A Survey of Macrophytes at Indian Lake and Little Indian Lake in Worcester, Massachusetts

An Interactive Qualifying Project Report:

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Degree of Bachelor of Science

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Executive Summary

Purpose

The first aspect of this IQP project was to survey the conditions, which promote and perpetuate a eutrophic condition of Indian Lake and Little Indian Lake. Subsequently, the project aims to outline the origins and effects of the pollution; as well as help in monitoring and preventing further eutrophication within both. The second aspect was to survey the surrounding storm drains which lead into the lake, documenting them whether they are properly stencilled and also re-stencilling any drains which have not been spray painted. All of these results were then displayed on the Indian Lake Watershed Association web page in a way that is assessable to the public. This IQP directly affects the local Worcester area as Indian Lake is used by the public for fishing, swimming, and boating throughout months of the year.

Methods

In order to physically assess the lake, the IQP group first took a tour of the lake on a pontoon boat while evaluating different areas of the lake for visual problematic areas. To gather and assess the density of weeds throughout the lake, an aluminium rake tied to a string was used. At every data point the rake was submerged from the front of the boat at a distance of about 10 feet away from the vessel. After giving the rake a few seconds to sink to the bottom, it would be pulled back, dragging the rake along the bottom which collected the plants along the bottom of the lake. Once the rake reached the surface, the quantity and type of weed were recorded. In order to provide an updated survey of the lake, the group used additional data points in problematic areas as well as the same location points used in the 2013 survey. The data collected at each point was uploaded into Google Maps. This program utilizes google earth and drops pins at specified geocoordinate location using latitude and longitude coordinates. Each coordinate was customized to display the plant species and density.

To carry out the assessment of the storm drains the group located approximately 750 catch basins using a paper map provided by the City of Worcester. When the group approached each storm drain the first job was to clean off the stone from any overgrowth. Once cleaned, the next step was to check if the stencilling was necessary. If stencilling was needed, we would check if the stencil fit on the stone easily. We then used white spray paint to stencil drains in which the stencil directly fit on. Some drains were too small to fit the stencil perfectly, therefore would require minor adjustments in order to fit all of the words. Other drains were much too small for stencilling, in which we displayed stickers provided by the City of Worcester on the stone. To record our data the team created an online mapping of the storm drains, using a GPS tracking smartphone app. A picture of each storm drain was taken and posted on the interactive map for every storm drain that was visited by the IQP team. Once uploaded on to Google Maps in a similar way as the weeds were, the maps was colour coded to display the status of the drain.

Results

Results from the survey indicates that Eurasian Milfoil had increased in both frequency of occurrence and area of coverage. The average cover area, which represents the density of the weeds found at each of the points, rose to 1.86 in comparison to the 2013 survey of 1.69. Data also showed that Small Pond Weed was less relevant throughout the lake, however it was higher densities in the parts of the lake where it was located. With 6 instances of small pond weed with average coverage area of 3.333 compared to 10 instances and average coverage area of 2.2 for the 2013 survey. Emergent plants showed a minor change between the two surveys with roughly the same occurrence and same average density. A new species called Canada Rush was also found in one instance during the 2016 survey. Sediment analysis showed high quantities of black substances which turned out to be decomposed organic material such as grass. This was contrary to the samples collected by Brown and Caldwell survey done in 2013, suggesting that weed growth and death has been excessive. At the end of the project the group had determined that 350 of the 774 storm drains leading to Indian Lake had been stencilled. There are currently 53% of the total storm drains left to be stencilled or updated.

Conclusion

In this study the group identified changes to the ecological composition of Indian Lake's macrophytes. In comparing them to two earlier studies we confirm that macrophytes growth has increased. Based on our survey and previous surveys the drawdown could be favouring two problematic species, which lead to the recommendation of other possible treatments for the ILWA.

Recommendations

Storm water runoff has shown to be the most direct influence on the trophic status of Indian Lake. With this said, the best way to prevent inflow of high nutrient laden water is to raise awareness in the community on the effects of anthropogenic activity on the quality of water. Direct solutions for the lake were researched, including the manipulating of light to physical kill off the submerged weeds by limiting light penetrating, thus inhibiting growth and causing death. Other direct solutions for treatment of the lake were also discussed and proposed to the ILWA. The current treatment of drawdown is very cheap and limits the growth of aquatic plants, but it is also known for promoting the growth of the problematic species. The drawdown cannot be a single, long-term solution for the lake. Dredging, which improves water circulation and removes weeds, is extremely expensive and not feasible for the ILWA at this time. Chemical treatments are cheaper than dredging but still expensive and can cost hundreds of thousands of dollars. Chemical treatments are effective in preventing aquatic growth by restricting available nutrients, however they insert foreign materials into lake which have the potential to disturb the natural ecology of the lake. The last treatment, light screens, is the best treatment option based on our research as stated earlier in the paragraph due to their ability to limit light. The ILWA could afford the light screens which are shown to be completely effective in areas where they have been previously applied. Some downfalls of these screens are required reapplication of the treatment every 2-3 years, which could result in additional costs.

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1.0 Introduction

The delicate balance of biodiversity within any area is subject to the continuous influence of human activity. Changes in environmental biodiversity often have cascading effects on ecology, and subsequently human behavior closely linked to that ecology.

One such location, which has undergone ecological reform, is Indian Lake in Worcester, MA. Historically, Indian Lake is a commercial, developmental, and recreational resource for residents and visitors of Worcester. In recent years both Indian Lake, and the adjoining smaller body of water: Little Indian Lake, have changed due to anthropogenic pollutants. These pollutants have triggered a process called eutrophication, which has attenuated or ceased human accessibility to the Lake. Eutrophication is a process in which a lake experiences a positive flux of organic nutrients.

The goal of this project is to characterize the propensity of anthropogenic pollutants to change the chemical and ecological composition of a lake during eutrophication. Subsequently, the project aims to outline the origins and effects of the pollution; as well as help in monitoring and preventing further eutrophication within the two lakes.

1.1 Past efforts in monitoring and treatment of the lakes

The Indian Lake Watershed Association (ILWA) was formed in 1985 to monitor the condition of the lakes. The group focused on the invasive species of macrophytes, quality of water, and general ecological health of Indian Lake. In conjunction with the city of Worcester, the ILWA proposed a lake drawdown to combat the issues of Indian Lake. Furthermore, the ILWA also promotes public awareness of the dangers of anthropogenic runoff within the surrounding community as a cause of eutrophication. The group members of this project have worked closely with the ILWA, as WPI students have in the past, to survey the lake and provide a general analysis on the conditions of the lake and surrounding areas.

1.2 Objectives and Deliverables

This project will survey the conditions, which promote and perpetuate a eutrophic condition within Indian Lake. The current biodiversity survey of this project extends to the areas of both Indian and Little Indian Lake.

Furthermore, the group will survey the surrounding storm drains, which lead into the Lake, and will continue to add any missing stencils warning about the consequences of inadvertent waste deposition.

Lastly, maps constructed from the surveyed data will be presented using two programs. The first is google maps and is directed towards the concerned public hoping to learn about the progressing condition of the lake. The second will use Revit LT™ with the intention of aiding potential future professional organizations involved with the treatment of the Lakes.

Google maps provide the user the ability both to view past and forthcoming biological surveys of Indian Lake, and also partially or collectively isolate specific variables within any mapping.

Maps made in Revit LT™ provide the user an accurate depiction of contour data within the lakes and surrounding area to be used in analytical models of water level control and lake hydrology.

Using these programs this projects also aims to provide hypothesis on the current status of the lakes and potential treatment for them as well as the importance of this treatment.

In summary, this project will give the ILWA a survey of factors promoting eutrophication in Indian Lake, continue the stenciling of storm drains which are missing the warnings of incidental waste deposition, present the data in clear and concise programs which allow for the viewing and manipulation of data, and finally discuss the current and potential future of the status of the lakes.

2.0 Background

2.1 Ecological composition and progression of eutrophic lakes

Generally, the process where one ecological formation is replaced by a different one is known as succession and is a natural occurrence in the world's dynamic biosphere. Succession in which a body of water is replaced by land or marsh is categorized as ecological extinction. The Environmental Protection Agency (EPA) considers the process of eutrophication to be a subset of succession due to the high probability of extinction in eutrophic lakes. (Barstch, 1972) The distinction between eutrophication and natural succession can be attributed to the time-scales at which each one occurs. As such, the Ecological Society of America has detailed that eutrophication is "the abnormal acceleration of a process (succession), which is regarded as normal, (and) has had diverse effects, some of which are not suitable for the best interests of man" (Jonge, Elliott, & Orive, 2002). The hypothesized natural pattern of succession, from lake formation to extinction, has been proposed to follow sigmoid growth curves as seen in Figures 1 and 2. Conversely, Figure 2 also illustrates the asymptotically accelerated extinction caused by unnatural influences.

