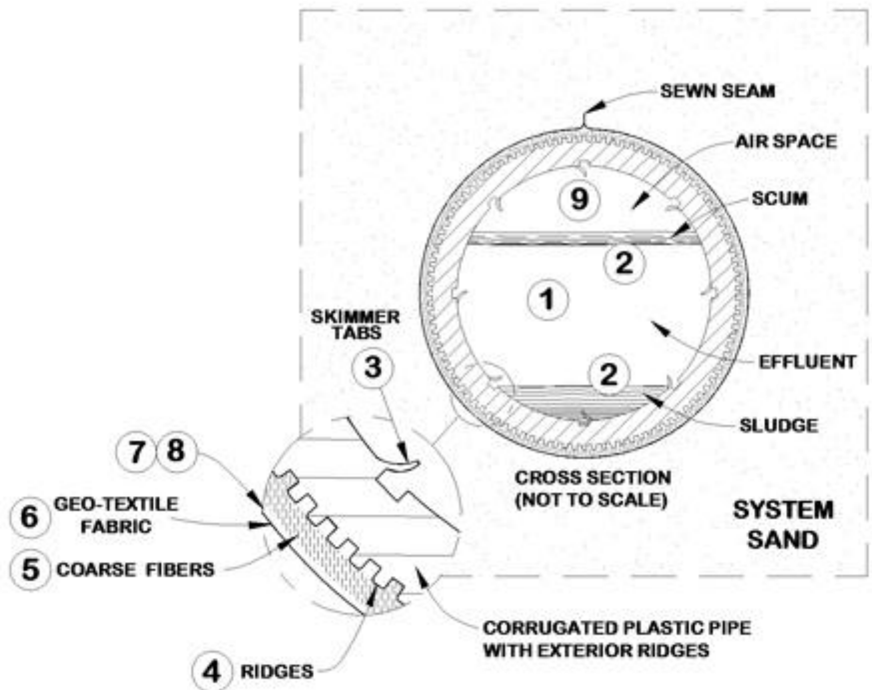
Table C-2: ANOVA Equations.

Name	Equation
Total sums of squares	$SS_T = \sum x^2 - \frac{\left(\sum x_T\right)^2}{N}$
Sums of squares between groups	$SS_b = \sum \frac{\left(\sum x\right)^2}{n} - \frac{\left(\sum x_T\right)^2}{N}$
Sums of squares within groups	$SS_W = SS_T - SS_b$
Degrees of freedom between groups	$df_b = \text{(number of groups } -1)$
Total degrees of freedom	$df_T = \text{(number of groups } -1)$
Degrees of freedom within groups	$df_W = df_T - df_b$
Mean squares between groups	$MS_b = \frac{SS_b}{df_b}$
Mean squares within groups	$MS_W = \frac{SS_W}{df_W}$
Critical value of F	$F = \frac{MS_b}{MS_W}$

Appendix D: Presby Enviro-Septic

ENVIRO-SEPTIC® WASTEWATER TREATMENT SYSTEM

NINE STEPS OF WASTEWATER TREATMENT: ENVIRO-SEPTIC® TREATS EFFLUENT MORE EFFICIENTLY TO PROVIDE LONGER SYSTEM LIFE AND TO PROTECT THE ENVIRONMENT.



STAGE 1:	WARM EFFLUENT ENTERS THE PIPE AND IS COOLED TO GROUND TEMPERATURE.
STAGE 2:	SUSPENDED SOLIDS SEPARATE FROM THE COOLED LIQUID EFFLUENT.
STAGE 3:	SKIMMER TABS FURTHER CAPTURE GREASE AND SUSPENDED SOLIDS FROM THE EXITING EFFLUENT.
STAGE 4:	PIPE RIDGES ALLOW THE EFFLUENT TO FLOW UNINTERRUPTED AROUND THE CIRCUMFERENCE OF THE PIPE AND AID IN COOLING.
STAGE 5:	A MAT OF COARSE RANDOM FIBERS SEPARATES MORE SUSPENDED SOLIDS FROM THE EFFLUENT.
STAGE 6:	EFFLUENT PASSES INTO THE GEO-TEXTILE FABRIC AND GROWS A PROTECTED BACTERIAL SURFACE.
STAGE 7:	SAND WICKS LIQUID FROM THE GEO-TEXTILE FABRIC AND ENABLES AIR TO TRANSFER TO THE BACTERIAL SURFACE.
STAGE 8:	THE FABRIC AND FIBERS PROVIDE A LARGE BACTERIAL SURFACE TO BREAK DOWN SOLIDS.
STAGE 9:	AN AMPLE AIR SUPPLY AND FLUCTUATING LIQUID LEVELS INCREASE BACTERIAL EFFICIENCY.

