An Analysis of Water Quality Issues in Charlton, Massachusetts and Recommendations for Management and Remediation of Surface Water Bodies

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by

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Abstract

The town of Charlton, Massachusetts lacked a comprehensive water quality analysis and management plan for their surface water bodies. Historical water quality data were obtained from water bodies throughout the town and new data were collected in three water bodies selected based on their sizes, the availability of historical data, sampling accessibility, and the town's desire for further analysis. The data demonstrated water quality issues including high total phosphate concentrations, low dissolved oxygen, and low pH in comparison to state and federal guidelines. A management plan was designed to address the current water quality issues and to prevent future degradation. Recommendations included a regular water quality monitoring plan, aeration to increase dissolved oxygen levels, planting native vegetation to filter excess nutrients in runoff, integrating stormwater drainage systems to filter pollutants, and educating Charlton residents on water pollution prevention.

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1. Introduction

Water bodies are protected under the 1972 US EPA Clean Water Act (CWA) which requires states to follow water quality standards based on their designated use. Water bodies are ecosystems that support aquatic life and may be used for recreation and as drinking water sources. Massachusetts water body classifications are based on the following water quality parameters: dissolved oxygen (DO), temperature, pH, bacteria, solids, color and turbidity, oil and grease, and taste and odor.

This Major Qualifying Project (MQP) was sponsored through the town of Charlton, Massachusetts Conservation Commission and focused on performing a water quality analysis and developing a management plan for the surface water bodies in the town. Charlton is known for its natural beauty and agricultural land use. For years, Charlton's water bodies and the water-based recreation have been a valued aspect of the Charlton community. A water quality analysis and management plan are necessary to ensure the continued preservation and appreciation of Charlton's natural resources.

Charlton identified excess nutrient loading and vegetation as high priority water quality issues within its water bodies. In order to manage their watersheds, the town currently uses best management practices such as seasonal water testing, weed control, stormwater management, and public outreach. Despite their current work, the town lacked a consistent water sampling schedule as well as a comprehensive water quality analysis of the water bodies within the town's three watersheds.

The project team's goal was to perform a water quality analysis of key locations in the watersheds in Charlton. Using the data from this water quality analysis, the MQP team identified major water quality issues within the water bodies and developed a management plan to address these issues. Additionally, preventative management plans were created to help prevent the continued development of these water quality issues in the future. Finally, the MQP team designed a public education plan focused on teaching residents about ways to protect and preserve the water bodies in Charlton.

2. Background

Water systems and water bodies are used as drinking water sources, locations for recreational activities, and important zones for biological diversity. In order to protect the United States' water resources, the US EPA created the Clean Water Act (CWA) in 1972; requiring states and authorized tribes to adopt water quality standards (WQS) consisting of three components: designated uses, water quality criteria, and antidegradation policies (EPA, 2018a). Section 303(c)(2)(A) of the CWA posits that states and authorized tribes are responsible for adopting water quality criteria in order to "protect the public health or welfare, enhance the quality of water, and serve the purposes of this Act." These water quality criteria are meant to represent the conditions (e.g. concentrations of particular chemicals) sufficient to restore and maintain the chemical, physical, and biological integrity of water bodies and to protect their applicable uses (EPA, 2018a).

In order to provide scientific guidance to states and authorized tribes, the EPA publishes and revises criteria for water quality under section 304(a) (sometimes referred to as "304(a) criteria"). The criteria are meant to provide quantitative concentrations or levels, and/or qualitative measures of pollutants, that if not exceeded, will generally ensure adequate water quality for the protection of a designated use. 304(a) criteria are organized into Human Health Criteria, Aquatic Life Criteria, and Organoleptic (taste and color) Criteria. 304(a) criteria are not regulations enforced by law. The EPA requires that each state and authorized tribe use the 304(a) criteria as guidance to create and submit their own water quality standards. These submitted standards are then reviewed by the EPA to be approved or denied (EPA, 2018a).

The WQS are needed to regulate pollution from both point sources, (single, identifiable sources of pollution, such as a pipe or a drain) and nonpoint sources (inputs and impacts which occur over a wide area and are not easily attributed to a single source). The National Pollutant Discharge Elimination System (NPDES) Permit Program was created as a part of the CWA in 1972 to help address water pollution by regulation of point sources that discharge pollutants to waters of the US. A permit is typically a license for a facility to discharge a specified amount of pollutant into a receiving water under certain conditions. This permit regulates the allowable discharges from various point sources and even helps regulate pollution from nonpoint sources by monitoring municipal separate storm sewer systems (MS4s) (EPA, 2018a).

To further help reduce pollution from nonpoint sources, the CWA also required states and authorized tribes to define Best Management Practices (BMPs). BMPs are schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the discharge of pollutants to waters. BMPs include treatment requirements, operating procedures, structures, devices, and/or practices to control plant site runoff, spillage, leaks, sludge, waste disposal, or drainage from raw material storage (EPA, 2018a).

2.1 Massachusetts Water Body Classifications

Massachusetts water body classifications are based on the following water quality parameters: dissolved oxygen (DO), temperature, pH, bacteria, solids, color and turbidity, oil and grease, and taste and odor. Also included in Massachusetts classifications for surface waters are criteria for aesthetics, bottom pollutants or alterations, nutrients, radioactivity and toxic pollutants (EPA, 2006). For inland waters, the classes are Class A, Class B, and Class C (see Table 1).

Table 1: Inland Waters Class Characteristics (EPA, 2006).

Class	DO Minimum (mg/L)	Max Temp	pH Range	Bacteria Limit	Solids	Color & Turbidity	Oil & Grease	Taste & Odor
A	Cold Water: 6.0 Warm Water: 5.0	Cold Water: 68°F Warm Water: 83°F	6.5-8.3	Unfiltered water supply intake: FC limit 20 orgs/100mL or TC limit 100 orgs/100mL Bathing beaches a single sample limit: 235 E. coli colonies/100mL Other waters: limit 235 E. coli colonies/100mL	Free from floating, suspended, and settleable solids in concentrations that would impair any use, cause aesthetically objectionable conditions, or impair benthic biota or degrade chemical composition of the bottom	Free from color and turbidity in concentrations that are aesthetically objectionable or would impair any uses	Free from oil and grease, petrochemicals and other volatile or synthetic organic pollutants	None other than of natural origin
B	Cold Water: 6.0 Warm Water: 5.0	Cold Water: 68°F Due to discharge +3°F Warm Water: 83°F Due to discharge +5°F	6.5-8.3	Limit for all waters: 235 E. coli colonies/100mL	Free from floating, suspended, and settleable solids in concentrations that would impair any use, cause aesthetically objectionable conditions, or impair benthic biota or degrade chemical composition of the bottom	Free from color and turbidity in concentrations that are aesthetically objectionable or would impair any uses	Free from oil, grease and petrochemicals that produce visible film on surface of water, impart an oily taste to the water or an oily/undesirable taste to edible portions of aquatic life, coat the banks or bottom of the water course, or are toxic to aquatic life	None in concentrations that are aesthetically objectionable, impair uses, or cause tainting for undesirable flavors in edible portions of aquatic life
C	5.0 at least 16 hours of 24 hour period, no less than 3.0 at any time	85°F Due to discharge +5°F	6.5-9.0 No more than 1.0 standard unit outside of natural background range	630 E. coli colonies/100mL	Free from floating, suspended, and settleable solids in concentrations that would impair any use, cause aesthetically objectionable conditions, or impair benthic biota or degrade chemical composition of the bottom	Free from color and turbidity in concentrations that are aesthetically objectionable or would impair any uses	Free from oil, grease and petrochemicals that produce visible film on surface of water, impart an oily taste to the water or an oily/undesirable taste to edible portions of aquatic life, coat the banks or bottom of the water course, or are toxic to aquatic life	None in concentrations that are aesthetically objectionable, impair uses, or cause tainting for undesirable flavors in edible portions of aquatic life

Class A waters and their tributaries are designated as potential sources of public water supply. They are excellent habitats for fish and other aquatic life and wildlife, with an excellent aesthetic value and are protected as Outstanding Resource Waters (ORWs). ORWs are water bodies of high quality and are to be protected and maintained to that level. Class B waters are designated as habitat for fish, other aquatic life and wildlife with a consistently good aesthetic value. They are a suitable source of public water supply as long as the water undergoes appropriate treatment. These waters are also suitable for irrigation and other agricultural uses and are compatible for industrial cooling and process uses. Class C waters are designated as habitat for fish, other aquatic life and wildlife and have good aesthetic value. They are suitable for irrigation of crops used for consumption after cooking and are compatible for industrial cooling and process uses (EPA, 2006).

The Clean Water Act works to ensure that each state is restoring and maintaining the integrity of its water bodies. To aid in the monitoring and assessment of the different classes of waters, Massachusetts further organizes its waters into categories based on status and use. Status refers to the water quality and the uses can include drinking water supply, recreation and support of aquatic life. Reports are sent to the EPA on these conditions, and in particular, Massachusetts combines the information into an Integrated Report. This Integrated List includes the categories described in Figure 1.

Category 1 –	"Waters attaining all designated uses"
Category 2 –	"Attaining some uses; other uses not assessed"
Category 3 –	"No uses assessed"
Category 4a –	"TMDL is completed"
Category 4b –	"Impairment controlled by alternative pollution control requirements"
Category 4c –	"Impairment not caused by a pollutant – TMDL not required"
Category 5 –	"Waters requiring a TMDL" (i.e., the 303(d) List)

Figure 1: Integrated List Categories of MA Water Bodies (Beaton, 2017).

Waters whose uses are either supported or not assessed are included in Categories 1-3. Category 4 includes waters whose uses are impaired but do not require a Total Maximum Daily Load (TMDL) and is further divided into subcategories based on why the TMDL is not necessary. Category 5 includes waters whose uses are impaired and do require at least one TMDL (Beaton, 2017). TMDLs are established maximum levels of pollutants that will not jeopardize the water quality standards of the body of water. These five categories are used to depict the water in Charlton.

2.2 Water Quality

As described above, water quality standards are designed to protect the quality and function of water bodies. In order to accomplish these water quality standards, it is important to understand the factors that may cause harm to human and ecological health, how they affect the water bodies, and where they come from. A few of the most common water quality components are described below. These components are organized into physical, chemical, and biological groupings.

2.2.1 Physical Water Quality

In projects monitoring water quality in rivers and streams, it is useful to measure the surface water flow. Flow rate is calculated as the product of the water velocity (ft/s or m/s) and the cross-sectional area of the water body (ft^2 or m^2) (Equation 1) (Meals, 2008).

$$Q = v \times A$$

$$Q = Flow\ Rate\ (\frac{ft^3}{s}\ or\ \frac{m^3}{s})$$

$$v = Velocity\ (\frac{ft}{s}\ or\ \frac{m}{s})$$

$$A = Cross - Sectional\ Area\ (ft^2\ or\ m^2)$$

(Equation 1)

Flow rates generally increase during periods of heavy precipitation and decrease as evaporation increases in warm weather. They are also affected by human intervention like dams and water withdrawals for agriculture and industry (EPA, 2012).

Flooding, stream geomorphology, and aquatic life are all directly influenced by streamflow, as well as the generation, transport, and delivery of pollutants (Meals, 2008). While some organisms require fast moving water, others require stillness. Fast moving streams also maintain a higher dissolved oxygen concentration due to increased aeration. Water bodies with a high flow rate are better equipped to receive and dilute pollutants, whereas small streams often retain pollutants at more harmful concentrations. Sediment is also affected by velocity; being more likely to settle quickly in slow moving water bodies, and to stay suspended in fast moving water (EPA, 2012).

Total solids in water include dissolved, suspended, and settleable solids. Sources of solids include industrial discharges, sewage, fertilizers, road runoff, and soil erosion (APHA, 1992). Total solids can be monitored using various parameters, including the concentration of total dissolved solids (TDS) and turbidity.

In surface water, total dissolved solids include calcium, chlorides, nitrate, phosphorus, iron, sulfur, and other ions that can pass through a filter with a pore size of around 2 microns (0.002 cm) in size. TDS concentrations often increase sharply after rainfall, especially near developed watersheds (APHA, 1992). The concentration of total dissolved solids (TDS) can affect the water balance in aquatic organism cells, causing them to expand and shrink based on osmosis. This can affect the organism's ability to maintain proper cell density and can cause aquatic plants to either float up or sink down to depths they are not adapted to. Toxins, such as pesticides, also adhere readily to suspended particles and can cause buildup of these toxins when a high concentration of suspended particles exists within a water body (APHA, 1992).

Turbidity is a measure of how much the material suspended in water decreases the passage of light through the water. Along with being aesthetically undesirable, higher turbidity inhibits the photosynthesis of aquatic plants.

Water temperature can have a significant effect on the rates of biological and chemical processes. It is measured in degrees Fahrenheit (F) or degrees Celsius (C). Aquatic organisms require certain temperature ranges for their optimal health. If temperatures are outside this optimal range for an extended time period, they can become stressed and die. Temperature also affects oxygen levels (the higher the temperature, the lower saturation concentration of the dissolved oxygen); the rate of photosynthesis by aquatic plants; the metabolic rates of aquatic organisms; and the sensitivity of organisms to toxic wastes, parasites, and diseases. Water temperature can change through variations of weather, removal of shading streambank vegetation, impoundments (a body of water confined by a barrier, such as a dam), discharge of cooling water, urban stormwater, and groundwater inflows to a stream or lake (EPA, 2012).

2.2.2 Chemical Water Quality

Conductivity measures the electrical current that passes through a solution. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions carrying a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions carrying a positive charge) (EPA, 2012). Stream conductivity is generally influenced by the geology of the area that the stream flows through. Conductivity is increased when a stream runs through subsurface materials that are easily ionized (easily dissolved into ionic components). For example, streams running through clay soils tend to have higher conductivity than granite, as clay soil is more likely to ionize in water. Temperature also affects the conductivity of a water body: the warmer the water, the higher the conductivity (EPA, 2012).

Dissolved oxygen (DO) is the amount of oxygen present in water. Stream systems gain oxygen through mass transfer with the atmosphere and from plants as a result of photosynthesis. DO is consumed in stream systems through aquatic animal respiration, decomposition, and various other oxygen consuming chemical reactions (EPA, 2012). Running water dissolves more oxygen than still water since running water exposes more water surface to the air; resulting in an increased rate of oxygen transference. Dissolved oxygen content can vary greatly depending on the time of year, time of day, and vegetation. Levels fluctuate seasonally and over a 24-hour period. Cold water has a higher maximum dissolved oxygen concentration than warm water and water holds less oxygen at higher altitudes. If there is a rapid die-off of either algae or rooted plants, the dissolved oxygen levels can drop significantly as oxygen is consumed in the decomposition process. A lack of dissolved oxygen can make it difficult for a water body to sustain aquatic organisms (EPA, 2012). A DO level of greater than 9 mg/l is optimal for aquatic plants and animals, a DO level between 3.5- 6 mg/l is stressful to most forms of aquatic life, and a DO level below 3.5 mg/l is often fatal to oxygen-consuming aquatic plants and animals (EPA, 2012).

pH is the logarithmic concentration of hydrogen ions (H+). When H+ and OH- ions are in equal concentration, the pH is 7.0 (neutral). Below 7.0, the water is considered acidic (possessing more hydrogen ions than hydroxide ions). When the pH is above 7.0, the water is considered alkaline or basic (possessing more hydroxide ions than hydrogen ions). According to the EPA, pH values between 7-8 are optimal for most aquatic organisms and pH 6.5-8.5 are generally acceptable. A pH below 6.5 stresses the physiology of most organisms, reproduction is reduced, and aquatic insect populations decrease. An acidic water can also release toxic metals from the surrounding soils into the water systems. Changes in acidity can be caused by both natural and human factors. Natural factors that influence pH include subsurface material composition, pine/fir forests, precipitation, seasonal differences, and photosynthesis. Different types of materials can alter the pH level of a stream. For example, granite has almost no effect on pH, whereas calcium carbonate in limestone rock can buffer the water against changes in pH. The decomposition of needles from pine or fir forests can add acidity to the soil and increase the acidity in nearby streams. Precipitation also adds acidity to nearby water bodies; as falling through the air causes rain to dissolve gases like carbon dioxide and form a weak acid that then enters the water bodies. Photosynthesis performed by aquatic plants removes carbon dioxide from the water, thereby raising the waters pH. Human factors that can influence pH levels include contributions to acid rain, and point pollution sources such as agriculture in which pesticides may drain into nearby water systems (EPA, 2012)

Most nutrients needed to sustain aquatic plant-life are present in lakes due to natural processes (precipitation, groundwater inputs, biological sources, etc.). Limiting nutrients, most often phosphorus or nitrogen, can restrict or limit algal growth when not sufficiently present or utilized. In most lakes, either phosphorus or nitrogen is the limiting nutrient. When these limiting nutrients are increased through watershed activities such as applying fertilizers, septic system failure, sewage effluents, or increased runoff due to impermeable surfaces, excessive algae growth can occur. Monitoring levels of phosphorus and nitrogen can help predict potential for algal growth (EPA, 2005).

2.2.3 Biological Water Quality

Sewage contamination can introduce pathogenic (harmful) bacteria, viruses, and protozoa to a receiving body of water. Fecal bacteria can enter water systems through faulty wastewater treatment plants, septic systems, animal manure, and stormwater runoff (Cabral, 2010). Since it is extremely difficult, expensive, and time consuming to test directly for the presence of a large variety of these pathogens, water is usually tested for coliforms and fecal streptococci instead. While not harmful themselves, coliforms and fecal streptococci are commonly found in human and animal feces and can be used as indicators of potential sewage contamination.

2.3 Town of Charlton

Charlton, Massachusetts is a rural town in Southern Worcester County. It has a total area of 43.95 square miles, 0.1 square miles (700 acres) of which are water bodies such as ponds, reservoirs, and streams. Charlton, which has historically been an agricultural area, is known as a rural, slow paced, and safe community. As of 2010, Charlton had a population of 13,126 residents with an average population density of 296 people per square mile. This is relatively low in comparison to the City of Worcester (4815 people per square mile), as well as the average population density in Worcester County (528 people per square mile) (Central Massachusetts Regional Planning Commission, 2017). In 2000, the town appointed an Assessor to survey land-use in Charlton. The results of this Assessor's study can be found in Figure 2. This study found that the majority of land in Charlton is used for either residential or open space purposes (43% designated as residential, 27% designated as open space) (Central Massachusetts Regional Planning Commission, 2017).

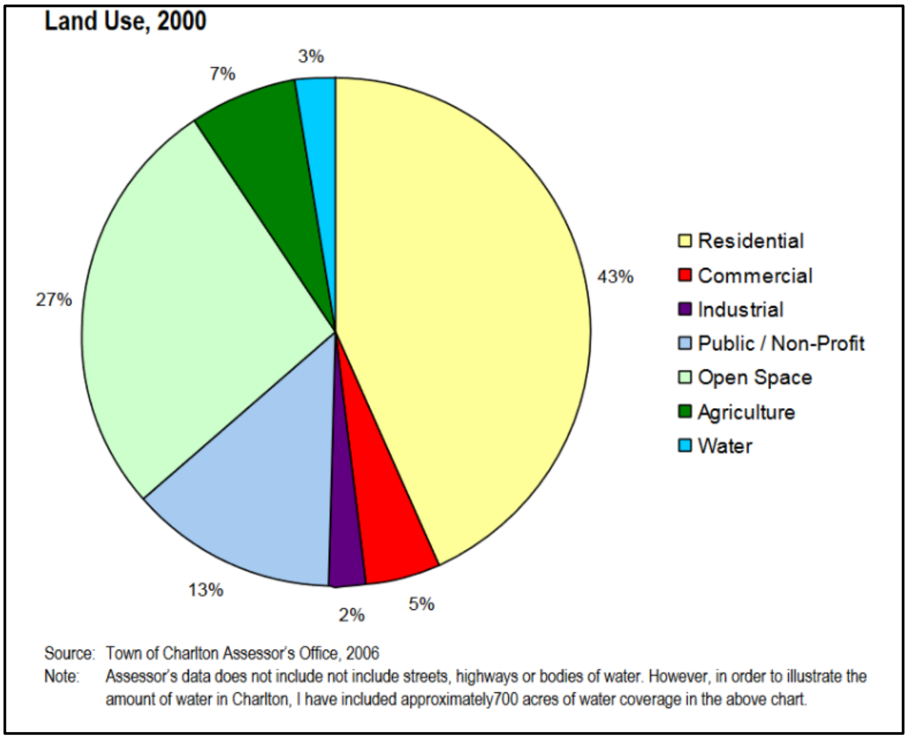


Figure 2: Land Use in Charlton (Central Massachusetts Regional Planning Commission, 2017).

In recent years, Charlton has been experiencing high growth rates in population, housing, and industry. This growth is expected to lead to a population of 14,775 residents by 2030. The water bodies in Charlton are an attractive feature of the town in regard to residential development, which caused the recent housing increase (Central Massachusetts Regional Planning Commission, 2017). Major roadways like Route 20 and the Massachusetts Pike run through Charlton, as shown in Figure 3. Increased runoff from these impervious surfaces may introduce pollutants to water bodies from road salts or gasoline residue from vehicles.

Figure 3: Map of Charlton with Major Roadways (Google Maps, 2018).

2.3.1 Drinking Water

Charlton does not have its own municipal water supply. The town has one medium yield aquifer (releases 100-300 gallons of water per minute) which covers about 62 acres of land. 90% of the residents and businesses in Charlton rely on private wells, while the other 10% have town water (Board of Health, personal communication, November 14, 2018). However, the town has had groundwater contamination issues in many private wells. The town experiences road salt contamination in wells in areas along Route 20 and the Massachusetts Turnpike. There is also a vein of naturally occurring arsenic that runs through subsurface soils (Central Massachusetts Regional Planning Commission, 2017). Several wells in Charlton have concentrations above regulatory levels of trichloroethane (industrial solvent) most likely from a "6-acre unregulated and uncapped landfill the town ran until it was closed nearly 40 years ago" (Lee, 2017b). In areas around Mass Turnpike 6W and 5E service facilities, there have been detections of benzene and MTBE (gasoline additives) in wells, which have migrated underground through bedrock fissures to pollute dozens of private wells. Responsible parties include the Mass Turnpike Authority and a few oil companies, including Exxon Mobil. These issues stemmed from storage tanks that failed in the 1980s (spilling thousands of gallons of gasoline) and a failed 6,000-gallon underground gasoline tank in 1986 (LaPlaca, 2015b; 2016). Exxon Mobil is the responsible party for the incidents and thus reached an agreement with the town in April 2016 for supplying water to those affected. Also, Casella Waste Systems operates a Southbridge landfill on the southwest Charlton border and is the responsible party for residential water contamination by 1-4 dioxin, a human carcinogen. In 2015, Casella Waste Systems reported that 21 residential wells tested positive for 1-4 dioxin, and the concentrations in four of the wells exceeded drinking water standards (LaPlaca, 2015a). There is current work on the construction of a water line for those residents with contaminated wells (Lee, 2017a). In the meantime, these residents are receiving deliveries of bottled water or whole-house filtration systems until the water line is completed.

Thus, the town has been working on solutions to supply water to residents and businesses. In 2009, an Inter-Municipal Agreement was created between Charlton and Southbridge to provide water to Charlton. Once the system improvements are completed, there would be a total of 500,000 gallons per day of water available to Charlton from Southbridge. These improvements are being funded by an agreement made in 2016 with ExxonMobil over the MTBE contaminated wells (locations include Charlton Middle School, Charlton Heritage Elementary School, Bay Path Regional High School, and the Masonic Home).

Charlton is still working on activating the water system. Currently, about 270 homes and businesses have public water (which is about 110,000 gallons per day) while the remaining have private wells (Water/Sewer Commission, personal communication, November 20, 2018). There are 11 community groundwater wells and 52 non-community wells (32 of which are transient). The community wells are a “public water system serving 15 service connections used by year-round residents, or regularly serves at least 25 year-round residents” (Central Massachusetts Regional Planning Commission, 2017).

2.3.2 Surface Waters

There are more than 700 acres of water in Charlton, MA consisting of ponds, reservoirs and streams (see Appendix A, Tables A-1 and A-2). In addition, wetlands cover 7% of the Charlton’s land area (about 2,000 acres). Many of the surface waters are man-made and are the result of industrial operations or farms. Most of Charlton “lies within the Quinebaug (14,861 acres) and French River (13,164 acres) Watersheds, and a small portion is in the Chicopee Watershed” (Central Massachusetts Regional Planning Commission, 2017).

Threats to surface water quality in Charlton include old, on-site waste disposal systems, runoff from roads, and runoff from farming operations. The environmental challenges faced continue to exist due to “new development, hazardous waste sites, erosion, and sedimentation” (Central Massachusetts Regional Planning Commission, 2017). The MassDEP lists 238 brownfield sites in Charlton, four of which are Tier 1 disposal sites and nine of which are Tier 1D disposal sites. Tier 1 disposal sites have “evidence of groundwater contamination with oil and/or hazardous material; an imminent hazard; at least one remedial actions are required as part of an Immediate Response Action” (Central Massachusetts Regional Planning Commission, 2017). Tier 1D disposal sites are if the “responsible party or potential responsible party fails to submit to MassDEP a Permanent Solution Statement or a Tier Classification Submittal, or the person undertaking response actions is noncompliant with any requirements" (Central Massachusetts Regional Planning Commission, 2017).

In 2016, the latest Integrated Lists of Waters in Massachusetts was released by the Massachusetts Department of Environmental Protection (Massachusetts DEP). Within the town of Charlton, five water bodies have completed Total Maximum Daily Loads (TMDLs), four have impairments not caused by pollutants so they do not require a TMDL, and seven need a TMDL. The status of the various Charlton water bodies is shown below in Tables 2, 3, and 4 from the Massachusetts 2016 Integrated List of Waters.

Table 2: Category 4a Water Bodies in Charlton (Beaton, 2017).

Name	Description	Size (acres)	Pollutants Addressed by TMDL
Buffumville Lake	Charlton/Oxford	199	Non-native aquatic plants; mercury in fish tissue
Dresser Hill Pond	Charlton	8	Turbidity
Gore Pond	Dudley/Charlton	169	Non-native aquatic plants; excess algal growth; dissolved oxygen; turbidity
Jones Pond	Charlton/Spencer	30	Aquatic plants (macrophytes); nutrient/eutrophication biological indicators
Pike Pond	Charlton	28	Turbidity

Table 3: Category 4c Water Bodies in Charlton (Beaton, 2017).

Name	Description	Size (acres)	Pollutants Addressed by TMDL
Buffum Pond	Charlton/Oxford	23	Non-native aquatic plants
Granite Reservoir	Charlton	207	Non-native aquatic plants
Pierpoint Meadow Pond	Dudley/Charlton	5	Non-native aquatic plants
Railroad Pond	Charlton	7	Non-native aquatic plants

Table 4: Category 5 Water Bodies in Charlton (Beaton, 2017).

Name	Description	Size	Impairment Cause
Little River	Headwaters, outlet Pikes Pond, Charlton to inlet Buffumville Lake, Charlton	3.5 miles	Aquatic macroinvertebrate bioassessments; dissolved oxygen
Cady Brook	Headwaters, outlet of Glen Echo Lake, Charlton to Charlton City WWTP outfall, Charlton	1.5 miles	Low flow alterations; ambient bioassays - chronic aquatic toxicity
Cady Brook	Charlton City WWTP outfall, Charlton to confluence with Quinebaug River, Southbridge	5.1 miles	Low flow alterations; E. coli; nutrient/eutrophication biological indicators
Glen Echo Lake	Charlton	115 acres	Dissolved oxygen
McKinstry Brook	Headwaters, east of Brookfield Road, Charlton, (excluding intermittent portion) to the confluence with the Quinebaug River, Southbridge	7.3 miles	Debris/floatables/trash; E. coli
Sibley Pond	North Basin, Charlton	22 acres	Aquatic plants (macrophytes); dissolved oxygen; turbidity
Sibley Pond	South Basin, Charlton	19 acres	Aquatic plants (macrophytes); dissolved oxygen; turbidity

2.3.3 Environmental Initiatives and Concerns Related to Water

Charlton is a conservation and sustainability conscious town. It has numerous events throughout the year focused on cleaning up the town and educating residents on how they can contribute to conservation efforts. Many of these conservation initiatives focus on the water bodies in Charlton. One of Charlton's newer conservation initiatives is their participation in the Think Blue Campaign. The Think Blue Campaign is a partnership between Charlton and the Massachusetts Statewide Municipal Stormwater Coalition and several other Massachusetts towns and cities. It focuses on preventing non-point source water pollution by educating residents on how to prevent litter and hazardous materials from polluting waters through stormwater runoff. The campaign used rubber ducks as an analogy to pollutants in order to demonstrate how debris and hazardous substances can be picked up by stormwater and carried to local water bodies. The campaign specifically focuses on common pollutants generated by the average resident such as litter and car oil that is spilled. Additionally, there is another education aspect of the campaign that focuses on teaching people to clear leaves and debris from sewer drains near their homes in order to prevent flooding and therefore prevent more runoff water from reaching waterbodies (Town of Charlton Conservation Commission, n.d.).

Another conservation initiative led by the town of Charlton is the 2017 Town of Charlton Open Space and Recreation Plan. This plan focuses on creating more and providing better access to open spaces and recreation opportunities within the town of Charlton. Regarding water bodies specifically, the town lists the "long term protection of surface and groundwater resources" as one if its four main objections for their plan. As explained previously, Charlton's water bodies attract housing development within the town which is a main motivating factor for Charlton's focus on protecting and preserving their water bodies. Additionally, these water bodies create space for recreation areas and conservation areas which are also important to Charlton residents. The plan identifies old, on-site waste disposal systems, runoff from roads, and runoff from farming operations as the three main contributors to water contamination within Charlton. In addition to working towards preventing these three sources of contamination, the plan also focuses on educating residents on all the access points to public water bodies in town as well as improving the public services such as parking lots and bathrooms at these water bodies (Central Massachusetts Regional Planning Commission, 2017).

Boating is a common recreational activity amongst Charlton residents due to easy access to numerous water bodies. One main environmental issue with boating is the introduction of invasive species into water bodies through boats. When boats are used at multiple water bodies, species from one water body may attach to a boat or a boat trailer and then are transported and introduced to a new water body when the boat is brought to that water body. Invasive species can be disastrous to water bodies as they are often able to out-compete native species and therefore drastically change the ecological make-up of a water body. Charlton is combatting this issue through education materials such as the Glen Echo Lake Safe Boat and Water Craft Operation document. This document outlines safe boating rules such as enforced speed limits, headlight rules, and other safety precautions and procedures. In addition to this safety aspect, the document also outlines how boat owners can prevent the introduction of invasive species into Charlton's water bodies by making sure their boat and boat trailers are clean before introducing them into Glen Echo Lake or other Charlton water bodies (Glen Echo Improvement Association, Inc., 2006).

Charlton also has many smaller conservation focused events throughout the year. For example, they hold a few household hazardous waste disposal days throughout the year. At these events, residents can dispose of their hazardous waste in a safe and environmentally friendly manner and can also receive education materials on stormwater runoff with similar education themes as the Think Blue Campaign described above. The town also holds clean up days such as the Annual Shoreline Clean Up Event, where participants pick up litter and debris along shorelines, and clean up events on Earth Day, where participants clean up farmlands and areas prone to collecting litter and debris (Town of Charlton, 2017).

Charlton has a strong focus on educating its residents on conservation initiatives throughout the school year. The local newspaper, which is free to all residents, regularly posts flyers relating to stormwater runoff and preventing non-point source pollution. The local broadcast channels also broadcast education materials with the same messages. Additionally, these educational flyers are posted in the local schools (Town of Charlton, 2017).

Residents of Charlton have many opportunities to get involved in the town's conservation efforts. As described above, residents can get involved by volunteering at town organized clean up events or by bringing their hazardous waste to household hazardous waste disposal events. Additionally, residents can sit on the Household Hazardous Waste Committee alongside town officials. This committee focuses on finding ways to limit the amount of hazardous waste making its way into the natural environment and local water bodies and also making sure there are resources available for residents to dispose of their hazardous waste. Additionally, local Boy Scout and Girl Scout troops and the local high school Science Club often volunteer at Household Hazardous Waste Disposal Days and clean up days (Town of Charlton, 2017).

2.4 Conclusion

Charlton, Massachusetts, historically known as a safe, rural community in Southern Worcester County, has a wide variety of water bodies with various levels of water quality and water classifications. The town has a total area of 43.95 square miles with 0.1 square miles (700 acres) of water bodies. These water bodies are locations for recreational activities, such as swimming and boating, and are important zones for biological diversity. To protect these water bodies, Charlton has adopted water quality standards (WQS) consisting of three components: designated uses, water quality criteria, and antidegradation policies as laid out by 1972 US EPA Clean Water Act (CWA). The water bodies within Charlton's limits greatly affect the day to day lives of the residents and improve the quality of life within the town. Many living in the community see the available access to various water bodies and water recreation as a key benefit of living in the town. To protect these integral cultural and environmental resources, Charlton has gone to great lengths to maintain and preserve high levels of water quality in its water bodies and to extend educational programs and resources about water quality protection to its residents. Despite these efforts, Charlton has noticed a decline in the conditions of some of its water bodies in recent years. This project seeks to identify water quality conditions of concern through water sampling and testing and includes a proposal of best management practices to address those water quality issues.

3. Methods

The goal of this project was to analyze Charlton's surface water bodies to identify areas of poor water quality and develop recommendations for sustaining and improving water quality. This chapter discusses the data collection methods, including collection of historical data and testing of water samples collected by the MQP group in 2018. For the 2018 testing, water bodies were selected for testing based on various criteria, and then water quality was testing in both the field and laboratory. Lastly, the chapter discusses data analysis methods.

3.1 Historical Data Collection

The Charlton Conservation Commission provided the MQP team with historical water quality sampling data which included measurements of locations, dates, water and air temperature, sampling depth, pH, turbidity, conductivity, total and fecal coliforms, DO, orthophosphate, nitrous oxide, nitrate, ammonia, total phosphorus, total phosphate, reactive phosphate, total dissolved solids, flow rate, total alkalinity, suspended solids, chloride, kjeldahl-nitrogen, phytoplankton, chlorophyll-a, secci depth, true color, apparent color, calcium hardness. Not all of these parameters were recorded for all the water bodies in the watersheds, and not all of these parameters were relevant to the MQP team's field of study. Therefore, only the parameters detailed in Section 4.1 were used in the analysis. These records were electronic documents given in the form of Microsoft Word documents, Microsoft Excel tables, and scans of physical documents. They were then combined into one master Microsoft Excel data sheet. This master data sheet included data from 852 separate sampling occurrences, and covered data from Baker Pond, Buffumville Lake, Cady Brook, Cranberry Meadow Pond, Glen Echo Lake, Little Nugget Lake, Prindle Lake, Putnam Pond, Snow Pond, and South Charlton Reservoir. The data ranged from December 1985 through November 2018; however, only data collected from 2008 to 2018 was considered in order to ensure that the analysis was current.

3.2 Water Quality Data Collection 2018

To supplement the provided historic data, the MQP team identified key sampling locations then developed standard field and laboratory test procedures. These procedures were subsequently used to conduct water quality sampling and testing.

3.2.1 Sampling Locations

This project focused on four sampling sites in three water bodies in the town of Charlton. These locations were chosen based on the following criteria: size, availability of previous data, accessibility of location site, and desire from the town of Charlton for data. It was also important to have at least one sample location in each of the three watersheds in Charlton (Chicopee, French, Quinebaug). This selection process is shown in Table 5.

Table 5: Sampling Site Selection Process.

Scoring Key: High score = High interest

Color	Red	Yellow	Green
Points	0	1	2

Watershed	Water Body	Size (acres)	Availability of Historic Data	Accessibility	Desire from Town	Score
Chicopee	Cranberry Meadow Pond	74.00	Low	High	High	7
French	Baker (Gore) Pond	169.00	High	Medium	Neutral	4
French	Buffumville Lake	200.00	Low	High	High	8
French	Little Nugget Lake	12.86	Low	High	Neutral	6
French	Little River	6.36	Low	Low	Neutral	3
French	Pierpoint Meadow Pond	90.00	Low	Medium	Neutral	5
French	Pikes Pond	32.00	Low	Low	Neutral	4
French	Potter Brook	1.16	Low	High	Neutral	5
French	Putnam Pond	19.66	Low	Medium	Neutral	5
French	Snow Pond	1.87	Medium	Low	Neutral	2
French	South Charlton Reservoir (Granite Reservoir)	206.85	High	High	Low	4
Quinebaug	Cady Brook	12.00	Low	High	High	7
Quinebaug	Glen Echo Lake	116.00	High	Low	Low	2
Quinebaug	McKinstry Brook	8.84	Low	Low	Neutral	3
Quinebaug	Prindle Lake	71.00	Low	High	Low	5

Sources: Central Massachusetts Regional Planning Commission (2017), VHB (2007), & EPA (2010).

Larger water bodies were favored because they have a relatively high impact on the overall Charlton water system compared to smaller water bodies. Therefore, water bodies with an area of 100 acres or more were the most desirable and are indicated in green in Table 5; water bodies with an area of 10 acres to 99.99 acres were moderately desirable and are indicated in yellow, and water bodies with an area of 9.99 acres or less were the least desirable and were therefore indicated in red.

Water bodies with a low availability of historical data were preferred since there was a greater need for new data to be collected, thus, these water bodies were highlighted in green in Table 5. Water bodies with some historical data but not a comprehensive amount were moderately desirable to collect new data for and therefore indicated in yellow. Water bodies with a high amount of historical water data available were least desirable for the purpose of this project because there was little need for further data collection.

In terms of accessibility, water bodies with safe access points were highly desired. Some water bodies had public access points while others had private entry ways that were made accessible to us through personal connections between the town of Charlton and land owners. These water bodies were highly favored. Some water bodies had roadside access points that were moderately safe and easy to access, and thus were indicated in yellow. Remaining water bodies only had private access points or had steep embankments making sampling access dangerous.

Finally, the Charlton town officials expressed their own interest in specific water bodies, indicated in green in Table 5. Those of lesser or of no importance are indicated in yellow and red, respectively.

In order to quantitatively rank the possible water body sampling sites, each color was converted into a numerical score. Green criteria earned a location site 2 points, yellow criteria earned 1 point and red criteria earned 0 points. The points for each sample site were then summed and the sites with the highest point values were chosen as sampling sites. As there were four criteria and the points ranged from 0 to 2 per criterion, the maximum score was 8 points. The three water bodies with scores of 7 or 8 (Cranberry Meadow Pond, Buffumville Lake, and Cady Brook) are highlighted blue in Table 5 as these three were selected for water quality sampling and analysis in 2018 by the MQP team. Details on the sampling locations are provided below.

Cranberry Meadow Pond (designated as sampling location “A”) was sampled from a backyard dock at 81 Cranberry Meadow Shore Road, Charlton, MA 01507 (Figure 4).