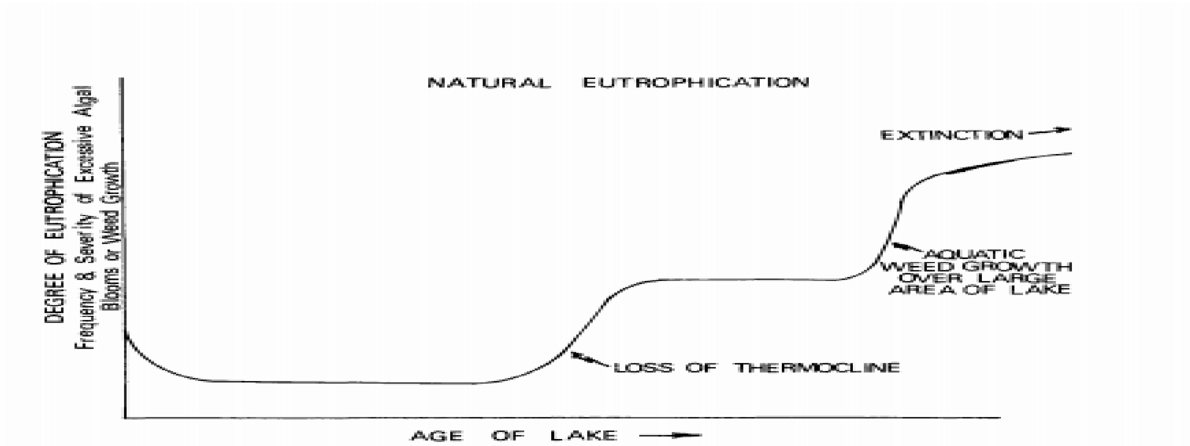


Figure 1 Sigmoid progression in a natural lake. Adapted from "Eutrophication", by G. Fred Lee, May 1972 Northeast Fish and Wildlife Conference, 1972

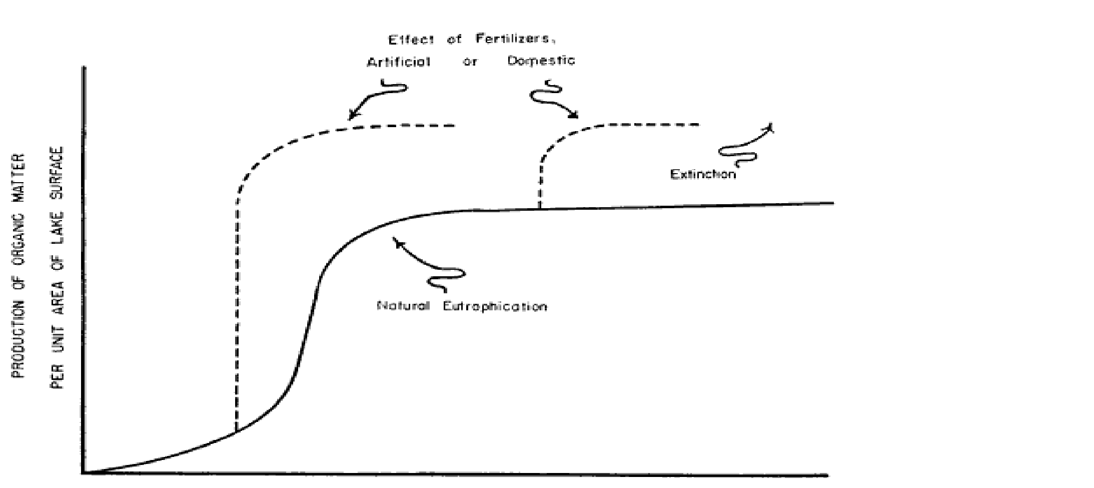


Figure 2 Comparison of proposed progression of Eutrophication in natural and accelerated lakes. Adapted from "Eutrophication of Lakes by Domestic Drainage", by Arthur D. Hasler, 1947, Ecology, p. 383-395 1984

Carlson (1977) developed the Trophic State Index to gauge the level of acceleration to ecological succession within a body of water. This index uses the three factors in Figure 3 to assign a trophic state to lakes.

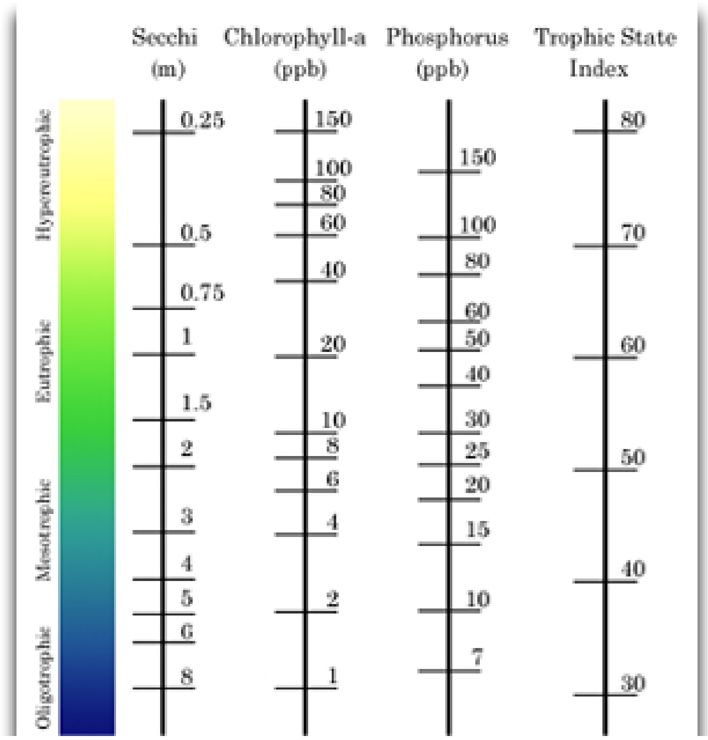


Table 1 Board of Regents of the University of Wisconsin system (image creator) Trophic Table [Table compiled of trophic elements] Retrieved from http://lakesat.org/maptext3.php

Brown and Caldwell (2013) identified Indian Lake to be hypertrophic according to Carlson's Index. The study's records of the contributing factors towards this classification can be seen in Table 1. The intent of the index was to provide a base level for the ecological impacts resulting from each index. Thus, Indian Lake has and will experience the most severe ecological problems from eutrophication.

Sample Location:	SW-1-Top Values				SW-2-Top Values				SW-3-Top Values			
	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV
Alkalinity (mg $CaCO_3$/l)	22	26	23.5	0.06	21	24	23	0.05	22	24	23.2	0.03
Total Suspended Solids (mg/l)	6.6	15	9.3	0.32	7.1	100	23.9	1.56	5.8	10	8.6	0.17
Hardness (mg/l)	36	43	39.5	0.06	36	43	39.2	0.06	35	42	38.5	0.07
Chlorophyll-a (mg/m³)	14.4	32.2	21	0.37	16	36.3	22	0.35	11	29.8	20.2	0.36
Fecal Coliform (col/100ml)	2	84	48	0.79	5	300	83	1.36	7	88	33	0.96
Nitrate/Nitrite Nitrogen (mg/l)	<0.1	<0.1	0.05	0	<0.1	0.21	0.21	0.82	<0.1	<0.1	0.05	0
Total Kjeldahl Nitrogen (mg/l)	0.35	1.1	0.78	0.33	0.65	0.83	0.75	0.10	0.62	1.1	0.816	0.22
Total Nitrogen (mg/l)	0.35	1.1	0.78	0.33	0.65	0.95	0.80	0.16	0.62	1.1	0.836	0.21
Orthophosphate (mg/l)	<0.005	<0.005	0.0025	0	<0.005	<0.005	0.0025	0	<0.005	<0.005	0.0025	0
Soluble Phosphorus (mg/l)	<0.010	<0.010	0.005	0	<0.010	<0.010	0.005	0	<0.010	<0.010	0.005	0
Total Phosphorus (mg/l)	0.026	0.086	0.045	0.49	0.025	0.057	0.036	0.33	0.023	0.089	0.041	0.62
Lead (mg/l)	0.0008	0.0014	0.0011	0.19	0.001	0.0029	0.002	0.51	0.0009	0.0013	0.001	0.13
Arsenic (mg/l)	0.0017	0.0036	0.0030	0.23	0.0018	0.0038	0.003	0.23	0.0018	0.0034	0.003	0.20
Copper (mg/l)	0.0012	0.0031	0.0020	0.33	0.0012	0.0025	0.002	0.28	0.0013	0.0022	0.002	0.22
Sample Location:	SW-1-Bottom Values				SW-2-Bottom Values				SW-3-Bottom Values			
	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV
Alkalinity (mg $CaCO_3$/l)	21	39	25.67	0.26	22	24	23.17	0.04	22	29	23.83	0.11
Total Suspended Solids (mg/l)	8.8	140	32.43	1.63	8.6	30	15.57	0.63	8.2	2600	454.35	2.31
Hardness (mg/l)	36	42	39.17	0.06	37	44	39.83	0.07	37	43	39.67	0.06
Chlorophyll-a (mg/m³)	13.2	69.8	33.1	0.64	12.4	35.4	22.97	0.43	15.7	30	21.5	0.27
Fecal Coliform (col/100ml)	8	170	72	0.91	17	260	112	0.93	7	500	148	1.35
Nitrate/Nitrite Nitrogen (mg/l)	<0.1	<0.1	0.08	0	<0.1	0.11	0.06	0.41	<0.1	<0.1	0.05	0
Total Kjeldahl Nitrogen (mg/l)	0.54	1	0.78	0.25	0.56	1.5	0.88	0.43	0.8	2	1.22	0.43
Total Nitrogen (mg/l)	0.54	1	0.78	0.25	0.56	1.5	0.91	0.40	0.8	2	1.22	0.43
Orthophosphate (mg/l)	<0.005	<0.005	0.0025	0	<0.005	<0.005	0.0025	0	<0.005	<0.005	0.0025	0
Soluble Phosphorus (mg/l)	<0.010	<0.010	0.005	0	<0.10	0.083	0.02	1.32	<0.010	0.038	0.01	1.09
Total Phosphorus (mg/l)	0.035	0.291	0.086	1.17	0.052	0.392	0.182	0.79	0.037	0.245	0.101	0.76
Lead (mg/l)	0.0008	0.0112	0.004	1.15	0.0009	0.0384	0.008	1.87	0.0009	0.041	0.008	2.08
Arsenic (mg/l)	0.0027	0.0046	0.003	0.20	0.0029	0.005	0.004	0.22	0.003	0.006	0.004	0.31
Copper (mg/l)	0.0013	0.0065	0.0026	0.77	0.0014	0.008	0.003	0.88	0.0013	0.0066	0.002	0.88

Notes:

CV = coefficient of variation.

