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Little Indian Lake: Diagnostic Study

Worcester Polytechnic Institute

Interactive Qualifying Project

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1. PROBLEM STATEMENT

Little Indian Lake is a subsidiary man-made resource that serves the community of Worcester, Massachusetts. The construction of Massachusetts state highway 122A separated Little Indian Lake from Indian Lake. Since that time water flow between the two lakes has been severely impeded. Consequentially the waters of Little Indian Lake have become stagnant, resulting in several problems that have led the Indian Lake Watershed Association (ILWA) to explore chemical treatment options. Ownership of the lake falls under the City of Worcester and abutter properties who have invested many resources in weed and algae control. The ILWA also contributes to offset the costs for the local residents. Many companies have been employed, such as Aquatic Control Technologies and Lycott Environmental, to regulate sustainability, but most solutions rely on chemical treatments. As prolonged chemical treatment can adversely affect lake and its surrounding environment, a diagnostic study was conducted to evaluate the conditions of Little Indian Lake and to prevent future damage to this water body. This report characterizes the conditions of the lake and its surroundings and provides recommendations for future management.

The following outlines the initiatives that were undertaken to assess Little Indian Lake.

1.1 Watershed Activity

In order to characterize the activity of the watershed, the group investigated the conditions of the inlets and outlets of Little Indian Lake. Currently the channel which runs underneath MA-122A, known as a culvert, allows for water flow between Indian Lake and Little Indian Lake. By studying the culvert, damage assessments were made as well as recommendations on methods of restoring water flow between the two lakes.

1.2 Wildlife Impact

The current effect Little Indian Lake has on the surrounding wildlife was also examined. In classifying the different types of wildlife, deductions were made on the water quality and overall well-being of the lake. Additionally, any relationship between the nuisance weeds/algae and the animals were investigated.

1.3 Bathymetric Survey

A bathymetric survey, which measures the depth of a body of water, provided essential information about the current status of Little Indian Lake. This survey assisted in indentifying the areas of the lake that were currently “choked” by nuisance plants. The survey also allowed for the creation of plans for dredging the lake.

1.4 Water Composition

Understanding the quality of the water in Little Indian Lake provided insight into how the problems Little Indian Lake experiences arise. The levels of organic chemicals in the water were measured to understand the cause of nuisance plant growth.

1.5 Plant Distribution

Identification of the current aquatic plant life within Little Indian Lake provided insight as to how they contribute to the current state of the water. A thorough examination of the various plants assisted in categorizing them as native, non-native, or invasive. This was an integral aspect of the research, since the main problem was centralized on controlling the plant and algae population and alternative solutions were suggested on how to treat these issues.

Research of the key topics outlined above allowed for the creation of this diagnostic study of Little Indian Lake. This report aims to restore the aesthetic beauty and recreational potential of Little Indian Lake.

2. BACKGROUND

The Mill Brook watershed and its subsidiaries have a rich history that dates back to the early part of the 19th century. North Pond, which was later renamed to Indian Lake, spanned 40 acres and was bordered by both farms and marshes. During the industrial era in the late 1820's, the Blackstone Canal was created in order to form a transportation line between Worcester and Providence. In order to control the flow of water through this canal, a dam was constructed at Indian Lake and Salisbury Pond to form the headwaters of the Blackstone Canal and River.

Indian Lake is the largest body of water that lies completely within the city of Worcester, totaling 193 acres in size. Currently the lake is a valuable commodity to the community in its capacity as a recreational resource, but it has suffered many environmental issues throughout the years (the main issue being water quality). In 1976, the Massachusetts Department of Environmental Quality, Engineering Division of Water Pollution Control found that eutrophication and nuisance aquatic plant life were the first problems to address (ESS Group, Inc., 2006). Nuisance plants including Eurasian milfoil have been present within the lake since ESS's analysis and continue to impact both the aquatic habitat value and recreational opportunities of Indian Lake. A study in 1982 by Tighe & Bond further characterized phosphorus loading to the lake by identifying Ararat Brook and the Kiver Pond tributary inlets as the prime contributors of this organic chemical, a nutrient which is central to the eutrophication process (ESS Group, Inc., 2006). Additionally, in 1989, new research reiterated that the storm water draining from the urbanized watersheds in Worcester was the primary reason behind phosphorus loading (ESS Group, Inc., 2006). The eutrophic condition caused by nutrient loading remains the main factor responsible for the success of many species of aquatic vegetation in the lake. The conditions of Indian Lake were so severe to merit its addition to the state’s *Integrated List of Impaired Waters* for nuisance aquatic plants, organic enrichment, and low dissolved oxygen in early 2009.

In 1985, the Indian Lake Watershed Association was incorporated as a nonprofit organization that focused on monitoring and reviving Indian Lake. The ILWA has been working for over 20 years on restoring and preserving the quality of Indian Lake, as well as improving the surrounding neighborhood. By working closely with the City of Worcester, the ILWA has completed numerous projects to improve water quality conditions in the lake by sewering homes within the lake’s watershed, repairing a sewer pumping station, and stenciling nearly 1,500 storm drains within the watershed (ESS Group, Inc., 2006).

Development over the past hundred years within the Mill Brook watershed has resulted in an increased number of water quality problems. As a result of the development and the urban runoff resulting from manufacturing, layers of sediment have accumulated on the floor of Little Indian Lake. This sediment raises concerns of toxicity, especially because of its links to industrial processes and poses a significant challenge to the ILWA. Toxins which contaminate the lake water and threaten residents and wildlife alike with bacterial contamination and mutagenic agents may be present in this sediment.

High phosphorous loading has led to eutrophication of Indian Lake and Little Indian Lake. Eutrophication presents a serious risk to the quality of a lake because it favors primary producers within the ecosystem, promoting excessive plant growth while simultaneously favoring nuisance plants. This effect is demonstrated by the algal blooms that occur in Little Indian Lake. During these blooms the populations of algae species increases dramatically, limiting the sunlight that reaches the lake floor and outcompeting other plant species. These periods of rampant algae growth cause the levels of oxygen dissolved in the water to drastically vary throughout the day – during the day plants photosynthesize sunlight and replenish the oxygen supplies, but at night the algae respire, consuming vast quantities of oxygen. As this process continues the lake eventually reaches a point where it is unable to support the vast quantities of plant life. Soon masses of algae begin to die and further deoxygenate the water creating a hypoxic, low-oxygen, zone where marine life cannot survive. Algal blooms can also pose a threat to human society because many species of algae release neurotoxins which are harmful to humans (Eutrophication, 2010).

ESS Group, Inc., an environmental and engineering solution firm, has addressed Little Indian Lake's aquatic life issues and conducted a "Plant Replacement Pilot Program" for both Indian and Little Indian Lakes in March of 2006. Although ESS Group focused on Indian Lake rather than Little Indian Lake, it was inferred that both lakes share similar problems: poor water quality, high nutrient levels, nuisance plants, organic enrichment, and low dissolved oxygen levels. ESS Group's goal was to determine whether it was effective and feasible to control Eurasian milfoil by eliminating it through the use of herbicides. They also focused on preventing this type of algae from re-establishing itself in the same areas by actively transplanting more desirable native aquatic plant species to the cleared area after the milfoil were killed.

Unfortunately ESS Group's attempts to transplant native aquatic species were unsuccessful. ESS Group attributed their failure to the poor water clarity within the lake, stating that water clarity is an issue which must be addressed early in any remediation process involving plant replacement.

The objectives of this project have allowed the ILWA to have a more comprehensive understanding of the current state of Little Indian Lake. The outline below analyzes the various problems that were examined in conducting this study.

2.1 Aquatic Plants

Aquatic plants have an integral role in the lake’s ecology. Floating-leaf and submerged plants provide nutrients for animals like fish, insect larvae, snails, and other invertebrates. These plants also offer shelter for organisms that inhabit or are dependent on the body of water (Wagner, 2004). Emergent plants are rooted in the lake floor and penetrate the water surface. These plants help protect shorelines and assist in stabilizing particles within the sediment, preventing the water clarity from deteriorating (Krischik et al., 2009).

Aquatic plants further benefit the lake by producing oxygen, while simultaneously absorbing nutrients like phosphorus and nitrogen. Although overgrowth of these plants certainly limits recreational activities such as swimming, boating, and fishing, it also affects the aesthetic appeal of the area. Unchecked plant growth also presents biological concerns in that certain plant species like weeds may overtake the natural flora, adversely affecting the ecosystem. Competition amongst native plants, which the local wildlife depend on for nutrition and energy, and nuisance plants, which offer little to nothing of value to local wildlife, threatens the survival of these animals. Aquatic plants are a vital contributor in maintaining stability within a lake’s environment.

Three General Classes of Aquatic Plants adapted from *A Guide to Aquatic Plants in Massachusetts* (Kelly, 1999):

2.1.1 Submerged Plants

Submerged plants grow completely beneath the water's surface. Flowers may appear above the surface floating on the water accompanied by small leaves for support, but the majority of leaves and the plant itself remain underwater: "Oxygenating plants grow totally submerged and perform the important functions of producing oxygen, competing with algae for nutrients in the water, and providing a spawning area for fish"(The Ohio State University, 2008). According to the Minnesota Department of Natural Resources, submerged plants grow from near shore to the deepest part of the littoral zone (see Figure 2.1, pp. 18) and display a wide range of plant shapes. They also state that various species exhibit different growing patterns; some form a low-growing and dense "meadow" near the lake bottom while others flourish with plenty of open space between plant stems. Submerged plants tend to be highly dissected, having numerous extensions to maximize surface to volume ratio for photosynthesis (UCLA Botany Gard, 2009). Since these plants are underwater, they tend to receive lower levels of sunlight because it is blocked by particles in the water. In order to compensate as photoautotrophs they have many filamentous protrusions that spread to obtain diffused carbon dioxide in order to synthesize organic compounds for use in cellular functions.

Common Name	Scientific Name	Descriptions
Small Pondweed	*Potamogeton pusillus*	Characteristics: -Small and leafy pondweed has linear leaves, 2-7 cm long, 0.5-2 mm wide, with pointed to rounded tips and 3 veins. -Has a slender stem that is profusely branched. Propagation: - "Seeds and winter buds form at lateral branch tips and near leaf bases" (Ecology, 2009). Importance: -Seeds and vegetation provide cover and food for aquatic animals. -Narrow leaved pondweeds much alike, so close attention must be paid to minute details to distinguish between them.
Stonewart	*Nitella spp.*	Characteristic: -Plant algae form often mistaken as higher plants because they appear to have leaves and stems. -Found in tangled mats along the pond or lake bottom (Kelly, 1996). -No true leaves or stems appear to have leave and stem like structures. Propagation: - Spore spread by wildlife and generate from vegetative fragments. Importance: -Provides shelter for fish, food for fish and waterfowl, and stabilizes the sediment. -Have no roots, so they remove nutrients directly from the water.

*Note: Unless another source is cited, the information present under the description column was obtained from Washington State's Department of Ecology website under the Aquatic Plants, Algae, and Lakes database (2010).

Table 2.1: Submerged Plant Species Documented in Little Indian Lake by ESS Group Inc. on June 11, 2004 (Ecology, 2009; ESS Group, Inc., 2006)

2.1.2 Floating-Leafed Plants

Floating-leafed plants are rooted to the floor of the lake, but have leaves on the surface of the water. Floating-leafed plants can be found with or without flowers. They have special air chambers called lacunae that enable to maintain buoyancy. These plants also have sclerids, hard cells, which are located within the internal tissue of plant. These cells provide toughness and structure to the leaf and prevent the layers from collapsing, assisting in flotation (UCLA Botany Gard, 2009). Floating-leafed plants thrive in protected areas where there is limited wave activity and assist in combating algae growth while simultaneously providing shade for fish. Table 2.2 (page 13) shows the floating-leafed plants that ESS Group found in Indian Lake during their survey.

2.1.3 Emergent Plants

Emergent Plants are rooted to the floor of the lake and have leaves that extend out of the water. The Minnesota Natural Resources website lists cattails as an example of an emergent plant that can be found in wetlands and along the shore, where the water is less than 4 or 5 feet deep. These plants closely resemble their terrestrial counterparts and have well developed mesophyll tissue on both sides of their leaves to take advantage of the abundant sunlight they receive (UCLA Botany Gard, 2009). Table 2.3 (page 14) presents the emergent plants documented in Indian Lake during ESS group’s survey.

Common Name	Scientific Name	Description
Duckweed	*Lemna minor*	Characteristics: - Duckweeds are among the world's smallest flowering plants. - Found scattered among emergent plants or massed together in floating mats. - No true leaves; the leaf-like body is called a thallus. -No stem. Propagation: - Rarely reproduces from seeds. -Distributed by wind and on the bodies of birds, and aquatic animals. Importance: - Food for fish and waterfowl and habitat for aquatic invertebrates. -Has high nutritive value, duckweeds have been used for cattle and pig feed in Africa, India, and southeast Asia. -Can be used in bioremediation of nutrients from sewage effluent.
Smartweed	*Polgonum amphibium*	Characteristics: -Similar to sprawling perennials with willow-like leaves and clusters of small pink flowers. -Leaves are lanced shaped; alternating leaves attached at swollen joints on stem (Kelly, 1996). - Plant Height: 4-30 inches (Connecticut Botanical Society, 2005) - Can form mats along the edges of lakes and ponds, but generally are not considered a nuisance. Propagation: - Seed and spreads by rooting from the trailing stems.
Watermeal	*Wolffia columbiana*	Characteristics: -Native of Florida; is 1 to 1.5 mm long and is the smallest flowering plant on earth (University of Florida, 2008). Importance: -Water meal is barely discernible to the naked eye and estimated probability is 99% under natural conditions in wetlands (University of Florida, 2008).
Yellow Pond Lily/ Spatterdock	*Nuphar variagatum*	Characteristics: - Spatterdock, is a perennial water lily-like plant that can form extensive stands in the shallow waters of lakes and ponds. - It has large green heart shaped leaves, around 10-45cm long and 7-30 cm wide, with a notched base, blunt tip, prominent midvein, and leathery surface. -Has bright yellow flowers that bloom from June to August. Propagation: -Seeds Importance: - Is a food source for mammals and waterfowl and provides spawning habitat for fish.