(Presby Environmental, 2009)

Appendix E: BMP Matrix

Table E-1: BMP Matrix

BMP Type	BMP Name	Pollutant Removal Efficiencies: Total Suspended Solids	Pollutant Removal Efficiencies: Phosphorous	Design Considerations: Drainage Area	Maintenance	Score
Structural Pretreatment BMP's	**Deep Sump Catch Basin**	25%	Insufficient Data	Small Urban lots	When the depth of deposits is greater than or equal to one half the depth from the bottom of the invert of the lowest pipe in the basin.	**9**
	Oil/Grit Seperator	25%	Insufficient Data	Parking lots with high contamination	Twice a year	**9**
	Proprietary Seperators	Varies by Unit (varies on placement in system)	Insufficient Data	Part of a stormwater treatment train	Remove sediment and other trapped pollutants at frequency or level specified bymanufacturer.	**11**
	Sediment Forebays	25%	Insufficient Data	Used with any size area	Four times per year and when sediment depth is between 3 to 6 feet.	**10**
	Vegetated Filter Strips	(25' wide filter strip) 10% (50' wide filter strip) 45%	Insufficient Data	Used with any size area	*Regularly mow the grass. *As needed to remove sediment from the toe of slope or level spreader and reseed bare spots.	**9**

Key	
Good	1
Neutral	2
Bad	3

		Pollutant Removal Efficiencies		Design Considerations		
BMP Type	BMP Name	Total Suspended Solids	Phosphorous	Drainage Area	Maintenance	Score
Treatment BMP's	**Bioretention Areas & Rain Gardens**	90% with vegetated filter strip or equivalent	30-90%	Small lots with space constraints	*Mow 2 to 12 times per year *Mulch, Fertilize, Remove dead vegetation, and Prune Annually	**6**
	Extended Dry Detention Basins	50% provided it is combined with sediment forebay or equivalent	10-30%	Contributing watershed greater than 10 acres	*Mow the upper-stage, side slopes, embankment, and emergency spillway. At least twice a year. *Remove sediment from the basin. At least once every 5 years.	**10**
	Proprietary Media Filters	Variable, depending upon media	Variable, depending upon media	Area where removal of pollutants ant TSS is critical	*Remove accumulated trash and debris During every inspection *Inspect to determine if system drains in 72 hours Once a year during wet season after large storm *Inspect filtering media for clogging; replace if clogged per manufacturer's specifications	**10**
	Sand & Organic Filters	80% with pretreatment	10-50%	Applicable to small drainage areas of 1 to 10 acres, although some designs may accept runoff of up to 50 acres.		**7**
	Wet Basins	80% with sediment forebay	30-70%	The minimum contributing drainage area must be at least 20 acres, but not more than one square mile.	*Mow the upper-stage, side slopes, embankment and emergency spillway at least twice a year. *Check the sediment forebay for accumulated sediment, trash, and debris and remove it at least twice a year. *Remove sediment from the basin as necessary, and at least once every 10 years	**7**

		Pollutant Removal Efficiencies		Design Considerations		
BMP Type	BMP Name	Total Suspended Solids	Phosphorous	Drainage Area	Maintenance	Score
Conveyance BMP's	**Drainage Channels**	0%	Insufficient Data	Drainage channels are suitable for residential and institutional areas of low to moderate density.	*Mow as necessary. Grass height shall not exceed 6 inches. *Remove sediment and debris manually at least once a year *Reseed As necessary. Use of road salt or other deicers during the winter will necessitate yearly reseeding in the spring	**11**
	Grassed Channel	50% for Regulatory Purposes (47%)	Insufficient Data	Properly designed grass channels are ideal when used adjacent to roadways or parking lots, where runoff from the impervious surfaces can be directed to the channel via sheet flow.	*Mow as necessary. Grass height shall not exceed 6 inches.	**9**
	Water Quality Swale	*Dry Swale (70%) *Wet Swale (70%)	20-90%	May be used to replace more expensive curb and gutter systems. Dry swales are most applicable to residential and institutional land uses of low to moderate density where the percentage of impervious cover in the contributing areas is relatively low. Wet swales may not be appropriate for some residential applications, such as frontage lots, because they contain standing water that may attract mosquitoes.	*Mow dry swales. Wet swales may not need to be mowed depending on vegetation as needed. *Remove sediment and debris manually At least once a year *Re-seed as necessary	**8**