NA, measured concentrations were below detectable limits.

mg $CACO_3$/l = Milligrams of calcium carbonate per liter

mg/l = Milligrams per liter

mg/m³ = Milligrams per cubic meter

col/100ml = Colonies per 100 milliliter

Table 2 Table consists of values for 6 areas designated SW around the lake. Adapted from "Indian Lake Phosphorous Reduction Study" by Brown and Caldwell, Feb 26, 2013

2.2 Using biodiversity as a determinant of trophic state and ecology in a eutrophic lake

Compared to oligotrophic and mesotrophic lakes, Eutrophic and hypereutrophic Lakes are marked by a large increase in the supply of organic matter in the form of aquatic, primary producers (McQuatters-Gollop, et al., 2009). The decomposition of these primary producers generates silt and soil in the lakebed. If this is compounded with poor water circulation in the lake this increase in production will widen the littoral zone and eventually shallow the lake. (Figure 3)

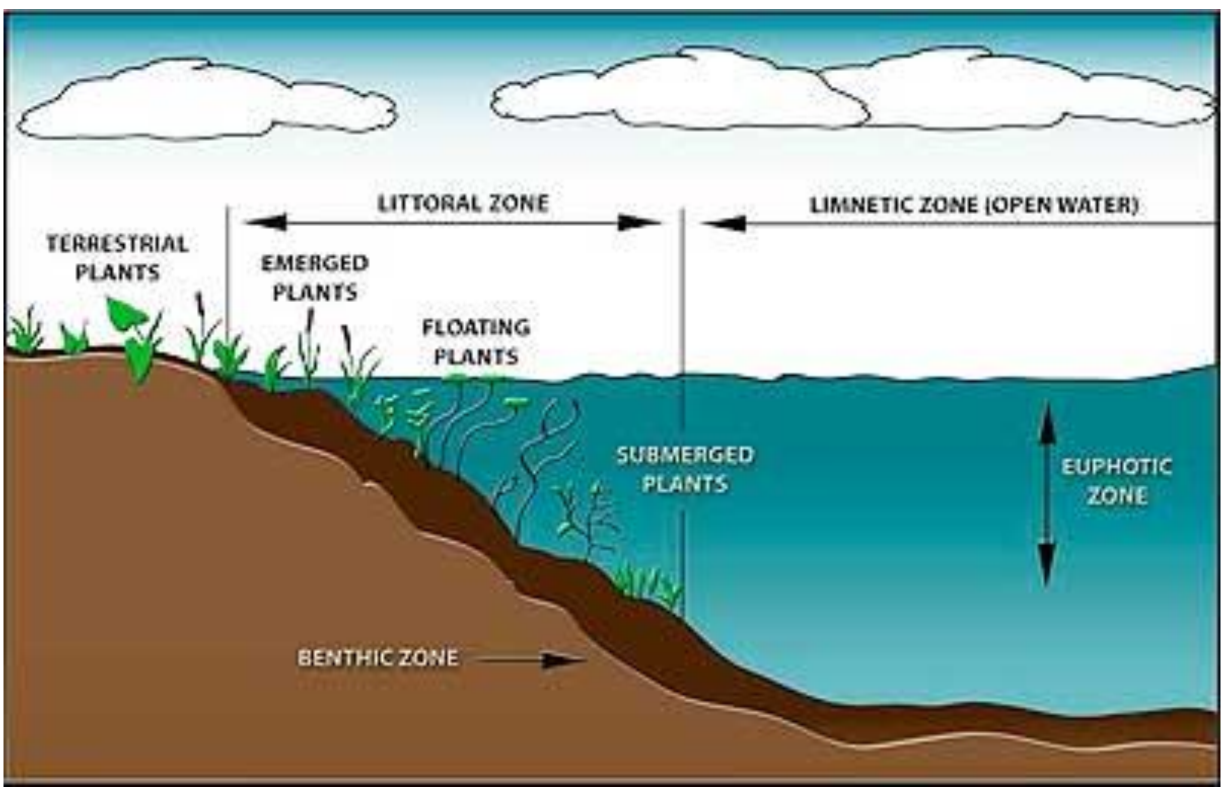


Figure 3 Effects of Sunlight on zones in lakes National Science Foundation (image creator) (2003) "Lake Zone" Retrieved from Water on the Web

The targeted widening of the littoral zone can be attributed to the primary producers that collectively compose the greatest amount of organic matter in a eutrophic lake: submerged macrophytes. The growth of submerged macrophytes is restricted by the large amount of sunlight they require for photosynthesis. Sunlight does not reach deeper parts of the lake such as the limnetic zone, and thus restricts macrophytes to growth in the littoral zone. This results in the sedimentation and growth of the littoral zone. Consequently, the growth of the littoral zone allows for more sunlit area for macrophytes to grow in and expedites the process of eutrophication. Essentially, the average depth predominantly determines the trophic state of a lake. (Reference the Secchi collumn in Table 1)

Due to the large influence macrophytes have on lakebed sedimentation, many studies use macrophytes as a prime determinant of ecological function and biological function in shallow lakes. This is the basis for surveying and documenting the macrophytes growing in Indian Lake.

2.3 Problematic Macrophyte Species of Indian Lake

2.3.1 Eurasian Milfoil (Myriophyllum spicatum)

Eurasian Milfoil is submerged perennial plant. The plant can be identified by the reddish tint to its stem and the feather-like leaves, clustered in whorls of 4-5 at nodes along the stem. The reproductive cycle of Eurasian Milfoil begins when water temperature reach 15 degrees centigrade in the spring and summer. The plant will sustain growth and eventually flower when the plant reaches the surface of the water. The cold weather of fall forces the plant to die down back to crowns, which are buried in the sediment, in order to sprout again during the spring. Eurasian Milfoil is classified as a perennial because of these crowns and the plants ability to survive the winter months. (Washington State Department of Ecology, 2016)

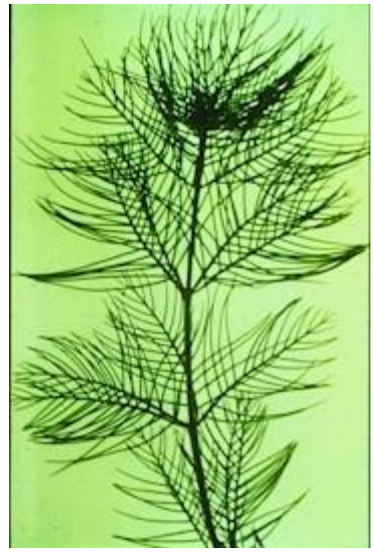


Figure 4 Example of Eurasian Watermilfoil (Washington State Department of Ecology 2016)

2.3.2 Small Pond Weed (Potamogeton pusillus)

Like Eurasian Milfoil, Small Pond Weed is a submerged macrophyte with a perennial growth cycle. The plant can be identified by its slender flat leaves growing in frequently branching patterns. Furthermore, the leaves typically have a large midvein which distinguishes the plant from similar Potamogeton plants. The reproduction of Small Pond Weed also begins with warmer weather and the plant experiences sustained growth

Figure 5 Figure of Small Pond Weed (United Phosphorous, Inc., 2008)

until flowering in the late summer. Furthermore, the plant can produce winter buds, however, can also regenerate from rhizomes and fibrous roots which makes the plant especially resistant to the cold. Furthermore, many different species of small pond weed are found to grow in conjunction with Eurasian Watermilfoil. (United Phosphorous, Inc., 2008)

2.4 Anthropogenic Promoters of Macrophyte Growth in Eutrophic Lakes

Both the United States and European Unions have recognized that anthropogenic activity is closely linked with the increase in organic matter causing lakes to undergo accelerated ecological change (Lewis, Wurtsbaugh, & Paerl, 2011). Several studies have cited that two main chemicals in anthropogenic pollution are responsible for the stimulation of the growth of macrophytes in lakes. These two chemicals are varied forms of phosphorous and nitrogen. Furthermore, many of these studies correlate an increase in human activity around the area of eutrophication and the influx of these two chemicals. A paper by the Department of Marine Biology at the University of Groningen has documented a handful of these studies which show an increased accumulation of nitrogen and phosphorous in various bodies of water around the world. This has been tabled and added in Appendix A. Another, long term study has tracked the specific influx of these two nutrients into the Rhine at Lobith over a 50 year period. (Figure 6) When cross-referenced to a graph of the world's population (Figure 7) there are specific correlations in influx of nutrients and population growth prior to the establishment of environmental agency restrictions.