*Note: Unless another source is cited the information present under the description column was obtained from Washington State's Department of Ecology website under Aquatic Plants, Algae, and Lakes database (2010).

Table 2.2: Floating-Leafed Plants Documented in Little Indian Lake by ESS Group Inc. on June 11, 2004 (Ecology, 2009;ESS Group, Inc., 2006)

Common Name	Scientific Name	Description
Cattail	*Typha latifolia*	Characteristics: -Long green leaves with a slender brown flower spike. -Grows in dense stands of shallow water or as a narrow band along the margins of deeper water. Importance: -Filter runoff as it flows into the lake and helps reduce nutrients inflow as well as mud, which enter lakes from surrounding land. -Prevent shoreline erosion. -Provide a habitat for many species of wildlife and birds.
Purple Loosestrife	*Lytrum salicaria*	Characteristics: -Invasive plant that disrupts wetland ecosystems by displacing native plants and animals. - A perennial that has annual stems which rise to about 9 feet tall. Short, slender branches spread out to form a crown five feet wide on established plants with a 4-6 inch magenta flowering spike.

*Note: Unless another source is cited the information present under the description column was obtained from Washington State's Department of Ecology website under Aquatic Plants, Algae, and Lakes database (2010).

Table 2.3: Emergent Plants Documented in Little Indian Lake by ESS Group Inc. on June 11, 2004 (Ecology, 2009;ESS Group, Inc., 2006)

2.2 Aquatic Distribution of Plants

Lakes have distinct zones of biological communities linked to their physical structures (National Science Foundation, 2004). Figure 2.1 displays the specified areas of plant growth that can be observed in lakes and ponds: wet meadow, littoral, and open water or limonitic zones. The littoral zone is dependent upon the elevation of the lake bottom. The Minnesota Department of Natural Resources (2009) states that if there is a steep slope the littoral zone can be narrow and extend several feet from the shoreline. If instead the lake is shallow and the bottom slopes gradually, the littoral zone may extend hundreds of feet into the lake or may even cover it entirely. All three plant types described above (submerged, floating leafed, and emergent) can be found in this zone because of their proximity to the shoreline where sunlight exposure is at a maximum (National Science Foundation, 2004). Plants that grow in this zone assist in providing shelter and resources for the aquatic life.

Another factor that contributes in classifying lakes zones are light levels. Areas which receive less than one percent of the amount of sunlight which reaches the surface of the water are defined as the littoral and eupothic zone, which is the layer from the surface down to the depth where light levels become too low for photosynthesizers to survive (National Science Foundation, 2004).

According to Water on the Web (2004), a site funded by the National Science Foundation, the limnetic zone is the open water area where light generally does not penetrate all the way to the bottom. The lake floor as known as the benthic zone and is abundant with organisms. Benthic organisms, most of which are invertebrates like insect larvae or small crustaceans, assist in mixing the organic sediments. The productivity of this zone largely depends upon three factors: the organic content of the sediment, the amount of physical structure, and in some cases the rate of fish predation. Sandy substrates contain relatively little organic matter for organisms and do not offer protection from predatory fish. Higher plant growth is sparse in sandy sediment, because the sand is unstable and nutrient deficient. Lastly, a flat bottom offers abundant food for benthic organisms, but is less protected and may have a lower diversity of structural habitats, unless it is colonized by higher plants.

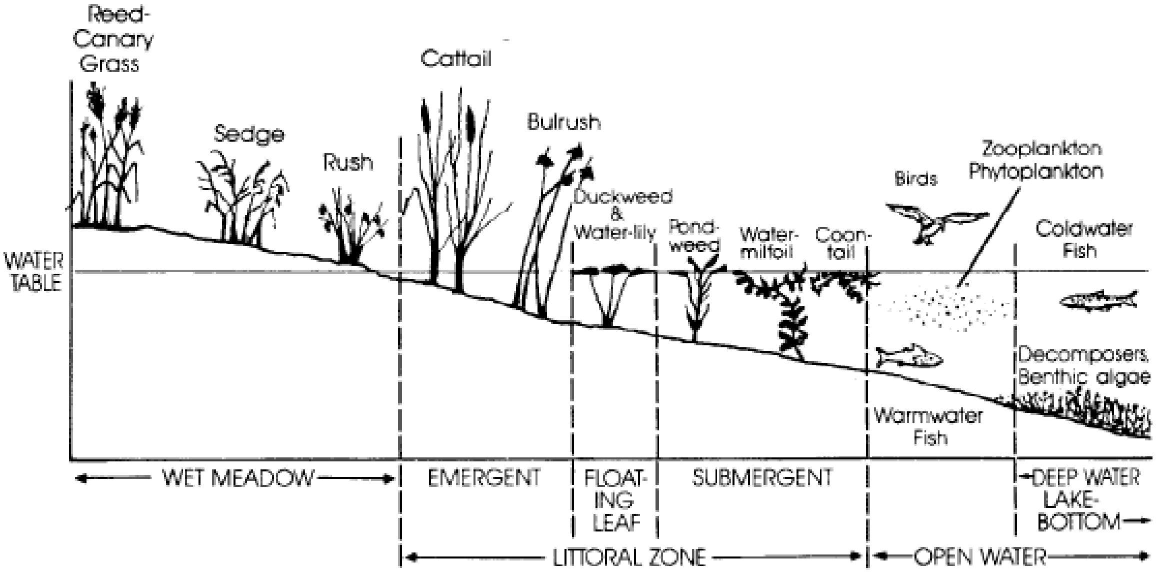


Figure 2.1: Typical Aquatic Plant Zones in Lakes and Pond (Wagner, 2004)

2.3 Algae

Algae are photosynthetic plants that contain chlorophyll, a green accessory pigment that assists in converting light into energy, a simple reproductive structure, and no true tissue with stems, leaves, and roots (United States Environmental Protection Agency, n.d., p. 11). As a basic component in the complex aquatic food web, they assist in converting inorganic matter into matter and adding oxygen to the water by the process of photosynthesis. According to the Missouri Department of Conservation (n.d.) algae can occur in three basic forms.

The first types of algae are single celled microscopic plants that float freely in the water known as *Planktonic algae*. When these plants are extremely abundant or "bloom," they make the pond water turn green. Less often, they can turn the water other colors, including yellow, gray, brown, or red.

The second basic type of algae is called *Filamentous algae*. Sometimes colloquially referred to as "pond moss" or "pond scum," this type of algae can form fine green threads that combine to create floating mats, which are often moved around the pond by wind. This type of algae is also commonly found attached to rocks submerged trees, other aquatic plants, and boat docks.

The final type of commonly found algae is *Macrophytic algae*. These algae resemble true plants in that they appear to have stems and leaves, and are attached the lake floor. Chara is a common macrophytic algae, often called stonewort, which has been found in Little Indian Lake in the past.

The type and quantity of algae are determined by numerous environmental factors, which are listed below (United States Environmental Protection Agency, n.d. p.11). In a natural ecosystem, there are constant changes that may favor the growth of a certain algae or even determine the survival of one. Due to this flux, there can be various successions of growth of different species in a year and throughout the years. Some of the factors which determine the growth rate of certain algae include the amount of light that penetrates the water, water temperatures, and the rate of physical removal of algae by sinking or flushing through an outlet. The growth of algae in lakes is also effected by grazing on the algae by microscopic animals and fish, parasitism by bacteria and fungi, and general competition pressure from other aquatic plants for nutrients and sunlight.

Although algae can be beneficial to a lake, they can also become problematic if too much accumulates. Algal blooms occur when there is an excessive amount of nutrients (normally nitrogen and phosphorous) that are introduced to the watershed and allow the algae to thrive; an often disturbing symptom of cultural eutrophication (p.12). Blooms can change the water color to a vivid green, brown, yellow or even red, color depending on the species, give the water an unpleasant taste or odor, and reduce clarity. Filamentous and colonial algae are especially troublesome because they can mass together to form mats on the lake surface which can clog water intakes, foul beaches, and affect recreational opportunities (p.12).

There are natural means of nutrient buildup, but human activity can accelerate the aging process or eutrophication of the water body. Runoff from fertilizers use in lawns, fields, pastures, feedlots, septic tanks and leach fields can contribute to nutrient loading and algal growth. Also the amount and composition of the sediment should be analyzed and excavated if deemed necessary (Missouri Department of Conservation, n.d., p.2).

Algal blooms can be controlled by mechanical, biological, and chemical means (Missouri Department of Conservation, n.d., p.2). Mechanical control is labor intensive and works best in conjunction with chemical treatment. Normally sieves, rakes, or screens are used to collect the algae, but this usually is a temporary solution. Use of grass carp, herbivore dieted fish which eat aquatic vegetation represent a biological solution to algal blooms. Chemical control is implemented by using Citrine Plus (liquid or solid form) or copper sulfate, but does not permanently control the algae; therefore repeated treatments are normally needed. If chemicals are used, consideration should be taken for how it will affect the current environment of the plant and water life as well as recreational activities.

2.4 Particulates

Particulates can be organic or inorganic organisms that are characterized to be 0.45 thousandths of a millimeter in length (Wagner, 2004). Larger or heavier particles like animals, algae, and bacteria may settle to the floor of the lake, but some may stay suspended due to their ability to stay afloat or move. Smaller or fine particles, such as those found in colloids, have the same density of water and can remain suspended. Particulates can also affect water clarity or turbidity. High concentrations of particulate matter can modify light penetration which can affect macrophyte growth, which in turn can affect organisms that are dependent upon them for food and shelter ("Turbidity in Lakes," 2010).

Inorganic particles are relevant to aquatic plants because they contribute to the nutrients that have been absorbed by floating particles: “[Inorganic particles] can accelerate the process of filling the lake to the point where a shallow, soft and nutrient-rich bottom is widely available for rooted aquatic plant growth” (Wagner, 2004). Although most inorganic particles have originated from terrestrial sources, human activity and wave action can redeposit and mix the lake bottom sediments.

In contrast, organic particles or detritus are composed on living or dead biota which includes plants, animals, and bacteria. As these particles settle to the bottom they can also decompose and release their nutrients.

2.5 Bacteria

In *The Practical Guide to Lake Management in Massachusetts* (Wagner, 2004), bacteria are classified as the most abundant group of organisms in a lake and have a vital role in converting organic matter into inorganic substances. They can be found floating freely in the water column, attached to a substrate, or submerged within the sediment. There are two classifications of bacteria – obligate aerobes and anaerobes. Obligate aerobes require oxygen to convert organic material into inorganic material (and energy). Anaerobes, in contrast, utilize other chemical pathways to derive energy (Wagner, 2004). Sulfate reducing bacteria can convert inorganic mercury into a highly toxic form, methyl mercury, and cause the sulfurous odors that affect the mud sediments of marshes, lakes, and ponds. There are also photosynthetic bacteria like cyanobacteria that grow profusely in blooms and produce potent toxins which can affect waterfowl and humans (Government of Alberta: Environment, 2009). Other bacteria like *Escherichia coli* can thrive in lakes after being introduced by improper sewage and septic practices, which can potentially transfer disease to both aquatic and human life (Frankenberger, 2009).

2.6 Eutrophication

Eutrophication of a lake can be a devastating process. Eutrophic bodies of water are nutrient rich (to a fault) and low in oxygen. This nutrient imbalance favors certain species while harming others, severely impacting the local ecosystem. In fact, eutrophication can affect virtually every constituent of an ecosystem (Ryding, S.-O, & Rast, 1989). Although sometimes a naturally occurring process, observable in depositional environments, eutrophication is most often a result of pollution stemming from urban, stormwater, and sewage runoff.

For many years scientists have wondered which nutrient is primarily responsible for eutrophication. In order to address this question David W. Schindler, along with other aquatic scientists, conducted a thirty-seven year-long study of the effects nutrients have on lakes (Schindler, 2008). During this time, Schindler supplied lakes within the Experimental Lakes Area in Ontario, Canada, with constant annual supplies of phosphorus and decreasing inputs of nitrogen. The goal of this experiment was to demonstrate that eutrophication of a lake can be controlled by controlling nitrogen inputs alone. For the last sixteen years of the experiment, the lakes were only supplied with phosphorus. Despite the lack of nitrogen inputs, eutrophication still occurred. Schindler and his team concluded that phosphorus is the main factor that caused eutrophication. To test this theory, they treated one half of Lake 226 with carbon, nitrogen, and phosphorus. In the other half, they only supplied carbon and nitrogen. As demonstrated by Figure 2.2, the half treated with carbon, nitrogen and phosphorus experienced eutrophication and dense algal blooms, whereas the other half was unaffected by these problems (Schindler, 2008). Some have suggested that the atmosphere may serve as a source of phosphorous, but phosphorus does not enter a gaseous phase in its biogeochemical cycle: "[Phosphorus's] concentration in the water is…determined by its rate of income and sedimentation to the lake bottom, by the rate of water renewal (phosphorous loss through the outlet), by dilution in the lake or reservoir basin, and by the rate of release of phosphorus from sediments, macrophytes, and other sources inside the basin" (Cooke, Welch, Peterson, & Newroth, 1986, p. 19). Thus, the atmosphere can be ruled out as a significant source of phosphorus and phosphorus loading can be directly managed by control of nutrient flow through the inlets and outlets of the lake body.

Figure 1.2: Experimental Lake 226 (Munteanu, 2008)

Although naturally present in appreciable quantities in certain environments, phosphorus responsible for eutrophication of lakes generally comes from human products, namely agricultural fertilizer. In fact, human activities have increased the rate of phosphorus cycling by four times (Eutrophication, 2010).