Figure 4: Sampling Location A: Top Image- Oliver Mass GIS Map of Cranberry Meadow Pond, 2019; Bottom Row-Sampling location off the dock at Cranberry Meadow Pond.

Cady Brook (designated as sampling location "B") was sampled from a field adjacent to the parking lot of Latour's Twisted Spoke motorcycle repair shop which is located at 6 City Depot Road, Charlton, MA 01508 (Figure 5).

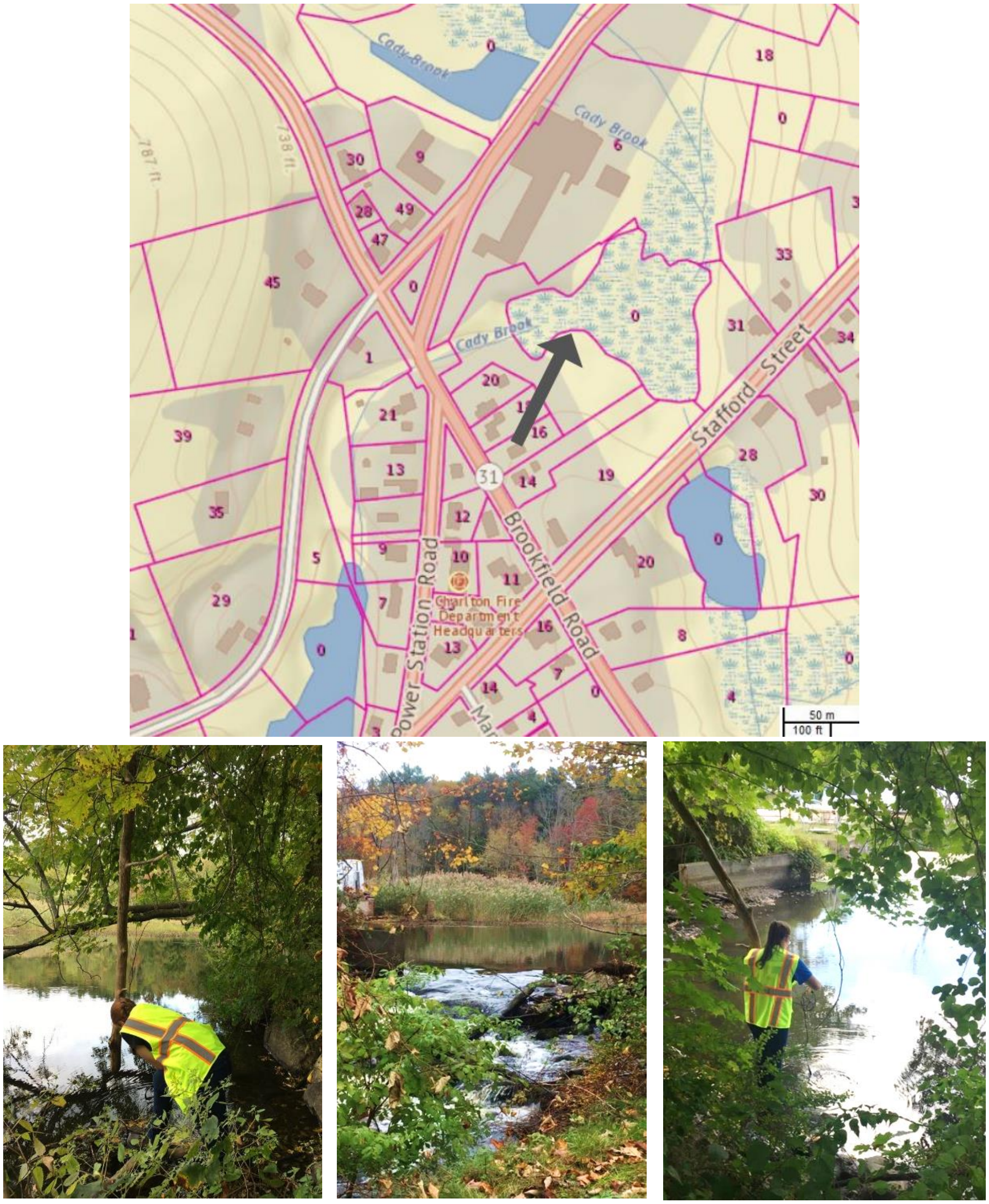


Figure 5: Sampling Location B: Top Image- Oliver MA GIS Map of Cady Brook, 2019; Bottom Row- Sampling location at Cady Brook.

Two sampling sites were chosen for Buffumville Lake in order to gather samples north of the major roadway, Oxford Road, that runs through it and samples south of that major roadway. The northern sampling site (designated as sampling location “C”) was located off a public hiking path. The parking area for this hiking path is located at 5 Fulling Mill Drive, Charlton, MA 01507. The specific sampling location was off a bridge located along the hiking path (Figure 6).

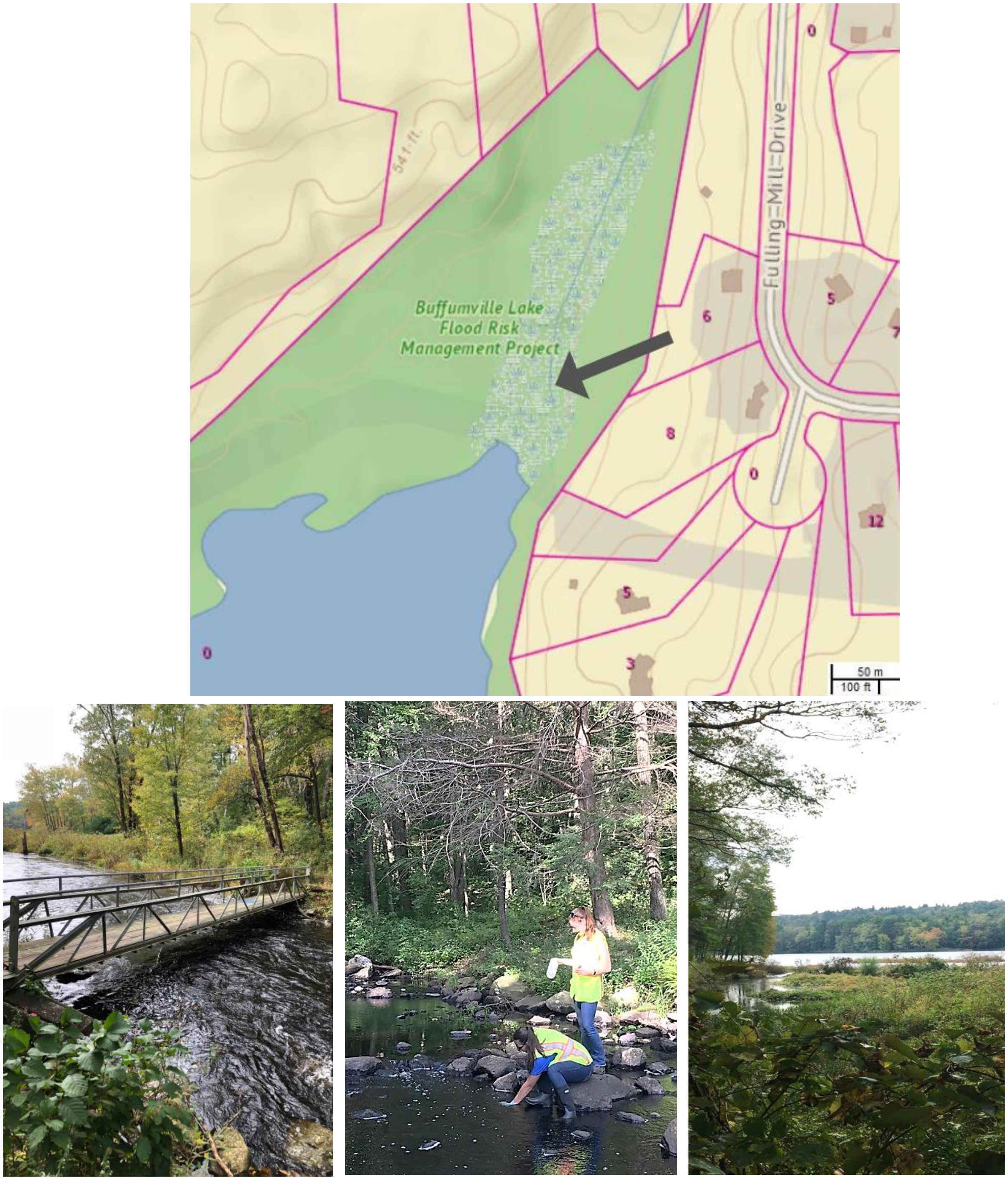


Figure 6: Sampling Location C. Top Image- Oliver MA GIS Map of Buffumville Lake off of Fulling Mill Drive, 2019. Bottom Row- Sampling location off of the embankment under the bridge running over the northern region of Buffumville Lake.

As shown in Figure 7, the southern sampling location (designated as sampling location "D") was located below the bridge on Potter Village Road, Charlton, MA 01507, that crosses over Buffumville Lake (Figure 7).

Figure 7: Sampling Location D. Top Image- Oliver MA GIS Map of Buffumville Lake off Potter Village Road, 2019; Bottom Row- Sampling location off of the bridge that runs over the southern region of Buffumville Lake, Sampling Location D.

The four sampling sites are shown in Figure 8 and are referred to throughout the report by their letter designations: Cranberry Meadow Pond (A), Cady Brook (B), North Buffumville Lake (C), and South Buffumville Lake (D).

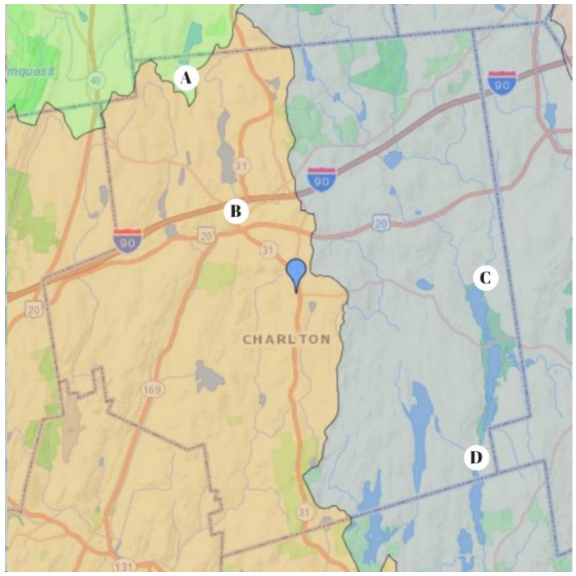


Figure 8: Four sampling sites chosen (MassGIS, 2019). Site A is Cranberry Meadow Pond, Site B is Cady Brook, Site C is North Buffumville Lake, and Site D is South Buffumville Lake.

The four sampling sites are representative of the three major Charlton watersheds. These watersheds are depicted above in Figure 8 as the French River (blue), Quinebaug River (orange), and Chicopee River (green) watersheds. These watersheds are influenced by the topography of the region. The water in each individual watershed flows from higher elevations to drain into a common outlet. According to the Charlton Town Conservation Commission, the water in the Chicopee watershed flows northwest, the water in the French watershed flows southwest, and the water in the Quinebaug River Watershed flows northwest (Todd Girard, personal communication, November 10, 2018).

Samples were collected from the selected water bodies and a series of water quality tests were performed in order to analyze the conditions of the water bodies. This included a mixture of both field tests, time sensitive laboratory tests, and non-time sensitive laboratory tests, as described in Sections 3.2.3 and 3.2.4.

3.2.2 Sampling Collection, Transport, and Storage

Samples were collected at the four locations described previously on five different occasions between September 4, 2018 and November 14, 2018. Sampling dates were planned on a bi-weekly schedule ranging from the beginning of our project work in early September until mid-autumn when weather, such as wind, rain, freezing temperatures, and falling leaves made sampling unsafe. Sampling dates were adjusted due to inclement weather multiple times and thus were rescheduled within a week of the original sampling date. On each sampling event, visual observations were recorded, water samples were collected, and field tests were conducted (see Section 3.2.3).

First, visual observations were made at each sampling location. These observations included the general weather, the color of the water bodies, the relative depth of the water bodies, the flow of the water bodies, and any changes in vegetation or accumulation of leaves alongside the water bodies. In addition to recording visual observations, pictures were taken to document these observations.

Next, field tests were conducted using two field meters, one of which measured flow rate while the other measured temperature, dissolved oxygen and conductivity.

Finally, water samples were collected at each location using a sampling pole and Nalgene polypropylene bottles. Two 1000 mL bottles and two pre-sterilized 500 mL bottles were filled at each site. Samples were placed in a cooler filled with ice packs until returning to the laboratory, at which time they were used for laboratory tests (see Section 3.2.4).

3.2.3 Field Test Procedures

Water quality tests that were conducted in the field included temperature, dissolved oxygen, conductivity, flow rate, and pH. The methods and instruments that were used for each test as well as the units of the water quality parameter and the range of the test are summarized in Table 6.

Table 6: Field water quality tests, methods, instrumentation, units and ranges.

Test Name	Method Used	Instruments Used	Units	Range of Test
Temperature	YSI Model 85 User Manual	YSI Model 85 Handheld Oxygen, Conductivity, Salinity, and Temperature System	℃	-5 to +65
Dissolved Oxygen	YSI Model 85 User Manual	YSI Model 85 Handheld Oxygen, Conductivity, Salinity, and Temperature System	mg/L	0 to 20
Dissolved Oxygen	YSI Model 85 User Manual	YSI Model 85 Handheld Oxygen, Conductivity, Salinity, and Temperature System	%	0 to 200
Conductivity	YSI Model 85 User Manual	YSI Model 85 Handheld Oxygen, Conductivity, Salinity, and Temperature System	mS/cm	0 to 200
Flow Rate	Global Water User Manual	FP111 Flow Probe	m/s	0 to 6.1

3.2.3.1 Temperature, Dissolved Oxygen and Conductivity

Temperature, dissolved oxygen and conductivity were measured using a YSI Model 85 Handheld Oxygen, Conductivity, Salinity, and Temperature System field meter (Yellow Springs, Ohio). The range of the field meter for temperature was -5℃ to 65℃. The range of the field meter for dissolved oxygen was 0 to 20 mg/L and 0 to 200 % saturation. The range of the field meter for conductivity was 0 to 200.0 mS/cm. The field meter was programmed before each use by turning the system on and giving it at least 15 minutes to go through its initial start-up protocol. The three measurements were then taken by inserting the probe into the water body and toggling between the three measurements on the field meter display screen. When the field meter was set to temperature or conductivity, the meter was given enough time for the readings to stabilize. When the field meter was set to dissolved oxygen, the probe was gently moved in a circular motion in the water in order to ensure that the probe was continuously exposed to new oxygen in the water body. The meter was again given enough time to stabilize. Details on the methods are provided in Appendix B.

3.2.3.2 Flow Rate

Flow rate was measured using a FP111 Global Water Flow Probe (College Station, Texas). The range of the field meter was 0 m/s to 6.1 m/s. The flow rate of the water was measured by submerging the probe of the meter into the same sampling location each week. The flow was measured over a one-minute period and the minimum, maximum, and average flow rate during the time period were recorded. The probe was positioned so that the water flowed through it in the direction that the indication arrow on the side of the probe was pointing. The meter was slowly moved side to side during the measurement in order capture the range of water movement. The meter was submerged to the same depth each time at the water body, water level permitting. Occasionally, water levels would be extremely low due to lack of rain and the previous depth was no longer possible, in which case the probe would be submerged to the lowest possible depth without the probe touching the bottom of the water body. Details are provided in Appendix B.

3.2.4 Laboratory Water Quality Testing

Water quality tests that were conducted in the laboratory included pH, nitrate, total phosphate, reactive phosphate, total coliforms, fecal coliforms, total dissolved solids, and turbidity. The methods and instruments that were used for each test as well as the units of the water quality parameter and the range of the test are summarized in Table 7.

Table 7: Laboratory water quality tests, methods, instrumentation, units and ranges.

Test Name	Method Used	Instruments Used	Units	Range of Test
pH	Accumet AB150 User Manual	Accumet AB150	Standard units	0-14
Nitrate	Hach Method #8192	Hach DR 6000	mg/L	0 to 0.50 mg/L
Total Phosphate	Hach Method #8190	Hach DR 6000	mg/L	0 to 3.5 mg/L
Reactive Phosphate	Hach Method #8048	Hach DR 6000	mg/L	0 to 5 mg/L
Total Coliforms	Standard Methods #9222	N/A	colonies/100 mL	0 to 200 colonies per plate
Fecal Coliforms	Standard Methods #9222	N/A	colonies/100 mL	0 to 200 colonies per plate
Total Dissolved Solids	Standard Methods #2540 C	Mettler Toledo AB104-S Mass Balance	mg/L	1 mg/L to 1100 mg/L
Turbidity	Nephelometric	Hach 2100N Turbidimeter	NTU	0-4000

Water samples that were collected at each site were taken to the laboratory where the following tests were conducted to determine various characteristics of the water:

- Time sensitive: pH, total and fecal coliforms, nitrate, reactive phosphate, total phosphate
- Non-time sensitive: total dissolved solids, turbidity

Laboratory procedures are detailed in Appendix C. Some attributes of water must be measured shortly after collection to get the most accurate results on its quality. Thus, six of the tests were performed upon immediate return to the laboratory. Other tests were performed within a day or two of water collection, and for those, the water samples were refrigerated overnight.

For total and fecal coliform tests, the collection bottles and all supplies were autoclaved before use to maintain aseptic conditions during testing. This was necessary to ensure that results were representative of the water samples and did not include any lab contamination.

Each laboratory test is described in Sections 3.2.4.1 through 3.2.4.7 and specific details regarding the procedures are provided in Appendix C.

3.2.4.1 pH

pH was measured using the Accumet AB150 pH probe (Waltham, MA). The pH probe was calibrated before each use by a 3-point calibration method using pH 4, pH 7 and pH 11 buffers. After the pH probe was calibrated, the pH of each water sample was measured by inserting the probe into a beaker of sample water until the meter displayed a stable reading. The probe was rinsed with reagent grade water and dried with a Kimwipe before being inserted into each new liquid in order to prevent cross-contamination.

3.2.4.2 Nitrate

Nitrate was measured in accordance with Hach Method #8192 and measured using a Hach DR 6000 spectrophotometer using program 351 N Nitrate LR (Loveland, Colorado). The test has a range of 0 to 0.50 mg/L. 15 mL samples were mixed with a Hach NitraVer 6 Reagent Powder Pillow, shaken to mix, and allowed to react. 10 mL of that mixture was then mixed with a Hach NitriVer 3 Reagent Powder Pillow, gently shaken to ensure mixing, and again allowed to react. The sample then sat for 15 minutes before being put in a clean, blank sample cell and then placed in the Hach DR 6000 in order to be measured.

3.2.4.3 Total Phosphate

Total phosphate was measured in accordance with Hach Method #8190 using a Hach DR 6000 spectrophotometer using the program 536 P Total/AH PV TNT (Loveland, Colorado). The test has a range of 0 to 3.5 mg/L. For each water sample, 5 mL of sample water was mixed with Hach Potassium Persulfate Powder Pillows, and then shaken until the powder was dissolved. The mixture was then incubated at 150°C for 30 minutes in order to allow the reaction between the powder pillow and the total phosphate in the sample to occur. After the incubation period, the mixture was allowed to cool and then mixed with 2 mL of 1.54 N Sodium Hydroxide Standard Solution. This mixture was used to zero the Hach DR 6000. After the Hach DR 6000 was zeroed, the mixture was further mixed with a Hach PhosVer 3 Powder Pillow and shaken for 25 seconds then allowed to sit for 2 minutes. This final mixture was then measured using the Hach DR 6000.

3.2.4.4 Reactive Phosphate

Reactive phosphate was measured in accordance with Hach Method #8048 using a Hach DR 6000 spectrophotometer under the program 535 P React PV TNT (Loveland, Colorado). The test has a range of 0 to 5 mg/L. For each water sample, 5 mL of the water sample was added to a Reactive Phosphorus Test ‘N Tube vial which contained the chemicals necessary for the test. The vial was then inverted to mix and used to zero the Hach DR 6000. After the spectrophotometer was zeroed, a PhosVer 3 Phosphate Powder Pillow was added to the vial and shaken for 20 seconds, then allowed to react for 2 minutes. After the 2-minute period was over, the vial was placed into the Hach DR 6000 in order to be read.

3.2.4.5 Total and Fecal Coliforms

Total and fecal coliforms were measured in accordance with Standard Methods #9222. Samples of various volumes were filtered through a sterile filter membrane with a grid pattern using a vacuum filter. Filter pads were then placed in sterile petri dishes with absorbent pads that contained either m-Endo media for total coliforms or m-FC media for fecal coliforms. Fecal coliform dishes were then stored in an incubator at 44.5℃ for 22 to 24 hours while total coliform dishes were stored in an incubator at 35℃ for 22 to 24 hours. After the incubation period, the number of colonies on each plate was counted and used to calculate a number of colonies per 100 mL of sample for each plate.

3.2.4.6 Total Dissolved Solids

Total dissolved solids were measured in accordance with Standard Methods # 2540 C. 100 mL of each water sample was measured, filtered through a 934-AH filter and added to a pre-dried and pre-weighed ceramic weighing dish. The weighing dish and water were then placed in an oven at 105℃ until the water completely evaporated (which took approximately 4 hours). The weighing dish was then cooled in a desiccator and weighed using a Mettler Toledo AB104-S Mass Balance. The mass balance has a range of 0.1 mg to 110,000 mg. The original mass of the evaporating dish was subtracted from the mass measured after the water sample was evaporated to determine the mass of the total dissolved solids in the water sample. The mass of the total dissolved solids was then divided by the volume of water sample added in order to determine the concentration of total dissolved solids in the sample, reported in mg/L.

3.2.4.7 Turbidity

Turbidity was measured in accordance with EPA Method 180.1 using a Hach 2100N turbidimeter (Loveland, Colorado). The turbidimeter measures scattering of light from suspended matter in units of NTU. The instrument has a range of 0 to 4000 NTU. The water sample was gently inverted to mix and then slowly poured into a turbidity vial in order to avoid creating air bubbles that would interfere with the reading. The vial was gently inverted twice to ensure sample uniformity and then the outside of the vial was rinsed using reagent grade water and a Kimwipe. The vial was then placed into the turbidimeter in order to be read.

3.3 Data Analysis

Historical data and data gathered by the MQP team were all analyzed graphically and statistically. The data were divided by watershed, and then further by water body and water quality parameter. For each parameter measured, water quality data within a watershed were plotted over time, with different colors for each water body. Massachusetts Department of

Environmental Protection (Mass DEP) and the Environmental Protection Agency's (EPA) Class A and B water quality standards were also plotted on these graphs. The graphs were then analyzed visually to determine if there were any trends in the data and to also determine the general quality of the water bodies based on the EPA and Mass DEP standards; i.e. data points above maximum standards or data points below minimum standards were considered poor and data points between minimum and maximum standards were considered acceptable.

Statistical analysis of water quality data was conducted to determine correlations between parameters within each watershed and also differences in water quality between watersheds using analysis of variance (ANOVA). NCSS 12 Statistical Software and Microsoft Excel Data Analysis Tool Pack were used to carry out these statistical analyses. Specifically, the Correlation analysis tool in NCSS 12 was used to carry out the correlation analysis and the ANOVA tool in Microsoft Excel was used to carry out the analysis of variance.

Within each watershed, the correlation between each parameter that was measured was analyzed. NCSS 12 Correlation Analysis was used to run each of the data analyses. The data analysis program compares two sets of parameters, with each pair of values being taken on the same day, and outputs a correlation coefficient. Pearson coefficients range from -1 to 1, with coefficients close to an absolute value of 1 indicating a strong correlation and coefficients close to 0 indicating no correlation. Negative coefficients indicate an inverse correlation (one value increases as the other decreases) and positive coefficients indicate a positive correlation (values increase or decrease in conjunction with each other). The correlation coefficients were then compared to a statistically significant r value that was determined based on degrees of freedom (number of paired data points minus 2) to determine if a statistically significant correlation exists at the 95% confidence level. The degrees of freedom and comparison of the Pearson coefficient to their value (to determine whether the parameters were correlated) was calculated by the NCSS 12 software.

Differences between parameter data for the three separate watersheds was analyzed statistically using the Microsoft Excel Data Analysis ANOVA tool. ANOVA measures how much data sets differ from each other so the MQP team used this analysis to determine to what degree a parameter differed from one watershed to another. ANOVA was performed on eight parameters (pH, turbidity, FC, TC, DO, nitrate, TDS, and total phosphate) with the data grouped by watershed (French, Quinebaug, or Chicopee River Watershed). The tool produces a p-value which was compared to the alpha value. For this project, a 95% confidence level was used for the ANOVA analysis and the alpha variable was equal to 0.05. If the p-value was greater than 0.05, there was no statistically significant difference in water quality between the three watersheds. If the p-value was less than or equal to 0.05, then there was a difference in water quality between the three watersheds.

4. Results

This section presents the water quality data for surface water bodies in the three watersheds in Charlton. The Conservation Commission provided us with historical water quality data from December 1985 to November 2018 in the French River and Quinebaug River Watersheds. The MQP team measured pH, dissolved oxygen (DO), total dissolved solids (TDS), nitrate, total and reactive phosphate, total and fecal coliforms, turbidity, conductivity, water temperature, and flow rate at selected locations in the French River, Quinebaug River, and Chicopee River Watersheds in the fall of 2018. The data were compared to water quality guidelines to determine potential issues and were graphically plotted over time to determine potential trends. Lastly, the data were statistically analyzed for correlations and variance based on each watershed.

Certain parameters are not presented in the results section. Reactive phosphate, water temperature, conductivity and flow rate were measured or included in new and historical data but are not discussed in detail for the following reasons. Reactive phosphate was measured as a quality control parameter for total phosphate; reactive phosphate levels needed to be less than the total phosphate value since total phosphate encompasses reactive phosphate. This indicates that the measurements and tests were carried out correctly. Reactive phosphate results can be found in Appendix D but are not discussed in depth because total phosphate measurements are a better indicator of nutrient loading in water bodies. Water temperature was excluded from this discussion because temperature naturally fluctuates with the seasons. A brief analysis of the data showed that there was no significant increasing or decreasing trend over long periods of time, and therefore no evidence of thermal pollution. Conductivity measurements were taken by the MQP team; however, they are not discussed due to lack of published standards on acceptable levels for water quality (results found in Appendix E). Flow rate was measured by the MQP team but not recorded in the historical data provided to the team. Flow rates indicate general trends in water velocity, however the water bodies measured had varying widths and depths, so the flow rates were not comparable and thus were excluded from this discussion.

The Charlton Conservation Commission provided a description of the preferred uses for Charlton's water bodies (see Table 8). Preferred uses describe the common ways in which residents and local organizations use the water bodies. Within Charlton, there is one water body in the Chicopee River watershed, ten water bodies in the French River watershed, and four water bodies in the Quinebaug watershed. Six of the water bodies (40%) are used for water skiing, nine of the water bodies (60%) are used for boating, seven of the water bodies (47%) are used for swimming, and all the water bodies are used for fishing. Of the nine water bodies that are used for boating, Prindle Lake does not allow gas engine boats and Pikes Pond is only used for canoeing. Additionally, Cranberry Meadow Pond, Pierpoint Meadow Pond, and South Charlton Reservoir allow boating but do not have a public access boat ramp. Five of the water bodies (33%) are either stocked with specific species of fish or contain fisheries. Only Little Nugget Lake, Buffumville Lake, and Prindle Lake have public beach areas. Snow Pond is the only water body that is used for agricultural uses as well as educational purposes within the local school system. South Charlton Reservoir is the only water body that is used for camps such as YMCA camps and local religious camps.

Table 8: Charlton Water Body Preferred Uses.

Watershed	Water Body	Preferred Use
Chicopee	Cranberry Meadow Pond	Water ski, boat, swim, fish, no public boat access
French	Baker (Gore) Pond	Water ski, boat, swim, fish, public car-top boat access*
French	Buffumville Lake	USACE**, water ski, boat, swim, beach, fish, public boat ramp
French	Little Nugget Lake	Boat, swim, fish, small town beach
French	Little River	Open access for fishing with occasional large open pools stocked with trout from the DFW***
French	Pierpoint Meadow Pond	Water ski, boat, swim, fish, no public boat access
French	Pikes Pond	Fish, canoe, limited access
French	Potter Brook	Contains several small rock dams creating large deep pools; easy access for fishing; DFW cold water fishery
French	Putnam Pond	Swimming, fishing, minimal boat canoe use
French	Snow Pond	Agricultural use, fish, local water for science club students and educational applications, this is town farm pond stocked with trout from the DFW
French	South Charlton Reservoir (Granite Reservoir)	Water ski, boat, swim, fish, YMCA & Religious camp facility, no public boat access
Quinebaug	Cady Brook	Fishing stocked with trout from the DFW
Quinebaug	Glen Echo Lake	Water ski, boat, swim, fish
Quinebaug	McKinstry Brook	Large pools and rifle areas; DFW cold water fishery
Quinebaug	Prindle Lake	No gas engine boats, swim, fish, small town beach car-top boat access

Notes:
* "Type of access for watercraft, usually used for small boats and canoes. This type of water access has less impact on receiving waters and boat ramps, but cannot accommodate trailer watercraft" (Todd Girard, personal communication, January 28, 2019).
** USACE (United States Army Corps of Engineers)
** DFW (Department of Fish and Wildlife)

4.1 Ideal Ranges

Ideal ranges were researched for each water quality parameter. Sources used include the US EPA Gold Book of Water Quality Criteria (EPA, 1986), MA DEP Class A and B Waters Classifications (EPA, 2006), and Recreational Waters US EPA Requirements (Cabelli & McCabe, 1974). These qualitative and quantitative criteria (listed in Table 9) were used to compare and analyze the Charlton water quality data and determine water quality issues present in the water bodies.

Table 9: Water Quality Standards and Guidelines for Surface Water Bodies.

Parameter	**Source**			
	US EPA Gold Book of Water Quality Criteria	*Recreational Waters US EPA Requirements*	*MA DEP Class A Waters*	*MA DEP Class B Waters*
pH	Domestic water supply: 5.0 - 9.0 Freshwater aquatic life: 6.5 - 9.0 Marine aquatic life: 6.5 - 8.5	N/A	6.5 - 8.3, no more than 0.5 units outside natural background range	6.5 - 8.3, no more than 0.5 units outside natural background range
Turbidity	Freshwater fish and other aquatic life: Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life.	N/A	Waters shall be free from turbidity in concentrations that are aesthetically objectionable or would impair any use assigned to this class.	Waters shall be free from turbidity in concentrations that are aesthetically objectionable or would impair any use assigned to this class.
TC	The microbiological criterion for shellfish water quality has been accepted by international agreement to be 70 total coliforms per 100 ml, using a median MPN, with no more than 10 percent of the values exceeding 230 total coliforms.	N/A	Unfiltered public water supply: 100 orgs/100 mL	N/A
FC	Shellfish Harvesting Waters: 70 colonies per 100 mL	Full Body Contact, Bathing	Unfiltered public water	Bathing beaches and other waters:

	Swimming beaches: 200 colonies per 100 mL	in Fresh Water (in MA): 126 colonies per 100 mL	supply: 20 orgs/100 mL Bathing beaches and other waters: 235 colonies/100 mL	235 colonies/100 mL
DO	Early aquatic life stages: 8.0 mg/L Other life stages: 4.0 mg/L	N/A	Cold water fisheries: no less than 6.0 mg/L Warm water fisheries: 5.0 mg/L	Cold water fisheries: no less than 6.0 mg/L Warm water fisheries: 5.0 mg/L
Nitrate	Domestic water supply (health): 10 mg/L Effect on warm water fish: max 90 mg/L. No criteria for coldwater fish	N/A	N/A	N/A
TDS	250 mg/L for chlorides and sulfates in domestic water supplies (welfare). Maximum of 500 mg/L for water supplies and irrigation 15,000 mg/L for freshwater fishes	N/A	Waters shall be free from floating, suspended and settleable solids in concentrations that would impair any class uses, cause aesthetically objectionable conditions, or impair benthic biota or degrade chemical composition of the bottom	Waters shall be free from floating, suspended and settleable solids in concentrations that would impair any class uses, cause aesthetically objectionable conditions, or impair benthic biota or degrade chemical composition of the bottom
Total Phosphate	Total phosphate phosphorus concentrations in excess of 100 µg/L may interfere with coagulation in water treatment plants. Concentrations above 25 µg/L	N/A	N/A	N/A

	at the time of spring turnover may stimulate excessive or nuisance growths of algae and other aquatic plants. Total phosphates should not exceed 50 μg/L in any stream at the point. Where it enters any lake or reservoir, not exceed 25 ug/L within the lake or reservoir.			

4.2 French River Watershed

The French River Watershed is located in the southeastern region of Charlton, MA. It encompasses the South Charlton Reservoir, Buffumville Lake, Little Nugget Lake, Snow Pond, Baker Pond, Little River, Potter Brook, Baker (Gore) Brook, Pierpoint Meadow Pond, and Putnam Pond (shown in Figure 9). The blue arrows in Figure 9 indicate direction of water flow in the French River Watershed. Note that the size of the arrows is not indicative of the volume of flow. Of these water bodies, the MQP team had access to water quality data for South Charlton Reservoir, Buffumville Lake, Little Nugget Lake, Snow Pond, Baker Pond and Putnam Pond. Historical data on South Charlton Reservoir, Little Nugget Lake, Snow Pond, Baker Pond and Putnam Pond ranged from December 11, 1985 to September 22, 2018 and was provided by the Charlton Conservation Commission. The MQP collected water quality data from two locations on Buffumville Lake ranging from September 4, 2018 to November 14, 2018. This data was combined in the subsequent sections with all historic data for analysis.

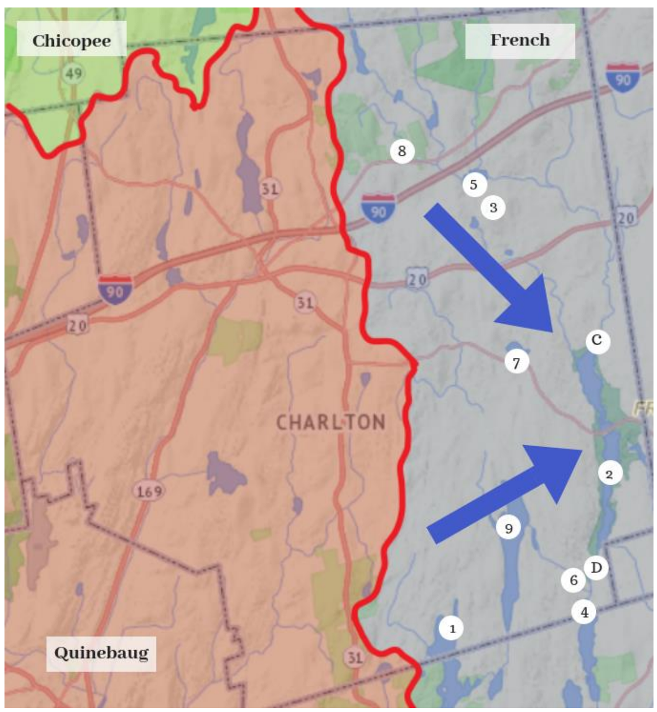


Figure 9: Flow Gradient and Location of Water Bodies in the French River Watershed (Oliver Mass GIS, 2019). (1) Baker Pond, (2) Buffumville Lake, (3) Little River, (4) Pier Point Meadow Pond, (5) Pike's Pond, (6) Potter Brook, (7) Putnam Pond, (8) Snow Pond, (9) S. Charlton Reservoir, (C) S. Buffumville Lake, (D) N. Buffumville Lake.

4.2.1 pH

pH measurements were taken in five water bodies within the French River Watershed; Baker Pond, Buffumville Lake, Little Nugget Lake, Snow Pond, and South Charlton Reservoir. pH measurements for Baker Pond were taken multiple times between 2015 and 2017. Multiple pH measurements were taken for Buffumville Lake in 2010 and then again in 2018 by the MQP team. Little Nugget Lake had pH measurements taken on two separate occasions, once in August 2015 and once in April 2016. pH measurements were taken for Snow Pond in 2015, 2016 and 2018. Finally, numerous pH measurements were taken in the South Charlton Reservoir between 2001 and 2018. These five data sets are depicted in Figure 10.

Figure 10: French River Watershed pH Measurements.

According to the EPA Gold Book Quality Criteria for Water Quality, the acceptable pH range in a water body supporting freshwater aquatic life is between 6.5 (dotted red line in Figure 10) and 9.0 (solid grey line in Figure 10) (EPA, 1986). According to the Massachusetts DEP, water bodies that are Class A or Class B must have a pH range between 6.5 (dotted red line) and 8.3 (solid pink line) (EPA, 2006). All pH values measured in the French River Watershed were less than 9.0. However, 4 out of 759 pH values (0.53%) were above 8.3 and 215 out of 759 pH values (28%) were below 6.5. All of the pH values that were above the Massachusetts DEP Class A and Class B Waters maximum pH level were from Little Nugget Lake. These pH levels were acceptable by the US EPA Gold Book standards but were too high by Massachusetts DEP standards, indicating that the high pH levels in this water body may be a problem. In terms of the pH levels that were below EPA Gold Book criteria and Massachusetts DEP criteria, the pH values in the French River Watershed appear to have an increasing trend over time. However, in

2018 there were still 27% of pH measurements that fell below the ideal pH range. These data indicate a potential problem with low pH the watershed. All water bodies within the watershed had at least one pH value below 6.5, which indicates that the problem is not centralized to a single location.

4.2.2 Turbidity

Turbidity measurements were taken in Baker Pond, Buffumville Lake, Little Nugget Lake, Snow Pond and South Charlton Reservoir in the French River Watershed. Baker Pond turbidity measurements were taken between 2015 and 2017. Buffumville Lake measurements were taken numerous times in 2010 and then again in 2018 by the MQP team. Turbidity measurements were taken in Little Nugget Lake in 2015 and 2016 and in Snow Pond in 2015, 2016 and 2018. Finally, measurements were taken for turbidity in South Charlton Reservoir numerous times between 2009 and 2018. The five data sets can be seen in Figure 11.