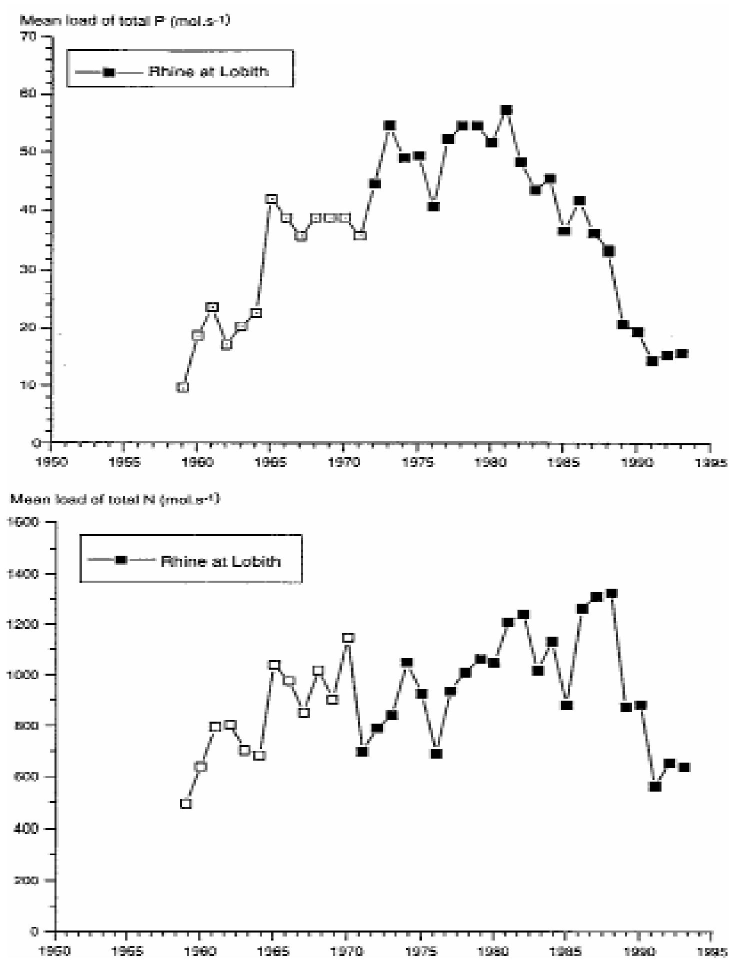


Figure 6 Influx of Nitrogen and Phosphorous into Rhine at Lobith over 50 year period (Jonge, Elliott and Orive 2002)

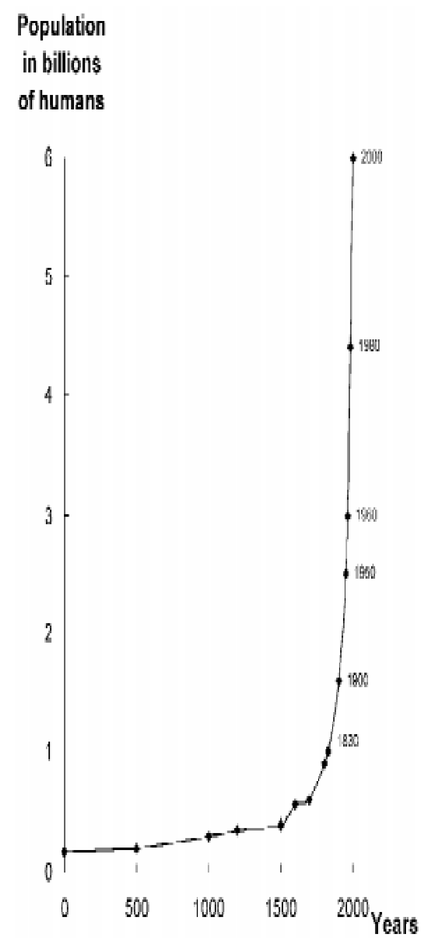


Figure 7 growth of human population over 50 years (Jonge, Elliott and Orive 2002)

2.5 Origin of anthropogenic Phosphorous and Nitrogen pollution in Indian Lake

Various Point and diffuse sources can account for the influx of phosphorous and nitrogen into bodies of water. “It has been established that detergents, domestic sewage, and fertilizers are the three major human made sources of nutrient enrichment in and eutrophication of natural water bodies” (Khan & Ansari, 2005)The scope of this study does not include the specific activities that produce these two nutrients and only identifies their origin to be a derivative of human function. The Massachusetts Department of Environmental Protection (MassDEP) has identified stormwater runoff as the primary source of total phosphorous loading to Indian Lake. This storm water runoff is primarily introduced into the water system upstream through Mill Brook. (Brank, et al., 2002). Another origin of these nutrients is the storm drains which drain into the lake. The contribution of the storm drains to nutrient loading is the basis for surveying and documenting the status of stenciled warnings on the storm drains.

The MassDEP has evaluated the total maximum daily loads (TMDL) of phosphorous to the lake from both these sources to be 1.43 kg/day in 2002 (Brank, et al., 2002). (Brown and Caldwell, 2013) affirmed this large flux of phosphorous in their 2013 phosphorous reduction study. Some other chemical components that the (Brown and Caldwell, 2013) study identified in lake have been added to appendix B.

2.6 Chemical Effects of Eutrophication on Water Quality:

2.6.1 Algal Blooms

The most concerning effect of eutrophication is that it compromises water quality due to the overgrowth of unwanted algae. The increased level of nutrients in lakes can cause a bloom of phytoplankton, some of which produce toxins that adversely affect human health. The effects on water quality vary based on the algal bloom. The geneses of phytoplankton, which cause the most detrimental effects on water quality, are dinoflagellates, diatoms, and cyanobacteria. (Giannuzzi, Sedan, Echenique, & Andrinolo, 2011)

2.6.2 Cyanobacteria

Cyanobacteria frequently produce harmful toxins that pose a threat to human health. With respect to Indian Lake this has caused the lake to close for recreational activities several times. A medical record documents a case where a patient who used Salto Grande Dam, Argentina as a recreational source experienced nausea, abdominal pain and fever mere hours after exposure. Furthermore, several days after exposure dyspnea and respiratory distress were reported by the patient at which point he/she had to be hospitalized for hepatotoxicosis until the effects of the toxin wore off (Giannuzzi, Sedan, Echenique, & Andrinolo, 2011).

2.6.3 Diatoms

Diatoms also adversely affect the quality of water by producing volatile, harmful substances, which affect the sensible organs in humans. Though this phytoplankton isn't known to be toxic it deteriorates the quality of water by affecting its taste and smell.

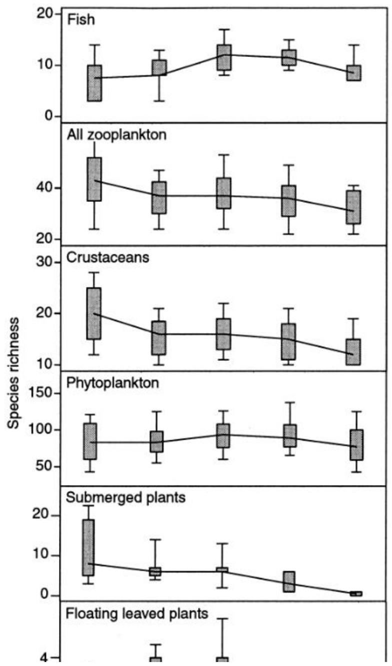


Figure 8 biodiversity of several lake Species compared to phosphorous load. Adapted from (Jeppsen, Jensen, SonderGaard, Lauridsen, & Landkildehus, 2000)

2.6.4 Dinoflagates

Algal blooms of dinoflagate can produce toxins that adversely effect fish and shellfish of the water body. This is more commonly know as red tide and can have adverse effects on humans who consume these animals (Vasconcelos, 2006).

2.7 Ecological Effects of Eutrophication

2.7.1 Macrophyte Biodiversity

A study of 71 shallow Danish, freshwater, shallow Lakes revealed that submerged macrophyte diversity had an inverse correlation with total phosphorus in the water (Jeppsen, Jensen, SonderGaard, Lauridsen, & Landkildehus, 2000). This is not only an issue because of the ecological ramifications of loss of species diversity. The niche separation of nutrients is an important role in the balance of water quality. Macrophytes of different species have been found to coexist by sharing nutrients instead of competing for them; especially in the case of invasive macrophytes (Stiers, Njamuya, & Triest, 2011). The reduction of macrophyte diversity thus results in a decrease in reuptake of nutrients by macrophytes and could result in algal blooms mentioned previously.

2.7.2 Fish Biodiversity

The study by Jepsen also noted a change in the biodiversity of fish. The general trend was for the loss of game fish in favor of cyprinidae. The succession of cyprinidae was attributed to their ability to feed on the overgrowth of macrophytes resulting from eutrophication. Fishermen of Indian Lake support this idea as they report catching mostly carp when questioned during surveying.