One direct effect of eutrophication is an increase in the biomass of phytoplankton, such as blue-green algae commonly seen on the surface of stagnant ponds (Schindler, 2008). These plants are crucially dependent on minerals such as nitrate, phosphorus, and sicillic acid. Although phytoplankton are photosynthetic (i.e. oxygen producers), they consume more oxygen when they respire than they produce, resulting in both a constant decrease in dissolved oxygen (dO_2) levels as well as huge swings in dO_2 levels throughout the day (Henderson-Sellers & Markland, 1987,

p. 10). For example, as the phytoplankton respire during the night dO_2 levels drop severely, leading to dramatic fish kills and a severe loss of biodiversity: “[Eutrophic] ecological systems tend to be unstable and can periodically ‘crash’ leading to total lake anoxia with subsequent large scale biomass death” (9). This loss of biodiversity, which will be commented on further in following sections, is of serious concern in both a conservational and recreational sense.

Some of the phytoplankton species favored by a eutrophic environment may be inedible or inedible (Government of Alberta: Environment, 2009). The consumption of toxic phytoplankton by zooplankton, which exists quite low on the food chain, can transfer the toxins throughout the entire ecosystem. These toxins become concentrated in the higher tiers of the food chain, specifically tertiary consumers. These toxins affect a loss of biodiversity both within and without a body of water. Toxic phytoplankton also pose a threat to humans as evidenced by the harmful algal blooms commonly referred to as red tides (Eutrophication, 2010). Furthermore, normal predators of phytoplankton cannot consume inedible species, resulting in unchecked population booms for these inedible species.

2.7 Algal Blooms

Dramatic increases in the populations of algae species are commonly referred to as algal blooms. During these blooms algae tend to out-compete other plant species due to exposure to high concentrations of phosphates. Many other plant species become "choked out" by these algae species and die. The resulting dead plant matter sinks to the lake floor where it provides food for bacteria which decompose it. Although normally a beneficial process, the decomposition of dead matter by bacteria takes dissolved oxygen out of an already deoxygenated environment (Algal Blooms, 2010). As the oxygen levels continue to drop plants continue to die, resulting in an abundance of nutrients for these bacteria, which then experience a population boom. Since more bacteria are present to decompose dead plant matter, the rate of dO2 consumption increases furthering the eutrophic conditions.

Sustained algal blooms can severely reduce or even block out the sunlight that would normally reach the lake floor. Since plants depend on sunlight for their energy, plants that dwell on the lake floor die (Algal Blooms, 2010). Many fish and invertebrate populations rely on lake-floor plants for food and consequently die. Furthermore, without these lake-floor plants rooted in to the bottom of the lake, which assist in holding the sediment in place, tiny particles can float out of the sediment. These particles further reduce the water quality and amount of sunlight that reach floor-level plants.

Figure 2: Algal Bloom in Freshwater Lake (Munteanu, 2008)

Long term blooms can seriously change the availability of species at the base of the food web. During these blooms only certain species are abundantly available as food sources. Therefore, species that feed on abundantly present sources excel while others fail. Over time this shift in producers at the base of the food web can affect zooplankton, fish, birds and other animals in the ecosystem.

Even after an algal bloom can no longer sustain itself, it can still affect the ecosystem. Phytoplankton that once thrived, die off and provide food for the bacteria, which decompose them. In this process more dO2 is taken out of the water column.

Eutrophic water conditions also present risks to the human population. Eutrophic lakes can contain carcinogenic and mutagenic compounds as a result of high nutrient levels: “High nitrate levels in drinking water may cause the formation of nitrosamines, which are carcinogenic” (Henderson-Sellers & Markland, 1987, p. 15). This risk to human health is of serious concern to the residents surrounding eutrophic areas.

One option for treating eutrophic waters is to introduce non-native plant species which help absorb undesired nutrients. One such plant is vetiver grass. Although unsuitable to the harsh climate of New England, analysis of vetiver grass treatment demonstrates how an environmentally friendly treatment option can be very effective. Vetiver grass can withstand prolonged submergence in water and efficiently absorbs dissolved nitrogen, phosphorus, mercury, cadmium, lead, and other dangerous heavy metals (Singh, Tripathi, & Singh, 2006). The efficiency of the system even increases with time, furthering the attractiveness of this option. Work done in China shows that vetiver grass can effectively remove dissolved nutrients (especially phosphorus and nitrogen from wastewater and runoff), as well as reduce the growth of certain species of phytoplankton, within two days. Vetiver grass has the potential to remove up to 102 tonnes of phosphorus per year per hectare of vetiver planted (Singh, Tripathi, & Singh, 2006).

2.8 Effects of Nutrients on Wildlife

Adapted from the National Guidelines and Standards Office (2004)

2.8.1 Dissolved Phosphates

Phosphorus, despite its toxic nature, rarely poses a threat as a toxin in nature. Phosphorus's indirect effects are often of more concern to aquatic scientists. All plants and algae require phosphorus, which is present in dissolved phosphates, in order to grow. However, high phosphorus levels can increase the plant and algae populations of a freshwater body. Eventually large amounts of organic matter fall to the floor of the lake. This fallen matter is then decomposed by bacteria and other organisms, a process that uses high levels of oxygen. With increased oxygen consumption rates, the gas can be in such short of a supply that fish kills occur. Cyanobacteria, a particular type of algae, grow especially well in increased levels of phosphorus.

High levels of cyanobacteria can result in problems such as, fish kills, foul odors, and contaminated drinking water. Additionally, cyanobacteria can produce toxins that are deadly to wildlife and livestock.

2.8.2 Dissolved Nitrates

The chief nutrient that controls plant growth in the presence of sufficient sunlight is nitrogen. Aquatic plants rapidly consume nitrogen, especially during the warm and sunny days of summer. Although not as important of a growth factor as dissolved phosphates, high levels of dissolved nitrates can increase the plant and algae population of a freshwater body. These population booms have a direct effect on other organisms that live in the water. Quickly growing algae cloud the water, which greatly limits the amount of light that can pass through the water. As with high levels of phosphorous, the oxygen supply of the water is depleted in nitrogen rich waters.

Excessive dissolved nitrate levels can also be very harmful to aquatic wildlife. Many species' survival rates drop sharply in the presence of high dissolved nitrate levels: "Aquatic invertebrates exposed to nitrate may be smaller, slower to mature, or have lower reproductive success" (Canadian Water Quality Guideline, 2004). High dissolved nitrate levels are particularly dangerous to young and growing organisms, specifically amphibians. The loss of biodiversity resulting from this nutrient imbalance not only reduces the natural aesthetic appeal of the lake, but also threatens to upset the balance of the ecosystem.

2.8.3 Dissolved Oxygen

Although here are numerous factors, such as changes in temperature, salinity, pH, and turbidity, that can explain a sudden fish kill in a body of water; low dissolved oxygen levels are typically the chief contributor to fish kills (Ohio Division of Natural Resources, 2010). Some fish are more susceptible to environmental strain at low dissolved oxygen levels than others because of metabolic rates and tolerances. Frequently a small change in environmental conditions can result in increased strain on one species but have no effect on another species. There are many factors that contribute to the amount of oxygen that a body of water can hold, such as the temperature of the water – as the temperature of the water increases, its ability to hold dissolved oxygen decreases. An additional factor which affects the level of dissolved oxygen in water is the quantity of other elements the water is already holding. As the amount of these elements being held by the water increases, the ability of the water to hold dissolved oxygen decreases (Texas Agrilife Extension Service, 2000).

Depending on the season and chemistry of the water, local bodies of water usually contain dissolved oxygen levels that are between zero and thirteen milligrams per liter. Most species of fish flourish in water that contains five milligrams per liter of dissolved oxygen and above. At dissolved oxygen levels lower than five milligrams per liter, some species of fish begin to become stressed and will migrate to areas of higher dissolved oxygen if possible. As the level of dissolved oxygen further decreases, additional organisms are affected negatively. Different species of fish have different particular requirements for dissolved oxygen levels. Below these levels, these species will not consume food, reproduce or survive. The size of the fish also dictates how much dissolved oxygen is required. Smaller fish use more oxygen than larger fish due to higher metabolic rates in smaller fish. Species that are more active need more oxygen than less active fish.

Adaptations of some fish have allowed them to live in water that is continually low in dissolved oxygen. In these conditions, some fish have been able to develop lung-like structures, produce more efficient oxygen carrying blood, and lower their oxygen demands. At dissolved oxygen levels of less than one milligram per liter however the adaptations are useless and they are not able to survive.

Below three milligrams per liter, a majority of fish will be distressed and will not feed (Palm Bay, Florida Department of Public Works). In order to compensate for the low levels of dissolved oxygen, the fish will go through the process of piping where they will come to the surface of the water in order to cover their gills with the small layer of higher dissolved oxygen water at the surface. This process is mostly seen in the early morning when dissolved oxygen levels tend to be at their lowest due to the lack of photosynthesis occurring in the dark. In shallow, confined bodies of water it may be difficult or impossible for the fish to undertake the process of piping and they may die. Additionally, if many consecutive days without sun occur, the fish will die.

A majority of the dissolved oxygen gets into the water by wind mixing at the body's surface and as a result of photosynthesis from aquatic vegetation submerged in the water. This vegetation includes the large grasses, as well as phytoplankton that give color to the water but cannot be seen with the naked eye. This oxygen is then used during the night time mainly by plants and other organisms that require the gas. Oxygen is also used in forming bonds with compounds in the water.

Growth and decay cycles are simultaneously occurring constantly in all ecosystems. Nutrients can enter the body of water from numerous sources. Common sources of nutrients include compounds carried into the water body by water currents and runoff of storm water, sediments, particulates blown into the body, or the effect of the death and decay of organisms in the water (ODNR Division of Wildlife, 2010). A closed body of water may eutrophy quickly if the rate of nutrients entering the system is much higher than the rate that they are removed. As nutrients are introduced into the water, they quickly become chemically incorporated into sediments, other compounds, and into living tissue so that the water remains at equilibrium. However, if this equilibrium is disrupted off due to factors such as wind, cloudy weather or warm temperatures there may be a partial or complete die-off. If the equilibrium moves towards an improvement with regards to environmental requirements such as sunny, windy days, there could be a sudden rapid increase in algae, plants, fish, and other organisms. This equilibrium is continuously being tested by naturally occurring factors. The occurrence and extent of this move away from equilibrium are often increased as a result of the actions of humans. Golf course water traps and stormwater retention ponds, both being manmade, are the most common settings for fish kills. These locations have high levels of nutrients and are not usually intended to support aquatic life. The system is thrown out of equilibrium when a series of consecutive sunny days with windy nights are immediately followed by a series of consecutive cloudy, still days and nights. If suddenly the weather shows an increase in temperatures and there is a thunderstorm carrying more nutrients, the frequency of fish kills will increase. When the rate of photosynthesis is reduced by many consecutive cloudy days, the plants cannot replenish the dissolved oxygen levels of the water. The plants and algae continue to use oxygen as they stay put in the reduced dark cycle of photosynthesis. These algae do not require as much dissolved oxygen than fish require. As a result, the algae deprive the fish of their necessary oxygen. Aeration of the water body can no longer occur without any wind present, and the water can hold less dissolved oxygen because of warm temperatures. Also, the higher temperature waters remove available oxygen from the body of water since the amount of oxygen necessary for chemical reactions to happen increases.

Chemicals introduced to the water body through storm water runoff compete with the fish for the same available dissolved oxygen. Additionally, precipitated solids from the chemicals block the passing of sunlight through the water. In a closed body of water such as a pond, this process may result in eutrophication. However, in open water bodies, die-offs as a result of very low dissolved oxygen are usually only temporary. In an open system it is rarely the case that all the fish are killed by low dissolved oxygen levels. Because the top inch of bodies of water are usually saturated with dissolved oxygen, smaller fish can usually obtain adequate dissolved oxygen from this top layer. Furthermore, individual species tolerance allows some fish to survive. Once the dissolved oxygen levels return to normal in these open systems, fish will migrate back to the area (Palm Bay, Florida Department of Public Works, n.d.).

In examining the mentioned aspects of the body of water, our group was able to create a comprehensive study that examines the feasibility of improving the water quality of Little Indian lake.

2.8.4 pH

According to the Department of Ecology for the State of Washington (2010), the pH of water sample measures the concentration of hydrogen ions. The term pH was derived from the manner in which the hydrogen concentration is calculated by the negative logarithm of the hydrogen ion concentration. Therefore at a higher pH, there are fewer free hydrogen ions, and a change of one pH unit reflects a tenfold change in the concentration of hydrogen ions. For example, there are ten times as many hydrogen ions available at a pH of 7 than at pH of 8. The pH scale ranges from 0 to 14. Solutions with a pH of 7 are neutral, a pH of less than 7 are acidic, and a pH of greater than 7 are basic.

The pH of water determines the solubility, the amount that can be dissolved in the water, and biological availability, the amount that can be utilized by aquatic life, of chemical constituents such as nutrients like phosphorous and nitrogen and heavy metals like lead and copper. For instance, in addition to affecting how much and what form of phosphorous is most abundant in the water, pH also determines whether aquatic life can use it. In regards to heavy metals, the degree to which they are soluble determines their toxicity; metals are more soluble and hence toxic at a lower pH.

Natural variations in pH occur due to photosynthesis. Since hydrogen molecules are used in this process when plants convert light into energy, this causes the concentration of hydrogen ions to decrease and therefore the pH to increase. For this reason, pH may be higher during daylight hours and during the growing season, when photosynthesis is at a maximum. Water bodies are also capable of buffering and controlling major pH changes. Although the pH scale goes from 0-14, the pH of natural water is generally around 6.5-8.5.