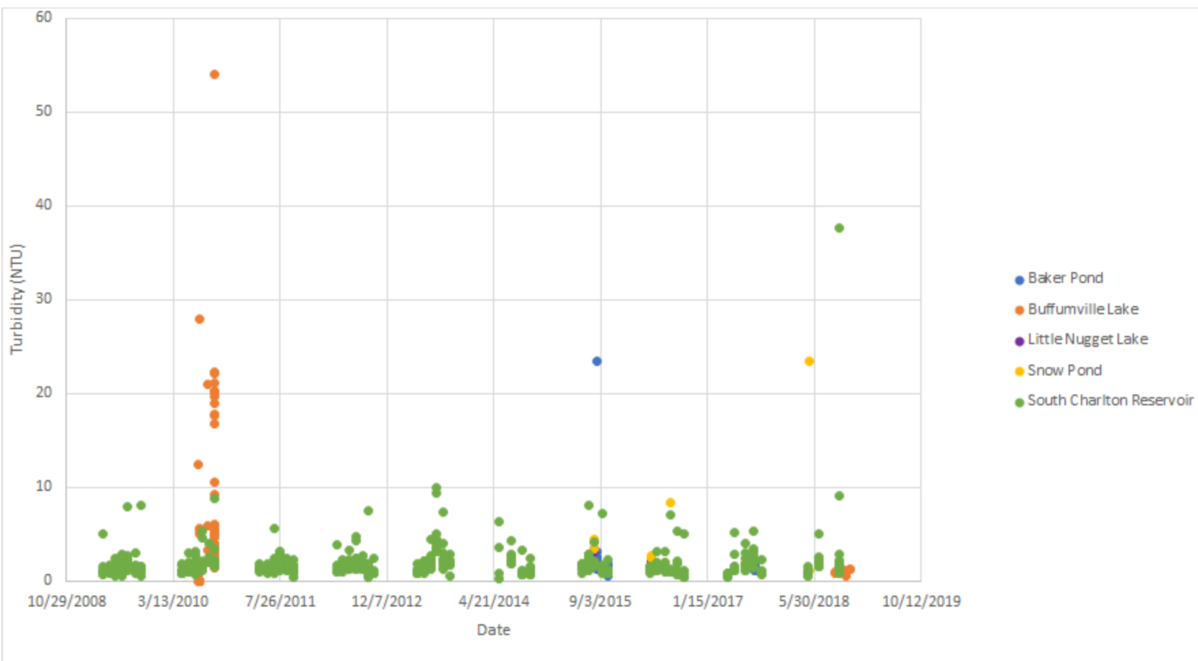


Figure 11: French River Watershed Turbidity Measurements.

According to the EPA Gold Book Criteria for Water Quality, in waters that support freshwater or other aquatic life, “Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life” (EPA, 1986). According the Massachusetts DEP, Class A and Class B water bodies “shall be free from turbidity in concentrations that are aesthetically objectionable or would impair any use assigned to this class” (EPA, 2006). 96% of the turbidity measurements within the French River Reservoir were between 0 NTU and 10 NTU with only 27 outliers out of 685 measurements. The World Health Organization defines water bodies with a turbidity over 5 NTU to be aesthetically undesirable to a community (WHO, 1997). 46 out of

685 turbidity measurements, or 6.7% of measurements, within the French River watershed fell above this maximum turbidity guideline and could therefore be considered aesthetically undesirable.

Turbidity is a measurement of the reflection of light in a water sample due to suspended solids. Lower turbidity measurements indicate less suspended solids in water and therefore clearer water. South Charlton Reservoir has the lowest overall turbidity measurements, meaning this water body has the clearest water. These data indicate good water quality based on the preferred use in the South Charlton Reservoir which is swimming, boating and summer camps, all of which are recreational activities in which clearer water is preferred. Therefore, low turbidity values indicate a high-quality water.

4.2.3 Total Coliforms

Total coliform concentration measurements were taken at Buffumville Lake and South Charlton Reservoir within the French River Watershed. Buffumville Lake measurements were taken by the MQP team in 2018. South Charlton Reservoir water measurements were taken in 1985 and 1986. It is important to note that historical data from 1985/1986 are not particularly relevant as they are over 30 years old; however, they were included in this case as they were the only historical data of total coliform concentrations available for the French River Watershed. It was decided that including older and less relevant historical data would be more beneficial than not including any historical data for the sake of comparisons. Both datasets can be seen in Figure 12.

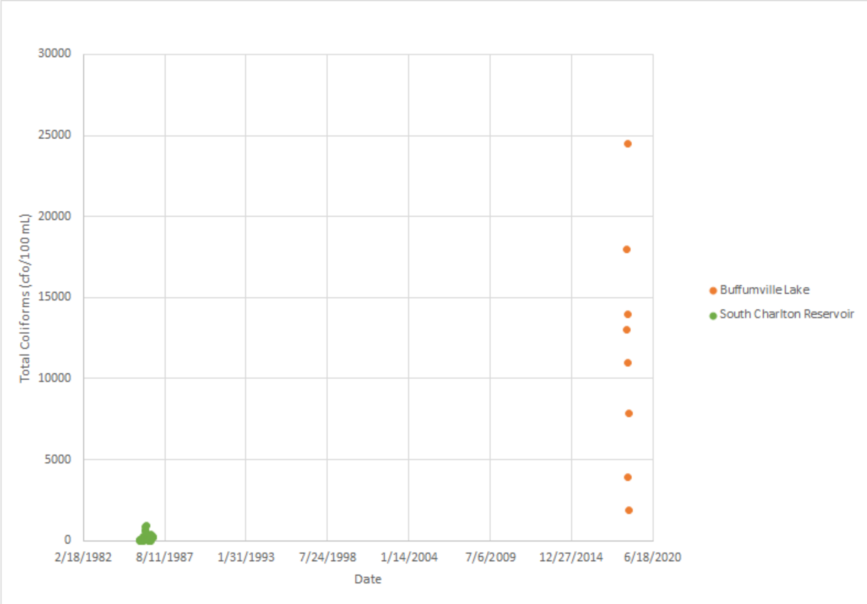


Figure 12: French River Watershed Total Coliform Measurements.

The total coliform concentrations from the South Charlton Reservoir in 1985 and 1986 range from 0 cfu/100 mL to 850 cfu/100 mL. The total coliform concentrations from Buffumville Lake in 2018 range from 1,850 cfu/100 mL to 25,000 cfu/100 mL. Note that the data from 2018 may not be accurate because the coliform counts on some petri dishes were outside of the ideal range. This concern is further addressed in Section 4.5 of the paper. The Massachusetts DEP has a total coliform recommendation of less than 100 cfu/100 mL for an unfiltered public water supply; however, none of these water bodies are used for that purpose and there are no TC limits for swimming and recreation as long as the fecal coliform counts meet the required levels. The total coliform concentrations measured in Buffumville Lake in 2018 were significantly higher than the total coliform concentrations measured in South Charlton Reservoir in 1985 and 1986. This may be indicative of a biological pollution source within the watershed or at the least, within Buffumville Lake.

4.2.4 Fecal Coliforms

Fecal coliform concentrations were measured in Buffumville Lake, Putnam Pond, and South Charlton Reservoir within the French River Watershed. Fecal coliforms were measured in Buffumville Lake in 2010 and again in 2018 by the MQP team. Measurements were taken in both Putnam Pond and South Charlton Reservoir in 2018. The three data sets are shown in Figure 13.

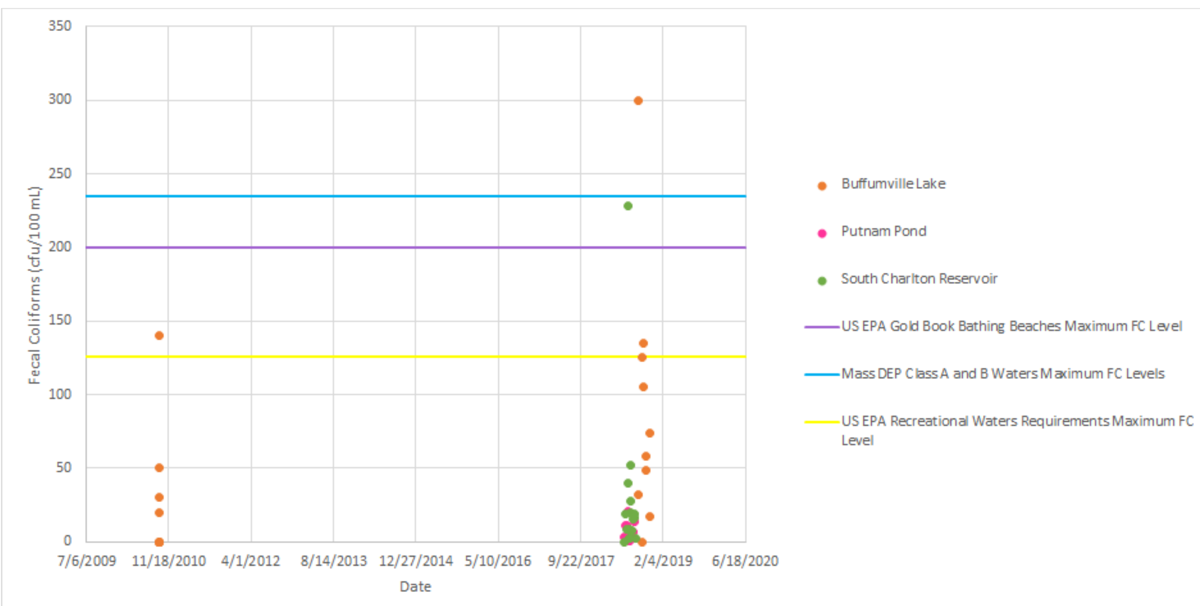


Figure 13: French River Watershed Fecal Coliform Measurements.

The fecal coliform values for the French River Watershed ranged from 0 cfu/100 mL to 300 cfu/100 mL. According to the EPA Gold Book Quality Criteria for Water, the maximum fecal coliform level for swimming beaches is 200 cfu/100 mL (purple line in Figure 13; EPA, 1986). According to the Massachusetts DEP, fecal coliform levels in Class A and Class B waters should not exceed 235 coliforms per 100 mL (blue line; EPA, 2006). Finally, according to the US EPA Requirements for Recreational Waters, the maximum fecal coliform level is 126 cfu/100 mL (yellow line; Cabelli & McCabe, 1974). The fecal coliform measurements for

Buffumville Lake from 2010 fell within the range of 0 cfu/100 mL to 150 cfu/100 mL, which was below all maximum fecal coliform levels, with the exception of one data point falling above the US EPA Recreational Waters Requirements. The data collected for Buffumville Lake in 2018 ranged from 0 cfu/100 mL to 300 cfu/100 mL, with only one data point measured in Buffumville Lake in 2018 above the allowable limit from the EPA Gold Book and the Massachusetts DEP. Three data points measured in Buffumville Lake in 2018 fell above the US EPA Recreational Water Requirements. Additionally, one data point measured in South Charlton Reservoir in 2018 fell above both the Massachusetts DEP criteria and the US EPA Recreational Waters Requirements. All other data points fit the three maximum fecal coliforms levels, indicating the fecal coliforms are not a significant issue within the French River Watershed.

4.2.5 Dissolved Oxygen

DO measurements in the French River Watershed were taken at Baker Pond, Buffumville Lake, Little Nugget Lake, Snow Pond, and South Charlton Reservoir. Baker Pond measurements were taken between 2015 and 2018. Measurements were taken at Buffumville Lake numerous times in 2010 and again in 2018 by the MQP team. Measurements were taken at Little Nugget Lake in 2015 and 2016, and at Snow Pond in 2015, 2016 and 2018. Finally, DO measurements were taken in South Charlton Reservoir numerous times between 2008 and 2018. These five data sets can be seen in Figure 14.

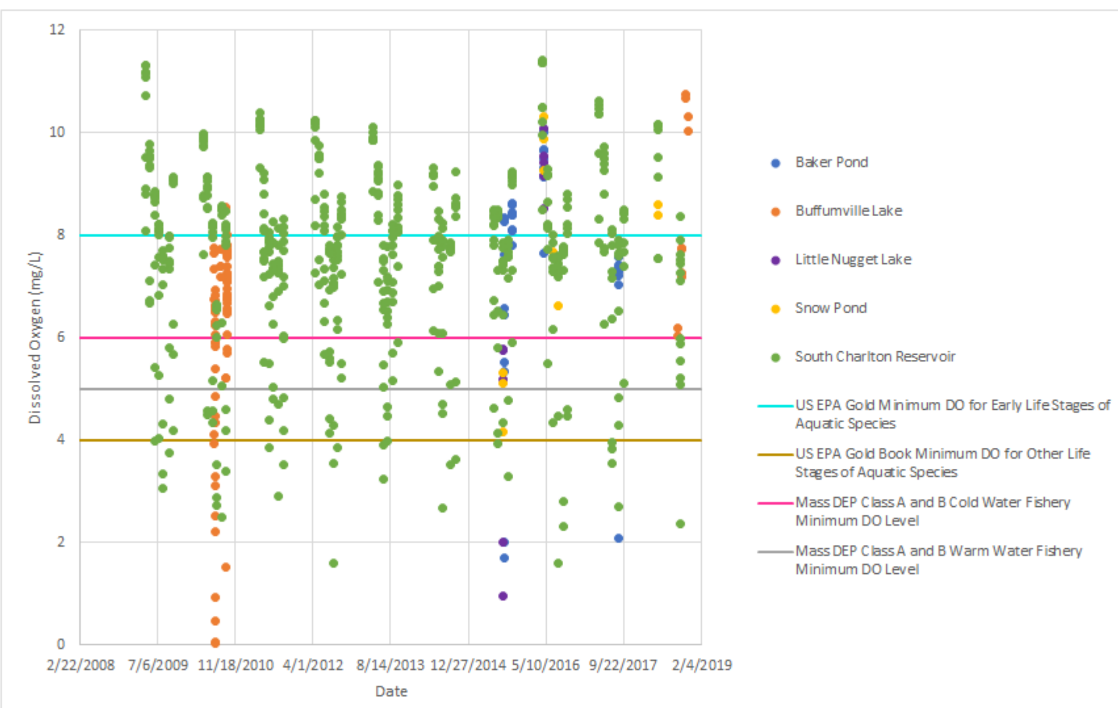


Figure 14: French River Watershed Dissolved Oxygen Measurements.

As DO measurements are dependent on temperature, the DO measurements from the French River Reservoir varied significantly as seasons and temperature changed. This trend can be seen most significantly in the South Charlton Reservoir data set in Figure 14. According to the EPA Gold Book Quality Criteria for Water, the minimum DO level to support early life stages of aquatic species is 8.0 mg/L (aqua line in Figure 14) and the minimum DO level to support other life stages of aquatic species is 4.0 mg/L (tan line; EPA, 1986). Out of 718 measurements, 433, or 60% of measurements taken from the French River Watershed fell below the minimum limit for early life stages of aquatic species and 51 out of 718 measurements, or 7.1% of measurements, fell below the minimum limit for other life stages of aquatic species. According to the Massachusetts DEP, Class A and Class B cold water body fisheries have a minimum DO level of 6.0 mg/L (pink line) and Class A and B warm water body fisheries have a minimum DO level of 5.0 mg/L (grey line). Out of 718 measurements, 138, or 19% of measurements taken from the French River Watershed fell below the cold water fishery minimum limit and 89 out of 718 measurements, or 12% of measurements, fell below the warm water fishery minimum limit. It should be noted that none of the water bodies in the French River watershed have warm waters, so the latter Massachusetts DEP limit is not relevant. Low DO measurements were observed multiple times throughout the entire time period from 2008 to 2018 and for all water bodies measured within the watershed, indicating that this issue is not centralized to a specific time period or water body but rather a recurring issue. DO is related to decomposition of vegetation and decreases when there is a higher amount of vegetation decomposing in a water body and therefore taking up the oxygen supply. These low values for DO may be indicative of a vegetation problem within the watershed.

4.2.6 Nitrate

Nitrate measurements were taken in Buffumville Lake and South Charlton Reservoir of the French River Watershed. Buffumville Lake nitrate levels were measured in 2010 and also by the MQP team in fall 2018. South Charlton Reservoir measurements were taken monthly in 1986 and also in late 2001 and early 2002. Results from both of these water bodies are indicated in Figure 15.

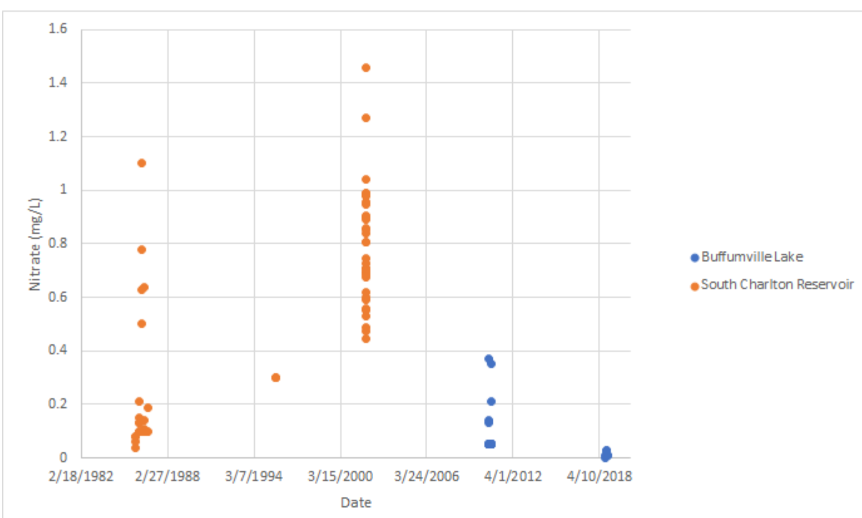


Figure 15: French River Watershed Nitrate Measurements.

According to the US EPA Gold Book Water Quality Criteria, the maximum contaminant level of nitrate in a water body is 90 mg/L before it begins to affect warm water fish (EPA, 1986). Values for Buffumville Lake ranged from 0.0 to 0.37 mg/L nitrate, and values for South Charlton Reservoir ranged from 0.04 to 1.46 mg/L. All measurements taken from the two water bodies were significantly below the US EPA level, signifying no outstanding issues with this nutrient in the watershed.

4.2.7 Total Dissolved Solids

TDS measurements were conducted for Buffumville Lake by the MQP team in fall 2018. For South Charlton Reservoir, data from 1986 was used; it should be noted that these data are not highly comparable to the 2018 data but due to lack of any other recent data, they are included in the data discussion. According to the US EPA Gold Book Water Quality Criteria, a maximum of 500 mg/L (blue line in Figure 16) makes a water suitable as a drinking water source or irrigation source, and freshwater fish can tolerate up to 15,000 mg/L (EPA, 1986). Buffumville Lake measurements were within a range of 55 mg/L to 218 mg/L, and South Charlton Reservoir measurements had a range of 18.3 mg/L to 108 mg/L. The measurements taken in both water bodies fall well below the US EPA maximum (see Figure 16), indicating high quality waters.

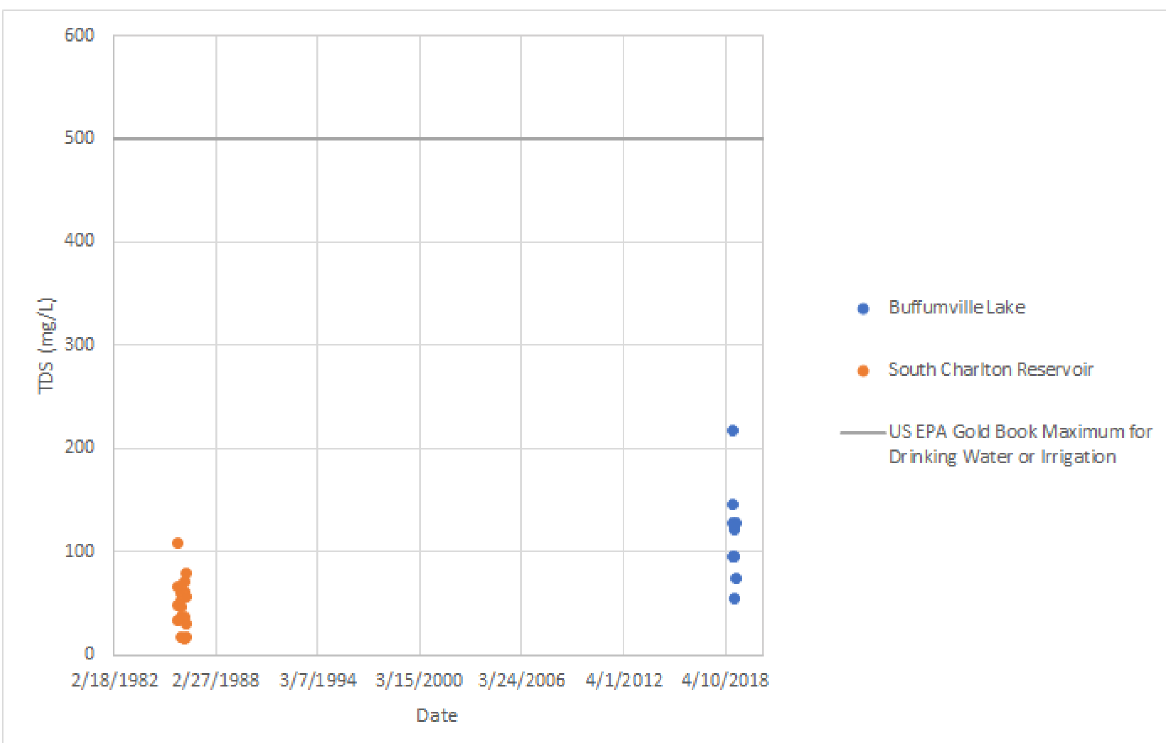


Figure 16: French River Watershed TDS Measurements.

4.2.8 Total Phosphate

Total phosphate levels were measured in Buffumville Lake and South Charlton Reservoir within the French River Watershed. Buffumville Lake measurements ranged from 0.01 to 1.34 mg/L and were taken in summer 2010 and by the MQP team in fall 2018. South Charlton Reservoir total phosphate measurements were taken in the winter of 2001 to 2002; these ranged between 0.001 mg/L and 3 mg/L. As shown in Figure 17, both water bodies have measurements exceeding the US EPA Gold Book Water Quality Criteria level of 0.025 mg/L within lakes and reservoirs (EPA, 1986).

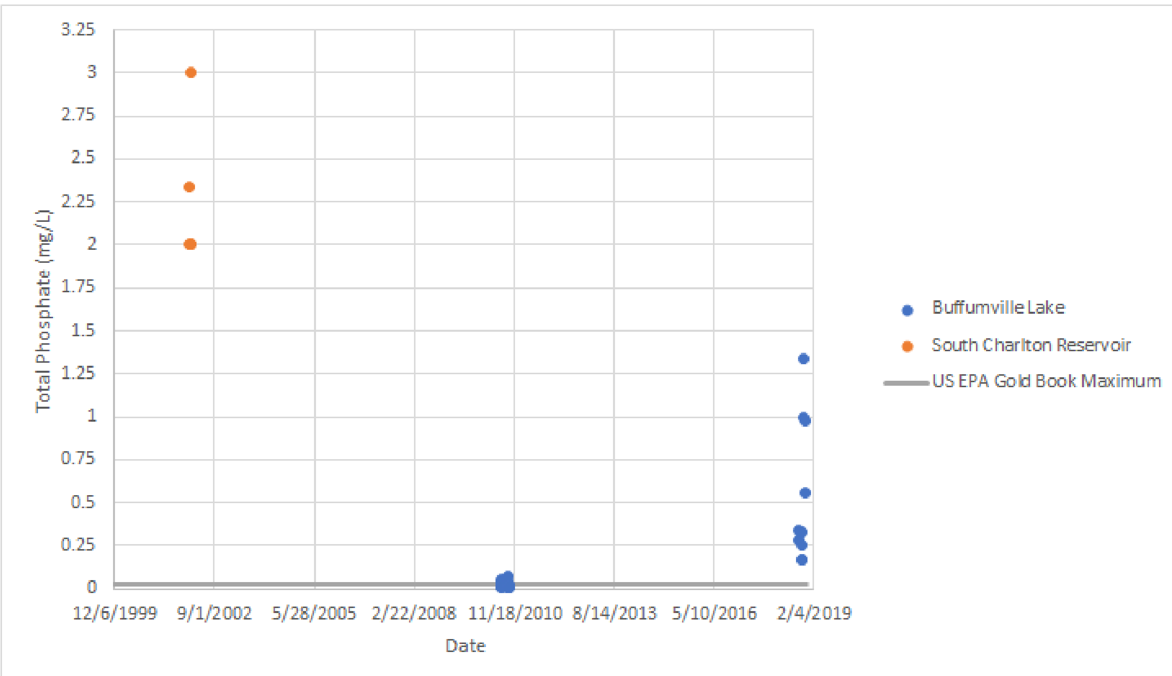


Figure 17: French River Watershed Total Phosphate Measurements.

These high levels of phosphate are commonly due to soil erosion and fertilizer or sewer runoff. Soil erosion carries phosphate from the soil into the water. Rainfall washes fertilizers used on lawns into the water bodies. Sewer systems that are not complying with regulations or have other issues will release phosphate into the soil which will eventually end up in the water body.

4.3 Quinebaug River Watershed

The Quinebaug River Watershed covers the Western portion of Charlton. The surface water within the Quinebaug River Watershed flows southwest (indicated by the blue arrow in Figure 18), eventually discharging to the Long Island Sound. This project collected water quality data from three water bodies located within the Quinebaug River Watershed. These three water bodies are shown in Figure 18: Glen Echo Lake (10), Cady Brook (B), and Prindle Lake (11). Glen Echo and Prindle Lakes are used for boating, fishing, and swimming, while Cady Brook is stocked with trout by the Department of Fish and Wildlife (DFW). Water quality data was collected on Prindle Lake and Glen Echo Lake between July 2015 to May 2018. The MQP team measured the pH, DO, TDS, nitrate, total phosphate, fecal coliforms, total coliforms, turbidity, and conductivity of Cady Brook from September 2018 to November 2018.

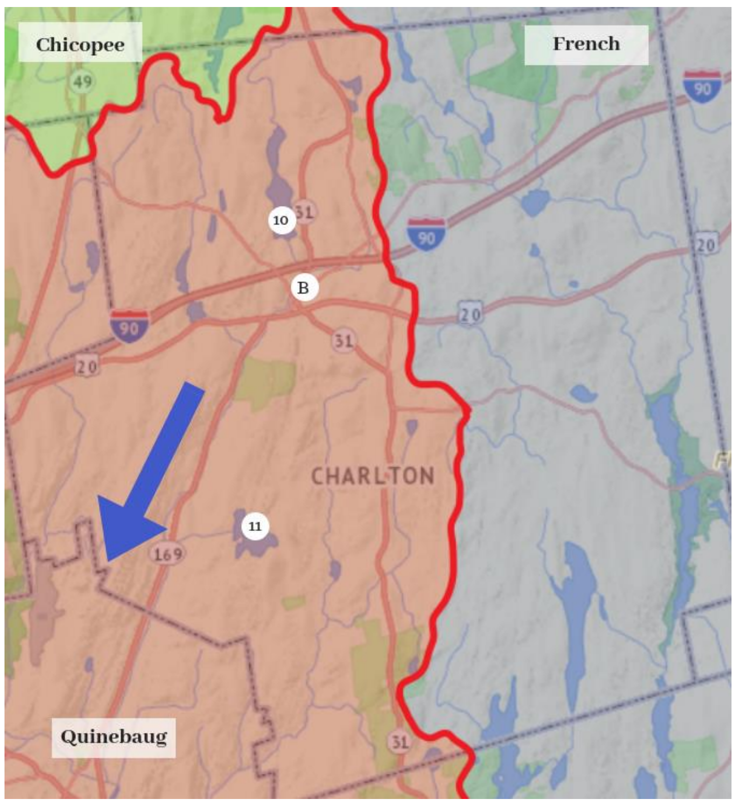


Figure 18: Flow Gradient and Location of Water Bodies in the Quinebaug River Watershed (Oliver Mass GIS, 2019).
(B) Cady Brook, (10) Glen Echo Lake, (11) Prindle Lake.

4.3.1 pH

The pH measurements in the Quinebaug River Watershed recorded between July 2015 to November 2018 ranged from 5.5 to 8.25 (see Figure 19). The US EPA Gold Book of Water Quality Criteria specifies an ideal pH range of 6.5-9 for supporting freshwater aquatic life. Three of the twenty-two results from Glen Echo Lake, and four of the five Cady Brook pH measurements fall below both the Massachusetts DEP minimum pH level (6.5) for Class A and B waters and the US EPA Gold Book of Water Quality minimum pH criteria (6.5). All the recorded Prindle Lake pH measurements fell within the referenced "ideal ranges".

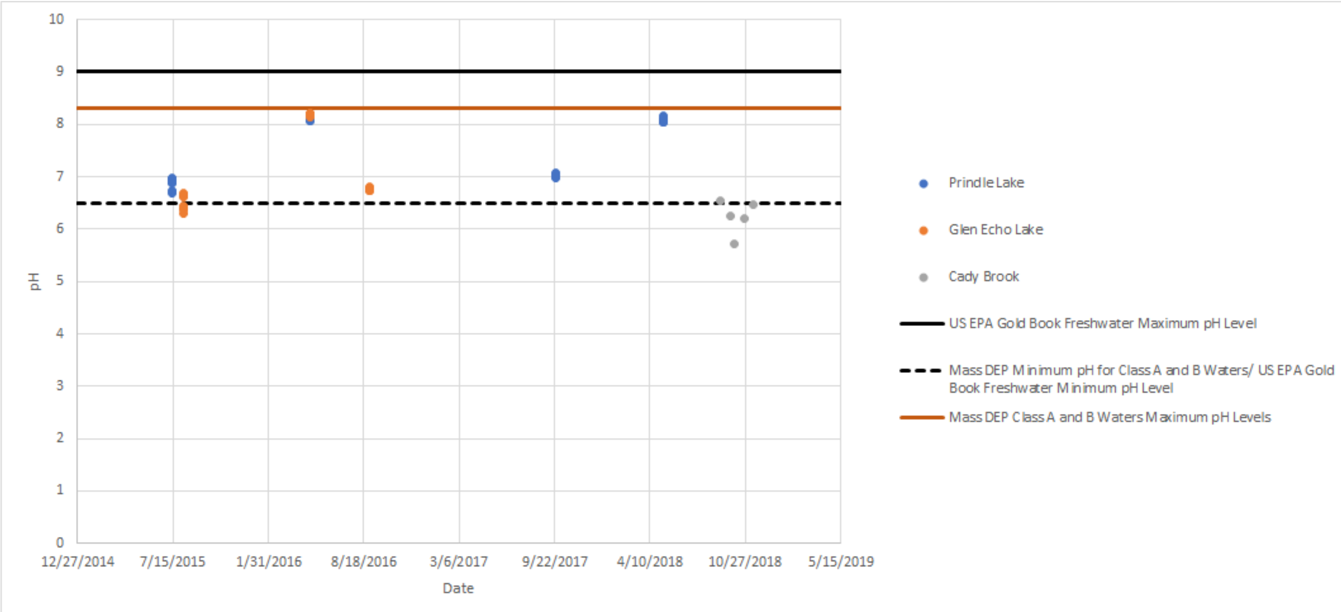


Figure 19: Quinebaug River Watershed pH Measurements.

Cady Brook's high relative pH could be attributed to its location adjacent to a mechanic's parking lot and between Route 20 and the Massachusetts Turnpike. Pollutants from these frequently trafficked impervious surfaces, such as salt may have drained into Cady Brook and decreased its pH. The relatively lower pH in Cady Brook, which is below the Massachusetts DEP recommended level, could prove detrimental to the trout stocked within it. Massachusetts DEP indicates that a maintained pH below 6.5 stresses the physiology of most organisms and reduces reproduction.

4.3.2 Turbidity

Turbidity data measured at Prindle Lake ranged from 0.7 NTU to 9.7 NTU, Glen Echo Lake ranged from 0.9 NTU to 5.9 NTU, and Cady Brook ranged from 1.77 NTU to 6.68 NTU (Figure 20). The World Health Organization suggests that a turbidity above 5 NTU may be aesthetically undesirable to the community (WHO, 1997). Of the recorded turbidity measurements in the Quinebaug River watershed, 93% of the values fell below the 5 NTU WHO recommendation. These results indicate a generally good aesthetic clearness for all three water bodies.

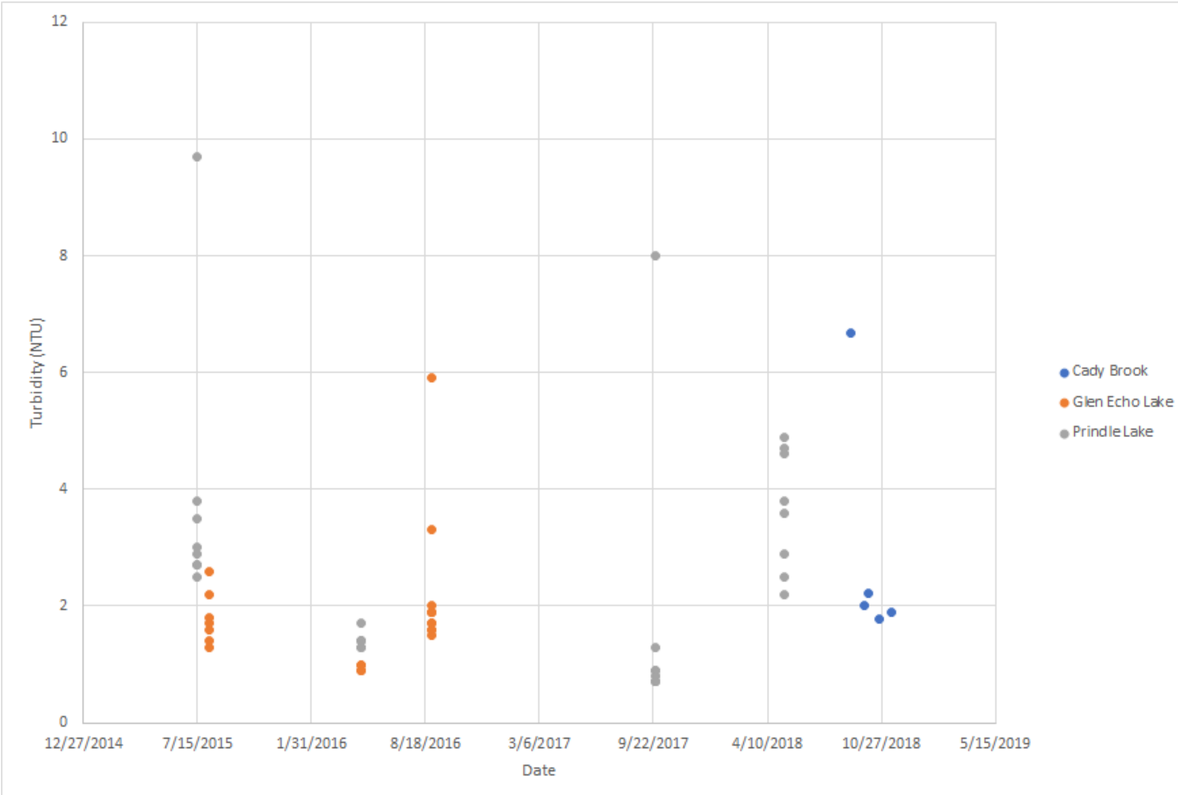


Figure 20: Quinebaug River Watershed Turbidity Measurements.

4.3.3 Total Coliforms

Total coliform data collected for Cady Brook ranged from 4,910 cfu/100 mL to 28,500 cfu/100 mL (Figure 21). As the Massachusetts DEP has a total coliform recommendation of less than 100 cfu/100 mL for an unfiltered public water supply, none of these water bodies are used for that purpose. There are no TC limits for swimming and recreation as long as the fecal coliform counts meet the required levels.

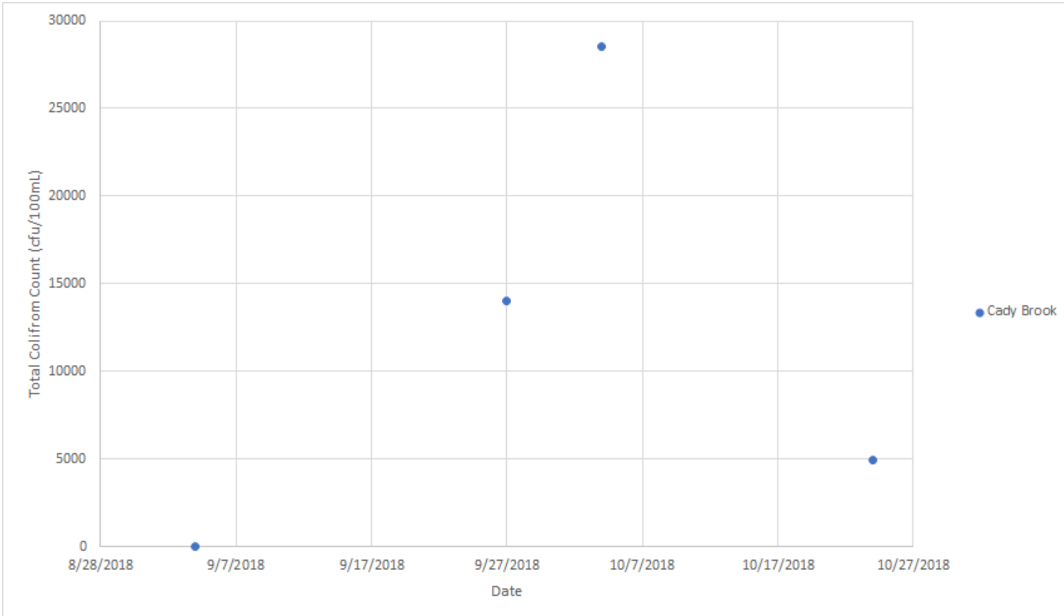


Figure 21: Cady Brook Total Coliform Measurements.

4.3.4 Fecal Coliforms

Fecal coliform counts from Cady Brook ranged from less than 1 cfu/100 mL to 59 cfu/100 mL (Figure 22). All these results were well below the maximum fecal coliform limits set out by the EPA Gold Book, Massachusetts DEP, and US EPA Recreational Waters requirements.