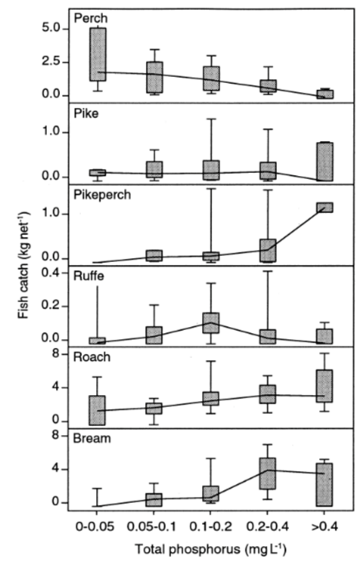


Figure 9 biodiversity of several fish species compared to phosphorous load. Adapted from (Jeppsen, Jensen, SonderGaard, Lauridsen, & Landkildehus, 2000)

2.8 Threats to Indian Lakes History

Indian lake serves as a historical landmark for the community of Worcester due to its involvement in converting Worcester to an Industrial City. The current 228 acre Indian Lake began as 30 acre pond called "North Pond". Damning Mill Brooke at North Pond and Salisbury Pond to form the headwaters for the Blackstone Canal converted this pond. Blackstone Canal was meant to connect Worcester to the trade hub of Providence Rhode Island and encourage the development of Worcester. (Brank, et al., 2002)Unfortunately, the advent of railroads rendered Blackstone Canal inefficient a few years later, however, its impact on Worcester remains.

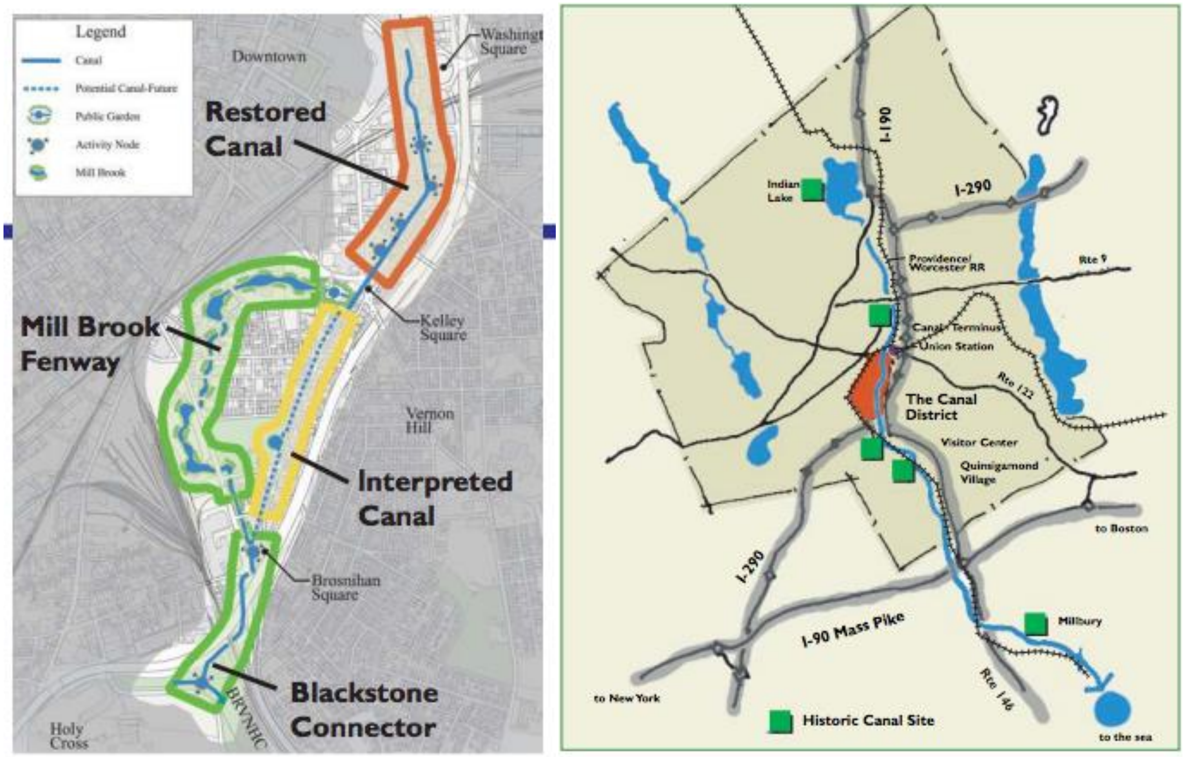


Figure 10 Connection from Indian Lake to Blackstone Canal. Adapted from "A water Resource-based 'Smart Growth' Urban Design Strategy for Worcester, Massachussettes", by Rizzo Associates, 2003, p. 1,5

2. 9 Threats to Recreational Value of Indian Lake

Many people use Indian Lake for recreational activities such as swimming, boating, and fishing. If the process of eutrophication continues within the lake then toxic phytoplankton will render any recreational activity that involves contact with water unsafe. Furthermore, the overgrowth of macrophytes will also make boating impossible because of its impact on motor boats engines.

2.10 Threats to Commercial Uses of the Lake

Though the commercially driven purpose of Indian Lake has changed since the Industrial revolution the lakes waterfront still serves as a home for many residents. The unaesthetic and sensory outcomes of eutrophication cause the value of the land around the lake to depreciate in value.

3.0 Methodology

The survey of the entire Indian Lake watershed was completed to update and assess its ecological state.

Figure 11 Indian Lake Watershed (Center) modeled in Civil 3d LTTM with respect to road systems

First, growth of submerged, floating, and emergent aquatic plants was surveyed. The data collection from the 2013 survey established a set of location points that were used for comparison (Cheston, Gribble, & Plante, 2013) Data collected from our survey will be useful when compared to prior surveys in order to determine any changes in the aquatic plant growth. The parameters that will be compared are growth rates, location and population of plants throughout Indian Lake.

Next, some storm drains leading towards Indian Lake were surveyed and stenciled to determine the current appearance of every catch basin and create an updateable system for the ILWA to use for future stenciling. Techniques used during the stenciling were in accordance with the City of Worcester and the ILWA.

The data from topographical maps was combined into a model-based environment using Revit LT™ software to render a three dimensional view of the lake and surrounding areas. Revit LT™ software is a simplified 3D tool that produces coordinated, high-quality architectural designs with embedded documentation. The model allowed us to display the elevation of surrounding areas as well as the depth of the water in relation to the Indian Lake watershed.

3.1 Preparing for Lake Surveying

Before going out onto the lake for surveying, the group took a tour of the lake to assess different areas of the lake for visual problematic areas. In order to provide an updated survey of the lake, we used additional points along with the location points used in the 2013 survey. In the more dense areas of the lake, as seen during the tour, more collection points were conducted. The group also spoke with local residents in the area to better understand their view of

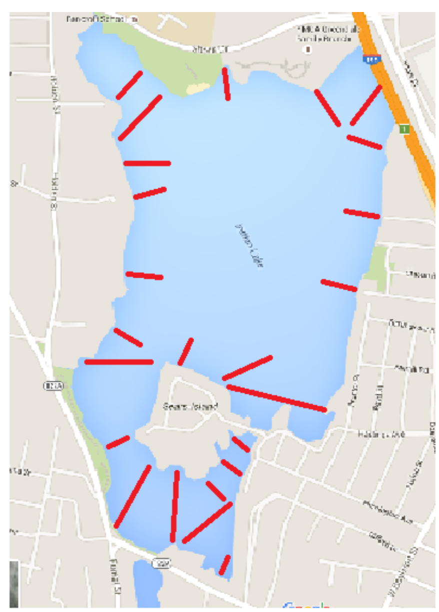


Figure 12 Transect Lines used for surveying

the plant growth on the lake. Most points surveyed started near the shore and additional points were surveyed while moving in a straight line away from the shore. (Figure 12) Most of the emergent plants covered the shoreline perimeter of the lake. A motorized boat was used to assess the aquatic plant growth in deeper areas of Indian lake and canoes were used to approach the shallow banks of the lake. With Little Indian being shallow, using a canoe was the only option to survey the entire Lake. In the end, 166 data collection points were recorded and shown on the final survey map of Indian Lake and Little Indian. In the combination of both 2013's survey and our survey, 283 different points can be seen. (Figure 13)

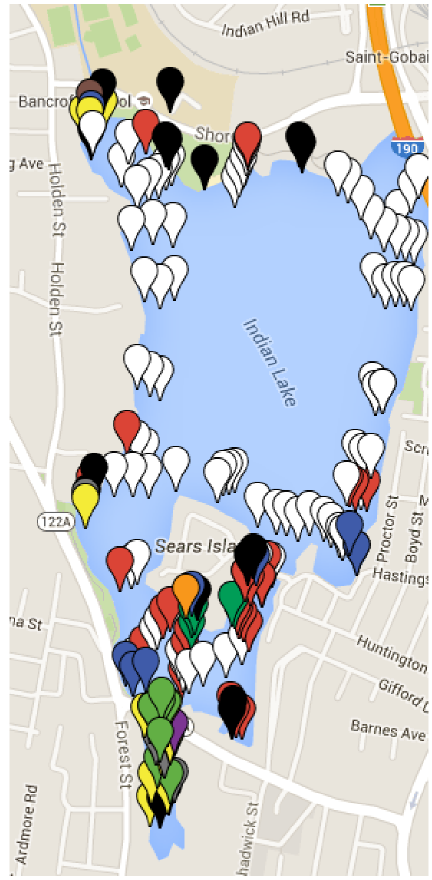


Figure 13 Collection of Points between 2013 and 2015

3.1.2 GPS locator for aquatic plant survey

All data points were used by a smartphone App "GPS Tracks" that was able to track our location and time of the point for easier reference at a later date. After researching different options, including a USB data logger and a boat GPS, we determined that the smartphone technology was precise enough for us to conduct the survey. The smartphone also allowed for easy transition of the data points to a computer. At each location the time, location, species of plant, and amount of plants were recorded.