Values for pH are reported in standard pH units, usually to one or two decimal places depending upon the accuracy of the equipment used. Since pH represents the negative logarithm of a number, it is not mathematically correct to calculate simple averages or other summary statistic; instead it should be a median or range of values.

3. METHODOLOGY

3.1 Aquatic Plant Survey

The following was adapted from *Mapping Aquatic Plants in Lakes and Ponds* manual by Rick McVoy (2006) from the Department of Environmental Protection of Worcester Watershed Management.

3.1.1 Introduction

The objective of conducting the aquatic plant life survey was to gain a greater understanding of current ecological environment of Little Indian Lake. One of the main concerns expressed by the ILWA was the lack of preliminary knowledge of the nuisance aquatic plants that have been problematic to the natural and inhabiting community. It has been recognized that prolonged algal management and chemical treatment is not a feasible and sustainable method of managing the issue. Therefore by thoroughly assessing the plant life more effective and beneficial solutions were created.

3.1.2 Mapping Location of Aquatic Plants

In order to map the location of the aquatic plants, a tour of the lake shoreline was conducted to observe areas of the lake where aquatic vegetation was present, whether below, near or at the surface. The row boat moved slowly around the designated shoreline area and a sketch was drawn to illustrate the extent of the vegetation beds. It was also noted if plants were near the surface (submerged), at the surface (floating), or penetrating the surface (emergent).The length and width of the beds were estimated as well.

For any significant plant beds an estimation of the areal coverage of the plants as either sparse (0-25% cover), moderate (>25-50% cover), dense (>50-75% cover), or very dense (>75-100% cover) was also observed. Cover was determined by imagining that all of the vegetation in the water column, at any given site, was projected to the surface and then approximating what percentage of the surface would be covered with vegetation. Areas of differing coverage were denoted on the map with different symbols, the more symbols drawn showed the more prevalent that plant species was.

A series of planned observation sites were designated on the map prior to entering the lake and a record of which species (or type) of plants occur most commonly within the lake were also kept. Poles were on placed on opposite sides of the lake and fishing line was used to connect them; there were seven transverses made spanning the horizontal length of the lake, line one was closest to MA-122A towards the most north end of the lake, where as line seven was located at the most southern point of the lake towards Forest Street. Various transects were created by tying orange fluorescent road tape and sectioning points along the line. In total thirty-seven sites were marked at fairly uniform intervals throughout the lake, which accounted for both shallow and deeper plant beds to get a representative sampling. During the course of the shoreline survey, stops were made at each of these sites and observations were recorded on the "Aquatic Macrophyte Observation Tally Sheet" (see Figure 3.3) to identify the species (or type) located at that site. The frequency of occurrence for each plant species was also calculated for each site.

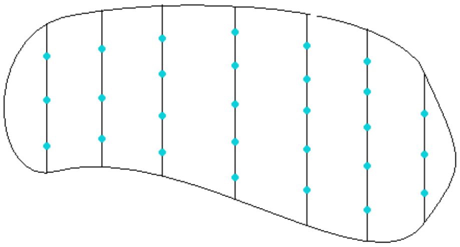


Figure 3.1: Little Indian Lake divided into individual sections by transverses (data collection points shown).

3.1.3 Collecting Aquatic Plant Samples

The same approach of sectioning the lake into collection sites for mapping the aquatic life was used in collecting the aquatic plant samples. The lake was sectioned horizontally from shore to shore and then divided into individual areas where samples were collected (Figure 3.1).

A row boat was used to access the individual sections along the divided areas. By anchoring at the appropriate site, samples were collected at each point by dropping a weed weasel at different angles around that point for 90°, 180°, 270°, and 360°. A weed weasel is a home-made contraption in which rope is attached to the end of a rake, and was utilized to collect samples from the bottom of the lake floor (Fig. 3.2). When collecting, the weed weasel was allowed to settle to the lake bottom and the line was then pulled up so that the teeth of the rake dragged along the bottom of the lake. The weed weasel was then raised out of the water with plant samples and brought into the boat. All the vegetation trapped on the teeth was put into separate piles, so that they were identified as Plant Type #1, #2, #3, etc. On the data sheet (Figure 3.4) the approximate percentage of each plant type found was marked as well as the rate of recovery for each plant type. The raking procedure was repeated at the different positions for the three other positions (90°, 180°, and 270°) at the collection site. Once these observations were recorded a few healthy specimens from each of the sorted piles of plant types were removed and placed in a properly labeled collection bag for identification on shore. Immature plants were avoided and if possible entire plant specimens, including stems, leaves, roots, flowers and/or fruits, were preserved

Figure 3.2: Weed Weasel (Massachusetts Water Watch Partnership, 2006)

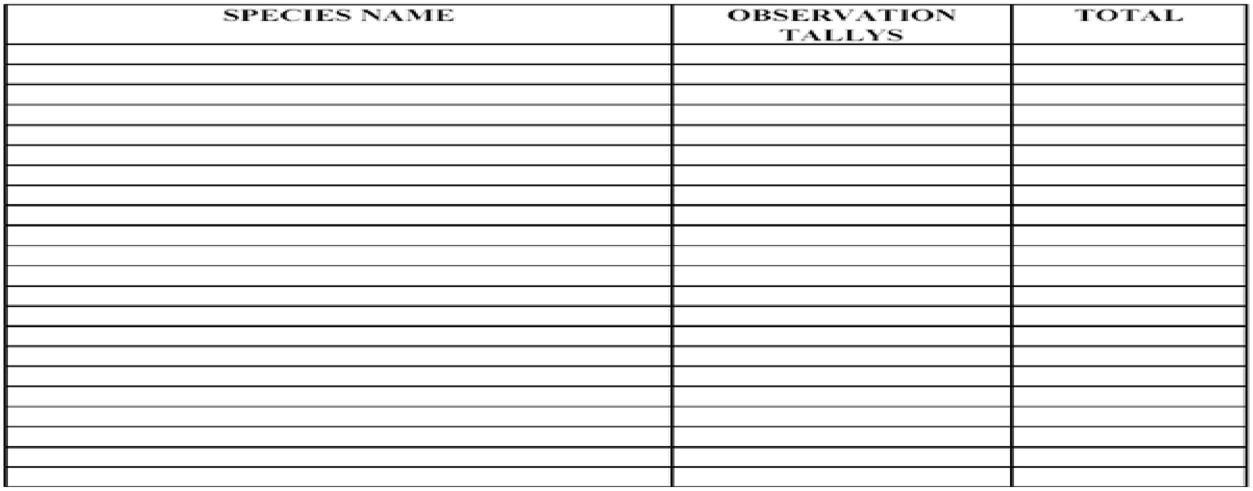
The boat then moved along the transect line to the next sampling point and the colleting procedure was repeated. The total number of sampling points was predetermined. Care was taken when collecting plant samples for proper disposal on land, since many nuisance species reproduce from fragments.

3.1.4 Identification of Samples

Once the samples were obtained they were preserved and taken on shore for examination and data collecting. After returning to shore, each specimen was removed from the collection bag, and carefully wrapped in several layers of newspaper for preservation. The wrapped specimen was then submerged in water, returned to a properly marked collection bag, and sealed securely. The bag was refrigerated in the interim when examining. *A Guide to Aquatic Plants in Massachusetts* (1999) was the main resource used when classifying samples.

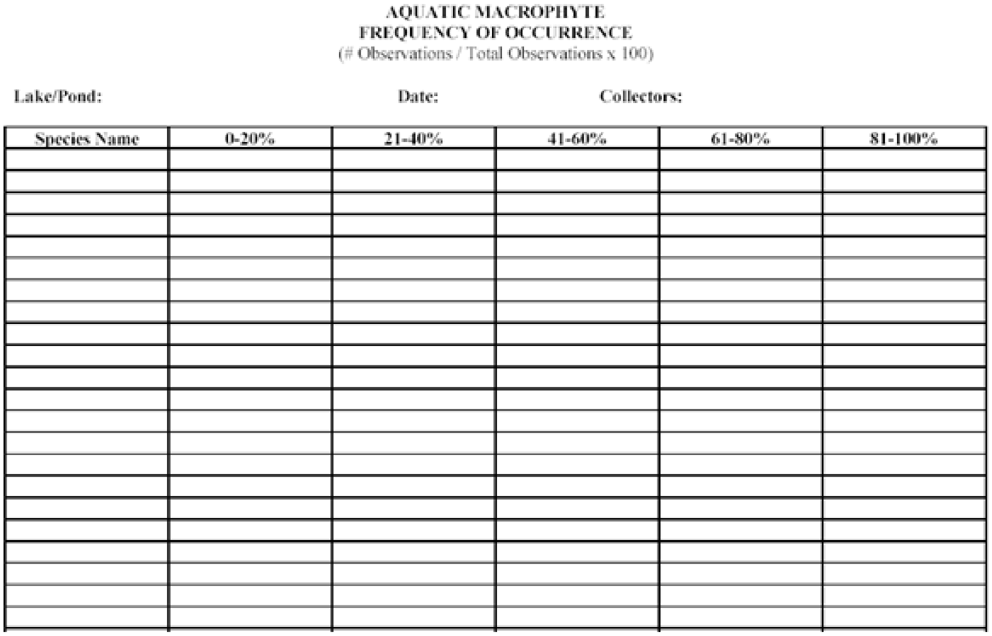
AQUATIC MACROPHYTE
OBSERVATION TALLY SHEET

LAKE/POND: ____
DATE:______________
COLLECTORS:____
TOTAL OBSERVATIONS:____



SPECIES NAME	OBSERVATION TALLYS	TOTAL

Figure 3.3: Observation Form



AQUATIC MACROPHYTE
FREQUENCY OF OCCURRENCE
(# Observations / Total Observations x 100)

Lake/Pond: **Date:** **Collectors:**

Species Name	0-20%	21-40%	41-60%	61-80%	81-100%

Figure 3.4: Aquatic Plant Frequency Form

3.2 Wildlife Survey

We attempted to use electro-fishing to quickly collect a large number of fish for identification. Electro-fishing is the act of sending an electric current through the lake, therefore forcing the fish to involuntarily swim toward the source of electricity where a net can then be used to collect large amounts of fish. This technique, although it may seem inhumane, is legal and is used frequently in fish surveys. Electro-fishing requires specific materials, all of which were easily attained. A portable power supply, a net, and a holding tank for the fish that had been caught were all the materials needed. Two cables running from the positive and negative terminals of the power supply were inserted into the water at the shore line. The power supply was cranked in order to produce a current in the water. We then waited with a net until the fish surfaced toward the current; this process was done while on the boat. This procedure was repeated in several sections of the coastline, which had been predetermined and marked on a map. In identifying the type of species present in the lake, our group was able to use the data collected as an indicator of the quality of the water and the lake's overall health.

In order to identify any other wildlife, photographs were taken from the row boat. Once the photographs were taken, a wild life identification book such as the "Collins Field Guide" was used in order to identify the species.

3.3 Storm Drains/Culvert

Through analysis of the problems that exist with the storm drains and culvert between Indian and Little Indian Lake, our group attempted to advise the feasibility of repairing these aspects of the body of water. Once the issues were identified through observations from the boat, our group contacted Beth Proko to obtain a map of the storm drains and culverts to see where they were located. Our group then attempted to contact Dave Harris with the City of Worcester to get an estimate of the cost of repairing the drains. Additionally, we hoped that Dave would be able to provide our group with a contact name from the State of Massachusetts for the culvert located under the state road of Route 122A. Unfortunately, we were unable to obtain estimates for repairing the drains and culvert.

3.4 Bathymetric Survey

Because of limited funding, the bathymetric survey of Little Indian Lake was conducted manually. The lake was divided into seven sections by a series of transverses (see Figure 3.1 pp. 27). Depth data was collected at specified intervals along each transverse by lowering a wooden cylinder which had inch markings along its length. Although this method of surveying Little Indian Lake did not generate results as accurate as those gathered from an electronic depth finder, it allowed us to generate a rough image of the floor of the lake.

3.5 Water Quality Testing

A water sample was collected from a couple of points along a few transverse. Our collection was incomplete because ice settled on the lake before we could take samples on the different transverses. This water was tested in lab to determine the pH and the concentrations of dissolved phosphate, nitrate, and oxygen. Many of these tests involved the use of a colorimeter, a device which assays the concentration of a known solute in a solution based on the color of the solution.

3.5.1 Dissolved Phosphates

To determine the concentration of the phosphates in the water, a clean colorimeter tube was rinsed and then filled with a 10 mL of sample water. The tube was then inserted into the colorimeter and the “ON/OFF” button was pressed. The test for phosphate concentration was then selected to calibrate the colorimeter. Afterwards, the tube was then removed and 0.1 mL of the included Phosphate Reducing Reagent (V-6283) was added, and then the tube was shaken until the reagent was thoroughly dissolved. Five minutes was required for full development of the solution. The tube was then reinserted into the colorimeter and the test for phosphate concentration was allowed to run again. The concentration of phosphates in the water (in parts per million) appeared on the device display.

3.5.2 Dissolved Nitrates

To determine the concentration of the nitrates in the water we rinsed and filled a clean colorimeter tube with 10 mL of sample water. We then inserted the test tube into colorimeter and pressed the “ON/OFF” button. Next we selected the test for nitrate concentration and calibrated the colorimeter. We then removed the tube and using a graduated cylinder discarded 5 mL of the sample. The remaining 5 mL of sample was returned to the test tube and then we added 5 mL of the included Mixing Acid Reagent (V-6278). We proceeded to cap the test tube and mixed the contents for 2 minutes. Then, using the 0.1 g spoon included in the kit, we added two measures of the included Nitrate Reducing Reagent (V-6279). To thoroughly mix this solution we held the test tube by index finger and thumb and mixed by inverting the test tube approximately 50-60 times for 4 minutes. Ten minutes was required for development. We then cleaned any fingerprints off of the test tube and wiped the tube dry. With the sample fully prepared, we placed the test tube in the colorimeter and ran the test for nitrate concentration. The concentration of nitrates in the water (in parts per million) appeared on the device display.