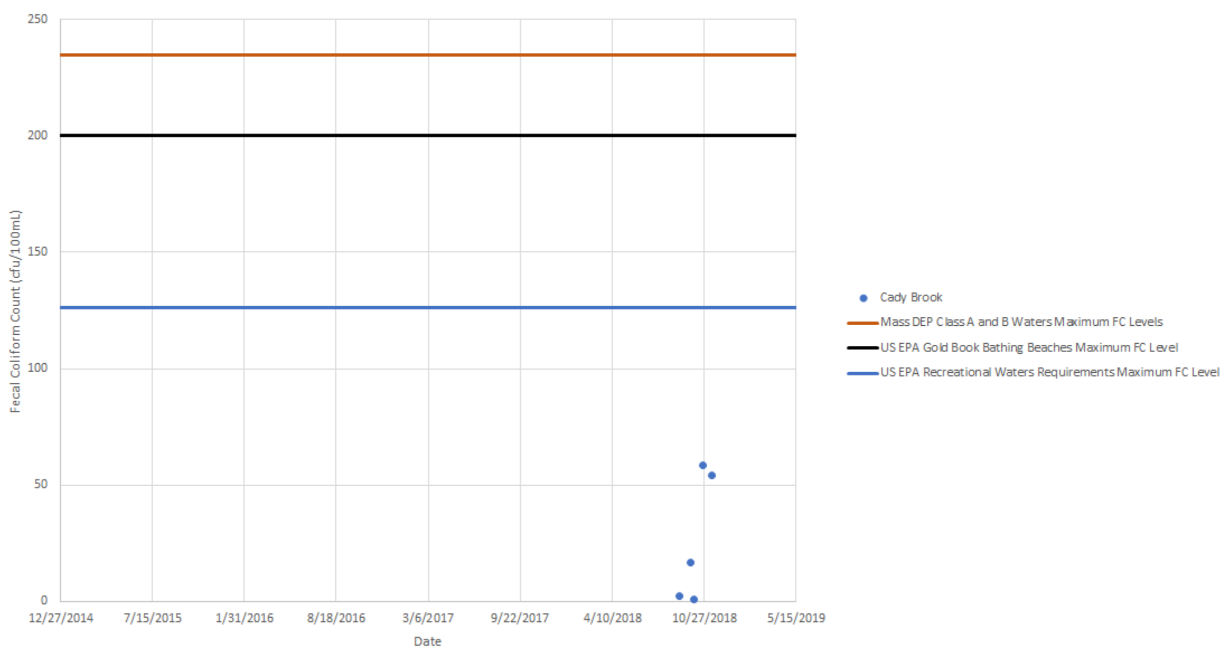


Figure 22: Cady Brook Fecal Coliform Measurements.

4.3.5 Dissolved Oxygen

DO data was collected for Prindle Lake and Glen Echo from July 2015 to May 2018. This MQP team recorded DO data in Cady Brook from September 2018 to November 2018. The combined data from the three Quinebaug water bodies within these timeframes are shown in Figure 23. The minimum US EPA Gold Book DO measurement is 8 mg/L and the Massachusetts DEP Class A and B cold water minimum DO level is 6 mg/L. While all of the recorded DO measurements for Cady Brook were above the Massachusetts DEP minimum DO level for Class A and B cold water bodies, three of the five Cady Brook measurements fell below the US EPA Gold Book minimum. Of the recorded DO levels collected at Prindle Lake, 38% of the 31 data points fell below the US EPA Gold Book minimum DO level and 86% of the 22 recorded DO levels at Glen Echo Lake fell below this minimum level. These results indicate a concern, as across time periods and various water bodies, the recorded DO levels are consistently lower than what is considered ideal by the US EPA. Low DO levels create a less habitable environment for aquatic life. As Prindle Lake, Glen Echo, and Cady Brook all serve as recreational fishing habitats, it is important for their recreational use that they are able to successfully support aquatic organisms. The consistently low DO levels may indicate a eutrophication issue resulting from an excess of vegetation decomposing in the water bodies.

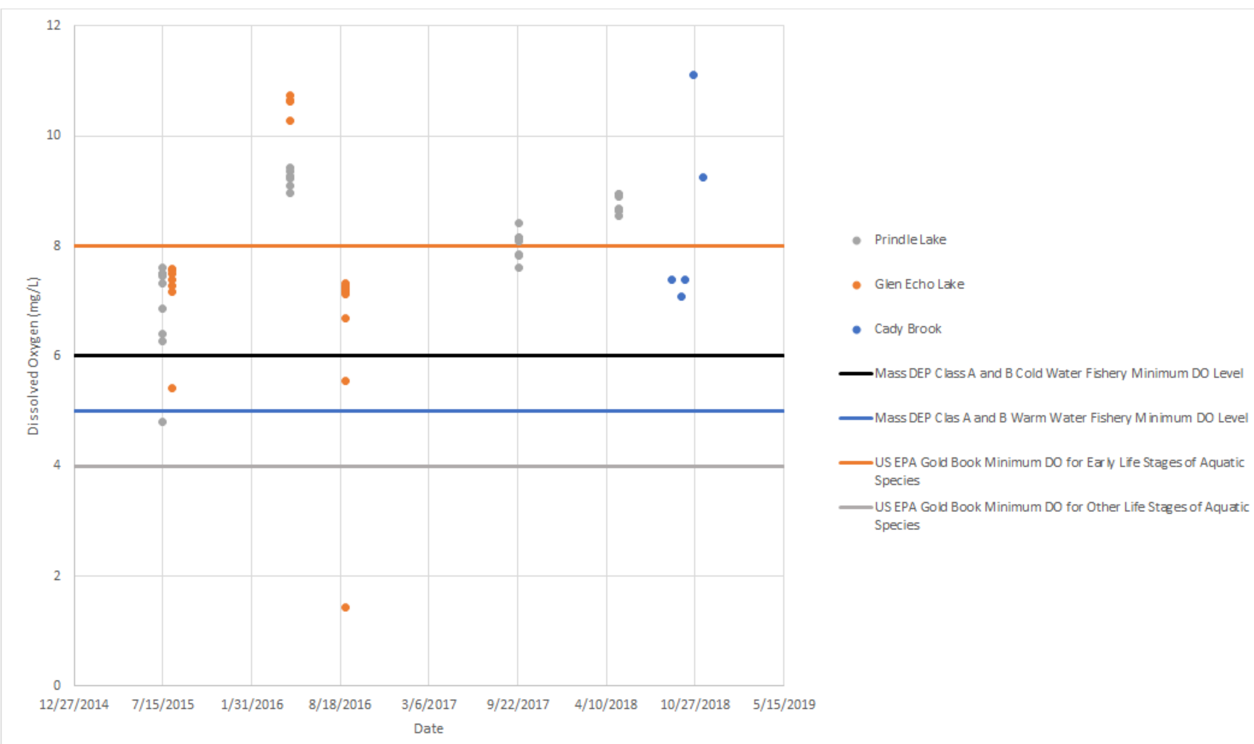


Figure 23: Cady Brook DO Measurements.

4.3.6 Nitrate

While our reference sources did not specify a maximum nitrate concentration for cold water fish, the US EPA Gold Book's maximum contaminant level of nitrate for effects on warm water fish is 90 mg/L. This MQP team collected nitrate measurements from Cady Brook between September and November 2018. The range of nitrate measurements from Cady Brook was 0.03 mg/L to 0.09 mg/L (Figure 24). Because all these measurements fell well below the nitrate limit, nitrate loading did not appear to be an issue in this water body throughout the duration of the sampling period.

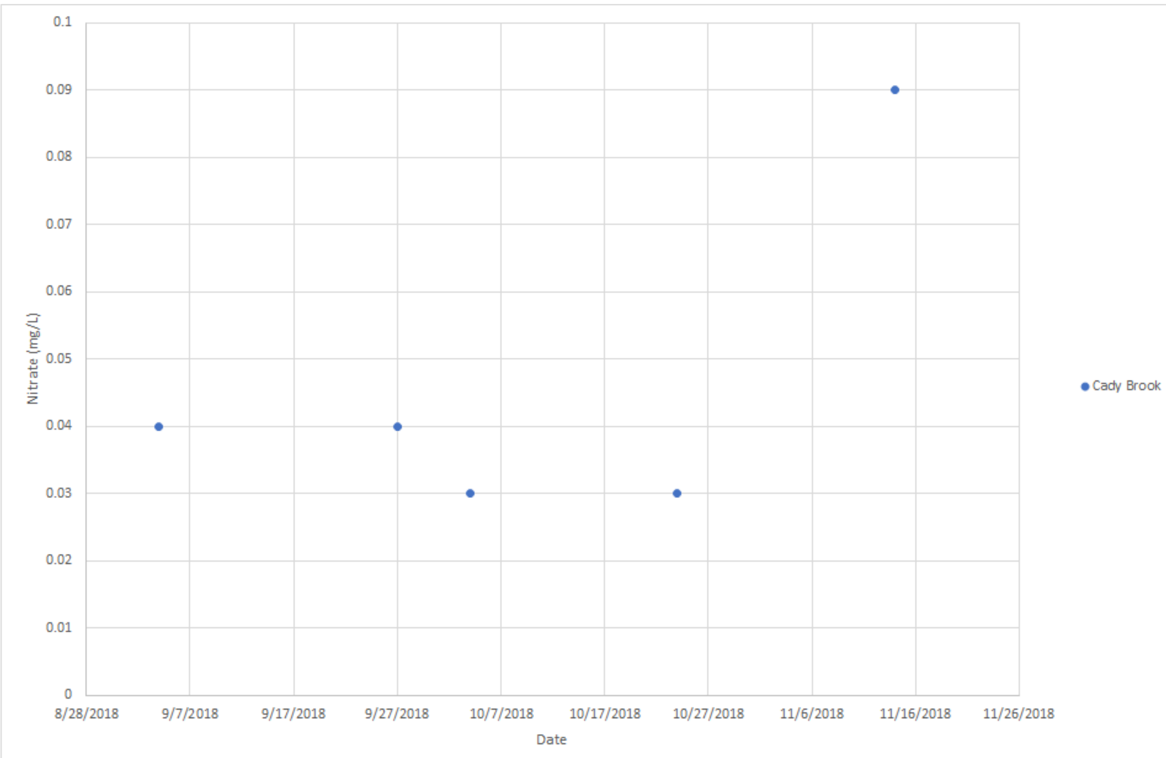


Figure 24: Cady Brook Nitrate Measurements.

4.3.7 Total Dissolved Solids

While there were no available records on TDS in Prindle or Glen Echo Lakes, the MQP team found that between September 2018 and November 2018, Cady Brook had a TDS range of 115 to 468 mg/L (Figure 25). According to the US EPA Gold Book Water Quality Criteria, a TDS concentration less than a maximum of 500 mg/L makes a water suitable as a drinking water source or irrigation source, and freshwater fish can tolerate up to 15,000 mg/L (EPA, 1986). All of the TDS measurements for Cady Brook within this team's testing period fell below these maximum concentrations.

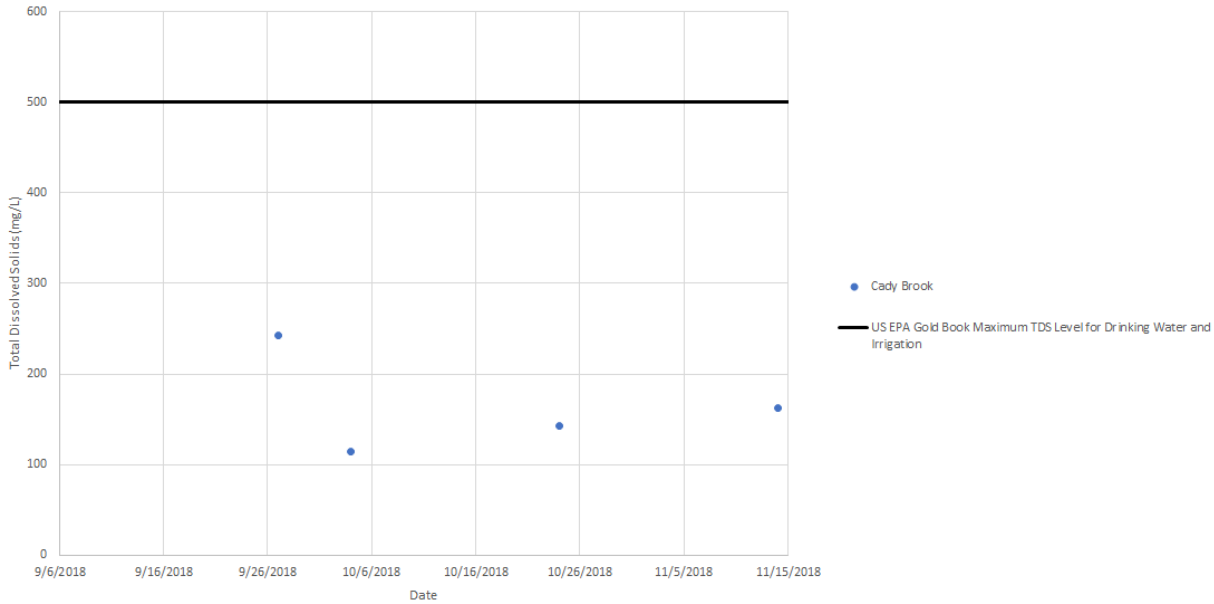


Figure 25: Cady Brook Total Dissolved Solids Measurements.

4.3.8 Total Phosphate

Total phosphate data were collected at Cady Brook and ranged from 0.29 mg/L to 0.88 mg/L. All of the measurements exceeded the US EPA Gold Book ideal maximum of 0.025 mg/L (Figure 26). Total Phosphate is generally a byproduct of watershed activities like farmland, septic system failure, or sewage effluent. Cady Brook's high total phosphate levels throughout this MQP teams' sampling period suggest an issue with excess phosphate in this region.

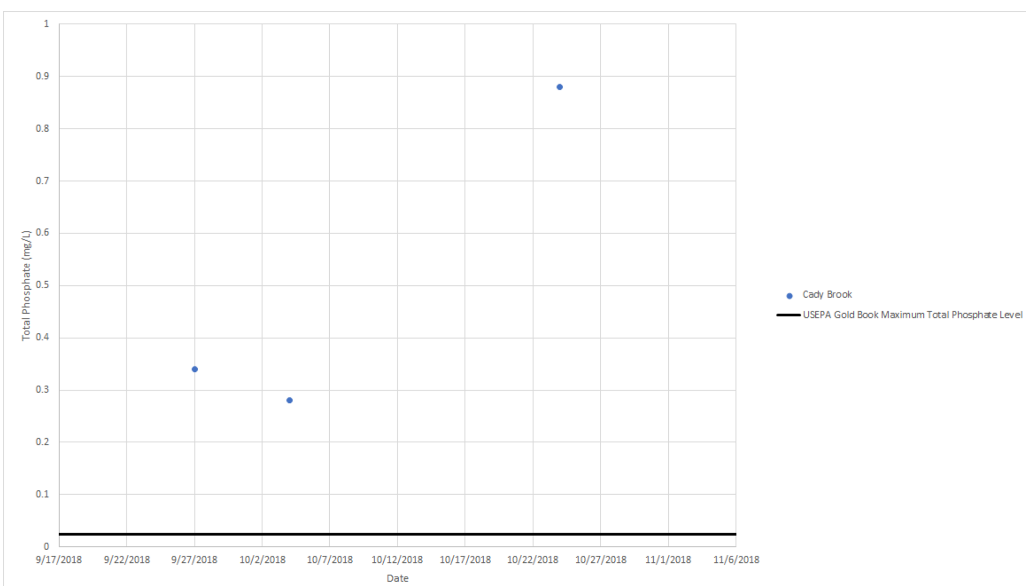


Figure 26: Cady Brook Total Phosphate Measurements.

4.4 Chicopee River Watershed

The Chicopee River Watershed is the largest watershed in Massachusetts, covering 39 cities (Commonwealth of Massachusetts, 2018). This watershed extends into the northwest corner of Charlton and the water flows northwest as shown by the blue arrow in the top left corner of Figure 27. Previously, no data had been collected on the Chicopee River Watershed. The MQP team collected data in fall 2018 at Cranberry Meadow Pond, indicated as "A" in Figure 27. Cranberry Meadow Pond is primarily used for water skiing, boating (no public access), swimming, and fishing (Todd Girard, personal communication, January 17, 2019).

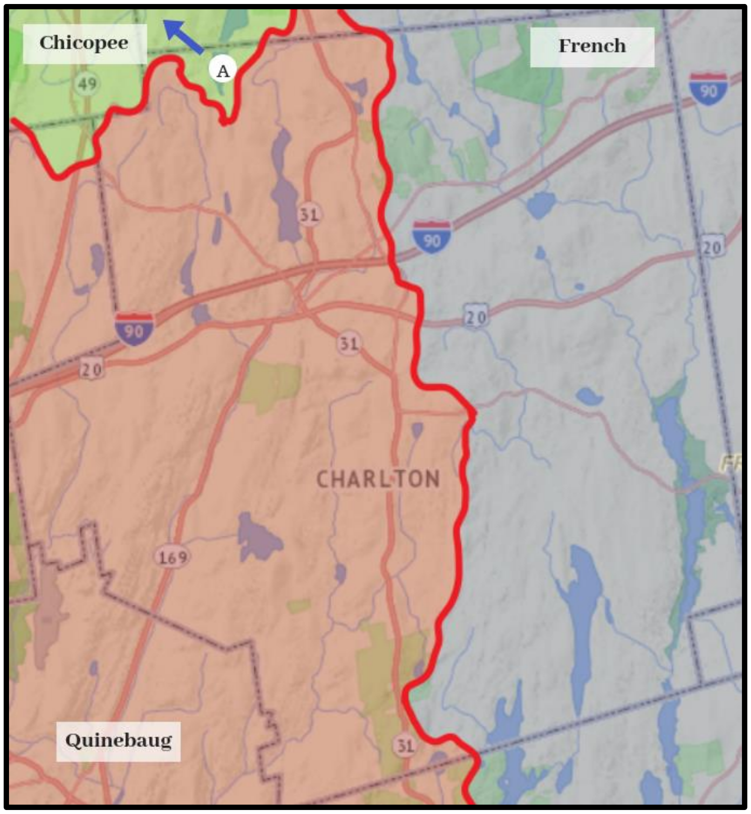


Figure 27: Flow Gradient and Location of Water Bodies in the Chicopee River Watershed (Oliver Mass GIS, 2019). (A) Cranberry Meadow Pond.

4.4.1 pH

pH for Cranberry Meadow Pond ranged between 5.84 and 6.41 over the five sampling weeks. This is just below the range of 6.5 to 9.0 range given by the US EPA Gold Book of Water Quality Criteria for freshwater aquatic life, and also below the range of 6.5 to 8.3 specified by the Massachusetts DEP for Class A or Class B water bodies (EPA, 1986; EPA, 2006). These data are shown in Figure 28.

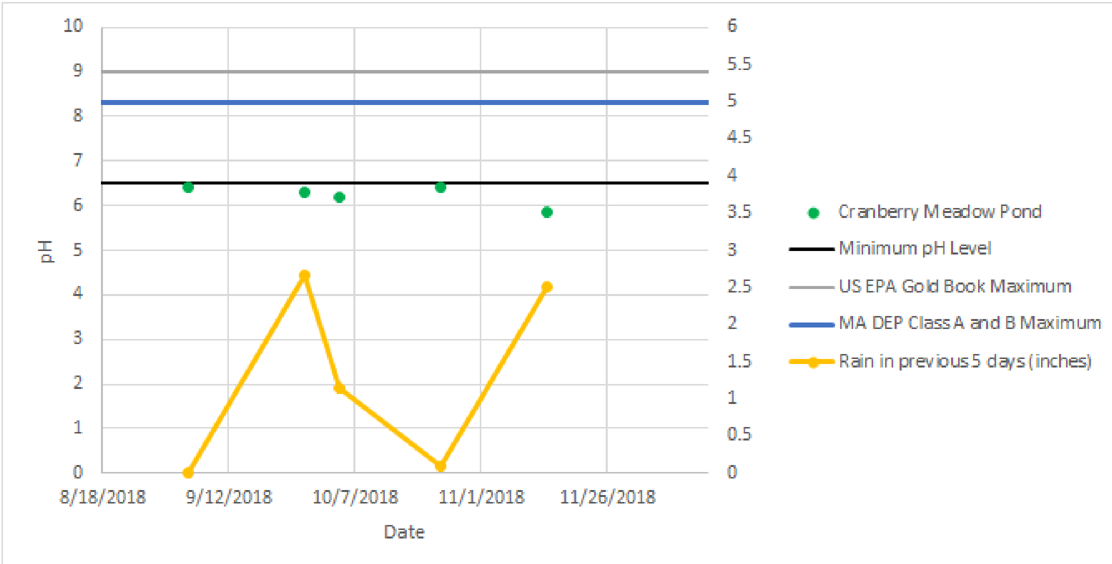


Figure 28: Chicopee River Watershed pH Measurements (Rain data: Weather Underground, 2019).

A low pH may be causing stress to aquatic organisms, especially if this is a new trend in the water body. Without previous data, this cannot be determined until more data are taken in the future. It should be noted that the fall 2018, three data points were taken after periods of high rain, and since the rain might have had a lower pH it may also have decreased the pH of the pond (as seen in Figure 28). Rainfall takes the minerals or contaminants and dissolves them, easily transporting them to the pond. The higher amount of impervious surfaces increases the amount of runoff in an area. Within a 0.5-mile radius of the Cranberry Meadow sampling location, 17.20% of the land is impervious. Driveways may be salted or vehicles may carry salts which will run into the water, causing a lower or more acidic pH. Pine trees border the pond in some areas and the acidity of the needles can be transferred from the soil to the water due to rain runoff. Runoff from yards also carries excess nutrients like phosphorus from the fertilizers and chemicals used to treat it. All these factors play a role in decreasing the pH of the pond.

4.4.2 Turbidity

Turbidity data measured at Cranberry Meadow Pond ranged from 0.69 NTU to 1.3 NTU. The US EPA Gold Book of Water Quality Criteria states that “settleable and suspended solids should not reduce the depth of the water compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life” (EPA, 1986). The Massachusetts DEP Class A and B water body classification criteria addresses turbidity criteria as the following: “Waters shall be free from turbidity in concentrations that are aesthetically objectionable or would impair any use assigned to this class” (EPA, 2006). Turbidity that is above 5 NTU is considered aesthetically undesirable to a community according to WHO (WHO, 1997). All values measured in fall 2018 by the MQP team fall below this value, indicating high quality waters as shown in Figure 29.

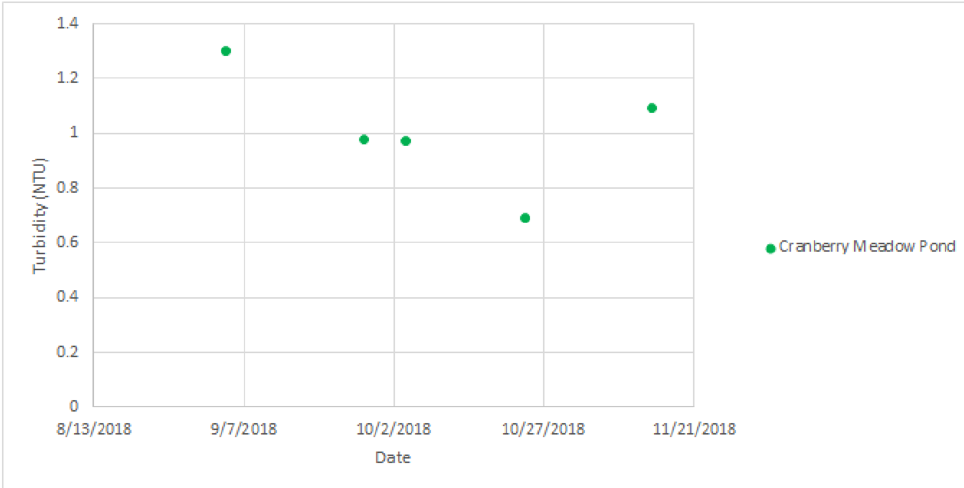


Figure 29: Chicopee River Watershed Turbidity Measurements.

4.4.3 Total Coliforms

Total coliform data in Cranberry Meadow Pond ranged from 1,600 cfu/100 mL to 5,225 cfu/100 mL (see Figure 30). Levels of total coliforms indicate the potential presence of biological pollution. The most likely source would be sewer runoff from a nearby house.

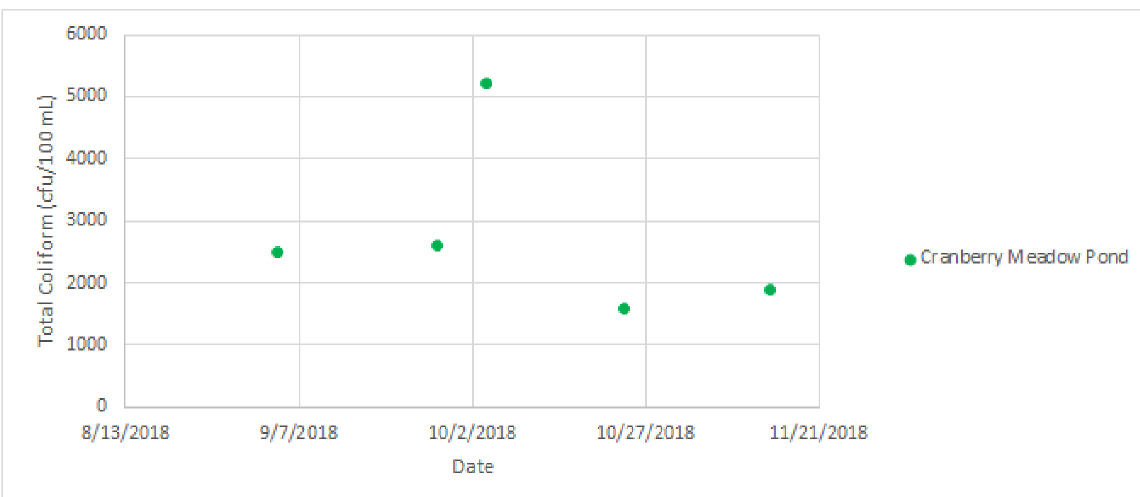


Figure 30: Chicopee River Watershed Total Coliform Measurements.

4.4.4 Fecal Coliforms

Fecal coliform concentrations in Cranberry Meadow Pond ranged from approximately 2 cfu/100 mL to 56 cfu/100 mL. The US EPA Gold Book of Water Quality Criteria states the maximum limit of 200 cfu/100 mL for swimming areas. According to the Massachusetts DEP Class A and B water body classifications, waters must not exceed 235 cfu/100 mL for swimming areas (EPA, 2006). The data collected by the MQP is below these limits as seen in Figure 31.

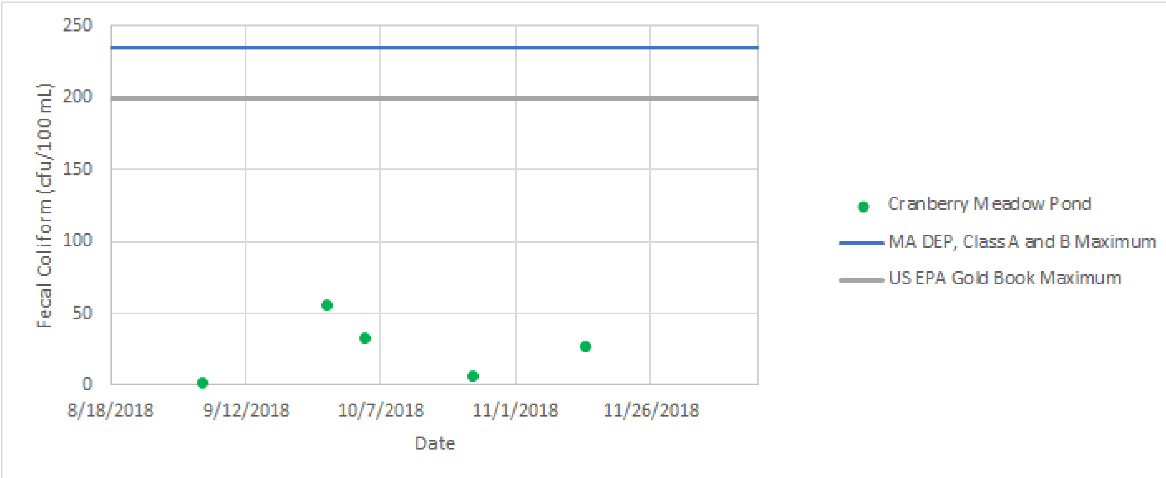


Figure 31: Chicopee River Watershed Fecal Coliform Measurements.

4.4.5 Dissolved Oxygen

DO data collected in fall 2018 ranged from 7.61 mg/L to 11.63 mg/L. The US EPA Gold Book of Water Quality Criteria states the minimum acceptable DO concentration to be 8.0 mg/L for early life stages of aquatic species and 4.0 mg/L for other life stages, which the data collected by the MQP team fell slightly below on two occasions, but three other instances were above that level (EPA, 1997). According to the Massachusetts DEP Class A and B water bodies criteria, the DO range measured by the MQP team is above the minimum of 5.0 mg/L and 6.0 mg/L (for warm water fishery and cold-water fishery, respectively) as shown in Figure 32 (EPA, 2006).

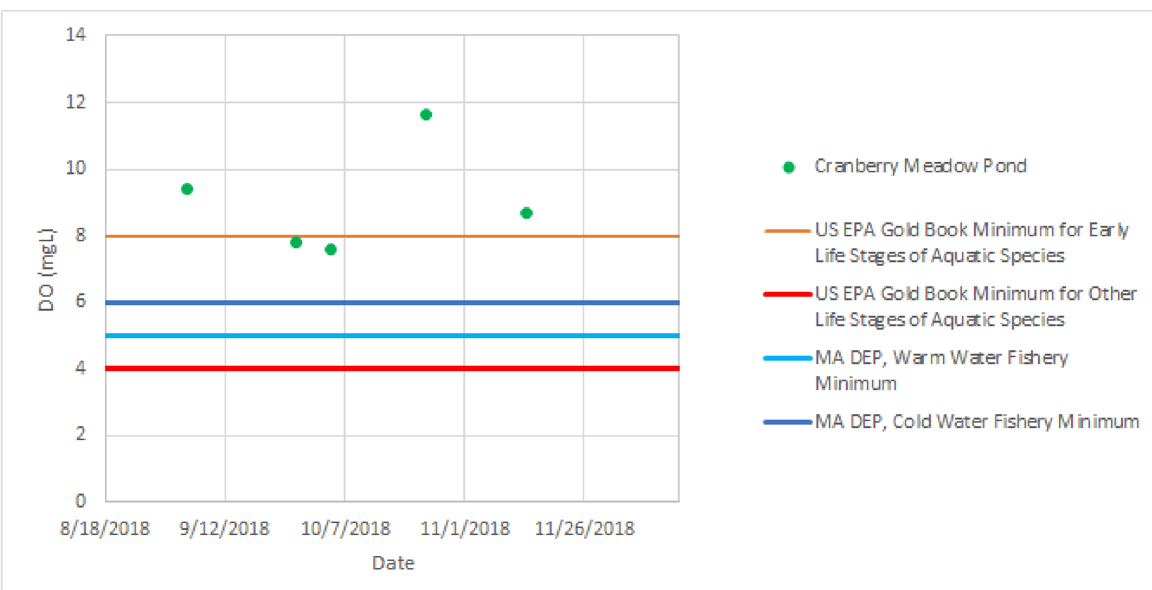


Figure 32: Chicopee River Watershed DO Measurements.

4.4.6 Nitrate

The US EPA Gold Book of Water Quality Criteria states a maximum level of nitrate as 90 mg/L for its effects on warm water fish, with no criteria for cold water fish (EPA, 1986). Nitrate data collected on Cranberry Meadow Pond ranged from 0.01 mg/L to 0.02 mg/L which is well below the level of effecting warm water fish, as seen in Figure 33.

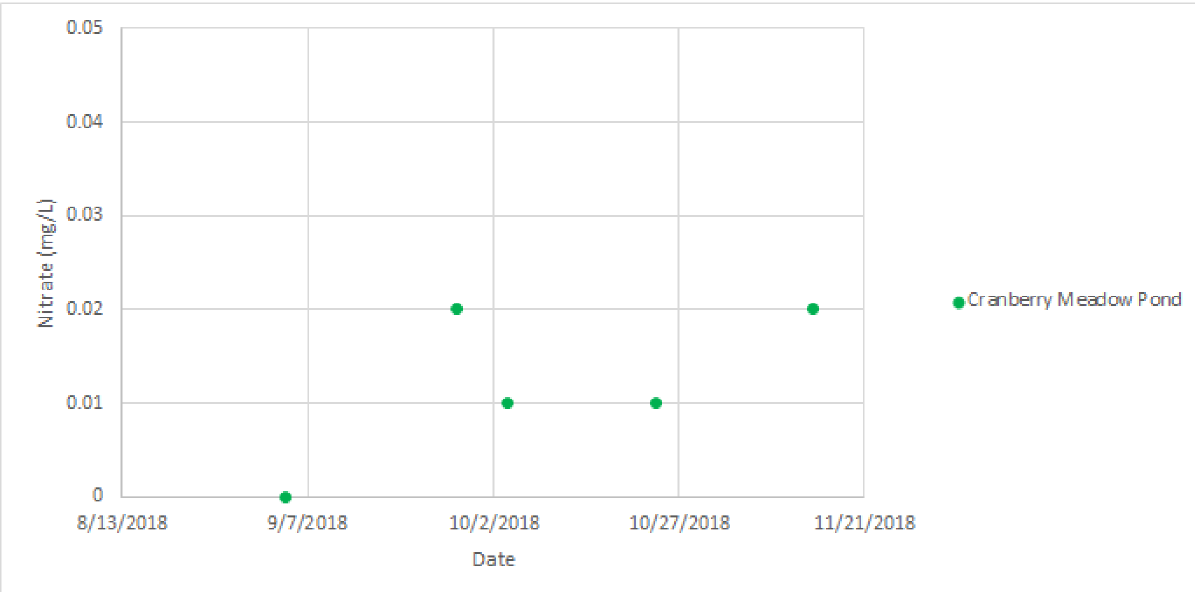


Figure 33: Chicopee River Watershed Nitrate Measurements.

4.4.7 Total Dissolved Solids

The data from Cranberry Meadow Pond on TDS levels ranged between 87 mg/L and 150 mg/L. The US EPA Gold Book of Water Quality Criteria states 500 mg/L dissolved solids is the limit for a water to be suitable for drinking or for irrigation, and freshwater fish tolerance to be 15,000 mg/L (EPA, 1986). Thus, the range measured by the MQP team would be acceptable conditions, as seen in Figure 34. Also, the Massachusetts DEP Class A and B water bodies require the water to be "free from floating, suspended and settleable solids in concentrations that would impair any class uses, cause aesthetically objectionable conditions, or impair benthic biota or degrade chemical composition of the bottom" (EPA, 2006).

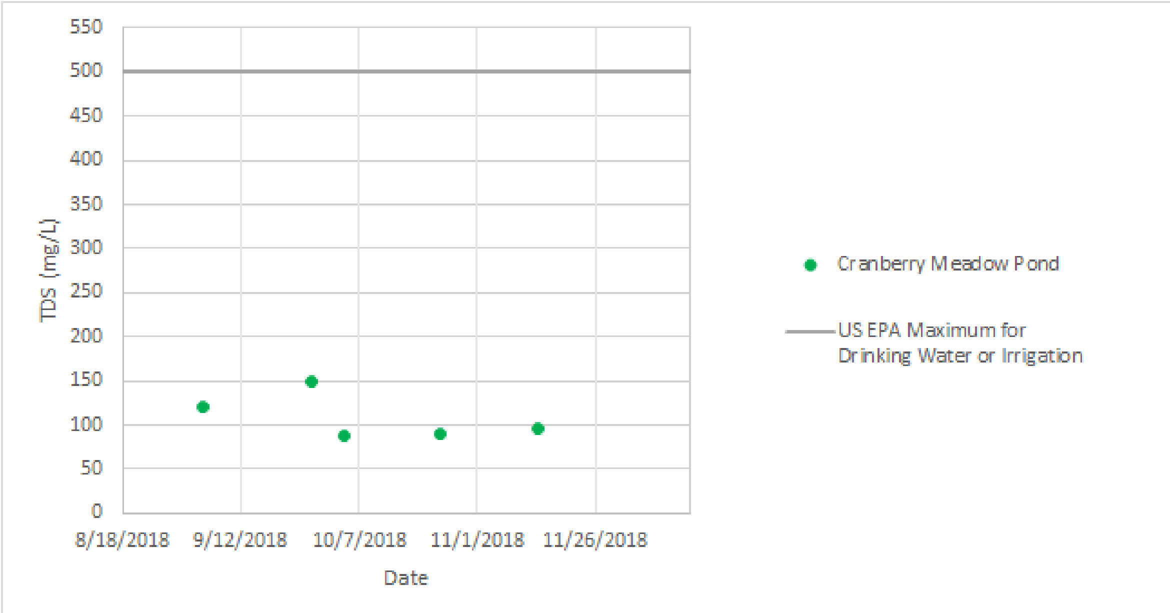


Figure 34: Chicopee Watershed TDS Measurements.

4.4.8 Total Phosphate

Data collected for total phosphate at Cranberry Meadow Pond ranged from 0.21 mg/L and 0.77 mg/L. The US EPA Gold Book of Water Quality Criteria states total phosphate levels within lakes and reservoirs should not exceed 25 µg/L (0.025 mg/L) (EPA, 1986). Therefore, as shown in Figure 35, very high levels of total phosphate were found in the pond and may be promoting excessive growth of vegetation.

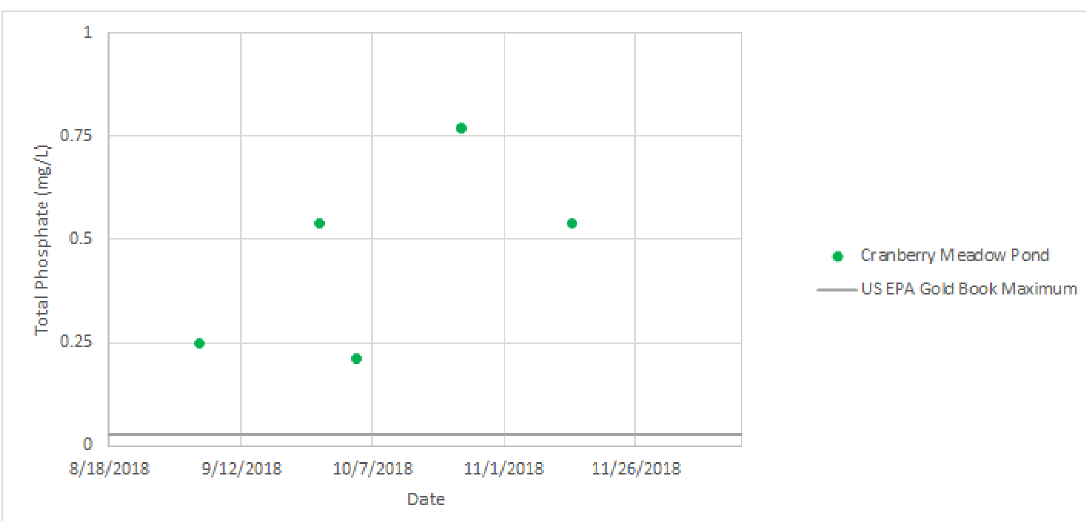


Figure 35: Chicopee River Watershed Total Phosphate Measurements.

4.5 Testing Limitations

Limitations on the MQP team's testing procedures should be noted with regard to interpretation of water quality results. For measurement of total coliforms, a volume of water sample is passed through a filter and coliform bacteria grown on the surface of the filter which is placed in a petri dish with nutrient media. Initially, the selected volumes were too large which led to excessive growth on the filters. Thus, the coliform counts per plate too numerous (outside of the ideal range when conducting this experiment). On the MQP team's later testing dates, the volumes were decreased to have less coliforms growing during the test period. In some cases, this led to the number of coliforms being too few to be considered reliable. Due to these issues, the calculations of the number of colonies per 100 mL of water was based on "non-ideal" counts and thus may not be accurate compared to the actual number of coliforms in the water bodies.