3.2 Meta data collected

3.2.1 Date and Time

The date and time of each point was recorded through a GPS tracking app on a smartphone. In addition to the use of the smartphone, we wrote down the time on paper along with the weed type/amount just in case the app information could not be transferred to a computer for any reason. After the first few times on the boat we determined the app was sufficient enough and was compatible with the computer, so we did not need to hand write the data anymore.

3.2.2 Density of Weeds

The group in 2013 modified an aluminum gravel rake to collect the weeds. The same rake was used during our surveying in order to keep the surveys as similar as possible. The rake was weighted to ensure that it would reach the bottom. Attached at the top of the rake was a rope that was used to pull the rake up. At every data point the rake was submerged from the front of the boat at a distance of about 10 feet away from the boat. After giving the rake a few seconds to sink to the bottom, we would begin to pull the rope, dragging the rake along the bottom. Once the rake reached the surface, the data were recorded.

Figure 14 Picture of Rake after Dredging

After inserting the rake, dragging it and pulling it onto the boat, we had to determine the amount and type of plants found. In order to determine the density of the amount of plants found, we divided the collection into five separate categories shown below, as developed by the U.S. Army Corps of Engineers. Sequential numbers starting at 0 were also assigned to their respective notation in order to average the density among collected points. High density yielded a higher number.

Notation	Description
Z (zero)	No plant life collected
T (trace	Finger-full on rake
S (sparse)	Handful on rake
M (moderate)	Rake-full of plants
D (dense)	Difficult to bring into boat

Table 3 Average Coverage Area

3.3 Identification of Invasive and Non-Invasive Species

The identification of plants was carried out by referring to a guide published by the Massachusetts Department of Environmental Management. Initially differences between Eurasian Milfoil and Small Pondweed were difficult to discern while at the lake. In such cases where the species of plant was difficult to determine a sample was stored in a ziploc bag until the guide could be more comprehensively referenced in identifying the species. This process was applied to submerged, emergent, and floating plants. The underlying cause behind the difficulty in identification was often depositions of silt and dead matter on the sample accumulated during the dredging process. When a comprehensive identification of the plants was permissible the sample was cleaned in order to facilitate species identification.

3.4 Interactive Data Mapping

Data were collected over a series of five non-consecutive days by hand while on site. Each day after surveying was completed the data were transferred to a computer in the form of a .csv file to back the data up. Csv files are spreadsheets of data and can be read by any excel type viewing program. When imported into the chosen program the titles of the spreadsheet columns were predetermined by the mapping app. These had to be renamed to the current titles of the spreadsheets in order to reflect similar depictions of data points as the 2013 IQP Group(Cheston, Gribble, & Plante, 2013). From here, the csv file was uploaded to myMaps; a function of google which uses google earth and drops pins at specified geocoordinate locations. MyMaps took the csv file and prompted the user to specify the longitude and latitude columns of the spreadsheet. The program also prompted the user to correlate the columns corresponding to the title and a short description of the point.

The map was then automatically generated with the user selected variables. Another advantage of myMaps was the ability to stratify the data by color and look at any combination of strata while others were hidden. By separating the main csv file into sub-csv files consisting of homogeneous aquatic plants a color could be chosen to represent the aforementioned aquatic plant on the map. Thus, all color depictions of plants were individualized and could be compared at will by turning the layer which housed the corresponding csv file on and off within myMaps. When each specific point had been checked to insure correct results and absence of grammatical errors the clearance of the map was changed to be viewable by everyone. As a result anyone with the url of the map would be referenced to the website and be able to view the map. It is important to note that the general public was not granted clearance to edit the map. This is so the data remains consistent and is not corrupted by those who have not actually performed the study.

3.5 Preparing for the Storm Drain Stenciling

There are approximately 750 storm drains within Worcester city limits that lead to Indian Lake. Using a map provided by the City of Worcester, we were able to geolocate each storm drain. The map has been added to Appendix C This map provided a general estimate of the last time the storm drains were monitored and stenciled. The first job was to clean off the stone from any grass or gravel on top of it. Once clean, the next step was to check if stenciling was necessary. Our group focused first on the groups of drains that did not have a date of when they were last stenciled. Once at the storm drain, we accessed the condition of the stenciling on the stone. The City of Worcester provided us with a brush, safety vests, the stencil, spraypaint, glue, stickers, and gloves in order to complete the stenciling of each drain.

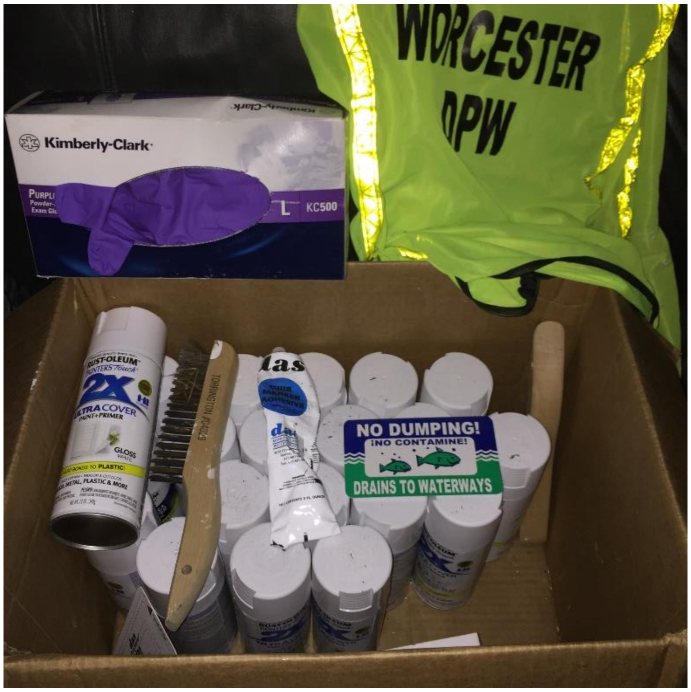


Figure 15 Materials Provided By the City of Worcester

3.5.1 Stenciling

Each storm drain was a different size, had different surroundings, and were in different conditions which forced us to assess each storm. If it was determined that stenciling was needed, we would check if the stencil fit on the stone easily. If the stencil fit, we used the white spray paint to stencil the drain. If the stencil would not fit directly, we would paint each word at different times so that we could adjust the stencil. The City of Worcester also provided stickers for us to put on the stone if we could not stencil the storm drain due to the size.

Figure 16 Storm drain with no Stenciling

3.5.2 Interactive Stenciling Monitoring

To make it easy for the ILWA to determine which storm drains need stenciling, we created an online mapping of the storm drains. Using the same GPS tracking smartphone app as we did for the plant survey, we were able to take a picture of each storm drain and post it onto an interactive map. Once uploaded onto the computer the map was color coded in accordance with the table 4 below.

Color	Status
Green	Stencil was recently completed
Yellow	Stencil is visible but could use retouching
Red	Needs to be stenciled

Table 4 Guidelines for Stenciling

3.6 Revit LT™ software

Using the map of Indian Lake with our data collection points, the same points were traced on AutoCad which was then imported to Revit LT™. The contour map was then imported to Revit LT™ in which we gave the lake depth at different areas.

Revit LT™ will allow the ILWA to have usage of a new program being used everywhere. Revit LT™ one has the ability to check the drawback effects of amount of water being drained from the lake.

4.0 Results

The differences in area coverage and frequency of occurrence were used to determine if a species spread in the time between the 2013 survey and our survey. These were documented in the google maps. We also incorporated contour data in a Revit map to be used by city officials for planning drawdowns based on where the areas of concern are for the two most problematic species: Eurasian Milfoil and Small Pond Weed.

Our group found that Eurasian milfoil had increased in both frequency of occurrence and area of coverage. The 2013 group observed 13 instances of Eurasian milfoil with an average coverage area of 1.69999. Our group observed 29 instance of Eurasian Milfoil with an average coverage area of 1.862069.

Our group found that Small Pond Weed occurred less frequently but in higher densities. The 2013 group found 10 instances of small pond weed with an average coverage area of 2.2. Our group found 6 instances of small pond weed with and average coverage area of 3.3333

Our group also found one instance of a new species of emergent macrophyte called Canada Rush.