BMP Type	BMP Name	Pollutant Removal Efficiencies: Total Suspended Solids	Pollutant Removal Efficiencies: Phosphorous	Design Considerations: Drainage Area	Maintenance	Score
Infiltration BMP's	**Dry Wells**	80%	Insufficient Data	Applicable for runoff from non-metal roofs and metal roofs located outside of the Zone IIs or IWPA of a public water supply, and outside industrial sites	*Measure the water depth in the observation well at 24- and 48-hour intervals after a storm. *Calculate clearance rates by dividing the drop in water level (inches) by the time elapsed (hr).	**9**
	Infiltration Basins	80% (with pretreatment)	60-70%	Contributing watershed area of approximately 2 to 30 acres	*Preventative maintenance Twice a year *Mow the buffer area, side slopes, and basin bottom if grassed floor; rake if stone bottom; remove trash and debris; remove grass clippings and accumulated organic matter Twice a year *Inspect and clean pretreatment devices Every other month recommended and at least twice a year and after every major storm event.	**5**
	Infiltration Trenches	80% (with pretreatment)	40-70%		Preventative maintenance	**5**
	Leaching Catch Basins	80% if combined with deep sump catch basin and if designed to be off-line	Insufficient Data	Use leaching catch basins as off-line devices in areas with highly permeable soils. Provide for the safe overflow from these devices in severe storm events, or in the event of clogging of the soils surrounding the device	*Remove sediment When the basin is 50% filled *Rehabilitate the basin if it fails due to clogging As needed	**9**
	Subsurface Structures	80%	Insufficient Data	Used in area with good quality runoff or pretreatment		**10**

		Pollutant Removal Efficiencies		Design Considerations		
BMP Type	BMP Name	Total Suspended Solids	Phosphorous	Drainage Area	Maintenance	Score
Other BMP's	**Dry Detention Basins**	Does Not Remove	5-50%	Not practical if the contributing watershed area is less than ten acres.	*Mow the upper-stage, side slopes, embankment and emergency spillway at least twice a year. *Check the sediment forebay for accumulated sediment, trash, and debris and remove it at least twice a year. *Remove sediment from the basin. As necessary, and at least once every 10 years	**9**
	Porous Pavement	80%	Insufficient Data	It can be constructed where the underlying soils have a permeability of at least 0.17 inches per hour.	*For porous asphalts and concretes, clean the surface using power washer to dislodge trapped particles and then vacuum sweep the area. For paving stones, add joint material (sand) to replace material that has been transported as needed *Inspect the surface annually for deterioration Annually *Assess exfiltration capability at least once a year. *When exfiltration capacity is found to decline, implement measures from the Operation and Maintenance Plan to restore original exfiltration capacity as needed, but at least once a year *Reseed grass pavers to fill in bare spots as needed	**9**
	Rain Barrels & Cisterns	*Offers no primary pollant removal benefits	*Rooftop Runoff presumed to be clean	Collects roof runoff to reduce overland flow.	*Seasonal emptying to elminate freezing.	**6**

(Department of Environmental Protection, 2001).

Appendix F: Total Phosphorous Lab Data

Table F-1: Calibration Curve Data (10.27.2010)

Standard (mg/L)	Absorbance
0.0	0.000
0.2	0.049
0.5	0.130
1.0	0.218
3.0	0.618
5.0	1.175

TableF-2: Calculated Phosphorous Data (10.27.2010)

Site	Date	Time	Absorbance	Total Phosphorous
W-7	9/30/2010	1343	0.043	0.168
W-7	9/30/2010	1453	0.065	0.269
W-7	9/30/2010	1508	0.049	0.195
W-7	10/6/2010	1630	0.059	0.241
W-7	10/6/2010	1700	0.035	0.131
W-7	10/6/2010	1730	0.016	0.044