In addition, it should be noted that trends concluded from only the MQP team's sampling dates are from a short time period (September to November 2018). Due to time constraints, the team was unable to do a long-standing study over multiple seasons and therefore the data sets for some water quality parameters or some watersheds are limited.

4.6 Summary

A summary of the water quality of each water body in Charlton can be seen in Table 10. Water bodies are listed vertically in the left-most column and water quality parameters are listed horizontally in the top row. In order to classify the water bodies and their water quality issues, the MQP team calculated the percentages of data points that fell outside of the ideal ranges of each parameter. The following are the ideal ranges used:

- pH: Massachusetts DEP Class A and B Waters (6.5 – 8.3)
- Fecal coliforms: Massachusetts DEP Class A and B Waters (235 cfu/100 mL, maximum)
- DO: Massachusetts DEP Class A and B, Warm Water Fisheries (5.0 mg/L, minimum)
- Nitrate: US EPA Gold Book Water Quality Criteria (90 mg/L, maximum)
- TDS: US EPA Gold Book Water Quality Criteria (500 mg/L, maximum)
- Total phosphate: US EPA Gold Book Water Quality Criteria (0.025 mg/L, maximum)

If no data points fell outside the ideal range, the parameter was shown as green (acceptable water quality). If 0.01% to 24.9% of the data points fell outside the ideal range, the parameter was shown as yellow (moderately impaired water quality). If 25% or more of the data points were outside the ideal range, the parameter was shown as red (poor water quality). If no data was available for the water body within the last 10 years, the parameter was shown as grey.

Occasionally, the original categorization (red, yellow, or green) insufficiently represented the data. For example, if a high percentage of data points fell outside the range but most were close in magnitude to the limits, the water body may not necessary be considered to have significantly poor water quality (warranting a red designation). In instances such as these, the MQP team made judgements to determine what designation was more fitting for the parameter.

Six parameter designations out of 32 were changed by the MQP team. These are noted by an asterisk and justified below Table 10.

Table 10: Water quality summary per parameter for water bodies within Charlton, MA.
(F = French River Watershed; Q = Quinebaug River Watershed; C = Chicopee River Watershed).

	pH	FC	DO	Nitrate	TDS	Total Phosphate
Baker (Gore) Pond (F)						
Buffumville Lake (F)	*	*				
Little Nugget Lake (F)	*					
Little River (F)						
Pierpoint Meadow Pond (F)						
Pikes Pond (F)						
Potter Brook (F)						
Putnam Pond (F)						
Snow Pond (F)						
South Charlton Reservoir (F)	*					
Cady Brook (Q)						
Glen Echo Lake (Q)						
McKinstry Brook (Q)						
Prindle Lake (Q)			*			
Cranberry Meadow Pond (C)	*					

The designations that were changed based on detailed analysis of the data are as follows:

- Buffumville Lake, pH: 25% of the data points fell outside of the ideal range. However, 16.7% of those data points were within 6.18 to 8.72, which is within 5% of the ideal range of 6.5 to 8.3. Therefore, only 8.3% of the pH data points were identified by the MQP team as falling significantly outside the ideal range. For this reason, the designation was changed from poor to moderate.

- Buffumville Lake, FC: 5% of the data points fell above the ideal maximum value, which was only 1 data point out of 20. Therefore, the MQP team classified this one point as an outlier and decided it did not justify identifying the water body as having moderately impaired water quality.
- Little Nugget Lake, pH: 100% of the data points fell outside of the ideal range of 6.5 to 8.3. However, 90% of those data points were within 8.18 to 8.72, which is within 5% of the ideal range. Therefore, only 10% of the pH data points were identified by the MQP team as falling significantly outside the ideal range. For this reason, the designation was changed from poor to moderately impaired.
- South Charlton Reservoir, pH: 27% of the data points fell outside of the ideal range. However, 20% of those data points were within 5% of the ideal range of 6.5 to 8.3. Therefore, only 7% of the pH data points were identified by the MQP team as falling significantly outside the ideal range. For this reason, the designation was changed from poor to moderately impaired.
- Prindle Lake, DO: 3.2% of the data points fell below the ideal minimum value, which was only 1 data point out of 31. Therefore, the MQP team classified this one point as an outlier and decided it did not justify identifying the water body as having moderate water quality.
- Cranberry Meadow Pond, pH: 100% of the data points fell outside of the ideal range. However, 80% of those data points were within 6.18 to 8.72, which is within 5% of the ideal range. Therefore, only 20% of the pH data points were identified by the MQP team as falling significantly outside the ideal range. For this reason, the designation was changed from poor to moderately impaired.

In summary, each watershed had different levels of water quality. Common problems in the French River Watershed were poor to moderately impaired pH, moderately low DO, and high total phosphate. In the Quinebaug River Watershed there was moderately low pH, moderately low DO, and high total phosphate. In the Chicopee River Watershed, there was only one water body that fell within Charlton's town boundaries and the boundaries of the watershed: Cranberry Meadow Pond. This waterbody has moderately low pH and high total phosphate levels. In all three watersheds, lack of data was a significant problem as many water bodies have no historical water quality data or only had historical data on some water quality parameters.

Across all three watersheds, high total phosphate was a concern. Within the last 10 years, three water bodies were tested for total phosphate, and all three had measurements that were higher than the acceptable range. This indicates that nutrient loading in surface water bodies may be a town-wide problem. Additionally, low DO levels were a problem in the French River Watershed and Quinebaug River Watershed. The low DO levels could be due to high total phosphate levels leading to increased plant growth in the water bodies which can cause eutrophication and oxygen depletion in water bodies. Finally, low pH was a common problem in all the watersheds. Nine waterbodies in Charlton have pH measurements; one of these has poor, seven have moderately low and one has acceptable pH levels. However, it should be noted that pH fluctuations in surface water bodies in the northeast regions of the United States are common.

4.6.1 Statistical Analysis of Data

In each watershed separately, a correlation analysis was performed on each pair of water quality parameters, for example, DO and TDS, and then DO and turbidity, and so on. This resulted in 45 pairs of data sets for comparison in the French River Watershed, 45 in the Quinebaug River Watershed, and 55 in the Chicopee River Watershed. In some cases, a relationship may be expected, such as DO and temperature which may be inversely related. In other cases, no relationship would be expected, such as TDS and fecal coliforms. The statistical software NCSS 12 was used to run these correlation analyses. The software compares two parameters and gives an output that includes the value of the Pearson coefficient, the number of data pairs from occurrences that were used in the analysis, the degrees of freedom, and whether or not the Pearson coefficient was statistically significant at the 95% confidence level, i.e., whether or not the parameter pair was correlated. Correlation coefficients range from -1 to 1, with coefficients close to an absolute value of 1 indicating a strong correlation and close to 0 indicating no correlation. Negative coefficients indicate an inverse correlation (one value increases as the other decreases) and positive coefficients indicate a positive correlation (both values increase or decrease in conjunction with each other).

The parameters compared in the French River Watershed are shown in Table 11. Correlated values are shown in green in the table, and non-correlated values are shown in red. The data for the French River Watershed was not a consistent data set, meaning that some parameters were measured on some occasions but not every parameter was measured on every sampling occasion. This resulted in there being different numbers of data pairs for different parameter comparisons, and therefore different degrees of freedom for each parameter comparison. The number of degrees of freedom in the French River Watershed ranged from 8 to 755. Degrees of freedom are used to determine the statistically significant r-value for a specific confidence level. Pearson coefficient values with a greater absolute value than the statistically significant r value are determined to be statistically significant and therefore, correlated. Since there were different degrees of freedom for each data set, a different statistically significant r-value was used for each correlation analysis.

Table 11: French River Watershed Correlation Analysis.

	Water Temp (°C)	Air Temp (°C)	pH	Turbidity (NTU)	TC (cfu/100mL)	FC (cfu/100mL)	DO (mg/L)	Nitrate (mg/L)	TDS (mg/L)	Total Phosphate (mg/L)
Water Temp (°C)	1									
Air Temp (°C)	0.7772	1								
pH	0.0670	-0.0955	1							
Turbidity (NTU)	-0.0201	0.1601	0.0351	1						
TC (cfu/100mL)	0.0938	0.7504	0.2049	-0.1903	1					
FC (cfu/100mL)	0.2450	0.3318	0.1224	-0.1833	0.7675	1				
DO (mg/L)	-0.3621	-0.4437	0.3542	-0.2420	0.2029	0.0670	1			
Nitrate (mg/L)	-0.6346	0.4772	0.4218	0.6095	-0.3212	-0.2613	0.1238	1		
TDS (mg/L)	0.5578	0.3650	0.3246	0.0537	0.7255	0.0215	-0.0309	-0.4573	1	
Total Phosphate (mg/L)	-0.6585	-0.7921	-0.4481	-0.2039	-0.6158	-0.0764	0.5636	-0.5222	-0.2742	1

Out of the 45 parameter pairs that were analyzed for correlation, 19 were found to have a Pearson's coefficient which was statistically significant and therefore correlated. Many parameters which were hypothesized to be correlated were shown to be not correlated by the statistical analysis (for example, turbidity and total dissolved solids) and many parameters which were hypothesized to not be correlated were shown to be correlated by the statistical analysis (for example, air temperature and total coliforms). The statistical analysis was carried out at a 95% confidence level, meaning that it would be expected that 95% of the correlation conclusions would be correct and therefore, the conclusions would be incorrect about 5% of the time. These unexpected conclusions compared to hypothesized conclusions could be attributed to statistical error or could occur due to other factors that were not considered in the analysis.

Some important parameter pairs to note are pH and water temperature, dissolved oxygen and total phosphate, turbidity and total dissolved solids, conductivity and total dissolved solids, and dissolved oxygen and water temperature. These five sets of parameters are known to be related to each other. In the French River Watershed, pH and water temperature had a Pearson coefficient of 0.0670, a degrees of freedom of 755, and were found to not be statistically significant at the 95% confidence level and therefore not correlated. This was not expected as pH tends to fluctuate with changing temperature. Dissolved oxygen and total phosphate had a Pearson coefficient of 0.5635, a degrees of freedom of 35 and were found to be statistically significant at the 95% confidence level and therefore correlated. A high correlation is expected between these two parameters, but a positive correlation is not expected. It would be expected that these two parameters would have a negative correlation as increased total phosphate usually leads to increased biomass in water bodies and increased BOD, leading to decreased dissolved oxygen. Turbidity and total dissolved solids had a Pearson coefficient of 0.0537, a degrees of freedom of 8 and were found to not be statistically significant at the 95% confidence level and therefore not correlated. Turbidity and total dissolved solids are both related to particulate matter in the water body, so a positive correlation was expected between the two parameters. Conductivity and total dissolved solids had a Pearson coefficient 0.7618, a degrees of freedom of 26, and were found to be statistically significant at the 95% confidence level and therefore correlated, which was expected. Finally, dissolved oxygen and water temperature had a Pearson coefficient of -0.4437, a degrees of freedom of 500, and were found to be statistically significant at the 95% confidence level and therefore inversely correlated.

The parameters compared in the Quinebaug River Watershed are shown in Table 12. Out of 45 sets of compared parameters, 16 were determined to be correlated in the watershed (highlighted green in Table 12).

Table 12: Quinebaug River Watershed Correlation Analysis.

	Water Temp (°C)	*Air Temp (°C)*	*pH*	*Turbidity (NTU)*	*TC (cfu/100mL)*	*FC (cfu/100mL)*	*DO (mg/L)*	*Nitrate (mg/L)*	*TDS (mg/L)*	*Total Phosphate (mg/L)*
Water Temp (°C)	1									
Air Temp (°C)	0.8582	1								
pH	-0.5265	-0.3909	1							
Turbidity (NTU)	0.2291	0.3331	-0.0472	1						
TC (cfu/100mL)	0.7665	0.5946	-0.7954	0.9909	1					
FC (cfu/100mL)	0.8610	-0.8990	0.3198	-0.5432	-0.8907	1				
DO (mg/L)	-0.6914	-0.5711	0.5811	-0.4114	-0.7579	0.9027	1			
Nitrate (mg/L)	-0.5875	-0.6312	0.5413	-0.1533	-0.2343	0.4668	0.1404	1		
TDS (mg/L)	0.7665	0.6942	0.6361	0.9361	-0.3188	-0.4686	-0.4406	-0.4406	1	
Total Phosphate (mg/L)	-0.7009	-0.7345	0.2015	-0.4235	-0.8493	0.9258	0.9884	0.9884	-0.0362	1

Some of these parameter correlations were expected to be correlated, such as water temperature and air temperature (Pearson coefficient 0.8582), water temperature and DO (Pearson coefficient -0.6914), and air temperature and DO (Pearson coefficient -0.5711). DO saturation values are inversely related to temperature. pH is also known to be negatively correlated with temperature. This is confirmed by this MQP’s NCSS 12 data, showing a negative correlation between water temperature and pH (Pearson coefficient -0.5265), as well as a negative correlation between air temperature and pH (Pearson coefficient -0.3909). Turbidity and TDS in this watershed were shown to be positively correlated (Pearson coefficient 0.9361), supporting the known positive correlation between TDS and turbidity. Nitrate and total phosphate's positive correlation in the Quinebaug River watershed was expected as many fertilizers and other nutrient runoff contains both phosphates and nitrates. While DO and total phosphate were expected to have a negative correlation, the NCSS 12 data instead identified a strong positive correlation between the two parameters (Pearson coefficient 0.9884). This information was unexpected, considering that increased total phosphate levels generally predict a decrease in a water body's dissolved oxygen levels. Aside from the DO and total phosphate relationship, there were no parameter pairs in the Quinebaug River watershed that failed to be shown as correlated by NCSS 12 when they were expected to show correlation. The remaining parameter pairs shown to be correlated were not expected to be so. These unexpected correlations are not necessarily a cause for concern as correlation does not mean causation.

The parameters compared in the Chicopee River Watershed are shown in Table 13. The Chicopee River Watershed includes five data sets, giving it three degrees of freedom. Using the "Critical Values of Pearson's r" table, 0.878 was determined as the r-value of statistically significant correlation at the 95% confidence level. Therefore, as shown in Table 13 highlighted in green, two sets of parameters were determined to be correlated in the watershed: water temperature and air temperature; and amount of rainfall and nitrate levels.

Table 13: Chicopee River Watershed Correlation Analysis.

	Water Temp (°C)	*Air Temp (°C)*	*Rainfall (in)*	*pH*	*Turbidity (NTU)*	*TC (cfu/100mL)*	*FC (cfu/100mL)*	*DO (mg/L)*	*Nitrate (mg/L)*	*TDS (mg/L)*	*Total Phosphate (mg/L)*
Water Temp (°C)	1										
Air Temp (°C)	0.9993	1									
Rainfall (in)	-0.3710	-0.3974	1								
pH	0.6566	0.6780	-0.6847	1							
Turbidity (NTU)	0.5789	0.5537	0.0644	-0.1677	1						
TC (cfu/100mL)	0.3341	0.3454	0.0144	0.0230	0.1050	1					
FC (cfu/100mL)	-0.0868	-0.1016	0.8637	-0.3034	-0.0891	0.3216	1				
DO (mg/L)	-0.2474	-0.2285	-0.6734	0.3930	-0.4520	-0.6512	-0.7639	1			
Nitrate (mg/L)	-0.6565	-0.6735	0.9123	-0.6415	-0.3191	-0.1591	0.7708	-0.3687	1		
TDS (mg/L)	0.5266	0.5047	0.3888	0.2703	0.3629	-0.1980	0.5010	-0.3604	0.1924	1	
Total Phosphate (mg/L)	-0.6718	-0.6677	0.1198	-0.0264	-0.7120	-0.7520	-0.0155	0.6259	0.4738	-0.0362	1

The water and air temperatures had a Pearson coefficient of 0.9993, which is positively correlated as expected, showing that as the air temperature increased or decreased so did the water temperature. The amount of rainfall was positively correlated with the nitrate levels in the pond (Pearson coefficient of 0.9123). This indicates the runoff into the pond is carrying nitrate, most likely from fertilizers used on lawns around the pond. However, the levels of nitrate found in the pond are well below the US EPA Gold Book maximum and therefore are not of high concern.

A few unexpected conclusions given by the software were for the following parameters: water temperature and pH; water temperature and DO; DO and total phosphate; and turbidity and TDS. These parameters are known to be related to each other based on physical, chemical and biological principles. In the Chicopee River Watershed, water temperature and pH were found to have a Pearson coefficient of 0.6566, making the two parameters statistically insignificant. This was unexpected because normally pH changes with water temperature. Similarly, DO is known to fluctuate with water temperature but had a Pearson coefficient of -0.2474, deeming it statistically insignificant. DO and total phosphate had a Pearson coefficient of 0.3930, which is unusual because of the low, positive correlation. These were expected to be a larger value and negatively correlated. Increased total phosphate levels is indicative of excessive plant growth, which should lead to a decrease in DO levels. Finally, turbidity and TDS are expected to have high correlation, but they had a Pearson coefficient of 0.3629. Turbidity is indicative of the clarity of the water, so a higher turbidity usually means there is a higher amount of dissolved solids in the water. These unexpected conclusions may be due to the 5% statistical error included when using the 95% confidence level; the number of data pairs in the data set; the presence of outliers; or the impact of other confounding factors that were not included in the analysis.

4.6.2 Analysis of Variance by Watershed

Using Microsoft Excel, the ANOVA test determined if there was a significant difference between the watersheds in Charlton in terms of pH, turbidity, total coliforms, fecal coliforms, DO, nitrate, TDS and total phosphate. The test was run for each parameter with the data grouped by watershed. It compared the variance *between* all the watershed data with the variance of data *within* each watershed to determine if the mean value of a parameter was statistically different by watershed. Analyzing the P-value output, if it was at or below 0.05 the parameter varied between watersheds. If the P-value output was above 0.05, there was low variance between the watersheds, meaning that the watersheds had similar values for that parameter. The results are shown in Table 14. It was determined that pH, total coliforms, nitrate, and TDS levels were statistically different in the different watersheds.

Table 14: Variance Between Watersheds in Charlton.

Key		
(orange)	Statistically Different	≤ 0.05
(blue)	Statistically Not Different	>0.05

Parameter	P-Value
pH	0.00001
Turbidity	0.71595
TC	0.00367
FC	0.79201
DO	0.13991
Nitrate	0.00331
TDS	0.00011
Total Phosphate	0.19812

The pH and nitrate levels may vary between the watersheds due to the amount of fertilizers and lawn chemicals used on the lawns nearby the water bodies within the watersheds. The more fertilizers used (either due to the higher population around the water body or just that the people used more fertilizers on their lawns than others) would increase the nutrient levels in the water body and also decrease the pH. In addition to fertilizers, runoff can carry solids like road salt and soil into a water body which increases the TDS levels of that water body. These levels would vary between watersheds based on how developed the areas around the water bodies are, which changes depending on locations in town, thus creating a high variance between the watersheds in Charlton. The total coliform levels also show high variance. This measurement indicates the presence of biological pollution; thus, these varying levels could be due to sewer runoff from nearby houses. This will vary based on the systems used in homes and the populations around the water bodies in the watershed.

5. Best Management Practices

Chapter 4 presented results of historical and current water quality testing in surface water bodies in Charlton. Based on the data, it was determined that the main water quality issues in the town were low pH levels, high total phosphate levels, and low DO levels. Another issue is a lack of water quality data in certain water bodies. Based on these results, this chapter provides recommendations for Best Management Practices (BMPs) to improve water quality and prevent future degradation. BMPs are effective methods to improve and preserve water quality.

5.1 Current BMPs in Charlton

Table 15 presents the current management practices that the town employs for the water bodies in Charlton. The information was received from personal correspondence with the Charlton Conservation Commission.

Table 15: Current Watershed Management Practices in Charlton, MA.
(Todd Girard, personal communication, January 23, 2019).

Watershed	Water Body	Current Management Practice
Chicopee	Cranberry Meadow Pond	Weed control plan and program in place, stormwater management
French	Baker (Gore) Pond	Seasonal water testing, weed control plan and program in place, stormwater management, annual drawdown
French	Buffumville Lake	Seasonal water testing by USACE* and town, weed control plan and program in place, stormwater management
French	Little Nugget Lake	Seasonal water testing, stormwater management
French	Little River	Stormwater management
French	Pierpoint Meadow Pond	Weed control plan and program in place, stormwater management
French	Pikes Pond	Unknown at this time
French	Potter Brook	Stormwater management
French	Putnam Pond	Privately owned and managed by Joslin Diabetes Camp, weed control program, TC/FC testing

French	Snow Pond	Seasonal water testing, stormwater management, pond is used for education location for regional school system
French	South Charlton Reservoir (Granite Reservoir)	Charlton Lake and Ponds Committee volunteer seasonal water testing, weed control plan and program in place, stormwater management, bi-annual drawdown
Quinebaug	Cady Brook	Seasonal water testing, stormwater management, wastewater treatment plant discharge plan
Quinebaug	Glen Echo Lake	Seasonal water testing, weed control plan and program in place, stormwater management, annual drawdown
Quinebaug	McKinstry Brook	Stormwater management
Quinebaug	Prindle Lake	Seasonal water testing, weed control plan and program in place, stormwater management

Notes:
* United States Army Corps of Engineers (USACE)

First, seasonal water testing is currently performed in 7 of 15 water bodies in Charlton. This testing is used to monitor and track water quality trends to ensure that they are at acceptable levels. Currently, the town of Charlton regularly samples at some water bodies, occasionally samples at other water bodies, and never samples at other water bodies. The MQP team recommends that regular sampling continue in order to maintain a consistent data set on water quality. Furthermore, the MQP team recommends that sampling be conducted on larger (greater than 100 acres) water bodies at least once a month, as this is the ideal water sampling frequency for surface water bodies. It allows for approximately three data sets per season and twelve data sets per year which gives a comprehensive idea of water quality fluctuations throughout the year (Ohio EPA, 2009). Medium and small sized (less than 100 acres) water bodies could be sampled seasonally (four times per year). This monitoring plan is explained more in Section 5.2.1.

A second BMP utilized by the town of Charlton is weed control. Weed control management plans are used in 7 of 15 water bodies, specifically in Cranberry Meadow Pond, Baker (Gore) Pond, Buffumville Lake, Pierpoint Meadow Pond, South Charlton Reservoir, Glen Echo Lake and Prindle Lake. One method of weed control that is used by the town of Charlton is drawdown. This BMP involves drawing down the water level of water bodies before the water freezes and then raising the water levels again after the first water freeze. This process exposes the aquatic plants to low temperatures which kills nuisance vegetation. While the water level is low, weeds can be removed near the shoreline. Killing and removal of weeds prevents nuisances with boating and swimming and also helps prevent nutrient loading which can lead to eutrophic conditions in the water bodies (New Hampshire Department of Environmental Services, 2011). The effectiveness of drawdown depends on the types of plants present in the water body, as drawdown is more effective at reducing some weeds compared to others (Wagner, 2004). The Town of Charlton has seen significant decreases in weed presence since they began drawdown management (Todd Girard, personal communication, January 23, 2019) and thus the MQP team recommends they continue the practice This management practice costs approximately $3,000-$10,000 per drawdown, and has no negative aesthetic value associated with it. Drawdown schedules can shorten the boating season and can also have a small disturbance to natural environments. However, disturbances to natural environments are short term and are outweighed by the positive effects on natural environments caused by clearing the weeds (Wagner, 2004). Currently, the town uses drawdown management every year in Glen Echo Lake and Baker (Gore) Pond, and every two years in South Charlton Reservoir. However, research has demonstrated that drawdown is most effective when performed once every three years (Wagner, 2004). Therefore, the town may wish to consider alterations to the drawdown schedule.

A third BMP used by the Town of Charlton is stormwater management, which is employed for all surface water bodies in the town. Stormwater can present several water quality issues for surface water bodies. When it rains or when snow melts, the water runs off impermeable or semi-permeable surfaces, such as roads and parking garages, and ends up in surface water bodies. This runoff can pick up pollutants on roads and other lands areas and carry them to water bodies. These pollutants can include gas or oil, road salt, fertilizers, animal waste, and trash, among other pollutants. These pollutants can cause imbalances in pH, nutrients, and TDS. Stormwater runoff can also lead to erosion and flooding (EPA Facility Stormwater Management, 2017).

As part of their stormwater management program, the Town of Charlton currently cleans and monitors their catch basins regularly. This prevents a build-up of debris such as leaves in the basins which would then prevent water from flowing into the basins, decreasing their effectiveness. Charlton also conducts street sweepings to pick up litter, sand, and salt and prevent it from running off into water bodies. They also have a program in which residents can report spills of chemicals, oils, or other pollutants, and the town can clean up the spill before it reaches water bodies. These stormwater management practices are all preventative and focus on removing pollutants before they reach water bodies. The MQP team recommends that the Town of Charlton continues with their stormwater management practices.

5.2 Future BMP Recommendations

The BMPs employed by the town of Charlton, as discussed in Section 5.1, have beneficial effects on water quality. However, there are current potential issues in some water bodies, including high total phosphate, low DO and fluctuating pH. As such, additional interventions may be necessary to improve these water quality issues and prevent future degradation.

BMPs can be grouped in many different ways. For example, they can be structural or non-structural. Structural BMPs involve the physical construction of treatment apparatuses. These can include storm drains, detention basins, and infiltration basins. These would decrease pollution from runoff by collecting the water or directing it away from the main water body. This type of BMP could reduce phosphate concentrations if phosphate was primarily entering the water bodies through runoff. Basins would also capture pollutants, like salt, which could alter the pH of a waterbody. Another structure that could be created to restore a body of water is a fountain to aerate the water by circulating it, adding oxygen. Non-structural BMPs are strategies to manage water quality without physically installing structures. For example, products such as aluminum sulfate and Phoslock help to bind and precipitate phosphorus molecules, allowing them to settle which prevents them from aiding plant growth throughout the water body. Dredging is a non-structural technique which involves the removal of sediments from the bottom of the water body with the goal to reduce the concentration of nutrients that are stored in the sediments. Dilution and flushing techniques could also be employed to lower phosphorus levels and increase the dissolved oxygen by adding large volumes of water to the water body, diluting the polluted water and flushing it out. Lastly, harvesting techniques remove aquatic life to lower nutrient levels of the water body. BMPs can also be grouped based on preventative measures versus restorative measures, and then evaluated based on what water quality issues they address. This section discusses some of the most common BMPs for handling DO, total phosphate, and pH. A few of these options are not presently recommended for the town of Charlton but may be considered in the future if conditions change.

Table 16 outlines the water quality issues within each watershed, additional possible BMPs for those water quality issues, and a ranking of the BMPs based on cost, environmental disturbance, aesthetics, and maintenance. Each criterion received a point value of zero to two, for a total score of zero to eight, with a high score indicating a highly recommended BMP. For the water quality issues of high total phosphate and low pH, BMPs that scored 6 or above out of 8 are highly recommended. For low DO, lack of data and community knowledge, there was only one BMP that was considered appropriate for each issue. This table was used as a tool to quantify the viability of different BMPs, but there are additional factors that cannot be appropriately represented by a weighted matrix. Therefore, the following sections discuss each option in more depth, including whether the MQP recommends its implementation or not.

Table 16: Best Management Practice Suggestions by Water Quality Concern.

Scoring Key: High score = High interest

Color	**Points**
Red	0
Yellow	1
Green	2

Abbreviations:

S	Structural
NS	Non-structural
P	Preventative
R	Restorative
E	Education

Issue	Water Bodies Affected	BMP Name	BMP Type	BMP Category	Cost	Env. Disturbance	Aesthetics	Maintenance	Total Score
Low DO	Baker (Gore) Pond, Little Nugget Lake, South Charlton Reservoir	Aeration	S	R					3
High Total Phosphate	Buffumville Lake, South Charlton Reservoir, Cady Brook, Cranberry Meadow Pond	Native Vegetation	S	P					7
		Storm Drains/Filter Media	S	P					4
		Detention & Infiltration Basins	S	P					4
		Retention Ponds	S	P					6
		Wetland Channels	S	P					6
		Bioretention	S	P					2
		Porous Pavement	S	P					6
		Green Roof	S	P					4
		Grass Swales	S	P					6
		Dilution & Flushing	S	R					3
		Chemical Additives	NS	R					5
		Dredging	NS	R					1
		Harvesting	NS	R					3
Low pH	Buffumville Lake, Cady Brook, Cranberry Meadow Pond	Native Vegetation	S	P					7
		Storm Drains/Filter Media	S	P					3
Lack of data	14 out of 15 water bodies	Consistent sampling of water bodies	NS	M					4
Community knowledge	All	Educational Materials	NS	E					7

5.2.1 Monitoring

A lack of knowledge on water quality is an issue in 14 of 15 water bodies in Charlton. A consistent sampling and testing schedule for each water body should be established in order to monitor water quality over time. For smaller water bodies (water bodies with areas less than 100 acres), the MQP team recommends sampling every three months. For larger water bodies (water bodies with areas greater than or equal to 100 acres) the MQP team recommends sampling every month (Ohio EPA, 2009). The parameters that should be tested for include water temperature, pH, TDS, nitrate, total and fecal coliforms, turbidity, conductivity, total and reactive phosphate, DO, and flow rate. More consistent sampling and testing would allow for a better understanding of the water quality parameters over time. This would encourage the town to take appropriate action when necessary.

Various water bodies are already being sampled more frequently than others due to extenuating circumstances. For example, South Charlton Reservoir is sampled weekly for fecal coliforms at locations where camps use the reservoir for swimming during camp season (late June through end of August). The MQP team recommends that the town continue to sample more frequently when deemed necessary for reporting or monitoring circumstances.

5.2.2 Prevention

Some management practices relating to water quality include measures that stop pollution from ever entering the water bodies. For non-point source pollutants, stormwater management systems are effective at reducing the amount of pollutants entering water bodies. A storm water management system should utilize various designs to reduce the amount of runoff entering water bodies. Some examples of stormwater management strategies for managing phosphate and pH are described below.

5.2.2.1 Storm Drains and Passive Filtering Media

Storm drains collect runoff from impervious surfaces and direct potential pollutants away from water bodies into receiving streams. While storm drains can direct runoff away from a receiving water body, the storm drains themselves do not treat water. In order to passively treat the stormwater in a storm drain before it is discharged into a water body, various media can be used to alter its water quality. Examples of this type of media filters include alum and sand filters, shown to remove a range of 30% to 98% of phosphate, depending on conditions (Mohd Sidek, Lariyah, 2014). Installing a storm drain for an average property could cost anywhere from around $1,000 to $5,000 (Town of Chelmsford, 2019). A combination of storm drains and media filters are a good solution for water bodies that are near heavily trafficked roadways and parking lots as they do not require much space.

Another filtering media option is privately designed stormwater quality treatment technologies. An example of this kind of technology is the Jellyfish ® Stormwater Treatment System, designed by Contech Engineering Solutions. The Jellyfish is a stormwater quality treatment technology which uses membrane filtration in a stand-alone system to remove floatables, trash, oil, debris, TSS, fine silt-sized particles, phosphorus, nitrogen, metals, and hydrocarbons. The Jellyfish's ® Filter has been tested and verified by the New Jersey Department of Environmental Protection (Contech Engineering Solutions, 2019). Many more privately designed stormwater treatment systems are reviewed and certified by the Washington State Emerging Stormwater Treatment Technologies (TAPE) Program (State of Washington Department of Ecology, 2018). A list of such technologies can be found on their website including technology like the Aqua-Filter™ System manufactured by Aquashield Inc. This technology uses a selection of filter medias such as Perlite, granular activated carbon (GAC), leaf compost, and zeolite to remove fine-grained sediment, heavy metals, residual oil, and excess nutrients (Aqua Shield, 2019). The phosphorus removal efficiency is 35% to 98% depending on flow and maintenance conditions.

An example where this system could be useful is Cady Brook, where installing storm drains adjacent to the parking lot along its border (shown in Figure 5) could reduce the amount of total phosphate entering the water body and regulate pH. Storm drains are a viable option to implement for Buffumville Lake and Cranberry Meadow Pond.

5.2.2.2 Retention Ponds

Wet retention ponds are storm water control structures that retain and treat contaminated storm water runoff. Stormwater would run into the pond where it would be collected in a permanent pool of water. The pond would naturally remove pollutants through physical, biological, and chemical processes. Sedimentation would remove particulates, organic matter, and metals. Dissolved metals and nutrients are removed through biological uptake. If improperly designed, sited, or maintained, wet detention ponds have the potential to adversely affect water quality, groundwater, cold water fisheries, or wetlands (EPA, 1999b).

Because wet retention ponds must maintain a permanent pool of water, they cannot be constructed in a location that is lacking precipitation. They can also not be built on small sites or in highly developed area. The EPA stormwater technology factsheet for wet detention ponds states that retention ponds have a 50% to 90% rate of removal for total suspended solids, 30% to 90% removal for total phosphorus, 40% to 80% removal for soluble nutrients, 70% to 80% for lead, 40% to 50% for zinc, and 20% to 40% BOD. A wet retention pond costs $0.50 to $1.00 per cubic foot of storage area (EPA, 1999b).

The MQP team recommends implementing retention ponds for phosphate control. Along with its high effectiveness and reasonable cost, wet retention ponds can be easily designed to fit the town's needs.

5.2.2.3 Detention and Infiltration Basins

Detention and infiltration basins could be installed along water bodies to decrease pollution due to runoff, including phosphorus. These basins collect runoff from paved areas and capture it before it reaches the surface water body (Minnesota PCA, 2004). According to studies performed by the Water Environment and Refuse Foundation, detention and infiltration basins can remove approximately 17% of phosphorus in runoff water (Water Environment & Reuse Foundation, 2016). Additionally, they can help to increase groundwater recharge and are inexpensive and easy to implement. They could also be implemented with a vegetative border to help filter the runoff as well. However, the basins require significant geological analysis before implementation; a large flat, surface to build on; and maintenance after installation. Maintenance includes checking the velocity outflow from the basin at least twice a year to ensure there is not clogging in the basin or flow that is above the design flow. Additionally, the lawn around the basin needs to be mowed and trash and debris need to be removed from the basin at least twice a year as well. General inspections of the basins need to be conducted at least twice a year and after major storms and the sediment within the basin needs to be replaced every five years (United States, Massachusetts DEP, 2008). Analysis and maintenance can be costly and time consuming. Detention and infiltration basins can also be aesthetically displeasing to residents (Susdrain, n.d.).

The major design considerations of implementing a detention or infiltration basin are total storage volume, discharge rate, and flow path length. These three factors alter the hydraulic residence time within the basin and therefore the amount of time that the water is being filtered. The total storage volume is dependent on the volume or size of the basin which would be dependent on the area of land available for the basin to be built on. Larger basins result in higher hydraulic residence times and therefore higher phosphorus removal. Detention basins are most effective when they are implemented in areas of high water runoff (especially near water bodies with high phosphorus problems), along the path the water naturally flows, and in areas where there is enough space to build a basin with a size sufficient enough to effectively remove phosphorus (Sargent & Lundy LLC, 2007). Additional research would need to be conducted to determine the average stormwater flow rate and the drainage area that would be flowing into the basin. This would allow for the area of the basin to be determined as well as the size of the pipes and pumps needed to move the water (Sargent & Lundy LLC, 2007). Design and installation of detention and infiltration basins costs approximately $1.30 per cubic foot (EPA, 1999c).

The MQP team does not strongly recommend this management practice due to the moderate cost and disruptive nature of implementing a basin in combination with its low effectiveness of total phosphate removal.

5.2.2.4 Dense, Native Vegetation

The main water quality issues seen in Charlton are high phosphate levels and low dissolved oxygen levels. A number of different best management practices can be employed to assuage these water quality issues. The first method of controlling high phosphorus levels is to plant dense, native plants along the edge of the affected water bodies. This is a low-cost solution that would help mitigate the high phosphorus levels, low DO levels, and low pH by naturally filtering the runoff from their yards. These plants will absorb phosphorus in runoff water before it reaches the surface water bodies and will therefore decrease total phosphate levels in the water bodies (SOLitude Lake Management, 2014). Decreased total phosphate will then limit plant growth in the water bodies which could then lead to an increase in dissolved oxygen due to decreased oxygen demand from plant life.

This best management practice has a low cost associated with it, meaning it is cost effective to implement. There are many options for native vegetation that could be planted along shorelines. Native shrubs to Massachusetts include silky dogwood, grey dogwood, and buttonbush; native ground cover to Massachusetts includes milkweed, riverbank grape, marsh marigold, and royal fern (Berkshire Regional Planning Commission, 2003). These shrubs and groundcover range in pricing from $6 to $15 each, varying on sizes. The drawbacks of this management practice include the negative aesthetic value associated with certain plant species as well as the possibility that dead plant matter could enter the lake and then increase nutrient loading. It is not feasible to ask homeowners to plant native vegetation along their water bodies due to the negative aesthetic value. However, the MQP team does recommend that the town of Charlton educate homeowners on the benefits of planting native vegetation along water body edges, which is detailed in Section 5.2.4.

Additionally, strips of native vegetation can be helpful in decreasing pollutants and nutrients in runoff water when they are installed along highways (Water Environment & Reuse Foundation, 2012). Strips of native vegetation can reduce nutrient loading in runoff water by greater than 50%, further proving that this management practice is not only affordable but also effective (Al-wadaey et al., 2012). Therefore, the MQP team recommends that the town of Charlton utilize strips of native vegetation along public areas like highways and major roadways. In Charlton, Oxford Road runs straight through Buffumville Lake which has a high phosphate problem, so a strip of native vegetation along this roadway may be useful.

5.2.2.5 Low Impact Development (LID)

As defined by the EPA, LID “refers to systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat” (EPA, 2018b). Many practices aim to have natural landscape features that create site drainage to treat stormwater as a resource and not as waste; these include bioretention facilities, green roofs, and porous pavements.

Bioretention

Bioretention serves to remove nutrients from runoff and consists of treatment areas that include a grass buffer strip, a sand bed, a ponding area, an organic layer or a mulch layer, a layer of planting soil, and plants. The water first runs through the sand bed which slows the water velocity and evenly distributes the flow over the entire treatment area. The water then reaches a ponding area which consists of a bottom layer of planting soil and then a top layer of either organic material or plants. The ponding area’s purpose is to uptake phosphorus through the plants and to filter runoff water through soil. Some bioretention systems also include a drain system under the sand bed layer which carries runoff water from upstream locations to downstream sewers to prevent pollution from entering a water body upstream and polluting the whole waterway (EPA NSCEP, 1999).