4.1 Total Collection

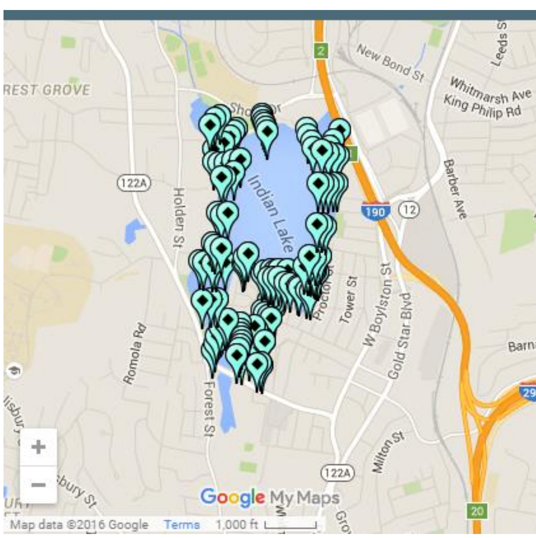


Figure 17 2013 Google Maps Total Collection Points

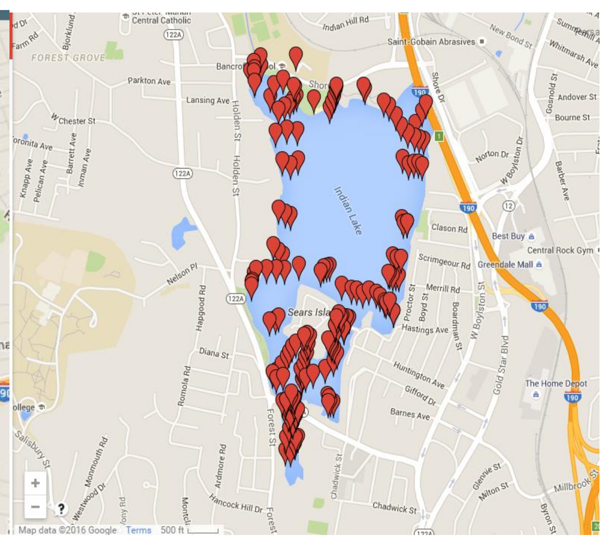


Figure 18 2015 Google Maps Total Collection Points

To keep our data consistent with the 2013 map survey, we made sure that we collected samples at the same coordinates or within a foot of each location. Comparing the data points of

2015 (right), we can see the same transect lines as that of the previous maps with additional points plotted for Little Indian Lake. Data was collected on the following dates: 9/27/2015, 10/4/2015, 10/12/2015, 10/27/2015. A total of 175 locations were sampled. A spreadsheet of the surveyed points has been added to appendix D. To compare the 2013 and 2015 survey's in detail we have isolated individual species in the following maps. The following sections have the left map display the results of the 2013 group and the right map display the results of our group. Additionally we have include a topographical surface map developed in Revit LT™ to correlate the depth data with the survey locations.

4.2 Revit LT™ depth distribution for the Lakes and surrounding areas

The map shows a topographical surface of the areas surrounding the Lake in black as well as a topographical surface of the Lake in yellow. The south end of the lake has contour line values denoting that is shallower than the north. This can also be seen with the addition of several contour lines.

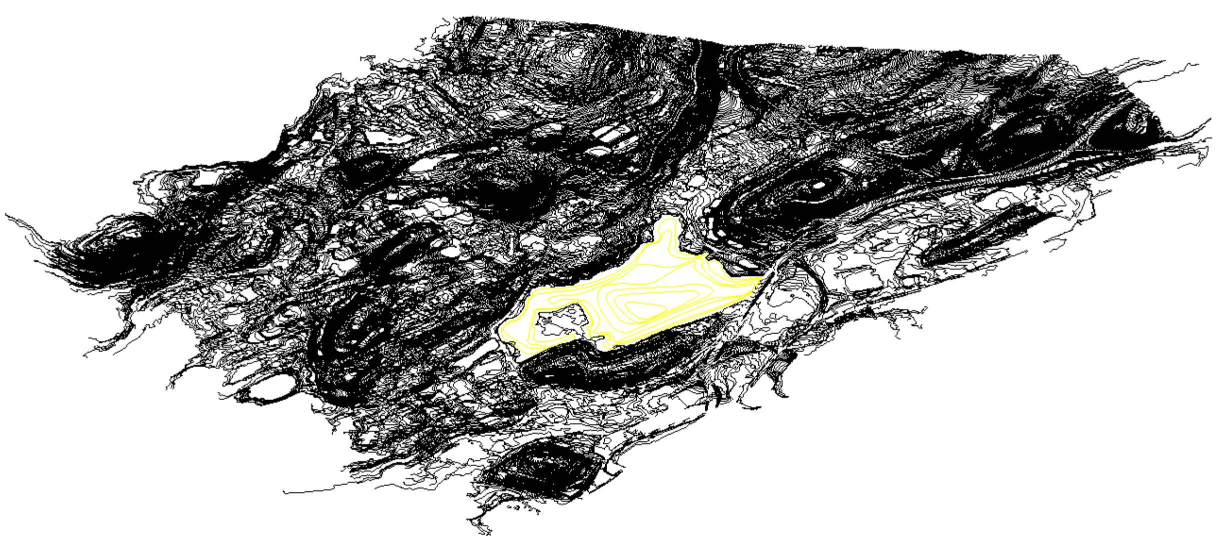


Figure 19 Rendered topographical map in Revit LTTM

4.3 Isolation of macrophyte species

4.3.1 Eurasian Milfoil increasing in Frequency of Occurrence

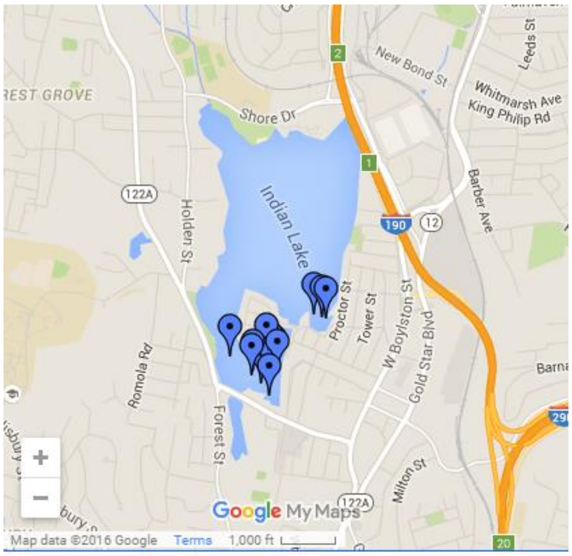


Figure 20 2013 Google Maps eurasian mifloil

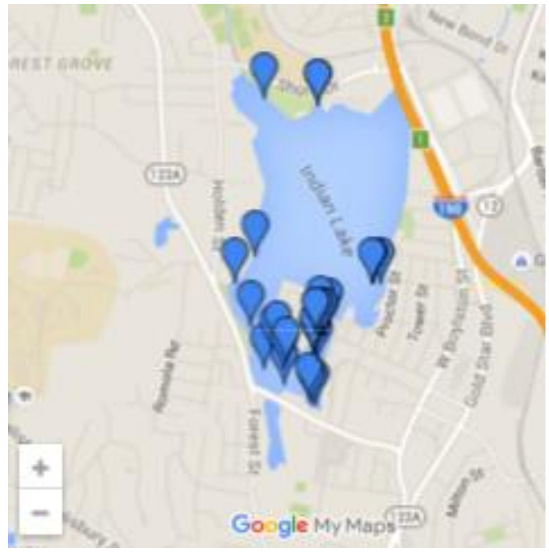


Figure 21 2015 Google Maps eurasian milfoil

In 2013 Eurasian Milfoil was primarily identified on the south side of the lake. Our sampling showed that the Milfoil population has spread throughout the Lake. Large concentrations are still located within the cove, south of Sears Island. Eurasian Milfoil requires sunlight to grow which is why we can see a trend of them growing near the shore line, where the water is shallow. There are many more instances of Eurasian Milfoil on the southern bank of Sears Island, which we did not report in this survey because our group was restricted to sampling along the transect lines outlined in the 2013 IQP Survey. We used this sampling method to keep both our survey and future surveys consistent. During survey dates our group visually observed that Eurasian Milfoil formed a dense matt extending 20 feet below Sears Island.

4.3.2 Reduction in Occurrence of Small Pond Weed and Increase in Density

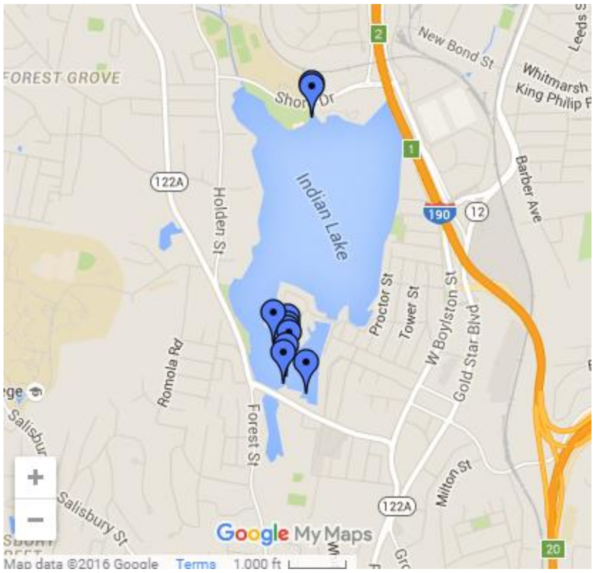


Figure 22 2013 Google Maps Small Pond Weed

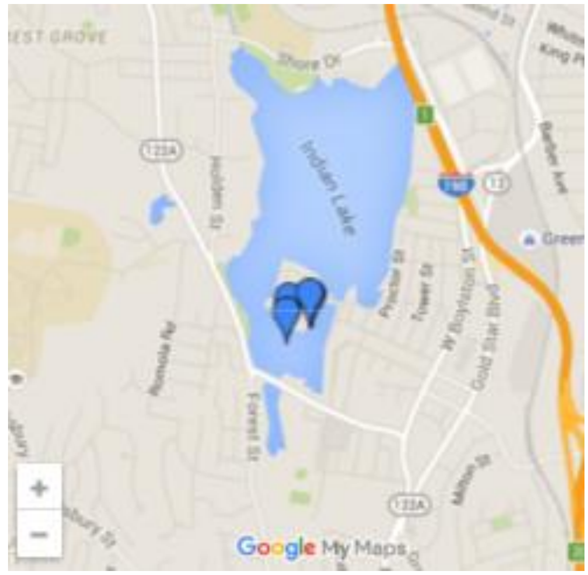


Figure 23 2015 Google Maps Small Pond Weed

Contrary to Eurasian Milfoil, we see a significant decrease in the locations of Pond weed grass in the 2015 data map. Pondweed was found in the north side of the Lake and, counting from the quantities of data points, there are about 50% less Pond weed grass around Sears Island. However, this does not mean that Pond Weed Grass are on the decline and are about to be eradicated from this lake, because the density of the weed collected at these points was 4 (difficult to pull up rake). In these locations it was found that Pond Weed Grass was growing among Eurasian Milfoil along the southern part of Sears Island. Furthermore, we observed that Small Pond Weed preferred to grow in the shallower sections of the lake, whereas Eurasian Milfoil dominated the relatively deeper areas of the southern cove.