3.5.3 Dissolved Oxygen

The dissolved oxygen levels present in the lake were determined using the LaMotte SMART 2 colorimeter according to the manufacturer's instructions. This test was run in triplicate. All dissolved oxygen values were recorded.

3.5.4 pH

To determine the pH of the lake water various water samples were from one point on a transect; once again ice did not permit us to collect more samples or see if there are variations of pH levels within Little Indian. 50 mL conical tubes were needed to collect the water and then taken to the lab to be tested using a pH probe and pre-prepared buffer solutions. Once in the lab, the probe was calibrated by using different buffer solutions that had set pHs. The probe was then rinsed, placed into the sample, allowed to equilibrate, and the reading was recorded. These steps were repeated for the other water samples as well.

4. RESULTS

4.1 Aquatic Plant Life

An aquatic plant life survey was conducted by first outlining the lake with transverses and transects. Percent recovery and a density rating for each algae/plant species recovered were noted. A percent recovery rate was based on a scale of 1-100%, 1% indicated that there was minimal amount of recovery on the rake where as 100% indicated that the rake's teeth were completely filled with the algae/plant. A density rating of 1 signifies that there was a minimal amount of the algae/plant species seen where as a rating 5 signifies that there was an abundant amount. The aquatic plant survey was conducted during the week of November 16, 2009. Since there were many places with limited or no algae/plant species, this part of the project was completed fairly quickly. Only two pond lilies and two types of algae, *Nitella spp.* and filamentous algae were observed. A thorough outline of the lake and the locations of where the different algae were are shown below.

Line #, Transect #	Plant Type	12 o’clock position % Recovery	3 o’clock position % Recovery	6 o’clock position % Recovery	9 o’clock position % Recovery	Density Rating (1-5)
1,1	-	-	-	-	-	-
1,2	*Nitella spp.*	-	10%	-	5%	1
1,3	-	-	-	-	-	-
1,4	*Nitella spp.*	10%	20%	20%	10%	4
1,5	*Nitella spp.*	10%	5%	10%	10%	3
1,6	*Nitella spp.*	20%	35%	25%	20%	4
1,7	*Nitella spp.*	5%	10%	5%	5%	2
2,1	*Nitella spp.*	2%	-	1%	-	<1
2.2	-	-	-	-	-	-
2,3	-	-	-	-	-	-
2,4	-	-	-	-	-	-
2,5	*Nitella spp.*	2%	-	2%	2%	<1
3,1	-	-	-	-	-	-
3,2	-	-	-	-	-	-
3,3	-	-	-	-	-	-
3,4	*Nitella spp.*	1%	3%	-	1%	<1
3,5	-	-	-	-	-	-
3,6	-	-	-	-	-	-
4,1	-	-	-	-	-	-
4,2	-	-	-	-	-	-
4,4	-	-	-	-	-	-
4,5	-	-	-	-	-	-
5,1	Filamentous Algae and *Nitella spp.*	5%	2%	2%	5%	1
5,2	Filamentous Algae and *Nitella spp.*	30%	40%	40%	50%	4
5,3	-	-	-	-	-	-
5,4	-	-	-	-	-	-
5,5	Filamentous Algae	30%	35%	20%	30%	3
6,1	Filamentous Algae	40%	45%	40%	45%	4
6,2	Filamentous Algae	45%	50%	50%	45%	4/5
6,3	Filamentous Algae and *Nitella spp.*	40%	40%	40%	40%	4
6,4	Filamentous Algae and *Nitella spp.*	35%	40%	40%	35%	3/4
6,5	Filamentous Algae	30%	25%	35%	30%	3
7,1	Filamentous Algae	60%	70%	65%	70%	5
7,2	Filamentous Algae	50%	60%	55%	65%	5
7,3	Filamentous Algae and *Nitella spp.*	45%	50%	40%	50%	4
7,4	Filamentous Algae	45%	40%	45%	40%	4

Table 4.1: Aquatic Plant Life Distribution

4.2 Shoreline Sketch

On November 9, 2009, a shoreline sketch was performed on the first boat outing. An outline was drawn of the shore and notes were collected on plant life and their prevalence while on the tour. *Nitella spp*. was the first algae species found which is indicated by the green dashed line. This algae predominated greatly along a majority of the coast of the lake and more so towards the north end of the lake that is near MA 112A. Filamentous algae was also collected and observed, which was mainly localized towards the south end of the lake and the lower end of Forest Street. Two floating plants, duckweed and watermeal, indicated by the dark and light green circles, were also seen and their presence was fairly consistent around the entire shore. Also, two pond yellow pond lilies, indicated by the yellow circles, were found towards the south end of the lake and the lower end of Forest Street.

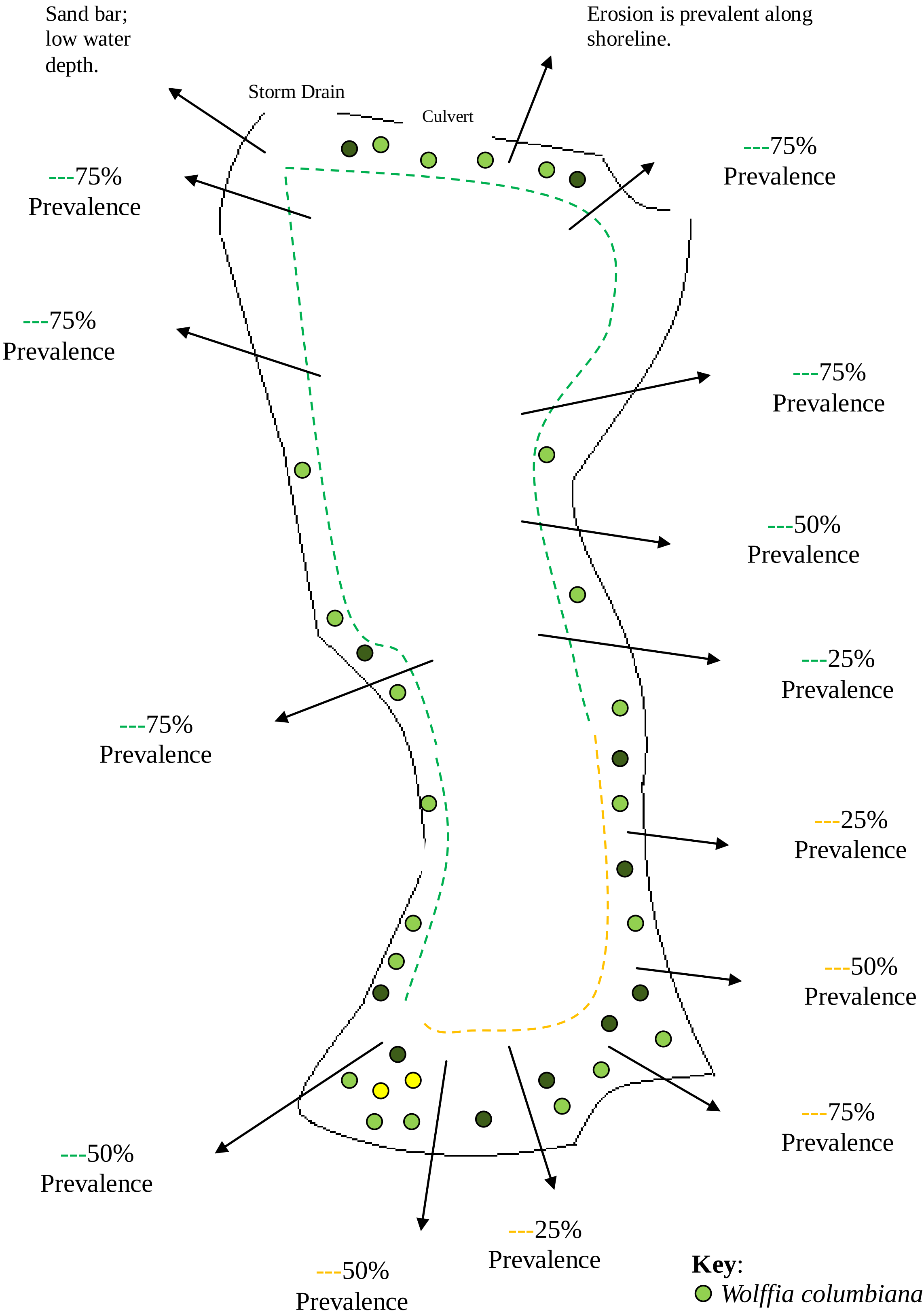


Figure 4.1: Shoreline Sketch

Key:
🟢 *Wolffia columbiana*, Watermeal
● *Lemna gibba*, Duckweed.
🟡 *Nuphar variagatum*, Yellow Pond Lily
------ *Nitella spp.*
------ Filamentous Algae

Shoreline Sketch Conducted on
November 09, 2009

4.3 Water Quality

4.3.1 Dissolved Phosphates

Trial	Phosphate Concentration (ppm)
1	0.15
2	0.21
3	0.20

Table 4.2: Dissolved Phosphate Concentration

These values represent the concentration of dissolved phosphates within the lake. Because of their link to eutrophication and algal blooms, dissolved phosphate levels are a serious concern of this study of Little Indian Lake. However, our investigation has demonstrated that current dissolved phosphate levels are well within acceptable limits, scoring between a 91 and 94 on the water quality index (Calculating NSF Water Quality Index, 2009).

4.3.2 Dissolved Nitrates

Trial	Nitrate Concentration (ppm)
1	0.25
2	0.29

Table 4.3: Dissolved Nitrate Concentration

These values represent the concentration of dissolved nitrates within the lake. Although Dr. Schindler's work showed that algal blooms and eutrophication depend heavily on dissolved phosphates, not dissolved nitrates, dissolved nitrates still pose a threat to the health of the lake -- specifically they threaten developing organisms. Similar to the case of dissolved phosphates, the level of dissolved nitrates in Little Indian Lake is acceptable, scoring a 97 on the NSF water quality index.

4.3.3 Dissolved Oxygen

Trial	Dissolved Oxygen Concentration (ppm)
1	9.2
2	9.2
3	8.9
4	9.1

Table 4.4: Dissolved Oxygen Concentration

4.3.4 pH

Trial	pH
1	7.3
2	7.2
3	7.2

Table 4.5: Lake pH

Unfortunately, only one water sample was collected to perform the pH test, since ice covered the lake before more samples could be collected. Based on this sample, three pH tests were performed to acquire an accurate reading. The lake was found to have a physiologic pH of around 7.2, showing that the water quality is not basic or acidic, but neutral. This also possibly indicates that at the time there were no chemical imbalances that would show a dramatic pH.

4.4 Bathymetric Survey

The depth data we gathered is summarized in Table 4.2. This data shows that the lake's floor is fairly regular, deepening as one moves towards the center and shallowing as one approaches the shoreline.

				Point Along Transverse			
		1	2	3	4	5	6
	1	---	-2.0	-2.1	-2.8	-2.3	-2.1
	2	---	-1.5	-2.5	-3.1	-2.4	-1.8
Transverse	3	---	-1.7	-3.6	-3	-2.4	-1.9
	4	---	-1.8	-3.5	-3.8	-2.5	-2.1
	5	---	-2.6	-3.4	-3.2	-2.4	-2.3
	6	-2.3	-2.4	-2.6	-2.6	-2.4	-2.0
	7	---	-2.1	-1.9	-2.0	-1.8	-2.3

Table 4.6: Depth Measurements

This data is presented in graphical form below in Figure 4.1.

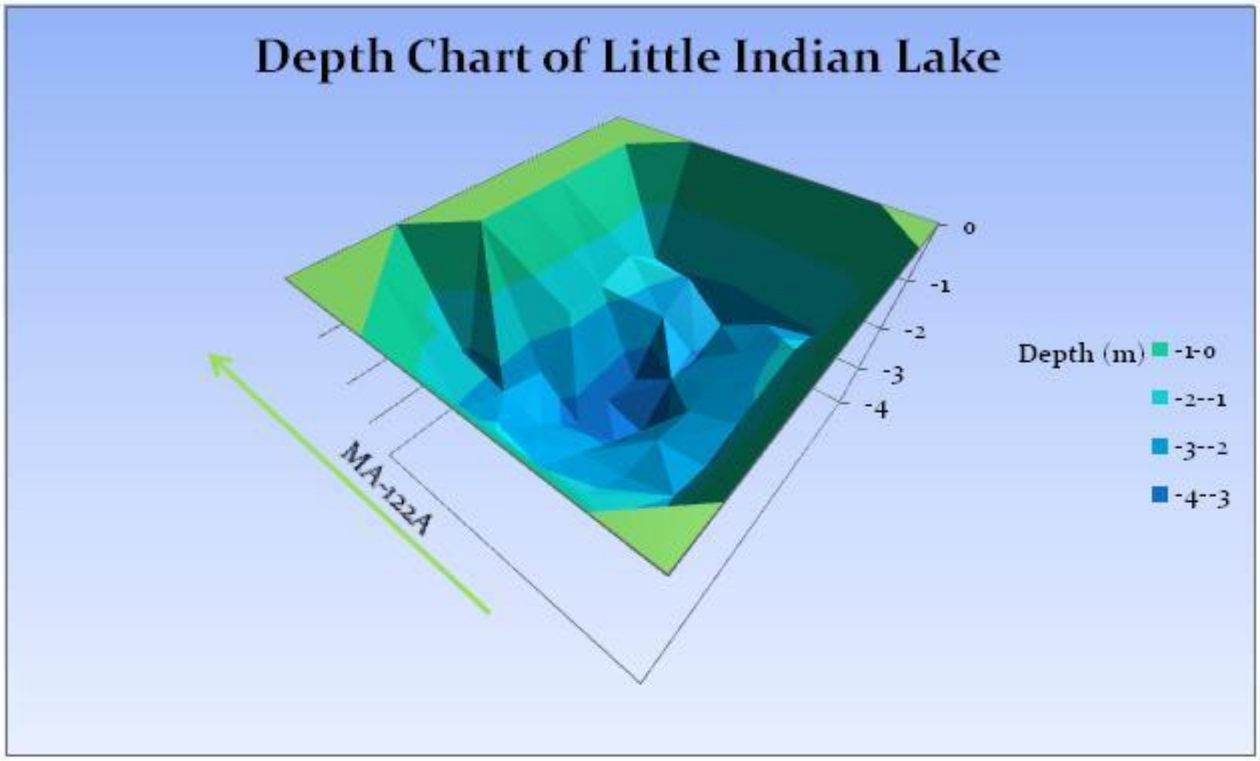


Figure 4.2: Depth Graph of Little Indian Lake

4.5 Wildlife

After the fishing process had been completed, there were no fish caught and there were no fish or reptiles observed from what we could see from the boat. There were, however, two species of birds observed and classified while we were on the lake. Blue herons (Figure 4.3) were identified at the southern end of the lake. Additionally, mallard ducks (Figure 4.4) were identified at the southern end of the lake.