The MQP team does not recommend this BMP for a number of reasons. First, bioretention systems are not effective in areas with cold climates because the soil layer freezes in cold months, decreasing the overall efficiency of the system (EPA NSCEP, 1999). Additionally, studies performed by the Water Environment & Reuse Foundation show that the average phosphorus in runoff water actually increased from the influent to the effluent of bioretention systems. According to a 2016 study on the effectiveness of various BMPs, the median phosphorus concentration increased from 0.13 mg/L to 0.24 mg/L, an 84% increase. Export of nutrients, such as phosphorus, was observed in BMPs like bioretention, indicating that this type of BMP is not a reliable method to remove phosphorus (Water Environment & Reuse Foundation, 2016). Further, design and installation of a bioretention system costs $5.30 per cubic foot (EPA, 1999c). Finally, implementation of a bioretention system would require development of a significant portion of land, would require maintenance and updates to the system, and could be considered aesthetically unpleasant to residents (EPA NSCEP, 1999). In conclusion, bioretention systems are invasive, costly, aesthetically displeasing, and most importantly, are not a reliable method of removing nutrients such as total phosphate.

Green Roof

Green roofs are an option to implement on homes around water bodies. The roof can grow vegetation that helps manage stormwater. Instead of rainwater falling on houses and then running onto the surrounding land, the plants and growing medium can help to soak in some of that water. This decreases the amount of pollutants that may enter bodies of water via rainfall runoff. The basic setup for the roof includes “vegetation, growing medium, filter membrane, drainage layer, waterproof/root repellant layer, roofing membrane support, thermal insulation, vapor control layer, structural roof support” (National Park Service, 2019). The roofing systems can be extensive or intensive (or a combination of the two), depending on what the consumer prefers. Extensive green roofs are low maintenance, suitable for large areas, most often do not need additional irrigation, and are relatively inexpensive. However, they may appear unattractive during the winter and do not have many other sues. Intensive green roofs can have a great diversity of plants and provide good insulation for the home (National Park Service, 2019). Intensive green roofs need systems for irrigation and drainage, are a higher cost to build and maintain, and more complex systems and expertise are required (National Park Service, 2019). It costs about $10 per square foot to install an extensive green roof, and about $25 per square foot to install an intensive green roof. To maintain the roof, it costs about $0.75 per square foot to $1.50 per square foot (EPA, 2014). This pricing varies based on growing medium choice, roof membrane, drainage system, type and quantity of plants. Overall, green roofs not only help to reduce stormwater runoff, but they also reduce a home’s energy use, outside noise, and temperature (EPA, 2014).

The MQP team does not see green roofs as a viable recommendation because the implementation is a decision to be made by homeowners. Therefore, the Charlton Conservation Commission cannot regulate its use. However, it is recommended the town use green roofs on old and new town-owned buildings. For example, the Charlton Conservation Commission plans to add one on the vestibule of the Charlton Middle School to help manage stormwater and also provide an educational opportunity for students.

Porous Pavement

If maintained properly, porous pavement filters pollutants from runoff by allowing snow and rain to pass through. There are two types of porous pavement: porous asphalt, and pervious concrete. Porous asphalt is made with an open-graded, coarse aggregate, bonded together by asphalt cement with interconnected voids. Pervious concrete is created with specially formulated mixtures of Portland cement, open-graded coarse aggregate, and water (EPA, 1999a). Pervious concrete has enough void space to allow rapid percolation of liquids through the pavement. The porous pavement surface is typically placed over a highly permeable layer of open-graded gravel and crushed stone. A filter fabric is placed beneath the gravel and stone layers to screen out fine soil particles. Porous pavement may substitute for conventional pavement on parking areas or areas with light traffic. The slope of the area needs to be either flat or very gentle, the soils on which the porous pavement is built must have permeability rates of higher than 0.5 in/hr and there needs to be at least 4 feet of clearance from the bottom of the system to bedrock or to the water table (EPA, 1999a).

Porous pavements reduce the need for storm sewers, increase recharge to local aquifers, and improve road safety based on better skid resistance. Two long-term EPA monitoring studies were conducted in Rockville, MD, and Prince William, VA and provide estimated pollutant removal efficiencies of porous pavement technologies. These studies indicate removal efficiencies of between 82% and 95% for sediment, 65% for total phosphorus, and between 80% and 85% of total nitrogen. The EPA estimates that the installation of porous pavement would cost approximately $1.60 per cubic foot and would require an annual maintenance fee of $4,942 per hectare per year (EPA, 1999a). Due to the efficient and nondisruptive nature of this stormwater technology, the MQP team does recommend the town consider using porous pavement as parking lots and side roads are updated.

5.2.2.6 Wetland Channels

Wetland channels are areas near water bodies that can have wetland plant species planted to help remove nutrients from water. In particular, wetland channels have been seen to remove about 12% total phosphorus from the water (Water Environment & Reuse Foundation, 2016). The channels can be constructed in “individual lots for rooftop, driveway or other on-lot impervious surface; landscaped parking lot islands; along roads; between buildings; conveyance between detention structures and receiving waters” (MPCA, 2018). However, they are unfeasible in areas “where the only area available for siting does not allow for a safe overflow pathway to the municipal separate storm sewer system or private storm sewer system; where there are restrictions on the proximity to building foundations" (MPCA, 2018). Wetland channels are not practical in steep sloped areas due to trouble "maintaining a constant water surface elevation or pool"; however, they should not be implemented in very flat areas due to "the lack of gradient which may cause excessive ponding and prevent positive drainage" (MPCA, 2018). Overall, this type of stormwater management may be best used along roadways near water bodies in order to filter the stormwater pollutants before water reaches water bodies. It is recommended for trout waters and drinking waters, but not for lakes as it does not remove a high amount of phosphorus for it to be a worthwhile investment. The initial construction of the wetland channel costs about $0.60 to $1.25 per cubic foot (EPA, 1999c). Typical wetland plant species include various ferns and shrubs; ferns, like the Royal Fern, cost about $8 each while shrubs (like Sweet Pepperbush or Sweet Fern) cost about $11 each.

Because wetland channels are sensitive to slope and can only be constructed in specific locations, the MQP team does not recommend implementing this BMP. Additionally, wetland channels only have a total phosphorus removal rate of about 12%, deeming them minimally effective.

5.2.2.7 Grass Swales

Total phosphate in runoff water can also be reduced through the use of grass swales, otherwise known as vegetated swales. Grass swales are very similar to strips of native vegetation, but the grass is planted in a shallow, parabolic shaped channel. The sloping sides of the channel allow for water to runoff into the swale and collect there. The vegetation within the channel uptakes the nutrients in the water, thereby lowering total phosphate levels (United States, Pennsylvania Department of Environmental Protection, 2006).

According to a study performed by the Water Environment & Reuse Foundation, grass swales tend to export phosphorus in runoff water instead of removing it. In this 2016 study, the medium phosphorus concentration in influent water was 0.12 mg/L and the median phosphorus concentration in effluent water was 0.20 mg/L which is a 67% increase in phosphorus. Grass swales cost approximately $0.50 per cubic foot to install (EPA, 1999c). Despite the fact that grass swales scored 6 out of 8 in Table 16, due to the lack of effective nutrient removal the MQP team does not recommend grass swales as a best management practice for high total phosphate.

5.2.3 Restoration

The MQP team recommends that restoration management practices be used to remediate current water quality issues within a water body. However, the team would suggest that preventative measures be taken first in the future as opposed to continuously implementing restoration activities.

5.2.3.1 Aeration

Aeration is a management technique that can be used to increase dissolved oxygen levels. Aeration usually involves the construction of man-made water fountains or waterfalls in water bodies in order to better circulate the water (Kirschner, 1995). This process increases oxygen in the water bodies due to better circulation (SOLitude Lake Management, 2014). These man-made structures, however, are sometimes undesirable due to their unnatural appearance in otherwise natural water bodies. It costs about $500 for small, shallow pond systems and up to $8,000 for larger or solar powered systems (Outdoor Water Solutions, 2019). Although variable, systems last about 2 to 3 years or even 5 to 7 years (Outdoor Water Solutions, 2019). Maintenance costs range depending on parts needed to be replaced, for example a diaphragm can be replaced for about $70 every 4 to 5 years (Outdoor Water Solutions, 2019).

The MQP team highly recommends aeration for water bodies with low DO as aeration is the only method available for treatment. These water bodies include Baker (Gore) Pond, Little Nugget Lake, Snow Pond, South Charlton Reservoir, Glen Echo Lake. For water bodies with high total phosphate and low DO (includes Buffumville Lake), the MQP team recommends treating for total phosphate before resorting to aeration treatment. This is because the MQP team hypotheses that treating for high total phosphate will lead to an increase in DO. If this does not occur, then aeration is an acceptable treatment method.

5.2.3.2 Chemical Additives

High phosphorus levels can be treated chemically. The addition of chemicals, most often aluminum sulfate (alum) but also calcium nitrate or ferric chloride, can decrease phosphorus levels by binding to phosphorus in the water bodies, precipitating it out of the water. This process can also seal off nutrients in the bottom sediments of the water body, preventing them from entering the water column (Kirschner, 1995). This management practice is expensive, due to the cost of the chemicals, and the chemicals must be reapplied as the chemical concentrations lower as they react with the phosphorus. On average, the treatment works for about 10 years (Welch & Cooke, 1999). Costs of the treatment is about $500/acre (Mattson, Godfrey, Barletta, Aiello, 2014), which is about $1.70/lb. After the first application, monitoring and further treatment costs about $10,000 (Mattson, Godfrey, Barletta, Aiello, 2014). Additionally, this management practice is not effective in shallow water bodies or water bodies with pH levels above 8.2. It is best to use alum in waters with a pH range of 4-6 (SOLitude Lake Management, 2014). If the pH is not closely monitored, fish kills result. Finally, increased stormwater inflow due to storms and rainfall can disrupt the chemicals which will result in increased phosphorus again. The water would need to be routinely tested to monitor pH and phosphorus levels, and reapplication of alum would then be needed depending on those levels. The process does not restrict human water use.

An alternative to alum application is the use of lanthanum modified bentonite clay products, such as Phoslock and WP-1™. Similar to alum treatments, the products absorb phosphorus molecules as they sink in the water column; once they reach the bottom, any unfilled binding sites continue to absorb phosphorus from the sediment forming rhabdophane, a stable mineral (SOLitude Lake Management, 2014). These products can be applied in waters with pH range from 4-11 (US Environmental Resource and Recovery Group LLC, 2019). Phoslock has been tested by SePRO Corporation and Phoslock does not harm aquatic life or human health (SePRO Corporation, 2012). WP-1™ has also been tested and states it has low-ecotoxicity as well (US Environmental Resource and Recovery Group LLC, 2019). To implement correctly, a full water assessment is needed to understand the water quality and phosphorus levels of the pond. Once an assessment is complete on the water body, including quantity of phosphorus loading and sediment reflux, the amount of Phoslock or WP-1™ can be determined. WP-1 ™ is available in 5, 15, 55-gallon containers or in 2,000-3,000 lb bags. Depending on the quantity of chemical needed, the price ranges from approximately $1.30/lb (for larger quantities) to $3.00 /lb (for smaller quantities) (Mike Pearce of SePRO, personal communication, February 11, 2019).

Chemical application could be recommended as a one-time treatment option in order to restore total phosphate water quality levels in Buffumville Lake (French River Watershed), Cady Brook (Quinebaug River Watershed), and Cranberry Meadow Pond (Chicopee River Watershed). However, due to the expensive costs for larger bodies of water, the MQP team recommends it only be implemented in Cady Brook since it is a smaller body of water. In addition, it is important to consider that while chemicals precipitate phosphorus out of the water body, they do not remove it. Therefore, repeated uses of chemicals will lead to an accumulation of the precipitate in the water body. It is for this reason that the MQP team recommends preventative BMPs over restorative BMPs in the future.

5.2.3.3 Harvesting

Harvesting of algae, plant life, and fish from water bodies can be used to decrease nutrient levels in water bodies (Minnesota PCA, 2004). When algae, plants, and fish die in water bodies, they sink to the bottom of the water body and decompose, adding nutrients to the water. Harvesting, or removing, aquatic life, lowers overall nutrients in the water body. This method can also be useful for controlling invasive species if the invasive species are the aquatic life being harvested. If there are no invasive species, harvesting would involve the removal of native species which can be disruptive to the natural environment. Harvested plant life can often be sold as agricultural nutrients or as a source of bioenergy (Yuckin, 2018). While harvesting would provide a sellable product, it would also cost money in the form of labor and equipment to remove the aquatic plants and animals. It would cost the town approximately $14/hr for labor wages, which is based on the average salary for fishermen in 2017 (Bureau of Labor Statistics, 2017) in addition to the equipment costs. The MQP team only recommends this management practice if invasive species and high total phosphate are a problem in conjunction with each other.

5.2.3.4 Dredging

Another management practice that could be employed to assist with high total phosphate levels is mechanical dredging of the bottom of the water bodies. Dredging of lake or pond bottoms involves the removal of sediments which are significant sources of phosphorus (Minnesota PCA, 2004). The MQP team does not recommend this management practice for any watershed as it is highly disruptive to the water body ecosystems, expensive, and the process of disposing of the removed sediments is often difficult.

5.2.3.5 Dilution and Flushing

Dilution and flushing techniques could also be employed to lower total phosphate levels and increase dissolved oxygen levels. Dilution and flushing involve adding large volumes of water low in phosphorus or high in dissolved oxygen to a water body and flushing some of the existing water out. This dilutes the existing water and therefore dilutes the high concentration of phosphorus as well as adding dissolved oxygen (Minnesota PCA, 2004). Dilution and flushing can be done by redirecting river or stream flows into the affected water body or by piping in treated water. If the process is performed using a stream or river, the water from that water body must have low phosphate and high dissolved oxygen levels. The treated water must also have these characteristics which is often unlikely due to phosphorus often being used in treated drinking water to prevent corrosion of pipes. In addition to a source of inflow being required, downstream structures and outlets of the water body must be able to support increased outflow due to the increased inflow. This management practice is not feasible for water bodies larger than small ponds as the amount of added water required to make a significant difference is phosphorus or DO levels is extremely high (New England Chapter of the North American Lake Management Society, 2018). The MQP team does not recommend this management practice for any watershed as it is expensive, difficult to implement, and extremely disruptive to the water body as well as surrounding water bodies and ecosystems.

5.2.4 Education Plan

Stormwater runoff is greatly impacted by the behaviors and activities of individuals, households, and the public. Practices such as littering, disposing of pet-waste, applying lawn-chemicals, washing cars, changing motor-oil, and disposing of household chemicals can significantly degrade stormwater quality depending on the individual's practices. Because of this impact, it is required by the US EPA's Municipal Separate Storm Sewer System (MS4s, as discussed in Section 2) to educate their community on the pollution potential of these various activities and to increase the community's awareness of these impacts (EPA, 2019). The EPA suggests various strategies for outreach programs including: Classroom Education on Stormwater, Stormwater Outreach for Commercial Businesses, and Tailoring Outreach Programs to Minority and Disadvantaged Communities and Children. The EPA also suggests materials and platforms to use: Educational Displays, Pamphlets, Booklets, Bill Inserts, Promotional Giveaways, and Social Media campaigns (EPA, 2019).

As discussed in Section 2.3.3, the town of Charlton already implements the following educational and community outreach programs:

- Think Blue Campaign
- Glen Echo Lake Safe Boat & Watercraft Operation document
- Household hazardous waste disposal days
    - Girls Scout and Boy Scout troops, and Charlton High School Science Club involvement
- Household Hazardous Waste Committee
- Annual Shoreline Clean Up Event on Earth Day
- Local newspaper publishes flyers about stormwater runoff and preventing nonpoint source pollution
    - Local broadcast channels also post these messages
    - Flyers posted in schools as well

In addition to these current practices, the MQP team recommends three major public education initiatives. The first initiative would be to address a new water quality issue each month and highlight the topics at town meetings and in social media posts. The second initiative would be to create a lesson plan that could be presented in classrooms, at Boy Scout or Girl Scout meetings, at camps, or at other youth education programs. This lesson plan would also include handouts that children can bring home. The final initiative would be to produce flyers and other educational materials targeted towards waterfront homeowners. These three initiatives were chosen because they would reach a wide array of residents while also focusing on some targeted audiences. They are also cost effective as the main costs associated with these education initiatives would be printing costs. Finally, these initiatives focus on the main water quality issues that were found in Charlton.

5.2.4.1 Town Meetings and Social Media

This educational initiative involves focusing on a specific water quality issue or water quality management technique for each month and discussing this water quality issue at monthly town meetings and online through social media posts. The discussions of these water quality issues focus on how residents can do their part in preventing storm water pollution. The water quality issues, by month, are as follows:

January – Litter
February – Oil Spills
March – Planting Native Vegetation along Waterfronts
April – Lawn Chemicals
May – Lawn Management
June – Mindful Use of Public Beaches
July – Boat Cleaning
August – Washing Cars

September – Pet Waste
October – Cleaning Storm Drains
November – Disposal of Household Chemicals
December – Salting and Sanding

These twelve topics cover a wide range of water quality issues that are easily affected, and therefore remediated, by the average citizen. For each month, talking points are listed regarding the water quality issue or management technique that can be discussed at monthly town meetings. These talking points can be presented by the Charlton Conservation Commission. Additionally, for each month, there are four social media posts including a graphic and a caption that can be posted one per week of each month. These social media posts give small tidbits of information that residents can learn from regarding how to prevent storm water pollution and harmful environmental practices within their home related to water quality. The town meeting topics will reach an audience of town officials and highly involved citizens while the social media posts will reach a wider audience of town residents who have a social media presence. The social media posts also appeal to a younger audience than town meeting discussions do. The materials can be found in Appendix F.

5.2.4.2 Lesson Plan

It is important to educate people starting at a young age about how their actions may impact the environment. Focusing on daily tasks or routines in their family's lives helps them to connect to the content and hopefully make some changes to decrease their negative effect on the environment. The lesson content contains two games. The first goal is to teach facts about daily tasks related to lawn care practices, waste, and household materials. The second game helps them to learn what trash items can be recycled and which go to waste. Additionally, handouts will be given to the students that highlight these key topics with the hopes they will bring home the papers to show to their families to help spread the knowledge. These educational materials are attached as Appendix G.

5.2.4.3 Flyers for Waterfront Homeowners

The town of Charlton consistently expressed concern about homes bordering the town's water bodies. A main issue appears to be how competitive households can be about manicuring their lawns. In order to spread ideas about environmentally responsible household lawn and garden practices, this MQP team produced an educational flyer targeted towards waterfront homeowners. This flyer can be found in Appendix H.

5.3 Summary

There are a number of BMPs that could be used to remediate the water quality issues in Charlton. These BMPs differ in their effectiveness, cost, and ease of implementation. Because there are multiple water bodies that vary in size, water quality issues, and importance to the town of Charlton, the treatment techniques must be prioritized keeping in mind the town's relatively low budget of $30,000 for water remediation.

Within the French River Watershed, water quality issues included moderately low DO, moderately low to poor pH and high total phosphate. Baker (Gore) Pond had moderately low DO, so the team therefore recommends an aeration system being installed to help increase DO levels. Aeration systems vary in cost from $500 to $8,000 based on water body size and system complexity. Since Baker (Gore) Pond is 169 acres in area, if the town was to implement an aeration system on the simpler side, the MQP team estimates that the cost would be in the approximate range of $1,000. Buffumville Lake has both moderately low pH and DO, and high total phosphate. Unfortunately, there is no publicly owned land around Buffumville Lake, so planting native vegetation along the shoreline is not feasible. However, native vegetation could be planted along Oxford Road, which is a major roadway that runs through the middle of the lake and contributes to significant amounts of runoff into the lake. In addition, since low DO is seen in conjunction with high total phosphate, the MQP team does not recommend an aeration system but rather recommends high total phosphate be treated first to see if it will also remediate low DO levels. In order to treat high total phosphate and moderately low pH, the MQP team recommends the implementation of storm drains with filtering media or retention ponds. Storm drains range in price from $1,000 to $5,000 and retention ponds range in price from $0.50 to $1.00 per cubic foot, so overall price would be dependent on the size of retention pond desired. Little Nugget Lake had moderately low dissolved oxygen and is a small water body (12.86 acres). Thus, a relatively inexpensive aeration system of approximately $500 could be implemented to remediate this water quality issue. Snow Pond had poor pH and moderately low DO levels as a relatively small pond. Thus, the MQP team would recommend a small aeration system (approximately $500) to prevent the low DO levels from worsening. Finally, South Charlton Reservoir had moderately low pH levels and DO. The MQP team would recommend implementing an aeration system. For a water body of about 207 acres in size, an aeration system costing about $2,000 may be used to increase the low DO levels.

Within the Quinebaug River Watershed, moderately low pH, high total phosphate and moderately low DO were observed. Cady Brook had both moderately low pH and high total phosphate. Cady Brook is mostly surrounded by impervious surfaces; therefore, a retention pond would not be feasible to install near this water body. As a result, the MQP team recommends storm drains with filtering media be implemented along the bordering parking lots in order to treat its water quality issues. Glen Echo Lake has moderately low DO and is a relatively large water body with an area of 116 acres. The MQP team does not feel as though the DO levels in this water body are severe enough to warrant the cost required to implement an aeration system, thus the team recommends no remediation at this time.

Within the Chicopee River Watershed, there is only one water body that fell within the town of Charlton, which is Cranberry Meadow Pond. Cranberry Meadow Pond had moderately low pH and high total phosphate. The MQP team recommends either storm drains with filtering media or retention ponds be installed near this water body in order to remediate these issues.

Low impact development is another BMP that can be used within the town of Charlton to prevent stormwater pollution. Green roofs and porous pavement are both options that can be implemented throughout the town, not just near water bodies, in order to remediate water quality issues like high nutrient loading. The MQP team recommends that green roofs be considered when Charlton develops new town-owned buildings. The team also recommends that the town of Charlton promote the use of green roofs amongst its citizens. In terms of porous pavement, the MQP team recommends the town of Charlton consider using this alternative to traditional paving as updates to streets are made. It is important to note that porous pavement can only be used in low traffic areas such as parking lots and side roads.

Finally, the MQP team recommends the town of Charlton sample all water bodies smaller than 100 acres once every three months and water bodies larger than 100 acres once every month. Consistent sampling and testing are important to track trends in water quality and plan for future prevention and remediation. It is also important to educate the community on water quality issues and steps that can be taken to prevent stormwater pollution. Therefore, the MQP team recommends the implementation of the various educational methods described in Section 5.2.4.

6. Conclusion

The town of Charlton, Massachusetts has 15 water bodies which have numerous uses including recreation and education. Many residents find the available access to various water bodies a key benefit of living in the town and as a result, Charlton wants to protect these resources. The Charlton Conservation Commission identified excess vegetation as the town's most prominent water quality issue. They enlisted the MQP team to help identify additional water quality issues and to create a management plan addressing these problems. In order to accomplish this goal, the MQP team gathered historic data, identified gaps in knowledge, and created a sampling plan to collect additional water quality data. The MQP team focused on water and air temperature, pH, turbidity, conductivity, TDS, DO, total and fecal coliforms, nitrate, and total phosphate in order to identify general trends in water quality. The 15 water bodies fall into three watersheds: French River Watershed, Quinebaug River Watershed, and Chicopee River Watershed. Based on the historic data and the data collected by the MQP team, the main water quality issues within each watershed were identified. The French River Watershed was found to have moderately low to poor pH, moderately low DO, and high total phosphate. The Quinebaug River Watershed was found to have moderately low pH, moderately low DO, and high total phosphate. The Chicopee River Watershed was found to have moderately low pH and high total phosphate levels. Additionally, lack of data and the need for additional community education on stormwater pollution were identified as issues that affected the entire town.

In order to address these problems, the MQP team suggested a number of BMPs. Within the French River Watershed, Baker (Gore) Pond had moderately low DO, so the MQP team recommended the installation of an aeration system to help increase DO levels. Buffumville Lake has both moderately low pH and DO, and high total phosphate. To remediate the low pH levels, the MQP team recommended native vegetation could be planted along Oxford Road (which is a major roadway that runs through the middle of the lake and contributes to significant amounts of runoff entering the lake). In addition, since low DO is usually seen in conjunction with high total phosphate, the MQP team did not recommend an aeration system but rather recommended high total phosphate be treated first to see if it will also remediate low DO levels. In order to treat high total phosphate and moderately low pH, the MQP team recommended the implementation of retention ponds or storm drains with filtering media. Little Nugget Lake had moderately low dissolved oxygen and therefore a small aeration system was recommended. Snow Pond had poor pH and moderately low DO levels as a relatively small pond. Thus, the MQP team recommended a small aeration system to prevent the low DO levels from worsening. Finally, South Charlton Reservoir had moderately low pH levels and DO and therefore the MQP team recommended implementing an aeration system.

Within the Quinebaug River Watershed, Cady Brook had both moderately low pH and high total phosphate. Cady Brook is mostly surrounded by impervious surfaces, making it infeasible to install a retention pond near this water body. As a result, the MQP team recommended storm drains with filtering media be implemented along the bordering parking lots in order to treat its water quality issues. Glen Echo Lake has moderately low DO and is a relatively large water body with an area of 116 acres. The MQP team does not feel as though the DO levels in this water body are severe enough to warrant the cost required to implement an aeration system, thus the team recommended no remediation at this time.

Within the Chicopee River Watershed, there is only one water body that fell within the town of Charlton, which is Cranberry Meadow Pond. Cranberry Meadow Pond had moderately low pH and high total phosphate. The MQP team recommended either storm drains with filtering media or retention ponds be installed near this water body in order to remediate these issues.

Low impact development (such as the use of green roofs and porous pavement) is another BMP that can be used throughout the town of Charlton to prevent stormwater pollution not just near water bodies. The MQP team recommended green roofs be considered when Charlton develops new town-owned buildings. The team also recommended the town of Charlton promote the use of green roofs amongst its citizens. In terms of porous pavement, the MQP team recommended the town of Charlton consider using this alternative to traditional paving as roads are updated. It is also important to educate the community on water quality issues and steps that can be taken to prevent stormwater pollution. Therefore, the MQP team recommended the implementation of various educational methods such as distributing educational flyers, posting education materials on social media, and distributing lesson plants to schools and camps that focus on stormwater pollution.

One of the main limitations in the MQP study was a lack of water quality data across all water bodies. As a result of this, some water quality characterizations were made based on very few data points. A more comprehensive characterization of the water quality in Charlton could be made if there was a more complete data set. To remediate this problem in the future, the MQP team recommends the town sample all water bodies smaller than 100 acres once every three months and water bodies larger than 100 acres once every month.

The information provided in this report represents a broad overview of Charlton’s water quality issues. Further research should focus on developing specific BMPs to implement in the watersheds. Specifically, storm drains with filtering media and retention ponds were recommended for a number of water bodies within the town. Future projects could focus on designing these BMPs based on the individual water bodies. Also, more consistent sampling may reveal additional water quality issues. Future projects could use the BMPs outlined in this report to address new issues.

Appendix A: Summary of Charlton's Water Bodies

Table A-1: Charlton Streams and Rivers

(Central Massachusetts Regional Planning Commission, 2017).

Water Body	Description	Average Width (ft)	Length (mi)	Location	Use
Cady Brook	Moderately flowing stream	15ft	6.6	Runs from outlet of Glen Echo dam to confluence with Quinebaug River in Southbridge	
Little River	Gradual flowing stream	15ft	3.5	Starts at discharge of Pikes Pond to confluence of Buffums Reservoir	Open access for fishing with occasional large open pools
McKinstry Brook	Low flowing stream	10ft	7.3	Starts east of Brookfield Rd flowing toward Southbridge to confluence with Quinebaug River	Large pools and riffle areas; DFW cold water fishery
Potter Brook	Stream	6ft	1.6	Starts at outfall of Granite Reservoir flowing south to confluence with Buffum Reservoir	Contains several small rock dams creating large deep pools; easy access for fishing; DFW cold water fishery

Table A-2: Charlton Lakes and Ponds

(Central Massachusetts Regional Planning Commission, 2017).

Water Body	Area	Creation	History	Present Day
Baker (Gore) Pond	169 acres, enhanced Great Pond	Created by construction of dam for water power in 1830s; shoreline has 40 homes; 500ft from shoreline are another 30 homes	Feasibility study 1987 - winter drawdown for weed control Pond also treated for blue-green algae	Continues to exhibit serious phosphate loading problem
Granite Reservoir	198 acres; Great Pond Maximum depth 14ft; average of 8ft	Privately owned and used for swimming and boating		
Buffumville Lake	199 acres	Constructed for flood control purposes; used for swimming, boating, fishing; public access		Owned and managed by Army Corps of Engineers
Pikes Pond	32 acres; without Great Pond status	Man-made, privately owned, used for passive recreation and fishing		
Little Nugget Lake		Man-made, public access		
Glen Echo Lake	112 acres; without Great Pond status Maximum depth is 25ft, average is 12ft	Heavily built-up on all shorelines	Previous water quality issues addressed with construction of town sewer; lake is used for fishing, boating, swimming and	
Prindle Lake	71 acres; without Great Pond status	Man-made, accessible to public		
Pierpoint Meadow Pond	90 acres Maximum depth of 14ft			

Appendix B - Field Test Procedures

Field Meter (Conductivity, Temperature, DO)

1. Check that cavity where probe is inserted is wet and field meter is properly calibrated.
2. Turn on at least 15 minutes prior to use.
3. Submerge field meter in sample water and press "mode" until the conductivity screen is showing (indicated by "µs" units). Allow reading to stabilize and then record conductivity reading.
4. Press "mode" until the temperature screen is showing (indicated by "°C" units). Allow reading to stabilize and then record temperature reading.
5. Press "mode" until dissolved oxygen screen is showing (indicated by "%" units or "mg/L" units). Slowly swirl probe in a circle in order to allow fresh oxygen to come in contact with the probe in order to ensure an accurate reading. Allow reading to stabilize and then record dissolved oxygen reading.

Flow Meter (Flow Rate)

1. Push readings attachment into the top of the flow meter.
2. Press the power button on the attachment to turn flow meter on.
3. Lower flow meter into water body up to the desired depth.
4. Align the arrow on the head of the flow meter facing against the water body's flow direction.
5. Press the black button in the middle of the attachment to begin taking flow rate readings and to begin the on-screen timer.
6. Wait one minute and monitor the flow rate readings.
7. Record the most common number that displayed on the screen throughout the time period as well as the minimum and maximum number that appeared.

Appendix C - Laboratory Test Procedures

Time Sensitive Tests

I. pH

1. Check the level of electrode solution and refill it if necessary.
2. Calibrate the pH meter according to the type of meter (see instructions below):
3. Rinse the electrode with reagent grade water.
4. Place the electrode into the sample water and wait for the pH meter to standardize.
5. Once the meter displays a standardized reading, record this number and remove the electrode.
6. Rinse the electrode before placing it back into the electrolyte solution.
7. Repeat these steps for each water sample, remembering to rinse the electrode each time the instrument is transferred from one solution to another.

Calibration Instructions:

1. Immerse the electrode in pH 4 buffer.
2. Press STD to access the standardization mode.
3. Wait for the reading to stabilize. This is indicated by "Wait for Stability" changing to "Press STD to Standardize" on the screen.
4. Press STD to store this standard. The meter will briefly display slope details on the Screen.
5. Repeat steps 2 – 4 for the pH 7 buffer, and again for the pH 10 buffer.
   Note: The pH meter automatically reverts to measure mode after each standard is entered.

II. Total and Fecal Coliform: Membrane Filtration Technique

Preparing the Culture Plates

1. Remove a sterilized petri dish with an absorbent pad from the packaging and label it with the date, test (FC or TC) and volume of liquid that will be filtered using a sharpie on the bottom of side of the plate
2. Add filter medium to the plate for either TC bacterial growth or FC bacterial growth, depending on the desired test
3. Close the culture plate until the sample is filtered

Filtering the Samples

1. Set up an autoclaved filter tower over a filter flask connected to a vacuum
2. Place a sterilized filter on the filter base and the reassemble the filter tower
3. Rinse the filter basin out with peptone from an autoclaved peptone bottle on order to ensure that the water sample is evenly distributed across the filter once it is added to the filter basin

4. Add the desired volume of sample to the filter basin and turn the vacuum on. Once the majority of the sample has been filtered through the filter, spray the walls and bottom of the filter basin with peptone and then turn off the vacuum once all liquid has been filtered through
5. Remove the filter from filter tower and put it in the prepared FC or TC culture plates

Incubation and Counting

1. Place the TC culture plates upside down in an incubator at 35℃ for 22 to 24 hours. Place the FC culture plates upside down in an incubator at 44.5℃ for 22 to 24 hours.
2. After the incubation period is done, remove the FC and TC plates from the incubators
3. Using a microscope count the number of colonies on the TC plates that have a reddish color or metallic sheen. Count the number of colonies on the FC plates that have a blue color. The target counts for TC colonies are between 20 and 80 colonies. The target counts for FC colonies are between 20 and 60 colonies

Computing Coliform Concentrations

1. Using the equation below to calculate the colfirms concentrations per 100 mL of sample

$$Coliforms/100\ mL = \frac{colonies\ counted \times 100}{mL\ sample\ \ filtered \times dilution}$$

2. Use data only from plates within the desired range of colony counts described above
3. If multiple plates have colony counts within the ideal range, use the above equation only once but alter it so that the numerator has a sum of all of the colonies counted on all of the plates that fell within ideal range and the denominator has a sum off the total amount of volume of sample filtered for all of the plates that fell within ideal range

III. Nitrate

1. Enter program 351 N Nitrate LR into DR 6000.
2. Fill a 15mL cylinder with 15mL of the water sample.
3. Add the contents of one NitraVer 6 Reagent Powder Pillow to the cylinder. Close the cylinder.
4. Shake the cylinder vigorously for 3-minutes during the reaction period.
5. After 3 minutes, let the cylinder sit for 2-minutes.
6. Pour 10mL of the sample into a sample cell.
7. Add the contents of one NitriVer 3 Reagent Powder Pillow to the prepared sample cell.
8. Put the stopper on the sample cell, while starting a 30-second timer for the reaction. Gently shake during this time period.

   Note: A pink color starts to show at this step if nitrate is present in the sample.
9. Let the sample cell sit for 15-minutes.

10. Prepare a blank of the water sample by filling a sample cell with 10 mL of the initial sample. Clean the blank sample cell and insert it into the cell holder of the DR 6000.
11. Push ZERO.
12. After the 15 minutes is up, clean the prepared sample cell and insert it into the cell holder of the DR 6000.
13. Push READ and record the results.
14. Repeat for all four of the water samples.

    Note: To be more time efficient, start steps 2-13 for each sample one after the other so they each are working through the procedure during the time in the laboratory.

IV. Reactive Phosphate

1. Enter program 535 P React PV TNT into DR 6000.
2. Add 5.0mL of a water sample to a Reactive Phosphorus Test 'N Tube vial.
3. Put the cap on the vial and invert to mix.
4. Clean the vial.
5. Insert vial into 16-mm cell holder in DR 6000.
6. Push ZERO.
7. Remove vial from DR 6000. Add contents of one PhosVer 3 Phosphate Powder Pillow.
8. Put cap on vial. Shake for at least 20 seconds.

    Note: The powder will not dissolve completely.
9. Let it sit for a 2-minute reaction to occur.
10. Clean the vial after the 2 minutes.
11. Insert the vial into the 16-mm cell holder in DR 6000.
12. Push READ and record the results.
13. Repeat for 4 water samples.

V. Total Phosphate

1. Preheat the incubator to 150°C.
2. Enter program 536 P Total/AH PV TNT into DR 6000.
3. Add 5.0mL of sample to the Total Phosphorus Test vial.
4. Add contents of one Potassium Persulfate Powder Pillow for Phosphonate to the vial.
5. Put cap on the vial and shake to dissolve the powder.
6. Insert the vial into the 150°C incubator and let reaction sit for 30 minutes.
7. Remove the vials from the incubator after 30 minutes, and let sit to cool to room temperature.
8. Add 2mL of 1.54 N Sodium Hydroxide Standard Solution to the vial.
9. Put the cap on the vial and invert to mix.
10. Clean the vial with a Kimwipe.
11. Insert the vial into the 16-mm cell holder in the DR 6000.

12. Push ZERO.
13. Remove vial and add the contents of one PhosVer 3 Powder Pillow to the vial.
14. Put the cap on and shake for 25 seconds. The powder will not dissolve completely.
15. Let the vial sit for 2 minutes for the reaction to occur.

    Note: Measure the sample within 8 minutes after the 2-minute reaction.
16. Clean the vial with a Kimwipe.
17. Insert the vial into the 16-mm cell holder of the DR 6000.
18. Push READ and record the results.
19. Repeat for all four water samples.

    Note: To save time, prepare all four at the beginning of the procedure and put them into the incubator at 150°C at the same time, running each step right after the other during the wait times of each sample. This will ensure the tests are done efficiently.

Non-Time Sensitive Tests

VI. Total Dissolved Solids

1. Dry 4 ceramic dishes in the oven for 1 hr (at 105°C).
2. Let cool for 30 minutes in dessicator. While cooling, invert each water sample bottle 3 times to mix the water. Filter 100 mL of each water sample through 934-AH filters into 4 different water beakers.

    Note: To set up filter, first run Reagent Grade water through the filter into a waste beaker. Then switch to a water sample beaker, and proceed with water sample filtration.

    To avoid contamination between samples, wash or have new apparatus setup for filtering.
3. When the ceramic dishes are cool to touch, weigh each separately and record their masses.

    Note: Handle ceramic dishes with care not to contaminate it - use metal tongs to move from dessicator to balance.
4. Pour 100mL of each of the filtered water samples into their corresponding ceramic dish.
5. Put dishes into oven. Let dry (takes about 2 hours).
6. Remove ceramic dishes from oven once they are completely dried.
7. Weigh each dish and record mass.