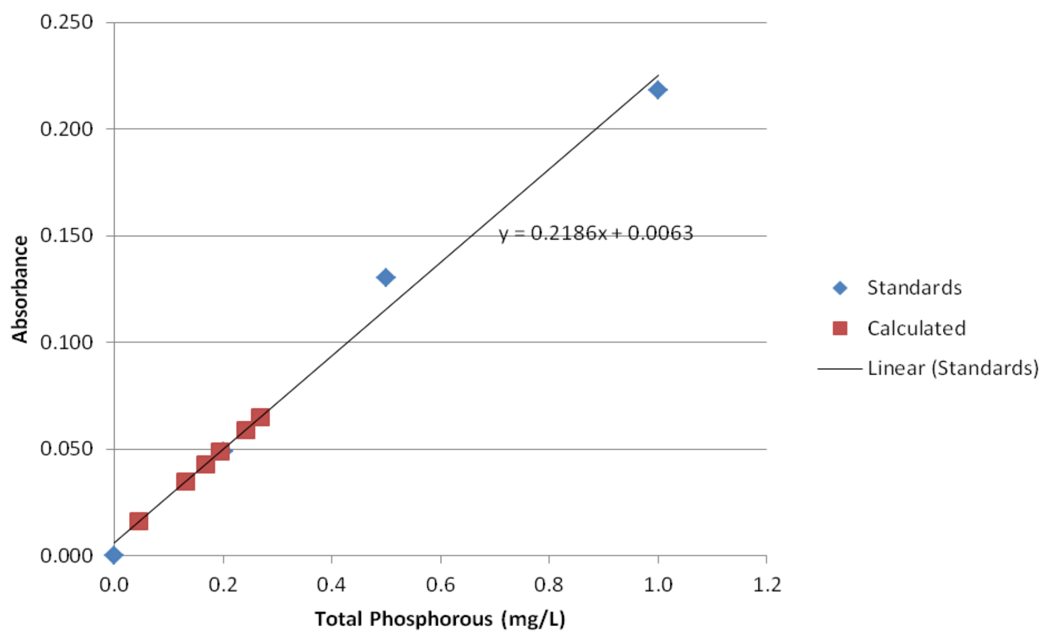


Figure F-1: Total Phosphorous Calibration Curve & Calculated Total Phosphorous (10.27.2010)

Table F-3: Calibration Curve Data (11.10.2010)

Standard (mg/L)	Absorbance
0.0	0.000
0.2	0.041
0.5	0.136
1.0	0.230
3.0	0.634
5.0	1.007

TableF-4: Calculated Phosphorous Data (11.10.2010)

Site	Date	Time	Absorbance	Total Phosphorous
W-2	11/4/2010	1200	0.109	0.456
W-2	11/4/2010	1230	0.064	0.264
W-2	11/4/2010	1300	0.015	0.055
W-3	9/30/2010	1325	0.018	0.068
W-3	9/30/2010	1435	0.032	0.128
W-3	9/30/2010	1454	0.004	0.009
W-3	10/6/2010	1630	0.022	0.085
W-3	10/6/2010	1700	0.014	0.051
W-3	10/6/2010	1730	0.001	-0.004
W-3	11/4/2010	1200	0.001	-0.004
W-3	11/4/2010	1230	0.006	0.017
W-3	11/4/2010	1300	0.025	0.098
W-7	11/4/2010	1200	0.177	0.745
W-7	11/4/2010	1230	0.148	0.622
W-7	11/4/2010	1300	0.090	0.375
W-7	11/5/2010	1500	0.031	0.124
W-7	11/5/2010	1530	0.015	0.055
W-7	11/5/2010	1600	0.011	0.038