Figure 4.3: Blue Heron[1]

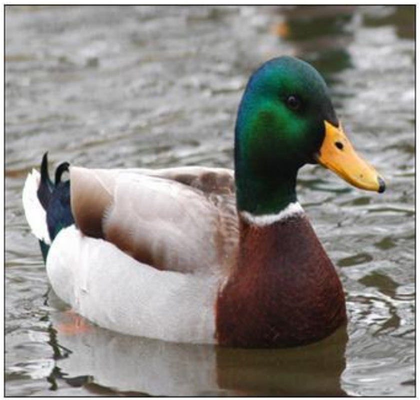


Figure 4.4: Mallard Duck[2]

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[1] Picture taken from: http://api.ning.com/files/rceLnAKn5My2XjnchvTa*beT41PAs3kTqd44thOTQLTdkwmwCcOGx3d8s-odx65fHXZotZb3XqqtLelzSfQbrdgtBYai0QeG/greatblueheron.jpg

[2] Picture taken from: http://www.laketemplene.org/images/mallard_duck.jpg

4.6 Storm Drains/Culvert

The following map, which shows the storm drains around the Little Indian Lake area and the culvert (shown as a black bar between the two bodies of water) that goes under Route MA122A that connects Indian Lake with Little Indian Lake, was obtained from Beth Proko. The biggest concern is the position and condition of the culvert that is present between the two lakes. Both the culvert and storm drains are filled with debris. Additionally, the opening to the culvert on Indian Lake is at a higher position above sea level than the opening of the culvert on Little Indian Lake. As a result of both issue, water cannot flow between Little Indian Lake and Indian Lake.

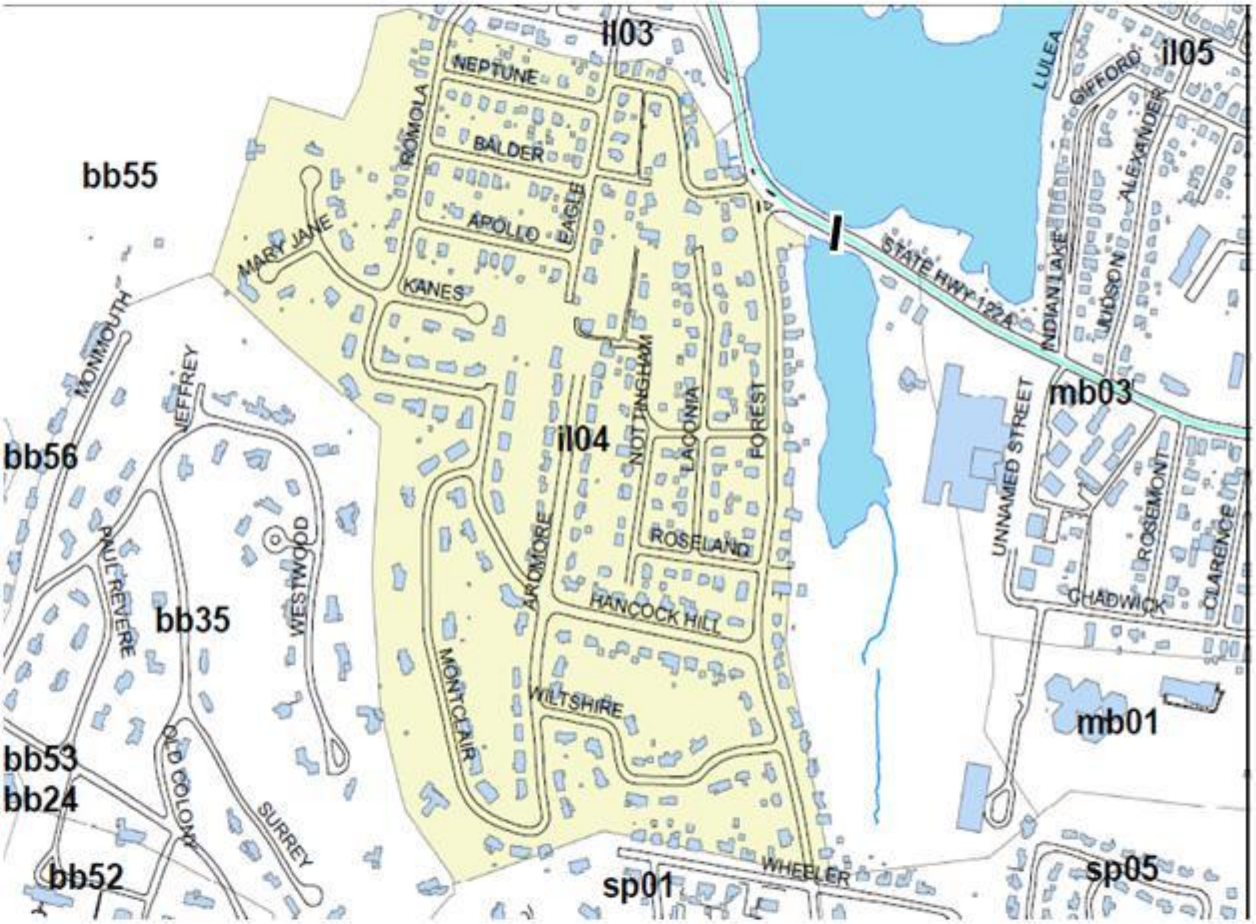

Figure 4.5: Storm Drain Map

5. DISCUSSIONS AND IMPLICATIONS

5.1 Aquatic Plant Life

Duckweed, watermeal, and yellow pond lilies were the only aquatic plants found while performing the shore line sketch. Unfortunately, when the aquatic plant survey was conducted a week later, the yellow pond lilies were not seen again. Duckweed (*Lemna spp.)* can range from 1-5 millimeter in size and watermeal *(Wolffia spp.)* is less than 1 millimeter and during the aquatic plant survey, since we were mainly observing larger algae/plant species that could be collected by the rake, we did not closely examine if these two plants were present in the samples ("Common duckweed (Limna gibba)," 2009; Texas AgriLife Extension Service, 2010c).

Duckweed and watermeal are free floating plants; duckweed has a root from 1-15mm in length where as watermeal is rootless and also the smallest flowering plant in the world ("Common duckweed (Limna gibba)," 2009; Lembi, 2002; Texas AgriLife Extension Service, 2010c). A single duckweed plant can be 1/8th to 1/4th inch in diameter with a single root extending from below the green little pad to obtain nutrients (Lembi, 2002; Lynch, 2010). Watermeal is significantly smaller than duckweed and tends to resemble small little seeds that are gritty to the feel and approximately 1/16th of an inch in width with no root (Lembi, 2002).

Duckweed is a valuable food resource for waterfowl and fish and can also help to some extent control algae growth. It has also been attributed to being a natural water purifier and has been used in treating sewage and is capable of blocking sunlight and out competing algae (Hussey, 2010). Although there are benefits to having duckweed in moderation, it also capable of negatively affecting the lake if given the ability thrive.

Watermeal tends to grow in dense populations on undisturbed water surfaces and can be associated with colonies of duckweed (Texas AgriLife Extension Service, 2010c). Duckweed and watermeal are aggressive invaders of ponds and lakes and are capable of completely covering the surface of a lake/pond (Texas AgriLife Extension Service, 2010c). This can prevent sunlight from reaching the deeper parts of water column, so that underwater plants and algae cannot photosynthesize and produce oxygen (Lembi, 2009). In turn, this can affect the wildlife and more importantly the fish population, since a lack of oxygen in the water can cause stress to them and prolonged conditions can lead to death or decrease in fish quantity over time.

Both duckweed and watermeal are typically found in quiet, nutrient rich wetlands or ponds and tend to aggregate around the shoreline or edges of the water body (Lembi, 2002; Lynch, 2010a). Both of these plants require high levels of nutrients to "bud" or reproduce profusely and thus, are indicators of lakes/ponds receiving excessive nutrients (Lynch, 2010). Lakes and ponds that are located near woodlots are more susceptible to duckweed and watermeal because of the rich, organic sources available by the tree leaves (Lynch, 2010). The sediment at the bottom of the infested water is best described by having a smelly, black ooze that is a result of decomposing organic matter, which is another nutrient source for the plants (Lynch, 2010). Therefore older bodies of water tend to experience more frequent cases of infestations because of the excessive build-up of organic matter at the bottom. Through this study it was found that both of these conditions exists at Little Indian and preventative measures can be taken to reduce these plants from flourishing.

According to Lynch (2010), an Ohio State University Extension Program Specialist, prevention is the key to eliminating the need for costly, annual measures to eliminate a nuisance duckweed and watermeal problem. He proposes two strategies that involve nutrient reduction and aeration.

- Nutrient Reduction: Unwanted nutrient inputs can lead to explosive duckweed and watermeal growth. Lawn fertilizer, agriculture field run-off, inefficient septic systems, and drainage from domesticated animal feedlots all contribute to increasing the organic nutrient levels in water bodies. Additionally, large amounts of leaves during the fall season can lead to problems as well. Therefore buttering properties on Little Indian should be cautious when cleaning their lawns and avoid contributing more to the natural eutrophication process of the lake. Limiting these nutrient inputs can eliminate or reduce the duckweed/watermeal presence, but it may take several years for total prevention to occur in older water bodies with a thick accumulation of black bottom sediments like Little Indian.
- Bubble Aeration: Stratification is a major cause of why black bottom sediments are produced in lakes/ponds and this is normally accompanied by a lack of oxygen in deeper waters. Thermal stratification is the result of temperature gradients that are created in the water, which causes warmer water to float on top of the cooler and more dense, colder water (Coke, 2008). As a result, the lower, cooler portion of the lake can become devoid of oxygen and is unable to process and break down waste at the lake bottom, producing an anoxic environment potentially filled with toxic gases and poor water (Coke, 2008; United States Department of Energy, 1997). By itself this is not a problem, but in the spring and fall when a turn over occurs because the temperature becomes the same from the surface down to the deepest area of the pond, this causes the water that was once in different temperature gradients to mix (Comer, Lynch, & Norland, 2010). Foul odors emitted from the lake are a result of hydrogen sulfide from the bottom being released and a buildup of partially decomposed organic material causes the color of the sediment to

become black (Coke, 2008; Lynch, 2010). The process of turning over in a body of water can lead to a decrease in the water life population especially in fish, since oxygen depletion occurs and the healthy water column that the fish normally live in is now contaminated with toxins from the lake bottom (Coke, 2008). Bubble aeration is a solution that sets up a circulation path that prevents stratification and inhibits the formation of black sediment. This requires the use of a compressor on shore that blows air through a plastic tube to a diffuser located near the bottom in the deepest area of the lake. The bubbles leaving the diffuser hydrologically lift the bottom waters to the surface allowing the nutrients to be dispersed better, which reduces the amount of decomposed matter along the bottom and resulting in less duckweed and watermeal. "To manage internal recycling, the water body should receive 24-hour diffused aeration year round" (Hussey, 2010). Although this is a costly endeavor, the ILWA could continue their relationship with WPI and offer another project related to the feasibility of having an aeration system or sponsor a MQP to create a sustainable and cost efficient aeration device for Little Indian.

Manual, biological, and chemical treatments can be pursued as well to control the duckweed and watermeal population (Lynch, 2010). Duckweed and watermeal can be physically extracted by seining or various netting techniques. But any of the plants collected must be properly disposed to ensure that they do not spread to other water bodies. Dredging efforts could also decrease the amount of nutrient supply by taking out sediment, but this would be a costly investment for the ILWA because of Little Indian Lake's size.

Grass carp and koi are suggested herbaceous fishes that feed on duckweed and watermeal. Carp tend to eat the larger plants available and then move to less favorable and smaller options like duckweed and water meal, so this may not be an ideal solution. Unfortunately, it is prohibited to have both of these fish introduced or present in Massachusetts' waters, so this will not be a feasible option unless the law changes (Massachusetts Division of Fisheries and Wildlife, 2010).

Duckweed and watermeal can also be treated with chemical herbicides, although watermeal is much harder to control than duckweed. Chemical treatment is most effective when used early and when the first signs of an infestation appear. Chemical treatments have been used in the past by the ILWA with successful results, but costs and prolonged use of chemical treatment can adversely affect the environment as well and other methods should be considered as well.