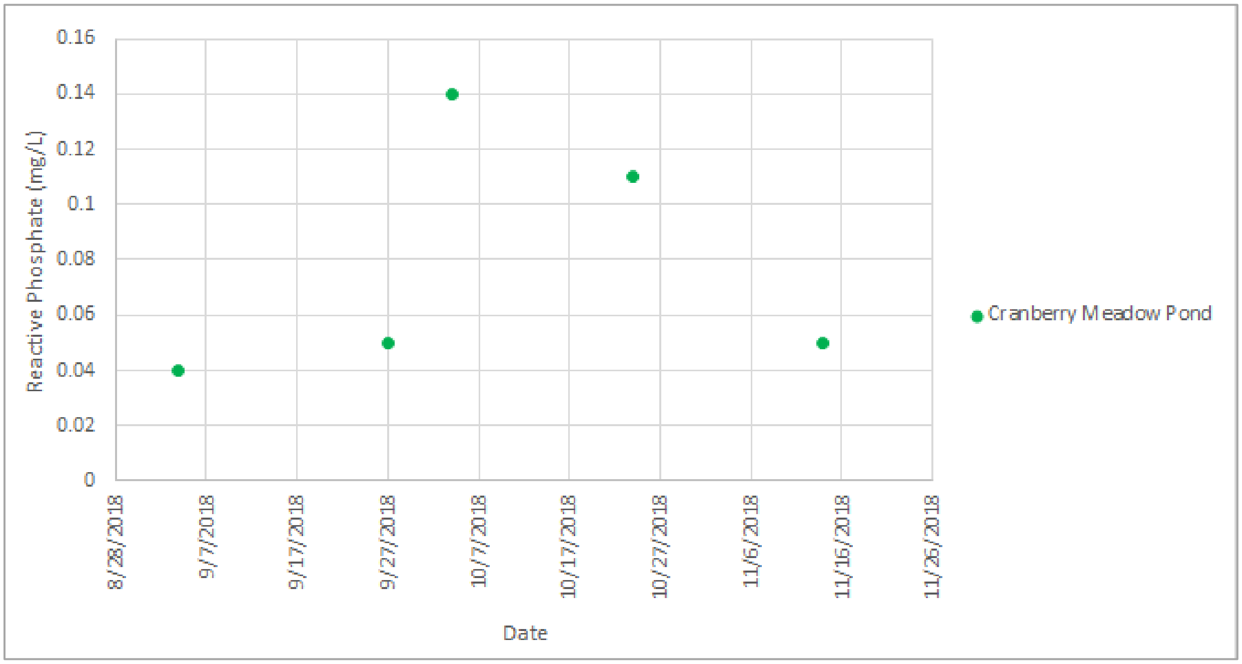
VII. Turbidity

1. Gently pour the water sample to the top line of the turbidity vial to avoid creating air bubbles that would interfere with the reading.
2. Screw the cap onto the vial. Gently invert the vial two times to ensure sample uniformity.

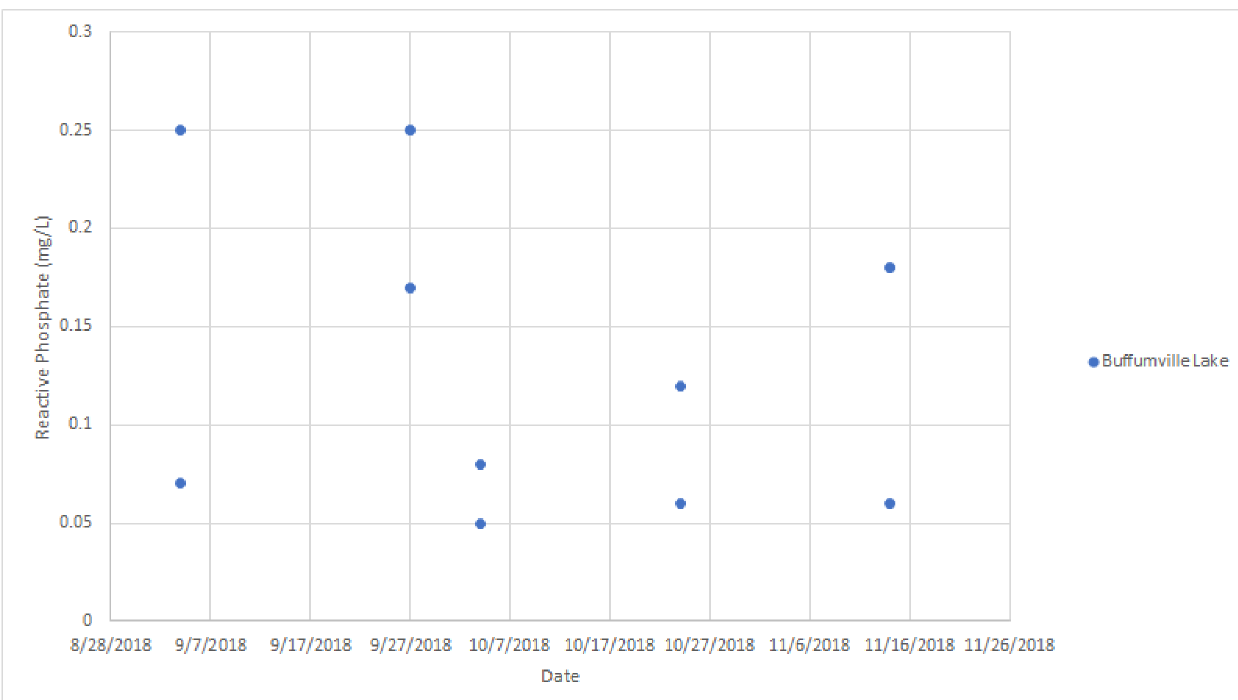
3. Rinse the outside of the vial with reagent grade water and wipe with a Kimwipe to remove any dirt or fingerprints. Hold the vial by the cap from this point forward.
4. Place the turbidity vial in the turbidimeter, lining up the arrow on the vial with the line inside the meter. Close the cover.
5. Wait about 10 seconds. Then watch the readout for another 10 – 20 seconds and use your judgment to determine the turbidity reading in units of ntu.
6. Repeat for the four water samples.
7. When cleaning: rinse with reagent grade water without sponges or brushes so they are kept free of scratches.

Appendix D – Reactive Phosphate Data

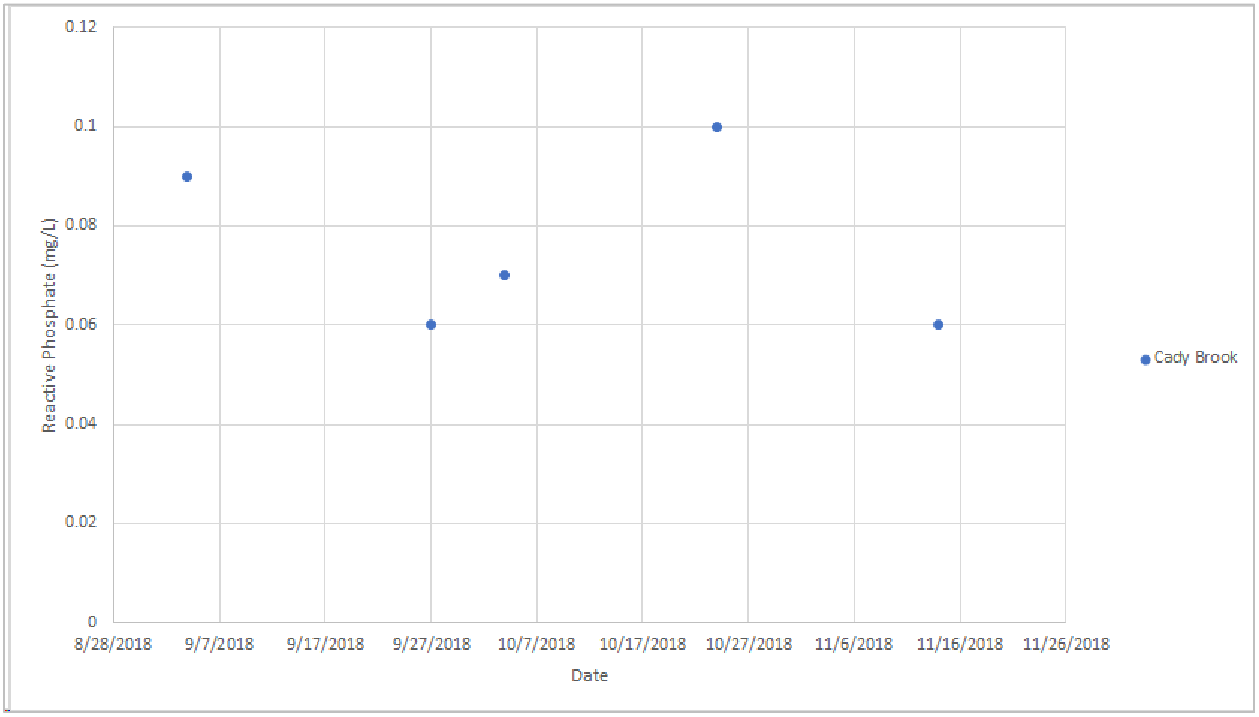
Chicopee River Watershed



French River Watershed

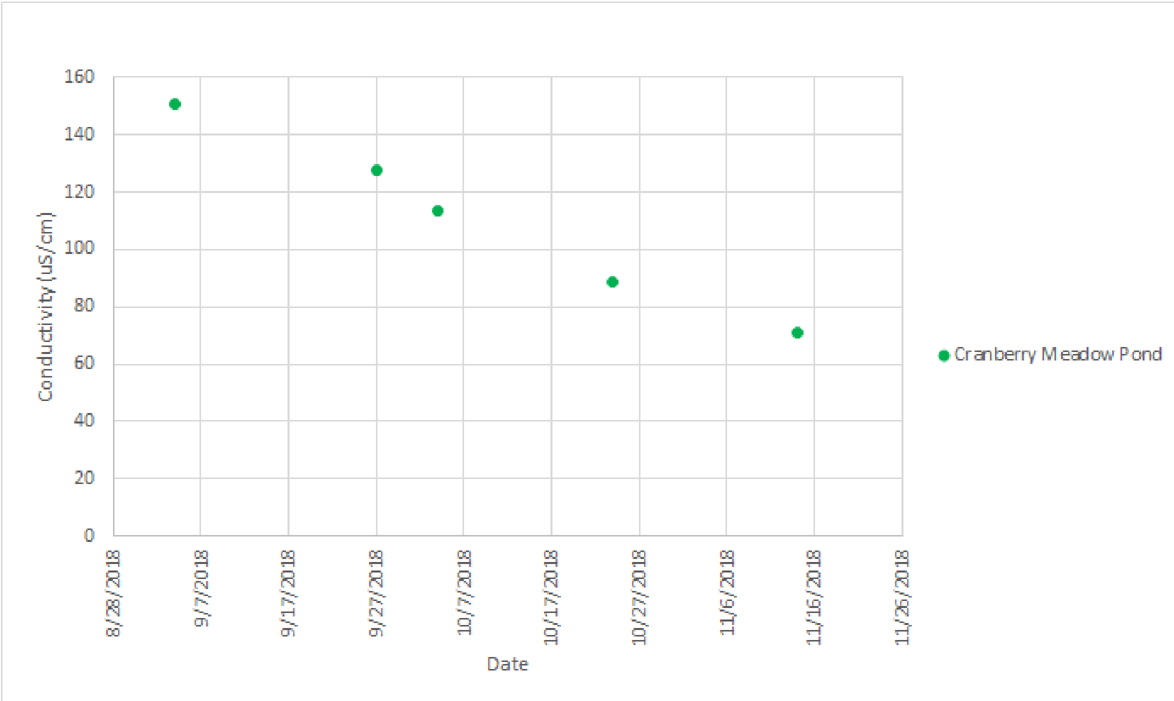


Quinebaug River Watershed

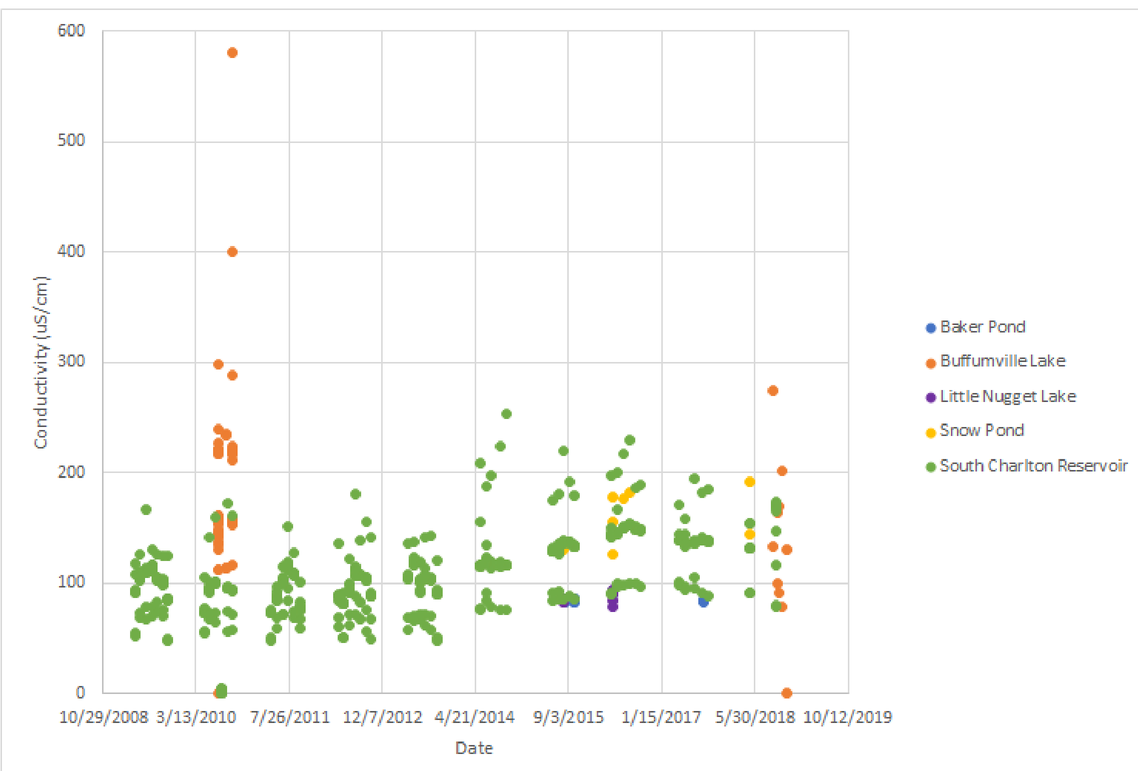


Appendix E – Conductivity Data

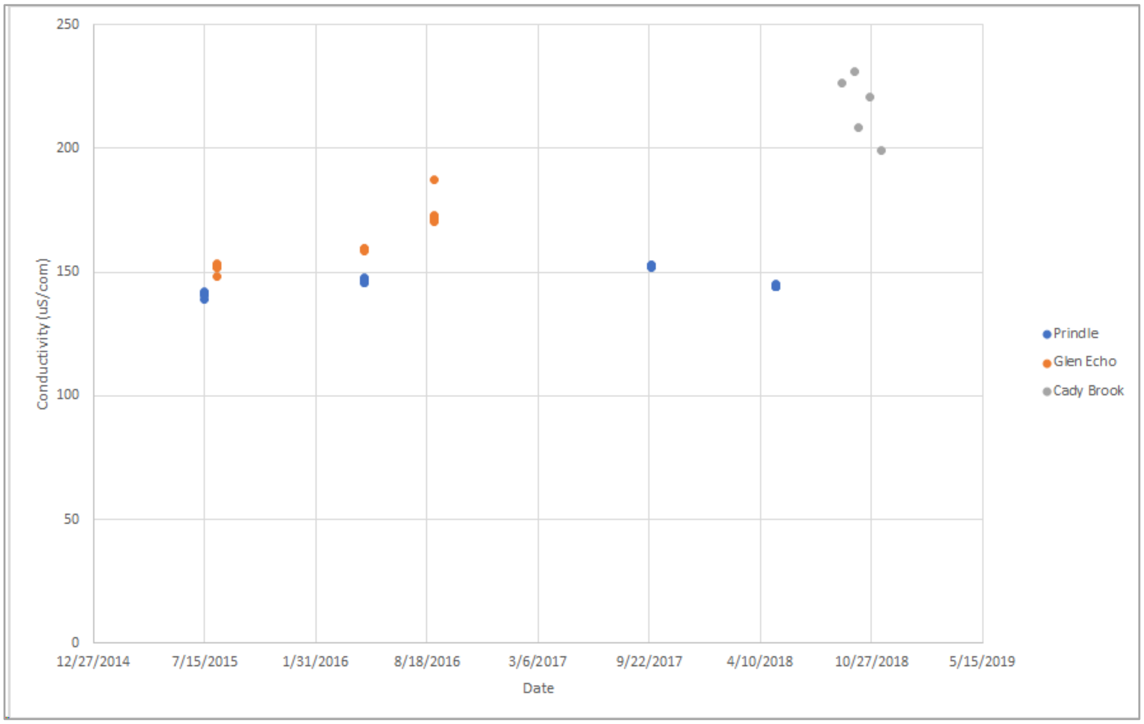
Chicopee River Watershed



French River Watershed



Quinebaug River Watershed



Appendix F – Town Meetings and Social Media Materials

January - Litter

Facts/Talking Points:

- Litter can be picked up in stormwater and carried to nearby water bodies
- Litter can carry bacteria biofilms which can lead to harmful bacteria growth in water bodies
- Plastic litter is one of the most harmful and prevalent types of litter affecting water bodies
- Plastic litter can be decreased by using reusable products like metal straws, canvas shopping bags, and glass water bottles
- Litter is sometimes mistaken as food by aquatic life and eaten
- When fish and other aquatic life eat litter, that litter may stay in their stomachs. This can be dangerous for humans who later consume those fish

Social Media Posts:

Week One:

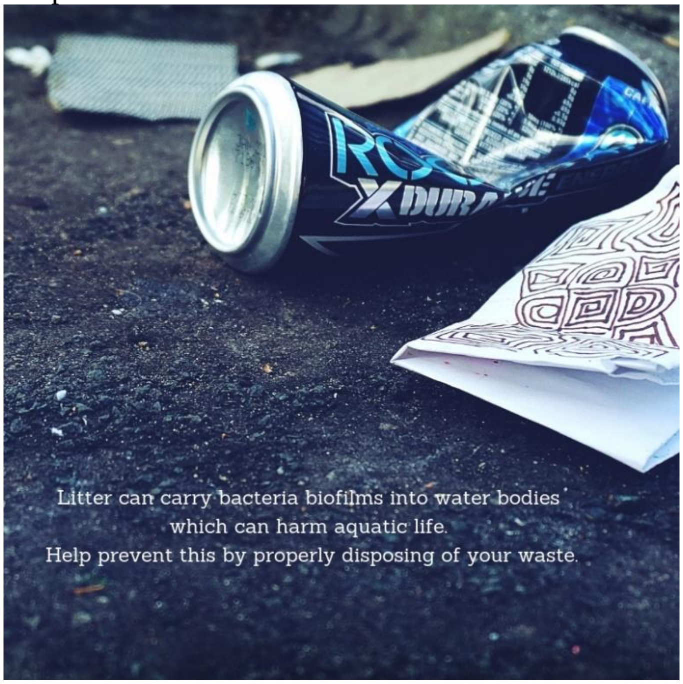
Caption: This month we will be focusing on preventing litter from entering water bodies through stormwater runoff. Litter that isn't properly disposed of can make its way into rivers, lakes, and ponds when it starts to rain so make sure you always throw your trash out in trash and recycling bins.

Graphic:

Week Two:

Caption: Litter can carry bacteria biofilms which can end up in water bodies, leading to the growth of harmful bacteria.

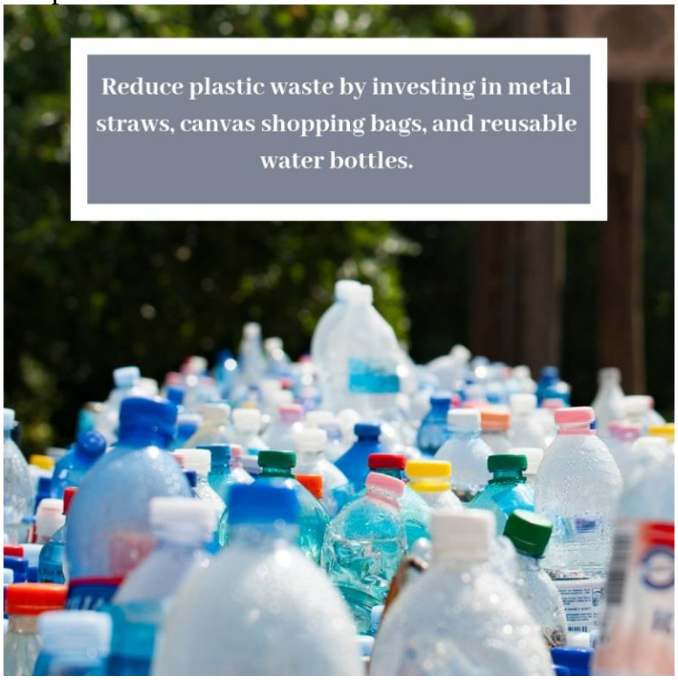
Graphic:



Week Three:

Caption: Plastic litter is the most harmful type of litter to the environment and water bodies. Cut down on the amount of plastic trash that you produce by investing in more sustainable products like metal straws, canvas shopping bags, and reusable water bottles.

Graphic:



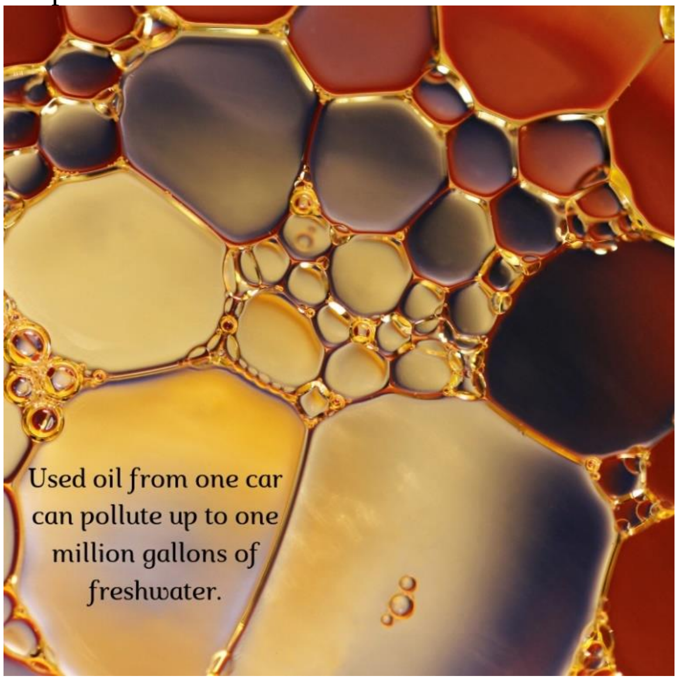
Week Four:
Caption: Litter in water bodies is often mistaken as food by aquatic life and ingested. This can either kill the aquatic life or can stay in the stomach of fish or other aquatic organisms, which are then eaten by humans. Help prevent the ingestion of litter by aquatic life by picking up your trash and throwing it away in a garbage bin.
Graphic:

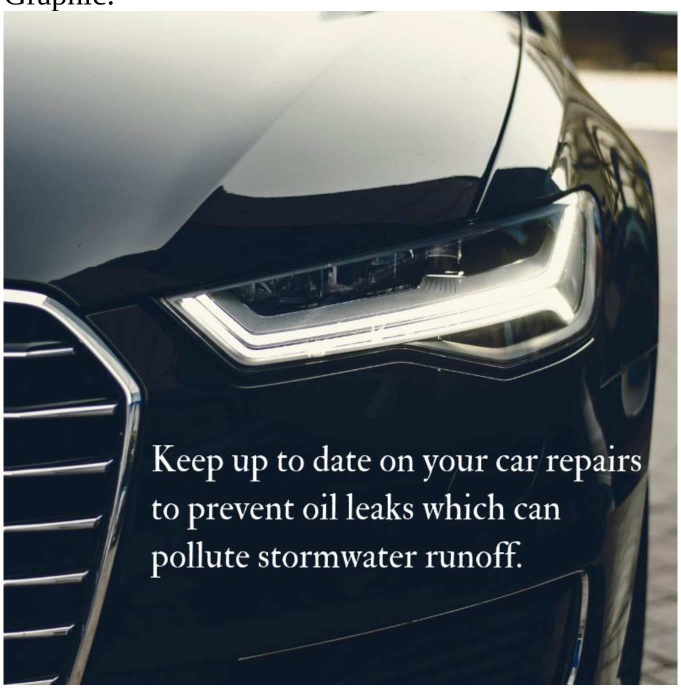
February- Oil Spills

Facts/Talking Points:

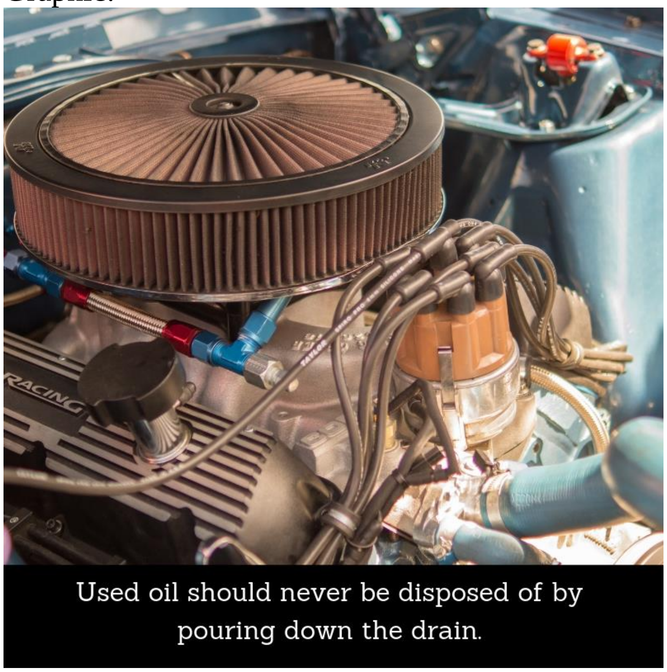
- Used oil and leaking oil from cars can be picked up by runoff water and carried to local water bodies
- Used oil from one oil change can pollute up to one million gallons of freshwater
- Always keep up to date on car repairs to prevent oil leaks
- Used oil should never be disposed of by pouring it down storm drains
- Dispose of used oil by putting it in a sealable container and throwing it away

Social Media Posts:
Week One:
Caption: Leaking and used oil from cars is a major pollutant of stormwater. According to the EPA, used oil from a single oil change can pollute up to one million gallons of freshwater.

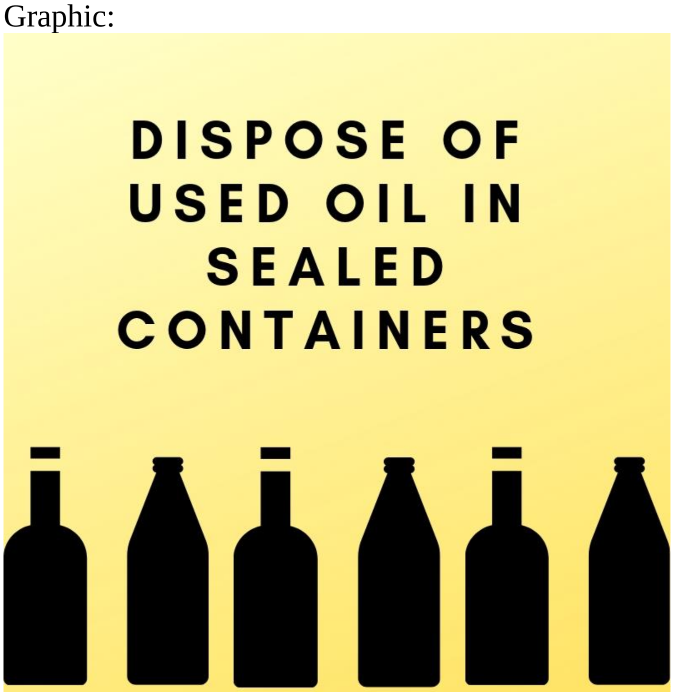
Graphic:


Week Two:
Caption: One way to prevent oil from polluting stormwater is make sure your car isn't leaking oil. Always make sure your car repairs are up to date and check for oil puddles left under your car to make sure there are no leaks.
Graphic:


Week Three:
Caption: Never dispose of used car oil down storm drains. That oil will be carried to nearby lakes and rivers and can harm aquatic life.
Graphic:



Week Four:
Caption: An estimate published by the EPA states that approximately 193 million gallons of used oil are improperly disposed of by households in the US each year. Do your part in preventing this issue by always disposing of your used oil in a recyclable container with a lid and throwing it in the trash.
Graphic:



March- Native Vegetation Along Waterfronts

Facts/Talking Points:

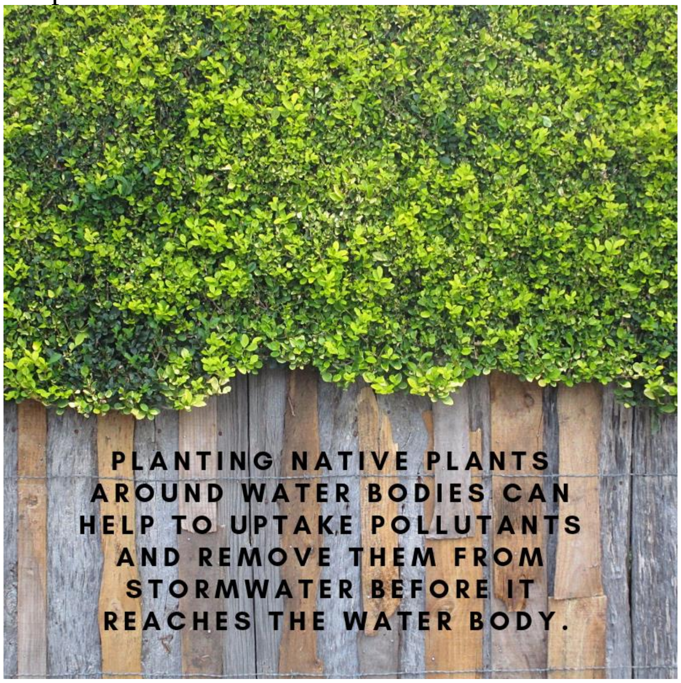
- Native vegetation can help to uptake pollutants out of stormwater before the runoff reaches water bodies
- Planting native vegetation along waterfronts is especially beneficial
- Ground cover that is native to Massachusetts includes milkweed, riverbank grape, marsh marigold, and royal fern
- Shrubs that are native to Massachusetts include silky dogwood, grey dogwood, and buttonbush
- Planting native vegetation can also decrease the need for watering and chemical applications to plants

Social Media Posts:

Week One:

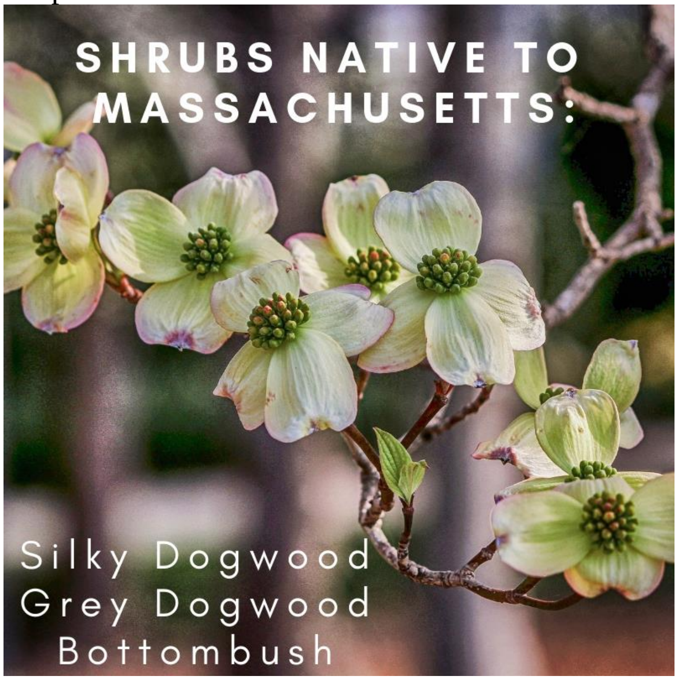
Caption: Planting native vegetation along waterfronts can help to remove nutrients and other pollutants from stormwater before it reaches the water body. Do your part by planting native vegetation in your yard, especially if you live on a waterfront property.

Graphic:



Week Two:

Caption: Native shrubs to Massachusetts includes silky dogwood, grey dogwood, and buttonbush.

Graphic:


Week Three:
Caption: Native ground cover to Massachusetts includes milkweed, riverbank grape, marsh marigold, and royal fern.
Graphic:


Week Four:
Caption: Not only does planting native vegetation along shorelines help to remove nutrients from stormwater, but it also decreases the need for chemicals and pesticides which can lower costs for lawn maintenance and prevent chemical pollution in water bodies.

Graphic:

April- Lawn Chemicals

Facts/Talking Points:

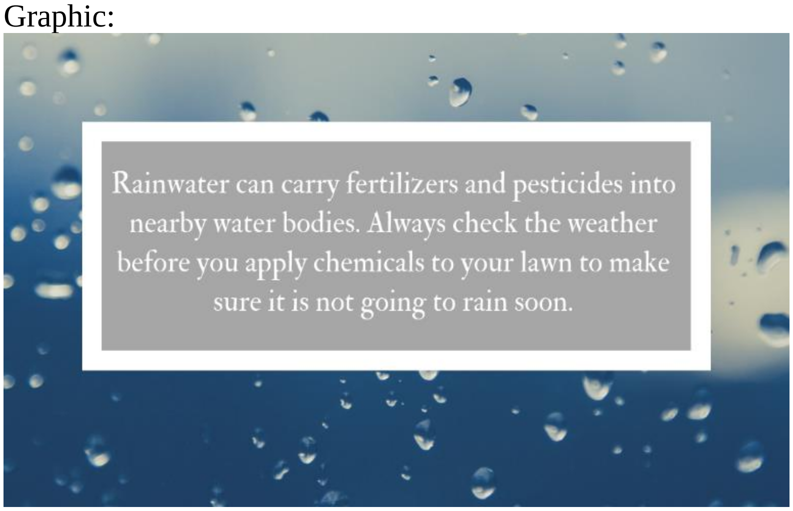
- To help prevent additional nutrient pollution, never apply chemicals to your lawn before it rains
- Use organic alternatives to chemicals and pesticides whenever possible
- Native vegetation and plants with longer roots require less water, pesticides, and fertilizers
- Bio-pesticides are another great, sustainable alternative to pesticides

Social Media Posts:

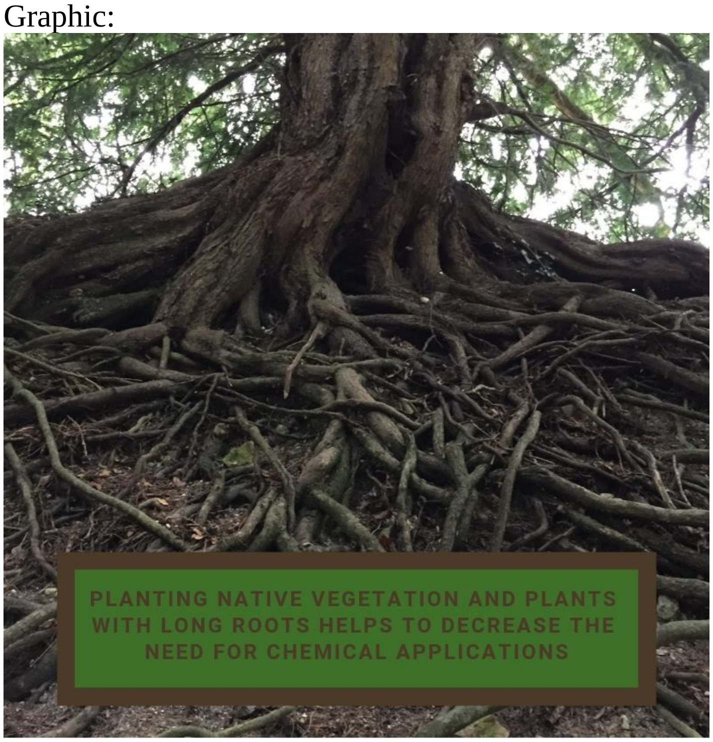
Week One:

Caption: Chemicals applied to lawns can be picked up by rain and carried to storm drains and local water bodies. Always check the weather before you apply chemicals to your lawn and never apply them before it rains to help prevent chemical pollution in runoff water.