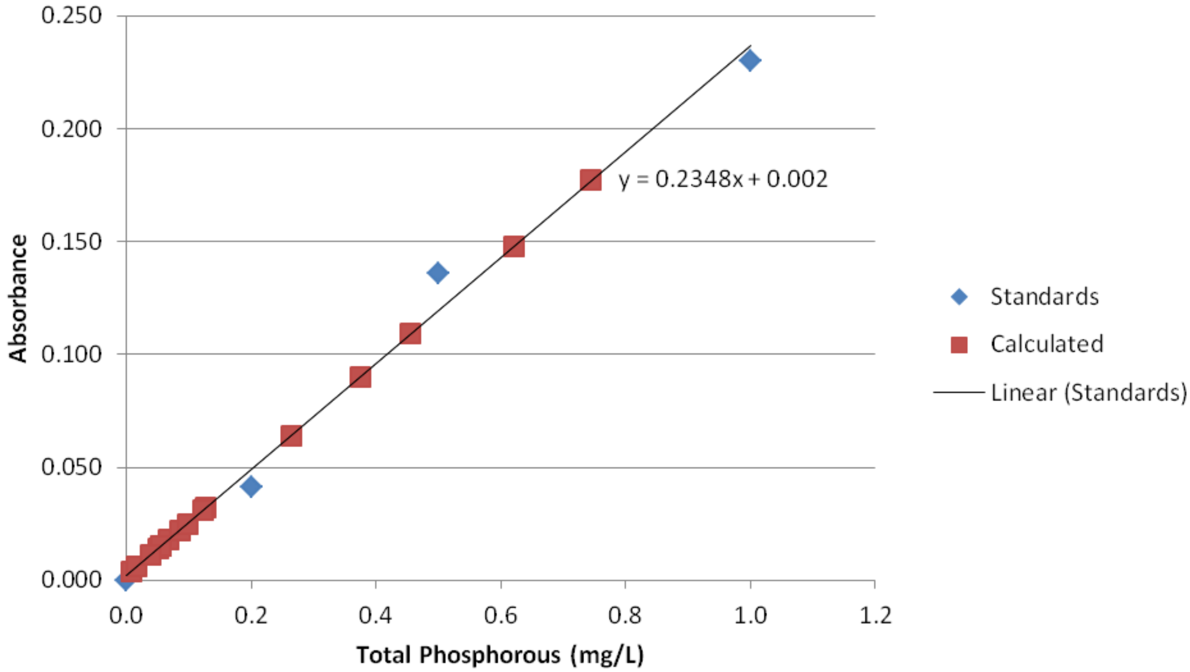


Figure F-2: Total Phosphorous Calibration Curve & Calculated Total Phosphorous (11.10.2010)

Appendix G: Total Suspended Solids Lab Data

TableG-1: Site W-2 TSS Lab Data

W-2							
Date	Site Description	Time of Testing	WB Weight Before Sample (g)	WA Weight After Sample (g)	(WA-WB) Weight of TSS (g)	Sample Volume (L)	Total Suspended Solids (mg/L)
9/30/2010	No Water Flowing/during rain	1342	n/a	n/a	n/a	n/a	n/a
		1435	n/a	n/a	n/a	n/a	n/a
		1508	n/a	n/a	n/a	n/a	n/a
						Average:	n/a
10/6/2010	No Water Flowing/during rain	1630	n/a	n/a	n/a	n/a	n/a
		1700	n/a	n/a	n/a	n/a	n/a
		1730	n/a	n/a	n/a	n/a	n/a
						Average:	n/a
11/4/2010	No Water Flowing/sample from Catch Basin	1200	47.1224	47.1286	0.0062	0.25	24.80
		1230	45.073	45.0775	0.0045	0.276	16.30
		1300	45.3544	45.3661	0.0117	0.28	41.79
						Average:	27.63

TableG-2: Site W-3 TSS Lab Data

W-3							
Date	Site Description	Time of Testing	WB Weight Before Sample (g)	WA Weight After Sample (g)	(WA-WB) Weight of TSS (g)	Sample Volume (L)	Total Suspended Solids (mg/L)
9/30/2010	Water stopped flowing halfway through first one liter bottle/rain stopped.	1342	n/a	n/a	n/a	n/a	n/a
		1435	48.6090	48.6124	0.0034	1.0	3.40
		1508	n/a	n/a	n/a	n/a	n/a
						Average:	3.4
10/6/2010	Raining	1630	51.1103	51.1139	0.0036	1.0	3.60
		1700	49.8314	49.8354	0.0040	1.0	4.00
		1730	50.2676	50.2708	0.0032	1.0	3.20
						Average:	3.60
11/4/2010	Raining	1200	42.7451	42.7484	0.0033	0.838	3.94
		1230	45.318	45.3221	0.0041	0.927	4.42
		1300	51.3361	51.3385	0.0024	0.925	2.59
						Average:	3.65

TableG-3: Site W-7 TSS Lab Data

W-7							
Date	Site Description	Time of Testing	WB Weight Before Sample (g)	WA Weight After Sample (g)	(WA-WB) Weight of TSS (g)	Sample Volume (L)	Total Suspended Solids (mg/L)
9/30/2010	Raining	1342	47.0927	47.0973	0.0046	0.9600	4.79
		1453	45.0402	45.0440	0.0038	0.6500	5.85
		1508	45.3264	45.3303	0.0039	0.6540	5.96
						Average:	5.53
10/6/2010	Raining	1630	42.7174	42.7213	0.0039	1.0580	3.69
		1700	47.3353	47.3396	0.0043	1.0	4.30
		1730	51.3070	51.3160	0.0090	1.0	9.00
						Average:	5.66
11/4/2010	Raining	1200	48.6359	48.6483	0.0124	0.314	39.49
		1230	51.1381	51.148	0.0099	0.306	32.35
		1300	49.8629	49.869	0.0061	0.308	19.81
						Average:	30.55
11/5/2010	Not raining during testing	1500	50.295	50.2972	0.0022	0.75	2.93
		1530	45.6892	45.692	0.0028	1.00	2.80
		1600	47.3616	47.3625	0.0009	1.111	0.81
						Average:	2.18

Note: A 1.5 micrometer Whatman Filter was used for lab testing of samples collected on, 9/30/2010 and 10/6/2010. A 1.2 micrometer VWR filter paper was used for lab testing of samples collected on, 11/4/2010 and 11/5/2010.