- Fluridone: Fluridone, which is sold as Sonar® or Avast!®, is a systemic herbicide that causes a slow degradation of photosynthetic activity in plants. It can take up to 30-90 days for a complete kill, but noticeable yellowing, chlorosis, of treated plants can occur within 14-21 days. It is by far the best herbicide available for eliminating watermeal. Two advantages of fluridone products are that (1) control often lasts for several growing seasons and the (2) slow killing of duckweeds and watermeal greatly reduces the chance of a fish kill caused by excessive decaying vegetation. General recommended application rate is 1.5 quarts per surface acre if average depth exceeds 5 feet. Best control is attained by treating with half the recommended rate initially, followed by the other half 10-14 days later. Fluridone is not appropriate for spot treatments of duckweeds and watermeal and can only be used in lakes/ponds where water outflow will be zero or very minimal for 30 days. (Paragraph 15)

- Diquat: Diquat is a contact herbicide that immediately causes exposed plant tissues to turn brown and die, with noticeable results within several days. Commonly available diquat products are Reward and Weedtrine-D. Diquat is effective in eliminating duckweeds, but is far less effective in killing watermeal. The general recommended application rate is one gallon per surface acre. It should be mixed with water at a 50:1 ratio and finely sprayed on top of the floating duckweeds. Effectiveness is greatly enhanced by adding nonionic surfactant to the mixture prior to application. Diquat allows for spot treatments of duckweeds, which can be an advantage both in cost and in prevention of fish kills. It is also recommended that application be done when duckweeds have collected along one side of the pond. Finally, multiple applications about two weeks apart are typically needed to fully eliminate duckweeds. Survivors of the initial treatment can quickly reproduce and become a problem once more. (Paragraph 16)

  -Chelated Copper: Copper compounds by themselves do not eliminate duckweeds and watermeal. However, combining chelated copper with diquat increases the effectiveness of diquat as a control measure. The copper slightly weakens the plant, allowing the diquat to be more lethal inside of it. The general recommendation is to mix one part chelated copper to two parts of a diquat product. Common chelated copper algaecides include Cutrine Plus, AlgaePro, and Clearigate. (Paragraph 17)

5.2 Algae

Two types of algae were found in Little Indian during the aquatic plant life survey: *Nitella spp.* and filamentous algae. Below is an outline on the characteristics of the algae, their affects on the lake, and solutions that can be implemented by the ILWA.

5.2.1 Nitella spp.

According to the Texas A&M University Department of Wildlife and Fisheries Sciences (2010b), stone warts are branched multicellular algae that resemble submerged flowering plants because they do not extend above the water surface; the main difference is that stonewarts do not have flowers. This algae is odorless and soft to the touch, unlike Chara that belongs to the same algae species and tends to feel gritty because of lime from hard water that tends to coat it (Washington State Department of Ecology, 2010). Their color can range from light to dark green with forked, bushy branches that are about 1/16 to 1/8 inches in diameter; they do not have true branches. They also have holdfasts which act as roots that stabilize them to the lake floor. Like many submerged portions of all aquatic plants, they help provide habitats for many micro and macro invertebrates. These invertebrates continue the food chain cycle and are sustenance for other wild life animals like amphibians, reptiles, and ducks. *Nitealla spp.* was found more toward the northern end of Little Indian near MA 112A and in various locations in conjunction with the filamentous algae towards the south end near Forest Street. Since there was a clear division in the lake of where the two algae were growing, it is possible that nutrient levels vary within the water and allow certain species to grow better than others.

5.2.2 Filamentous Algae

According to the Texas A&M University Department of Wildlife and Fisheries Sciences (2010a), filamentous algae are single algae cells that form long visible green chains, threads, or filaments. Filamentous algae start growing at the bottom of shallow water and can float or surface to form mats, which are referred to commonly as "pond scum." As it grows, algae produce oxygen that becomes entrapped by the dense mat and this provides the buoyancy it needs to rise to the surface where it covers large areas of lakes and ponds (Lynch, 2009). Its abundance is dependent upon nutrient levels, particularly phosphorous, in the water (Lynch, 2009). High nutrient levels generally elevate the amount of algae present. Lynch (2010), an Ohio State University Extension Program Specialist, says that there are many species of filamentous algae and normally microscopic examination is required for proper identification. However, the more common ones can be distinguished by their texture. *Spinogyra* is bright green and slimy to touch; *Cladophora* has a cottony feel; and *Pithophera* is often referred to as "horse hair" algae because its course textures resembles that of horse hair. There are many species of filamentous algae and more than one can be present at one time in a lake. They share the same ecological role as *Nitella spp.* with micro and macro invertebrates. An abundance of *Spinogyra* was found mainly along the south end of the Little Indian Lake and was characterized by its appearance and slimy exterior. As mentioned earlier, high nutrient levels in the water could be the reason for its presence and since increased phosphorous levels encourage filamentous algae growth, this nutrient may be at a higher level in this part of the lake.

Solutions for both these algae types fall under the same methods proposed for the nuisance aquatic plant species. Two new treatment options are expanded upon below.

5.2.3 LG Sonic® (LG Sound, 2010)

LG Sonic® is an algae control device that transmits sound pulses into the water at very high pressures that can break down the cell walls in algae. The sound waves have different frequencies, but all lie in the ultrasound range and are thus inaudible as well as harmless to animals in the water. Sound pulses are generated within a power box and can create several frequencies simultaneously to send to the transducer, which would be in the water; LG Sonic® is the only product that utilizes multiple frequencies to effectively inhibit several different species of algae instead of targeting just one. It is capable of affecting an area of about 500ft in front of where the transducer is placed and is especially designed so that the transmitted sound waves are not hindered by the area of contact between the transducer and the water. This lengthens the range of the waves as well as the lifespan of the product itself. Fortunately, plant cells and algae cells differ structurally, so the ultrasonic waves do not affect the other aquatic plant life. This product is one of the best environmental practices available for algae control and is an alternative for the ILWA instead of using chemicals.

5.2.4 NT-MAX Biological Digester Treatment (NewTechBio, 2010)

NT-MAX Biological Digester Treatment utilizes bacterial colonies that quickly multiply to digest the nutrients and heavy sludge buildup on lake bottoms, shorelines, decks, docks, and ornamentals. Solids are broken down and digested by the bacteria, and the byproducts that result are water and carbon dioxide, while nutrients composed of dead algae, duckweed, and other lake/pond weeds are eliminated. Sludge and decaying organics are consumed and the odor that is normally associated with it disappears. NT-MAX multiplies rapidly while aggressively digesting up to 1,000 pounds of organic matter in a twenty-four hour period and assists in neutralizing the adverse chemicals effects that have upset the water's ecosystem. Water quality can be restored, while powerful bacterial strains digest the nutrient sources that are related to troublesome water conditions. NewTechBio has a 100% success rate with those that have used the product, which is guaranteed to eliminate sludge and alleviate a water body's decaying algae, scum layer, and decomposing duckweed problems. This company is also a world leader in bioremediation and clarity control by using natural methods without harmful chemicals. Since dredging may not be an ideal solution for the ILWA, this product could reduce the nutrient issues related with the sediment that increases aquatic plant and algae growth.

5.3 Water Quality

5.3.1 Dissolved Phosphates and Dissolved Nitrates

Despite reports of problems with algal blooms and other nuisance plant growth, the dissolved phosphate and dissolved nitrate levels within Little Indian Lake are well within acceptable, healthy limits. Throughout the entire observation period, which lasted from November 2009 until February 2010, no algal blooms or rampant growth of nuisance plants were recorded. The lake's health in this area may be explained by the treatment plans currently being applied to Little Indian Lake. Specifically the success of the boom installed by Lycott Environmental, which dispenses chemicals to prevent nuisance plant growth over the surface, may be represented in this data.

Although the dissolved phosphate and nitrate levels we measured were acceptable, it is important to remember that many of the problems of eutrophic lakes, including algal blooms, occur during the late summer. Furthermore, one must be aware of the fact that the concentrations of nutrients in the lake can change as the seasons change. The data gathered during this research serves as a baseline to which comparisons can be made in the future. One comparison of value would be analyzing the difference in dissolved phosphate/nitrate concentration during the late summer months to the data we collected. This comparison would help the ILWA to understand the source of problems like nuisance plant growth in Little Indian Lake and perhaps draw parallels between the lake's problems and nutrient concentrations.

5.3.2 Dissolved Oxygen

The dissolved oxygen levels in the samples we obtained from Little Indian Lake fall well within acceptable limits. One must remember that the samples we used were obtained during the winter and dO_2 levels vary with the seasons. Furthermore, it is possible that the concentration of dO_2 in the lake appears to be acceptable because it has returned to its normal state following a period of algal growth and fish kills. This test benefits in the same way as the tests for dissolved nitrates and phosphates benefit with increased sampling.

5.3.3 pH

The water samples we obtained from the lake measured a 7.2 on the pH scale, falling well within the average range of 6.5-8.5. The water's pH shows that it is capable of sustaining life and is not an immediate threat to either aquatic or terrestrial life.

5.4 Bathymetric Survey

The bathymetric survey conducted during this study is a valuable tool for the Indian Lake Watershed Association. Specifically, comparison of this bathymetric survey with the depth diagram in ESS Group Inc.'s report from 2004 will show how the lake's floor is changing with time.

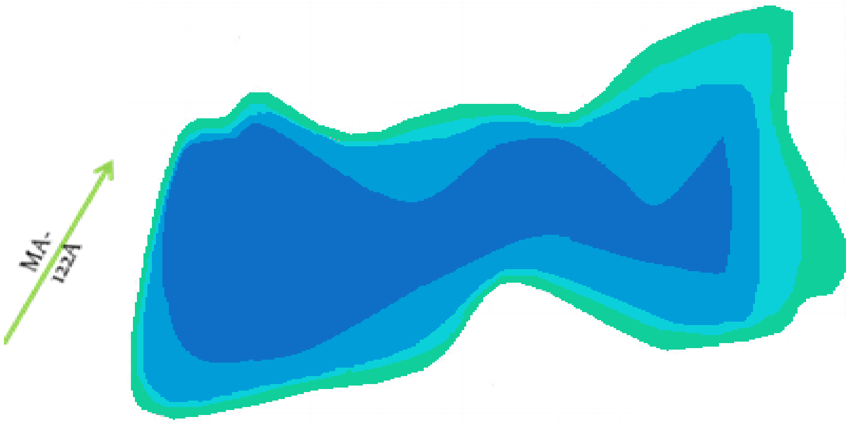

Figure 5.1: Depth Diagram from ESS Group (ESS Group, Inc. , 2006)

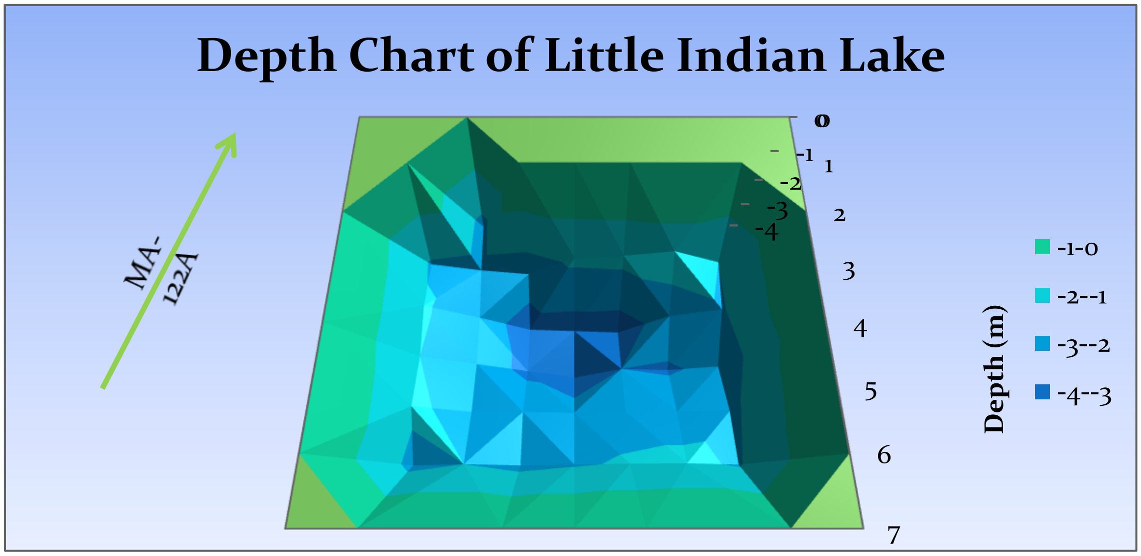

Figure 5.2: Depth Diagram (2010)

This comparison demonstrates that the average depth of Little Indian Lake has decreased during the past four years. Although evaporation may account for a small fraction of water loss, accumulation of sediment is primarily responsible for the decreasing depth of Little Indian Lake. The accumulation of sediment on the lake floor presents a significant long-term problem for the ILWA which, if ignored, may result in the disappearance of Little Indian Lake. One of the most effective methods of remedying the problem of accumulation on lake floors is dredging.

Dredging should be carefully considered by the ILWA. In order to maintain the health of a lake it must contain enough water that water loss by evaporation and seepage into the ground do not remove all of the water in the lake. According to the U.S. Department of Agriculture a depth of 1.5 to 4.5 meters is necessary to ensure the survival of the lake (Cooke, Welch, Peterson, & Newroth, 1986, p. 139). Since Little Indian Lake's depth reaches a maximum of 3.8 meters (Table 4.2), this should cause some concern to the association.

Furthermore, dredging can help remove unwanted nutrients from the lake. Shallow lakes are especially vulnerable to periodic releases of nutrients from the sediment (139). Although the dissolved phosphate and nitrate levels observed in Little Indian Lake were normal and did not cause great concern, this result of dredging would only strengthen the integrity of Little Indian Lake. Additionally, if further analysis of Little Indian Lake exposed the presence of toxins, dredging could be used to remove those toxic compounds.