Graphic:



Week Two:
Caption: One way to reduce chemical pollution in stormwater runoff is to use organic alternatives to pesticides and fertilizers.
Graphic:


Week Three:
Caption: Planting native species is another method of reducing chemical use in yards. Native species, especially species with longer roots, need less water and chemical applications.
Graphic:


Week Four:
Caption: The EPA defines biopesticides as "naturally occurring substances that control pests (biochemical pesticides), microorganisms that control pests (microbial pesticides), and pesticidal substances produced by plants containing added genetic material (plant-incorporated protectants) or PIPs". Biopesticides are a more sustainable and natural way of controlling for pests in your lawn.
Graphic:

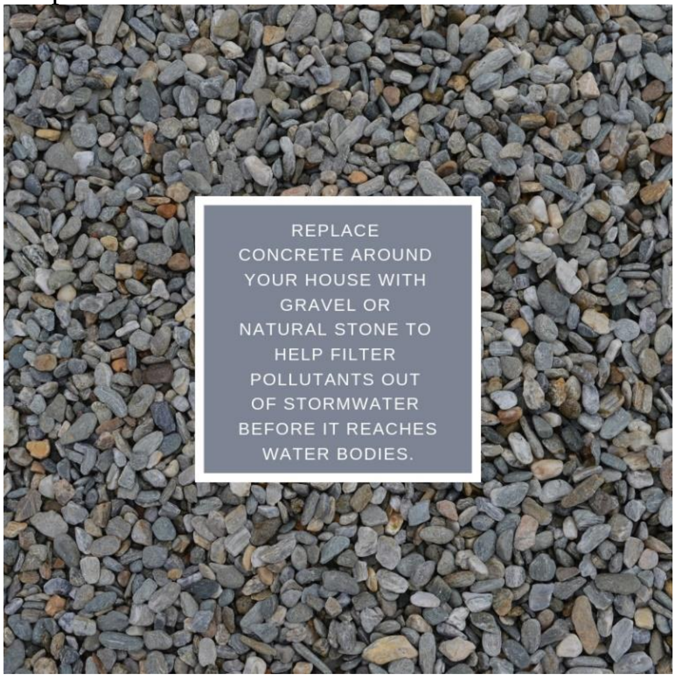
May- Lawn Management

Facts/Talking Points:

- The perfect lawn isn't necessarily a lawn with green grass and lots of flowers and foliage
- Building a rain garden can also help to filter stormwater and remove nutrients
- Rain gardens consist of native shrubs, perennials and flowers that are planted slightly below the surrounding ground level and on hills
- Minimizing impervious surfaces by replacing concrete with gravel and natural stone can help reduce runoff and increase filtration of stormwater before it reaches water bodies
- Rain barrels can help to catch rainwater which can then be used to water plants
- Keeping your lawn at 3 inches helps to repel weeds and pests as well as trap moisture which decreases the need for watering
- Leaving lawn clippings on your lawn can also decrease pests and weeds
- Never water your lawn when it is already raining. This wastes water and also increases stormwater runoff

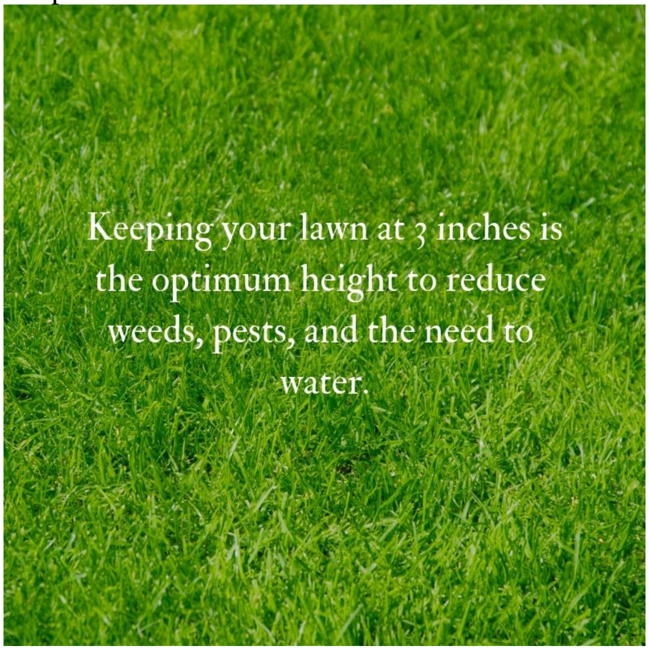
Social Media Posts:

Week One:
Caption: For the month of May, we will be talking about how you can manage your lawn in an environmentally friendly way. One way that you can do this is by minimizing impervious

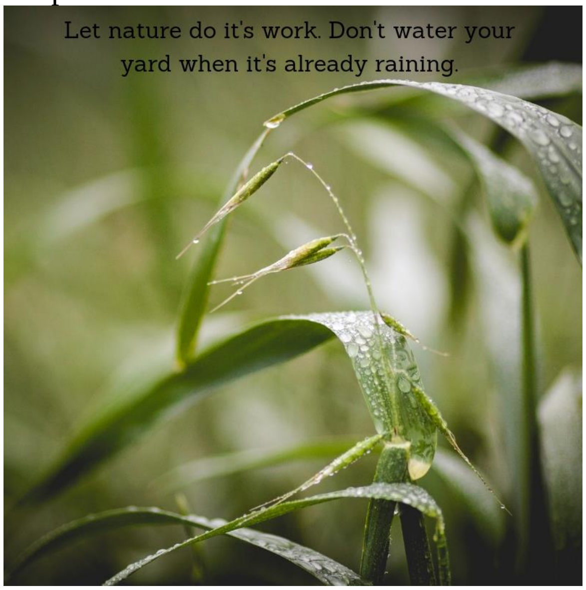
services around your home by replacing concrete with gravel or natural stone. This helps to filter pollutants from stormwater before it reaches water bodies.
Graphic:


Week Two:
Caption: Building a rain garden in your yard can help to filter stormwater runoff and remove nutrients from it. Rain gardens consist of shrubs, perennials and flowers planted on a slope and slightly below the surrounding ground level. Rain gardens are both aesthetically pleasing and beneficial to the environment.
Graphic:


Week Three:
Caption: Mowing your lawn less and keeping it at a height of approximately 3 inches can prevent weed growth, reduce water needs, and decrease the presence of pests. Leaving your lawn clippings on your lawn can help to block weeds and retain moisture, further decreasing the need for watering.
Graphic:



Week Four:
Caption: Water your lawn less helps to prevent additional runoff; especially avoid watering lawns when it's raining.
Graphic:



June- Mindful Use of Public Beaches

Facts/Talking Points:

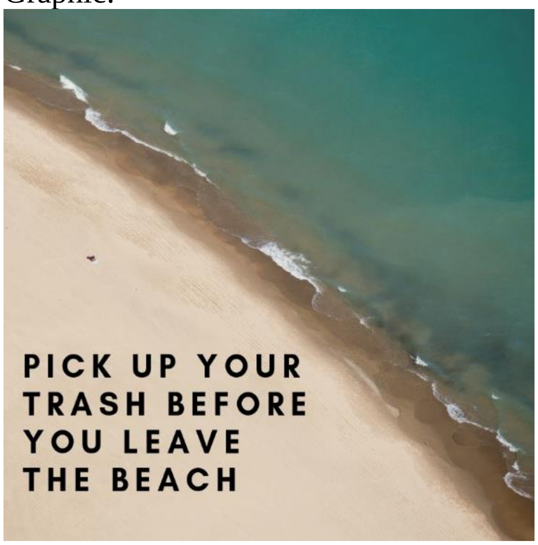
Never leave trash behind when you leave the beach
Never dump food waste or foreign liquids in or near water bodies
Don’t use sunscreens that contain oxybenzone. This chemical can be harmful to aquatic life
Take a couple minutes each beach trip to pick up some trash and leave the beach cleaner than you found it

Social Media Posts:

Week One:

Caption: Public beaches along rivers and lakes can be a great place for recreational activities such as fishing, boating, swimming, and relaxing. Help preserve these natural resources by making sure to never leave litter behind when you visit the beach.

Graphic:

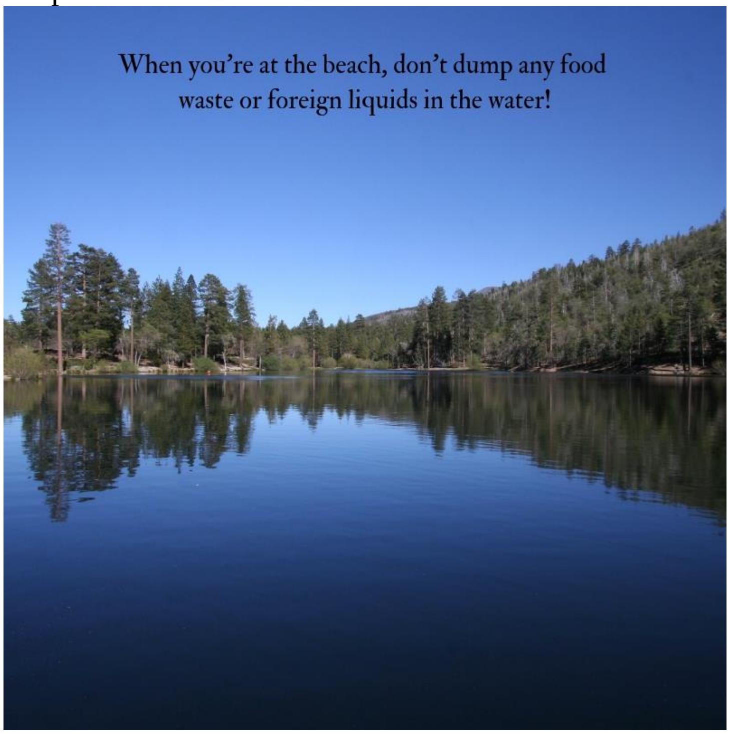


Week Two:

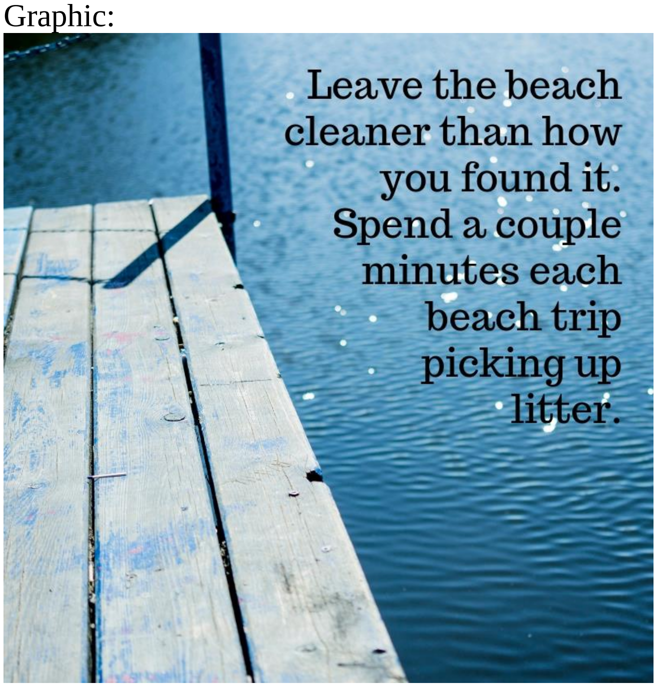
Caption: Some sunblock contains ingredients that are harmful to aquatic life. Avoid using sunblock that contains oxybenzone, an ingredient which is toxic to aquatic life such as coral.

Graphic:

Week Three:
Caption: When at the beach, don't dump any food waste or foreign liquids into the water bodies. These wastes can upset the natural ecosystems in the water.
Graphic:



Week Four:
Caption: One of the best ways to help prevent water pollution at beaches is to leave the beach cleaner than when you came. Take a couple minutes out of your next beach trip to pick up any litter you see on the beach.
Graphic:



July- Boat Cleaning

Facts/Talking Points:

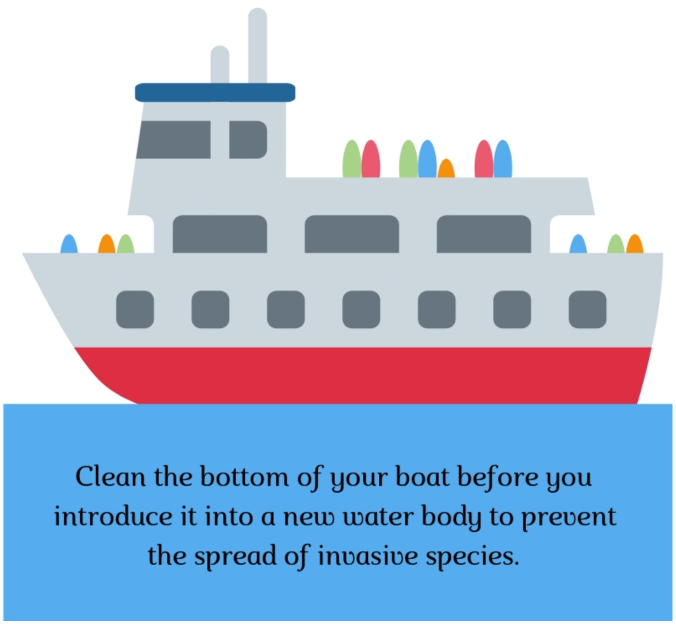
- Always clean your boat before transferring it from one water body to another
- Make sure water is eliminated from all equipment before transferring your boat to a new water body
- Check for aquatic life stuck to the bottom of your boat and remove it to prevent the spread of invasive species
- Always dispose of the removed aquatic life far away from any water bodies
- Zebra mussels are one of the most disruptive invasive species in lakes

Social Media Posts:

Week One:

Caption: Boats can be carriers of invasive species when they are transported from one water body to another. Always clean your boat and check the bottom for any aquatic life that may be clinging to it to make sure that you don't introduce any species to a water body that aren't supposed to be there.

Graphic:



Week Two:

Caption: Zebra mussels are one of the most common invasive species that are spread through boat transfers. When introduced to a new lake, zebra mussels often have no predators and have abundant food sources, allowing their population to rapidly grow. Their presence leads to a number of environmental and economic issues, including outcompeting of native species and blocking of pipe ways in the lakes. If you are a boat owner, do your part by checking for zebra mussels and other aquatic life on the underside of your boat before you introduce your boat to the water body.

Graphic:

Week Three:

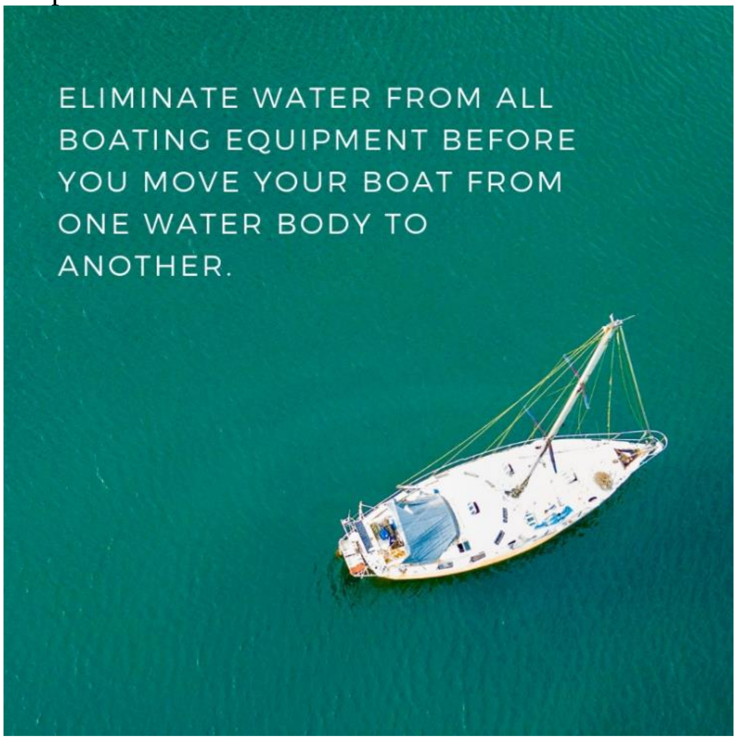
Caption: If you do find aquatic life stuck to the bottom of your boat, make sure you remove and dispose of it far away from any water bodies. Stormwater runoff can carry the aquatic life and invasive species into the water body if you don't dispose of them properly.

Graphic:

Week Four:

Caption: Invasive species can be transferred from one water body to another through water stored in boats. Make sure to eliminate water from all boating equipment before you transfer a boat from one water body to another.

Graphic:



August- Washing Cars

Facts/Talking Points:

- Soap and grime produced from washing your car can pollute stormwater and local water bodies
- Wash your car over grass or gravel as opposed to concrete to increase filtration of the water before it reaches water bodies
- Use organic, non-toxic, and phosphate free soaps when you wash your car
- Water used at commercial car washes is treated before being released into the environment so help decrease stormwater pollution by washing your car at a commercial car wash instead of at home

Social Media Posts:

Week One:

Caption: This month, we will be focusing on how to prevent stormwater pollution while washing your car! Soap and grime runoff produced during car washing can pollute local water bodies once it enters storm drains and is carried to local water bodies.

Graphic:

Week Two:

Caption: Washing your car over gravel or grass helps to neutralize the soap and dirt before it reaches water bodies. Washing your car over pavement leads to the dirty, soapy water running off into storm drains where it drains directly into nearby water bodies.

Graphic:

Week Three:
Caption: Many soap products contain phosphates which can lead to excessive growth of vegetation and depletion of oxygen if it enters water bodies. Try washing your cars with biodegradable, non-toxic, and phosphate free soap!
Graphic:


Week Four:
Caption: Commercial car washes recycle and treat their wastewater before the water is discharged into water bodies. Save yourself some work and help save the environment by bringing your car to a car wash instead of washing it yourself!
Graphic:


September- Pet Waste

Facts/Talking Points:

- Pet waste contains bacteria that is harmful to aquatic life
- Introduction of this bacteria can also make water harmful for humans to swim in
- Pet waste also contains bacteria that can cause harmful algae blooms in water bodies
- Algae blooms can lead to oxygen depletion in water bodies
- Dispose of your pet's waste by flushing it down the toilet or throwing it in the trash
- Don't leave your pet's waste outside, even in your own yard

Social Media Posts:

Week One:

Caption: Pet waste contains bacteria which can be harmful to aquatic life. Always pick up your pet's waste outdoors to prevent this bacteria from entering local water bodies through stormwater runoff.

Graphic:

Week Two:

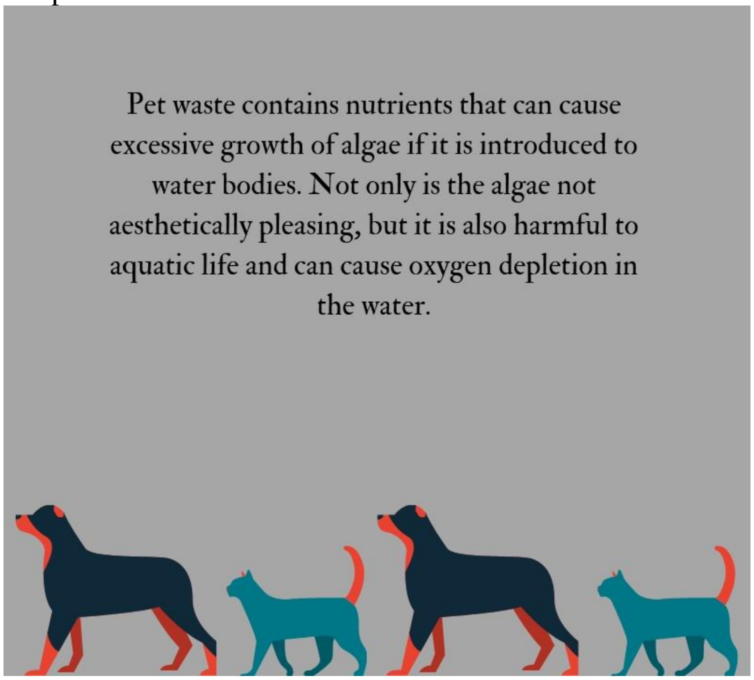
Caption: The bacteria in pet waste is not only harmful to aquatic life but also to humans. Pet waste in water bodies can lead to them not being safe to swim or play in. Help preserve the recreational spaces in Charlton by always picking up your pet waste.

Graphic:

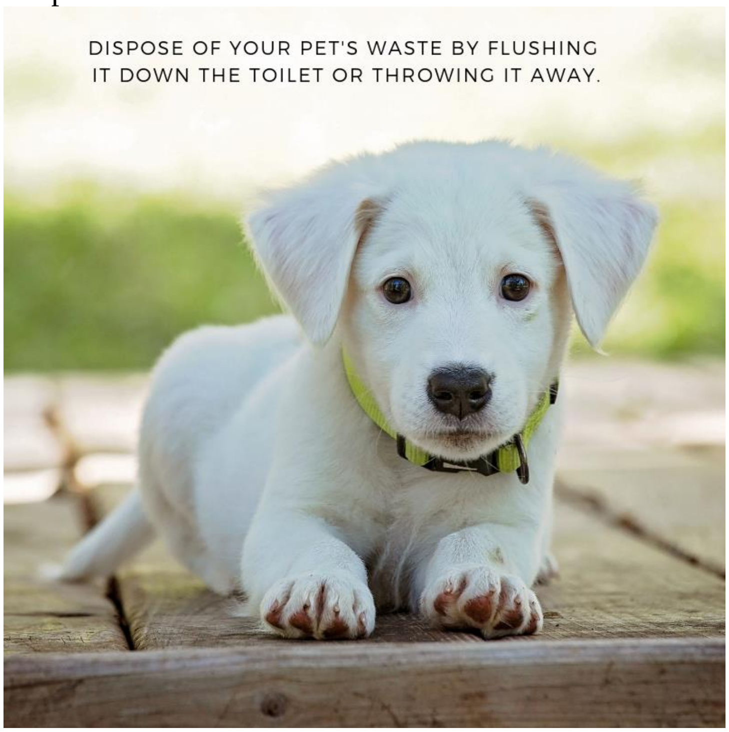
Week Three:

Caption: Pet waste also contains nutrients that can lead to excessive algae growth in water bodies. This can be harmful to aquatic life, lead to oxygen depletion, and decrease the aesthetic value of the water bodies.

Graphic:



Week Four:
Caption: The best ways to dispose of your pet’s waste is to dispose of it in the trash or to flush it down the toilet. Never leave your pet waste outside, even if it is in your own yard.
Graphic:



October- Cleaning Storm Drains

Facts/Talking Points:

- Clean leaves and debris from storm drains to prevent blockages
- Remove litter from storm drains to prevent trash from getting into the water stream
- If it hasn’t rained it 72 hours, there shouldn’t be water flowing in the storm drains. If you see water running in storm drains when it hasn’t rained, report it. This could be caused by water main breaks or other infrastructure issues that need to be fixed.

Social Media Posts:

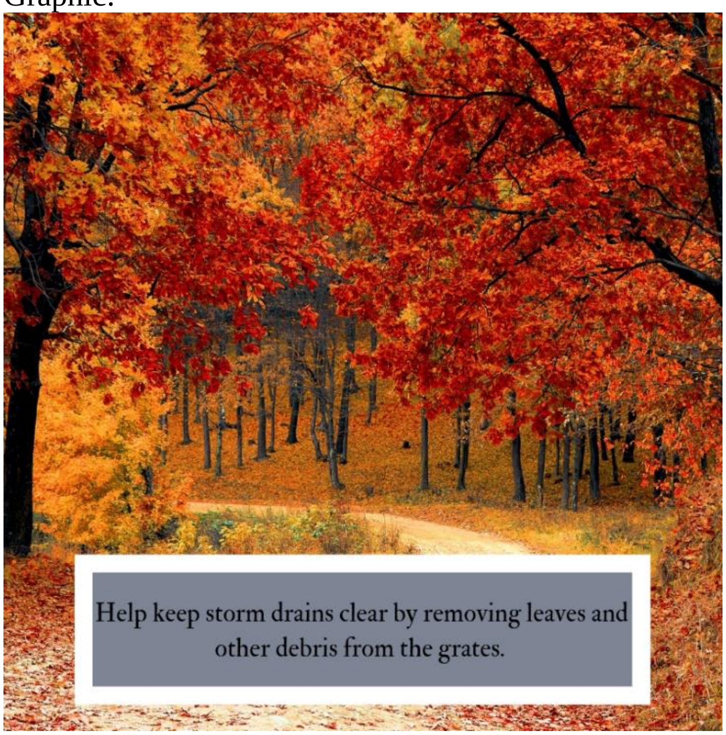
Week One:
Caption: Storm drains are important for collecting stormwater and quickly transporting it from impervious surfaces to nearby water bodies. If storm drains are clogged, water drainage is less efficient and increased flooding and runoff can occur. This can lead to runoff water picking up more pollutants and carrying those pollutants to water bodies.

Graphic:

Week Two:

Caption: Leaves are one of the most common items that block storm drains, especially in the fall. Residents can help to eliminate blockages by removing any leaves or other debris from storm drains near their house.

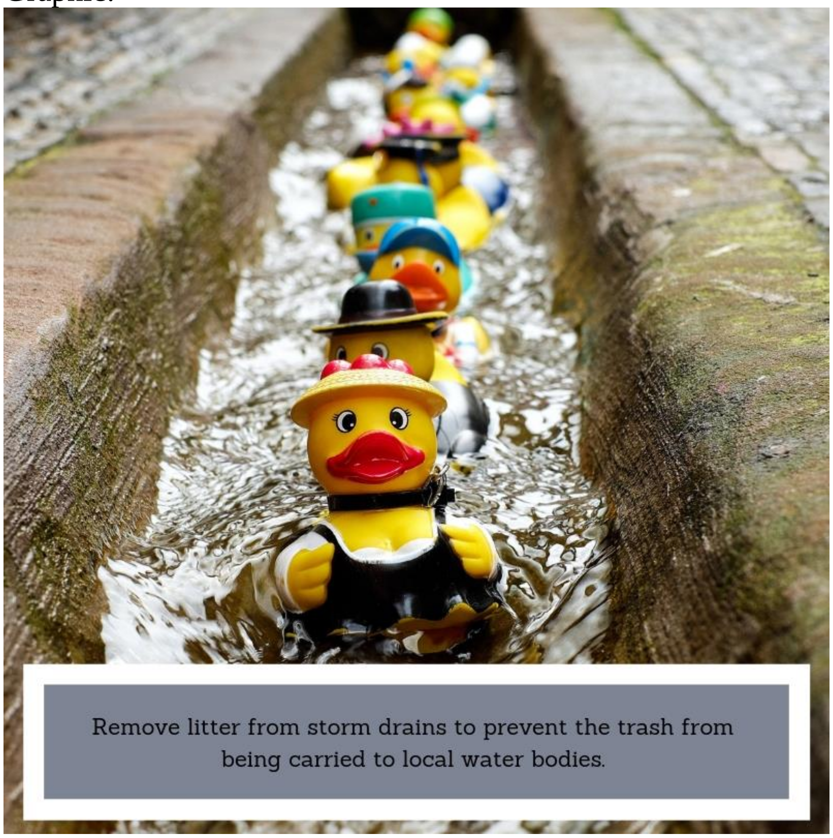
Graphic:



Week Three:

Caption: Not only can leaves get caught in storm drains, but litter and other unnatural debris can also be carried to storm drains with runoff water. If you see litter sitting on top of a storm drain, make sure to pick it up and dispose of it properly to prevent it from being carried to local lakes and rivers.

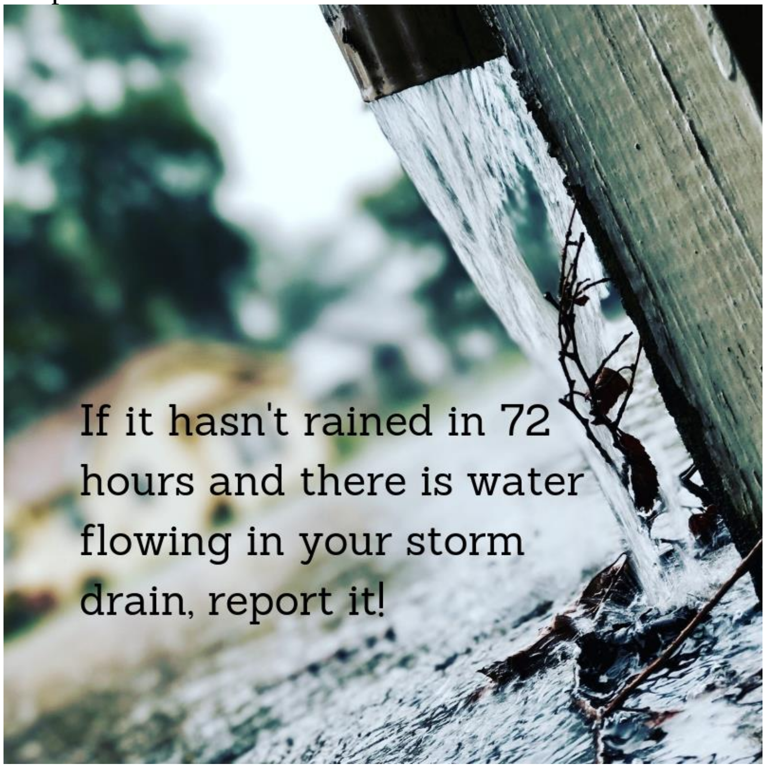
Graphic:



Week Four:

Caption: Water flow in storm drains is directly related to rain, meaning that there should not be water running through storm drains if it hasn't rained recently. If you ever see a storm drain with water running through it and it hasn't rained in 72 hours, call Charlton Conservation Commission to report it.

Graphic:



November- Disposing of Household Chemicals

Facts/Talking Points:

- Check the EPA website and the labels on chemicals to see how to properly dispose of them
- Household hazardous wastes and chemicals can be brought to household hazardous waste collection events
- Medications should not be disposed of down the drain or by flushing them down the toilet
- To dispose of medication, mix uncrushed pills with unpalatable materials like dirt or cat litter. The mixture should then be sealed in a closed container and thrown away

Social Media Posts:

Week One:

Caption: While some household chemicals and cleaners can be disposed of by pouring them down the drain, not every chemical is safe to pour into our water system. If you are unsure of how to properly dispose of a household chemical, visit the EPA website for reference: https://www.epa.gov/hw/household-hazardous-waste-hhw.

Graphic:

Week Two:

Caption: In addition to the EPA's website, product labels are another great resource to reference when disposing of household chemicals. Check the label on the product's bottle for directions on how to dispose of the waste as well as any health and safety precautions.

Graphic:

Week Three:
Caption: The Town of Charlton hosts multiple household hazardous waste collection days throughout the year. Bring any used or unwanted household chemicals to these collection days to dispose of them safely.
Graphic:

Week Four:
Caption: Medications are often disposed of down drains or in toilets but very few water treatment facilities are capable of removing pharmaceuticals from the water they treat. These pharmaceuticals then make their way into water bodies and can be harmful and disruptive to the aquatic life there. Always dispose of your old or leftover medications by mixing the uncrushed pills with an unpalatable substance, such as dirt, sealing it in a bag or container and throwing the whole container away in the trash.

Graphic:

December- Salting and Sanding

Facts/Talking Points:

- Salt and sand can upset the chemical balance of water bodies
- Try to remove as much snow and ice by shoveling before you apply salt and sand
- Use organic deicer brands like MELT and Safe Paw as a sustainable alternative to salt and sand
- Use salt and sand sparingly

Social Media Posts:

Week One:

Caption: Applying sand and salt to roads and driveways in the winter months is important to ensure safe driving conditions and human safety. However, salt and sand can be carried in stormwater runoff and melting snow to nearby water bodies where it can disrupt the pH and turbidity of the water.

Graphic:

Week Two:

Caption: Always remove as much snow from your driveway as possible by shoveling before applying salt or sand. This can help decrease the amount of salt and sand that you have to apply, cuttings down on stormwater pollution and helping you save money on salt and sand.

Graphic:

Week Three:

Caption: Organic, salt-free deicers have been developed as a sustainable alternative to regular salt or sand. While these options are a bit more expensive, they are significantly less harmful to

local water bodies. Consider using deicer brands such as MELT and Safe Paw to get rid of the ice in your driveway.
Graphic:

Week Four:
Caption: The best way to decrease the amount of salt and sand ending up in water bodies is to just make sure that you are not over applying these deicers. Only spread salt and sand on icy parts of your driveway and when a storm is underway. When it does come time to apply, apply only a thin coat of sand or salt, large piles aren't necessary.
Graphic:

All information used in social media posts and town meeting talking points was compiled from the following citations:

Citations:

Erie County, NY Environment & Planning. (2019, January 25). How Can YOU Prevent Stormwater Pollution? Retrieved from http://www2.erie.gov/environment/index.php?q=how-can-you-prevent-stormwater-pollution#YouCan.

Glen Echo Improvement Association, Inc. (2006, January). Boating Rules and Courtesies. Retrieved from http://www.glenecholake.org/boatingrules.htm.

University of Arkansas, Division of Agriculture. (2019). Ten things you can do to prevent stormwater runoff pollution. Retrieved from https://www.uaex.edu/environment-nature/water/stormwater/nwastormwater/10_things.aspx.

Appendix G – Lesson Plan Materials

Your Backyard Ecosystem

Age:	8 – 12 years old
Time:	1 hour
Objectives:	The lesson provides an opportunity for students to learn how their daily actions may affect the water environment and what they can do in their own yards that would not harm ecosystems.
Materials:	• PowerPoint document • Trash items • Recyclable items • Trash bin • Recycling bins

Introduction (5-10 minutes)

Introduce environment as a topic. Questions like, how many of you live near a lake, pond or stream? How many of you help your parents/guardians with yardwork, walking your dog, washing the car? All of these activities can affect the water in your town!

New Learning (30 minutes)

Go through PowerPoint document. Have students play individually or as teams. Uncover each questions one at a time, allow students to submit an answer. Discuss right/wrong answers accordingly. Student/team with most points for correct answers at the end of the questions wins.

Game (20 minutes)

Split students into two relay teams. Place one bin with both trash and recyclable items in front of each of the two teams. Each team's goal is to sort their items into the correct trash or recycle bins the fastest. One student at a time from each team grabs something from their bin and runs to the correct waste receptacle. Team with most correct or first to finish wins.

Conclusion (5-10 minutes)

Have students share new facts they learned today, and how they might change what they do at home to help the environment. Hand out flyers and ask students to share them with their parents/guardians.

New Learning Statements/Answers:

Category – Lawn

200: If these are left on the lawn they act as a natural fertilizer.

Ans. Clippings.

400: Applied seasonally to lawns, rain makes these run into nearby water causing harm to the aquatic life.

Ans. Fertilizers.

600: These help uptake extra nutrients before they reach the water, decreasing harm to aquatic life.

Ans. Native plants.

Category – Waste

200: If not thrown away properly, it can get into the water and hurt fish and other animals.

Ans. Litter.

400: Using reusable water bottles and bags helps to reduce this kind of waste from entering water bodies.

Ans. Plastic.

600: This contains harmful bacteria; it can get washed into the water, negatively affecting its quality.

Ans. Pet waste.

Category – House

200: These may help keep your house clean, but if disposed of incorrectly they may contaminate the water.

Ans. Cleaning supplies.

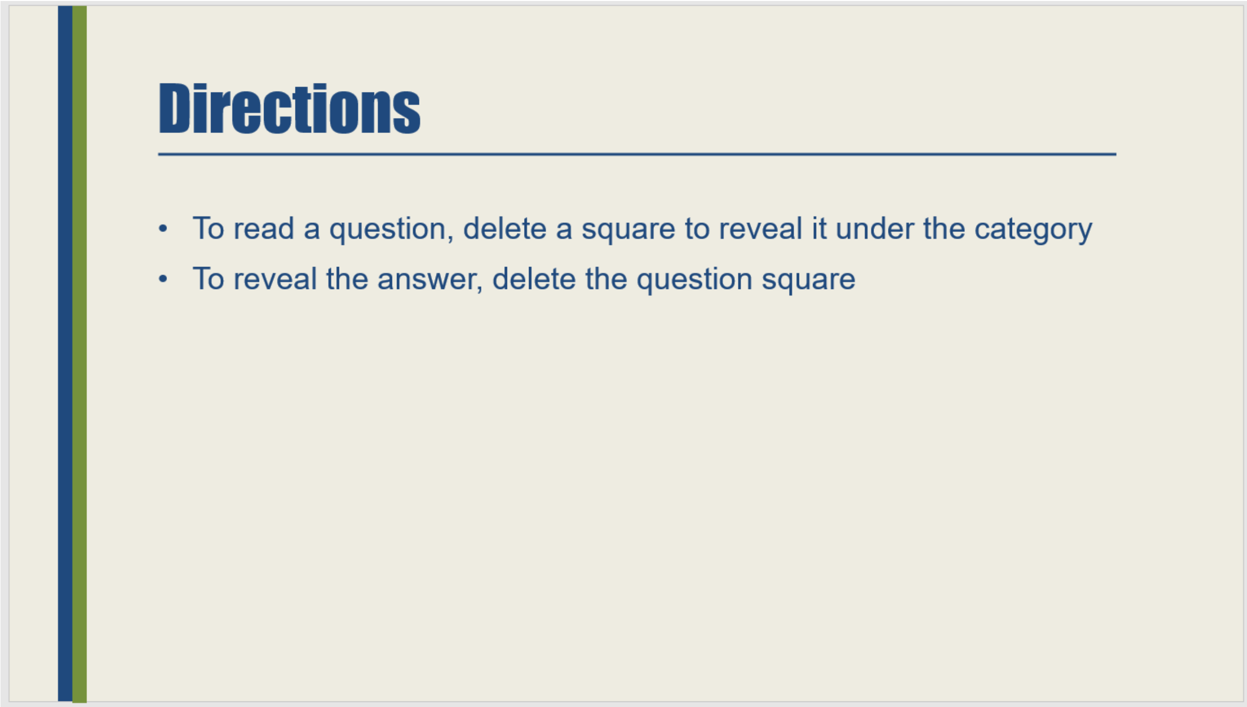
400: Washing them carries soap, dirt, oils, grease into the water.

Ans. Cars! Alternative: Wash on lawn or gravel to help filter water naturally.

600: These help capture rain to water your garden and reduce runoff.

Ans. Rain barrel.

PowerPoint game slides:



Points

Lawn	Waste	House
200	200	200
400	400	400
600	600	600

Statements

Lawn	Waste	House
If these are left on the lawn, they act as a natural fertilizer.	If not properly thrown away, it can get into the water and hurt fish and other animals.	These help keep your house clean, but if disposed of incorrectly they may contaminate water.
Applied seasonally to lawns, rain makes these run into nearby water causing harm to the aquatic life.	Using reusable water bottles and bags helps to reduce this kind of waste from entering water bodies.	Washing them carries soap, dirt, oils, greases into the water.
These help uptake extra nutrients before it reaches the water, decreasing harm to aquatic life.	This contains harmful bacteria; it can get washed into the water, negatively affecting its quality.	These help capture rain to water your garden and reduce runoff.

Answers

Lawn	Waste	House
Clippings	Litter	Cleaning supplies
Chemicals (fertilizers)	Plastic	Cars! Alternative: Wash on lawn or gravel to filter water naturally.
Native plants	Pet waste	Rain barrel

Handout for after the game:

CARING FOR THE HOME AND THE COMMUNITY

How do we take care of our homes in the safest way for ourselves and for our community?

(All information compiled from the U.S. EPA website)

LAWN AND HOUSEHOLD CHEMICAL HAZARDS

Many household products such as cleaners and pesticides can harm children, pets, or the environment if not used and stored correctly

- Read the label first!
- Use products with **EPA's Safer Choice label**
- Do not apply products where they can run into ponds, creeks, or other water supplies. **They can contaminate water and harm wildlife**
- Never pour lawn and garden products down the drain

RESOURCES

Visit the EPA's website for proper hazardous waste disposal methods:

https://www.epa.gov/hw/household-hazardous-waste-hhw

Finding locations to recycle hazardous materials near you!

https://search.earth911.com/

LITTER

Trash poses a risk to children and the environment

- Litter often ends up in waterways! Sharp debris and fishing equipment **can harm recreational swimmers and aquatic life**
- Trash materials contain **persistent, bio-accumulative and toxic (PBT) substances** that can enter the environment. PBTs are chemical compounds that are resistant to breaking down,and are highly mobile

PET WASTE

Pet waste can contain bacteria that threatens the health of people and animals

- Always pick up your pet wast and **flush it down the toilet**, so it can be treated at a sewage treatment plant

Additional Information:

https://www.epa.gov/trash-free-waters/impacts-mismanaged-trash

https://cfpub.epa.gov/npstbx/files/KSMO_PetWaste.pdf

Appendix H – Flyers for Waterfront Homeowners

FERTILIZER DOS AND DON'TS

NUTRIENT POLLUTION

Fertilizers, yard and pet waste, and certain soaps and detergents contain nitrogen and phosphorus and can be carried into nearby water bodies with the rain.

Excess nutrients cause algal blooms that decrease the environmental, aesthetic, and recreational use of water bodies

MAINTAINING YOUR BEAUTIFUL LAWN RESPONSIBLY

- **Apply fertilizers only when necessary and at the recommended amount.**
- **Apply fertilizer during the time period of maximum uptake and growth for grass and other plants (usually spring and fall in New England)**
- **Avoid applying fertilizer close to waterways.**
- **Don't apply fertilizer before windy or rainy days.**
- **Do not over-water lawns and gardens (excess water carries away more nutrients)**
- **Fill fertilizer spreaders on a hard surface so that any spills can be easily cleaned up.**
- **Properly store unused fertilizers and properly dispose of empty containers.**

ALTERNATIVES TO FERTILIZERS

- **Select the right grass seed for your climate.**
- **Aerate lawn annually.**
- **Feed soil biology with grass clippings and light layers of mowed leaves in the fall.**

THIS INFORMATION WAS SUMMARIZED FROM THE U.S. EPA; VISIT THEIR WEBSITE FOR MORE INFORMATION:

https://www.epa.gov/nutrientpollution/what-you-can-do-your-yard

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