Despite its usefulness as a tool to help the health of water bodies, dredging poses some environmental concerns. The main concern is that unwanted nutrients suspended within the sediment will be agitated and raise dissolved nutrient concentrations within the water. Past experimentation with dredging has demonstrated that although there is usually a spike in the concentration of nutrients such as phosphorus while dredging is underway, the long-term gains greatly outweigh the short-term losses. Similarly, the possibility of liberating toxic compounds in the sediment is of concern. However, these problems seldom result in nuisances such as algal blooms (142).

There are multiple techniques that can be employed to dredge a lake. One common method is called grab bucket dredging. Grab bucket dredges use a crane and bucket, which is dragged along the lake floor, to collect sediment, which is then deposited either at the disposal site or in a truck for transportation to the disposal site.

Grab bucket dredges offer certain disadvantages over other methods. For example, the disposal of sediment represents one of the weaknesses of all grab bucket dredges -- the sediment must be discharged in the immediate vicinity of the removal area (146). All grab bucket dredges also share some other disadvantages. First, they create a rough and uneven contour on the lake floor. Secondly, sediment removal rates are comparably slow: "Production rates [of grab bucket dredges] are relatively slow, due to the time-consuming bucket swing, drop, close, retrieve, lift, and dump operating cycle" (146). Finally, use of grab bucket dredges often results in highly turbid waters, owing to the buckets disruption of the sediment.

Despite their shortcomings, grab bucket dredges offer some advantages over other techniques. One such advantage is the mobility of grab bucket systems. The main component of such systems is the crane, which is easily transported from one project site to another. Thus, a grab bucket dredge system would prove advantageous were the decision to dredge multiple sites around Little Indian Lake and Indian Lake made. Additionally, grab bucket systems can work in relatively confined areas, making it ideal for the cluttered residential shoreline of Little Indian Lake.

Two grab bucket dredges are displayed below in Figures 5.3 and 5.4.

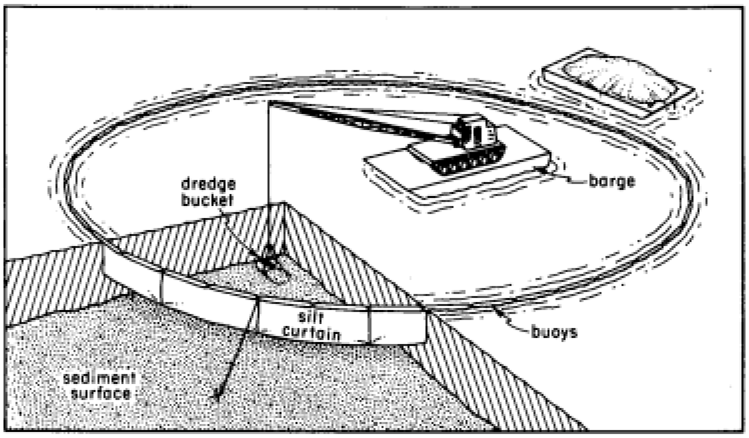

Figure 5.3: Clamshell Grab Bucket Dredge (Cooke, Welch, Peterson, & Newroth, 1986, p. 147)

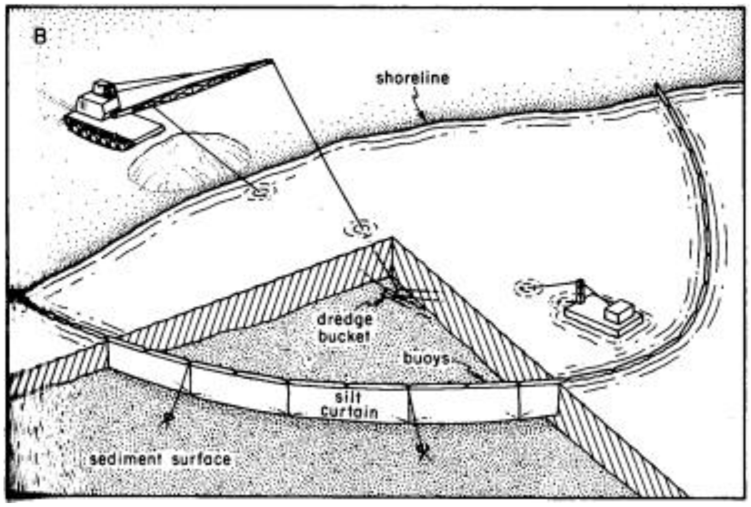

Figure 5.4: Sauerman Grab Bucket Dredge (Cooke, Welch, Peterson, & Newroth, 1986, p. 147)

The clamshell grab bucket dredge uses a floating barge to hold a crane. Then the bucket is lowered into the water to collect sediment, which it then deposits at a predetermined disposal site. Due to the small size and depth of Little Indian Lake employing this system makes little to no sense. Instead, a Sauerman grab bucket dredge would be a far superior grab bucket system. In this system the crane operates on the shoreline and drags a bucket from a certain point in the lake to the shoreline, collecting sediment along the way. Additionally, any stump or large objects, such as the toilet and large rocks encountered during our field days, would not impede the operation of the Sauerman grab bucket dredge (148).

Offering an alternative to grab bucket dredges, hydraulic dredges pump sediment out of the lake. Although there are many types of hydraulic dredges, most are ill-suited to meet the needs of Little Indian Lake (148). We recommend the use of a cutterhead hydraulic pipeline dredge. A typical cutterhead hydraulic pipeline dredge is displayed below in Figure 5.5, which is labeled with key components.

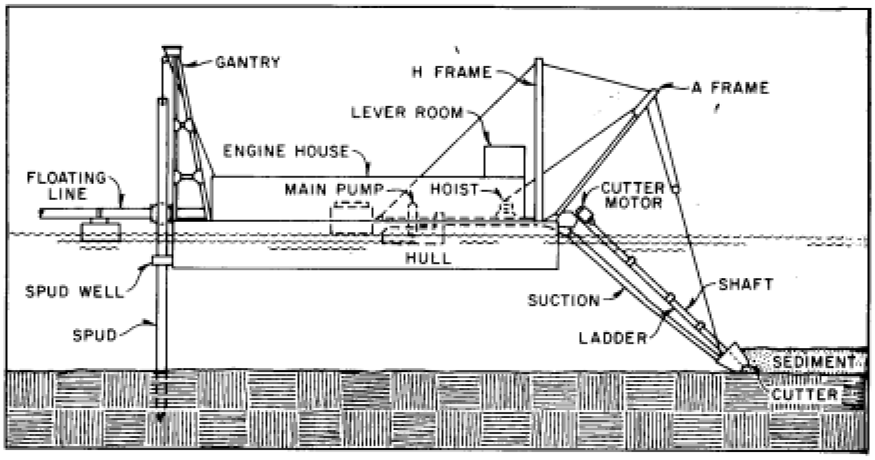

Figure 5.5: Typical Cutterhead Hydraulic Pipeline Dredge (Cooke, Welch, Peterson, & Newroth, 1986, p. 150)

Cutterhead hydraulic pipeline dredges operate by having a cutter, consisting of smooth or toothed blades, rotate to loosen sediment. The sediment is then delivered through the pipeline by creating a pressure gradient (supplied by the pump). The spuds function as the legs of the system, allowing the dredging system to "walk" around the lake by alternately raising and lowering them (149). The walking and cutting patterns which result from the alternating spuds of the system are shown below in Figure 5.6.

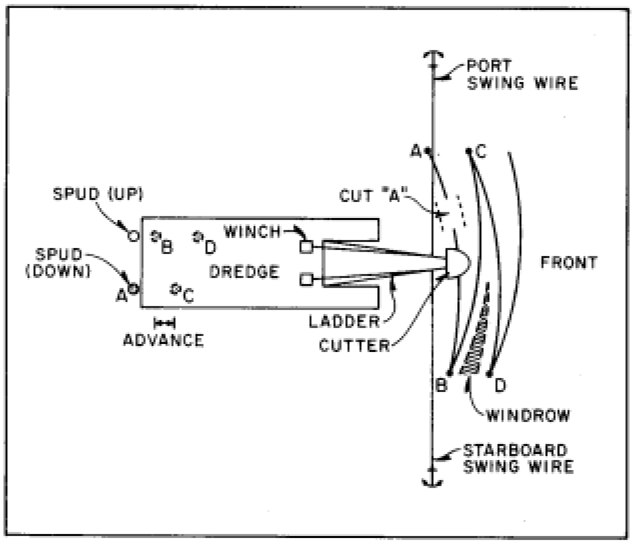

Figure 5.6: Cutterhead Dredge Walking and Cutting Pattern (Cooke, Welch, Peterson, & Newroth, 1986, p. 150)

Cutterhead dredges offer certain advantages over grab bucket dredges. One major advantage is that cutterhead dredges are not limited by cable lengths, whereas a grab bucket dredge can only reach as far as its cable is long, cutterhead dredges can move across bodies of water. However, that walking requires power increasing operational costs. Although this quality would be considered an advantage, it does not come into play when considering Little Indian Lake because of its relatively small size.

Because of size constraints, traditional cutterhead dredges are not particularly reasonable options. Instead, the Mud Cat dredge is essentially a miniature version of large cutterhead dredges. The Mud Cat boasts a horizontal auger which dislodges and transports sediment through its pipeline (151). The primary advantage of the Mud Cat is its extreme mobility, critical for the cramped shores of Little Indian Lake. Furthermore it has been shown that the Mud Cat can produce slurry with nearly double the solids content of conventional cutterhead dredges: "... the Mud Cat dredge should be capable of producing slurry containing 30-percent to 40-percent solids. This represents nearly a doubling of the solids content commonly produced by conventional cutterhead dredges" (151-152).

Figure 5.7: Mud Cat Dredge (Mud Cat Dredges, 2010)

Mud Cat dredges have been used with great success on small lakes. Its guidance system makes it ideal for work on small lake restoration projects. The dredge relies on a cable, anchored at both shorelines, and its guidance system to make passes on the lake floor: "The guidance system permits uniform dredging of the bottom, with few missed strips" (152). Finally, the increased water turbidity due to dredging with a Mud Cat has been shown to be within acceptable limits: "... turbidity plumes due to dredging with a Mud Cat machine were confined to an area no more than 6 m from the dredge" (151). All of these factors combine to make the Mud Cat dredge a strongly competitive choice when deciding how to dredge Little Indian Lake.

5.5 Wildlife

The limited wildlife that was found was most likely a result of the time of year we were on the lake. However through interviews, cormorants, swans, snapping turtles, and Canadian geese have said to be observed. Additionally, eleven species of fish have been identified in Indian Lake including white perch, yellow perch, largemouth bass, golden shiner, black crappies, bluegills, pumpkinseeds, yellow bullhead, brown bullhead, carp and white suckers. This wide variety of wildlife suggests that the lake is thriving and in a better condition than originally predicted.

5.6 Storm Drains and Culverts

The opening to the culvert on the Indian Lake side is oriented higher than the opening of the culvert on Little Indian Lake side. As a result, the flow between the two bodies of water is limited. Additionally, the culvert was filled with debris that inhibited water flow between the two lakes. Unfortunately, changing the position of the culvert to allow for adequate flow between the two lakes is very expensive because it involves the excavating of route MA122A in order to access the culvert. Removing the debris however from the storm drain and culvert is a much less expensive process which has already been done in the past and should be considered again.

Because of the limited flow, when Indian Lake is drained in order to freeze and kill the nuisance plants in that lake, the water level in Little Indian Lake remains unchanged. This prevents the nuisance plants in Little Indian Lake from freezing and dying. Furthermore, underwater springs constantly are supplying Little Indian Lake with a water source. This constant water supply also prevents the aquatic nuisance plants from freezing. The underwater springs also make dry dredging impossible. The storm drains that empty into Little Indian Lake add unwanted contaminated storm water and debris into the body of water.

5.7 Conclusion

This project characterized the existing conditions, wildlife, and the bordering watersheds that have impacted the lake's condition and recommendations for the ILWA were provided for future management. From this study, it was seen that the current state of the lake is in a much better condition than it was predicted to be when the initial project was started. The results presented here should be used as a baseline against which comparisons can be made in the future. Specifically, a follow up study during the summer should be conducted. By collecting samples to test at regular intervals throughout the year the ILWA can create a more complete characterization of Little Indian Lake.

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APPENDIX

LaMotte SMART 2 Colorimeter Instructions

To avoid contamination, thoroughly rinse the screw cap Sample Tube with sample water. Tightly cap the Sample Tube and submerge it to the desired depth. Remove the cap and allow the Sample Tube to fill. Tap the sides of the submerged tube to dislodge any air bubbles clinging to the inside. Replace the cap while the Sample Tube is still submerged. Retrieve the Sample Tube and examine it carefully to make sure that no air bubbles are trapped inside.

Once a satisfactory sample has been collected, proceed immediately with adding the reagents. Add 2 drops of Manganese Sulfate Solution and 2 drops of Alkaline Potassium Iodide Azide. Cap the sample tube and mix by inverting several times. A precipitate will form. Allow the precipitate to settle below the shoulder of the tube before proceeding. Add 8 drops of Sulfuric Acid, 1:1. Cap and gently mix until the reagent and the precipitate have dissolved. A clear-yellow to brown-orange color will develop, depending on the oxygen content of the sample. It is very important that all “brown flakes” are dissolved completely. If the water has a high DO level this could take several minutes. If flakes are not completely dissolved after 5 minutes, add 2 drops of Sulfuric Acid 1:1 and continue mixing. Press and hold the ON button on the colorimeter until it turns on. Press ENTER to start. Press ENTER to select TESTING MENU. Select ALL TESTS (or another sequence containing 39 DO) from TESTING MENU. Scroll to and select 39 DO from menu. Rinse a clean tube with untreated sample water. Fill to the 10 mL line with sample. This tube is the BLANK. Insert tube into chamber, close lid and select SCAN BLANK. Fill a second tube to the 10 line with the treated “Fixed” sample. This tube is the SAMPLE. Remove BLANK from the colorimeter, insert SAMPLE tube into chamber, and close the lid and select SCAN SAMPLE. Record the result.