4.3.3 Cattails

Dispersion of Cattails are widespread in the North Eastern part of the United States. Compared to submerge plants these cattails are wind pollinated, they are wind pollinated and the seeds can be spread to any shore line. From the comparisons between the maps of 2013 and 2015, we see a minor increase in the locations of the Cattails appearing in a new location by Hastings Avenue (Furthest right point)

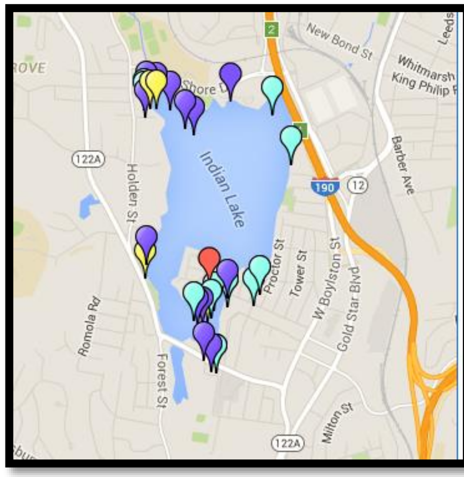


Figure 25 2013 Google Maps Cattails

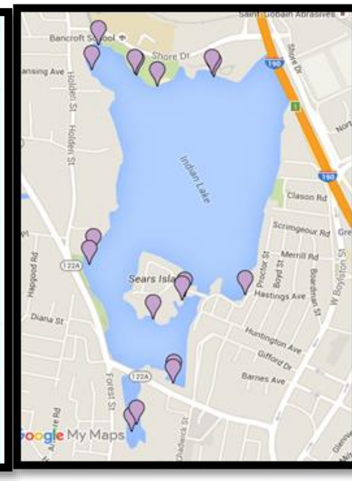
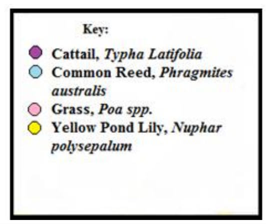


Figure 24 2015 Google Maps Cattails



4.3.4 Reeds

Comparing both maps, the 2015 shows that Reeds have disappeared from the north eastern side of the lake near I-190, but new shoots have sprouted near 122A road. We can conclude Reeds and Cattails grow in the same conditions and they can co-exist amongst each other.

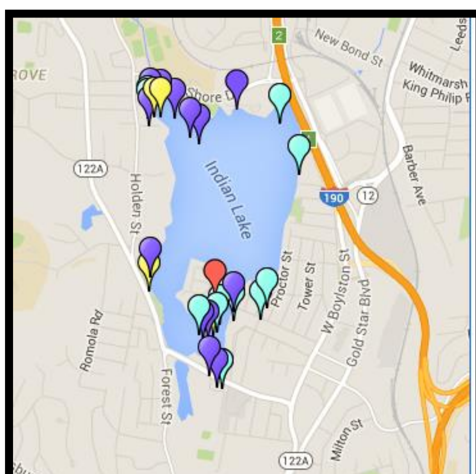


Figure 26 2013 Google Maps Collective Emergent Species

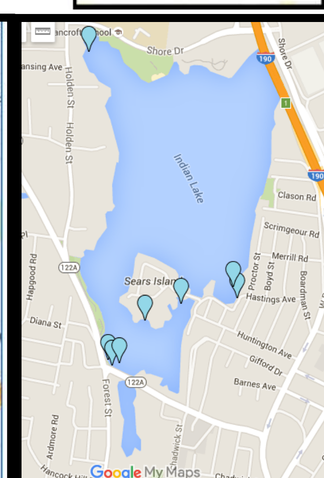


Figure 27 2015 Google Maps Common Reed

4.3.5 Lilies

In Indian Lake, Yellow pond lilies were found in the exact locations in both years, but in 2015 White lilies (labelled dark grey) were also found. Data from 2015 shows high density of the both types of lilies in Little Indian Lake which might suggest that there were already white lilies present in 2013 but hasn't spread on to Big Indian Lake. From this trend we can expect more white lilies to show up around the same existing locations and in newer areas as well.

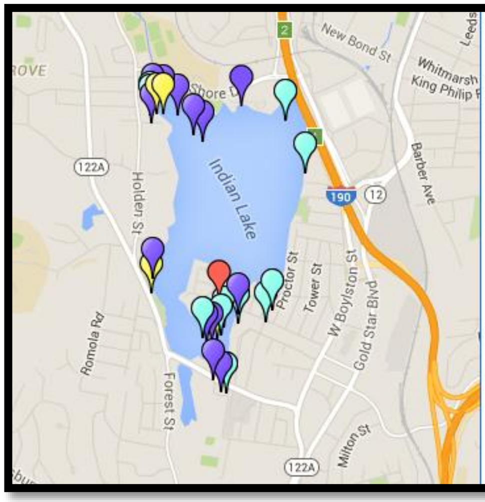


Figure 28 2013 Google Maps collective emergent plants

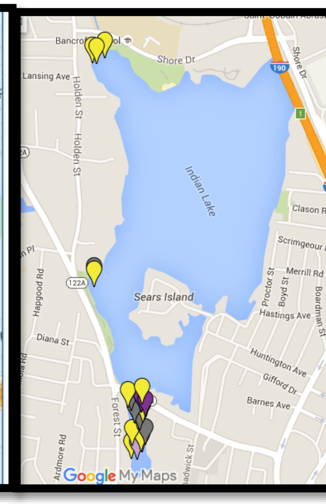


Figure 29 Google Maps 2015 Lillies

4.3.6 Canada Rush

A species called Canada rush has been found in 2015 survey (labelled in orange) which wasn't previously found in 2013. This species is prevalent in Massachusetts, New Hampshire, Rhode Island, Connecticut and

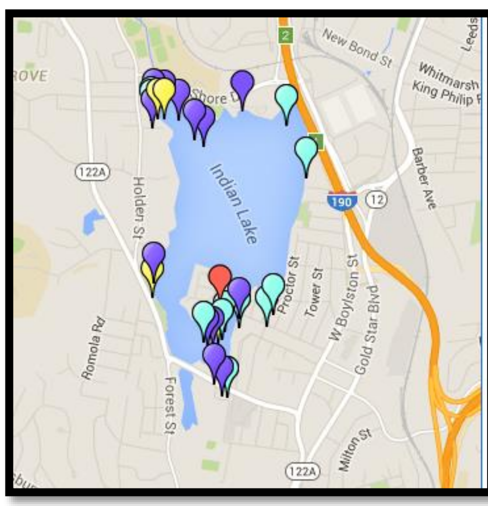


Figure 30 2013 Google Maps Collective Emergent Species

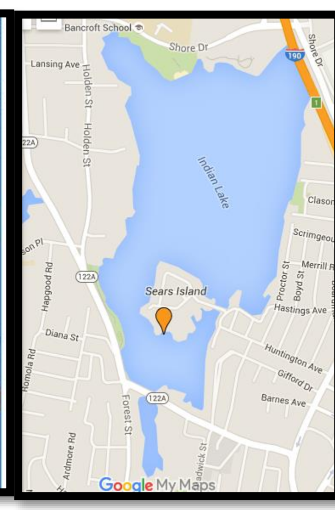


Figure 31 2015 Google Maps Canada Rush

Vermont. There is a likely chance that there are more Canada Rush plants along the shore line of Indian lake, but with the size of the plant, finding them can be a challenge.

4.4 Hydrologic Results of Water in Indian Lake

Figure 32 Map of Inflows at Indian Lake

Figure 32 shows the 4 main water inlets into Indian lake labelled from top to bottom in chronological order. We experienced the strongest current around stations 1 and 2 and little to no current at 3 and 4. There was a strong correlation between the presence of a strong current and depth of water. This correlation is affirmed by comparing topographical map created in

Revit LT™ and figure 32. We experienced heavily reduced flow in the area of the causeway." We also noted that inhabitants of the area reported the pipe underneath the causeway as blocked or not functional thus preventing water circulation.

During our time on Little Indian Lake we also experienced little to no currents while surveying for macrophytes.

4.5 Sediments at the Bottom of the Lake

Previous dredging samples were collected in 2013 by (Brown and Caldwell, 2013) company consist of mostly of sand. However, during the 2015 sediment samples were also collected and results show high quantities of black substance which turned out to be decomposed organic material such as grass. This means there has been such high quantities of weeds in the lake that the rate of decomposition is far less than the growth rate of the weeds

4.6 Local accounts of Human Inhibited Activity

During our survey we asked people their thoughts on the condition of the lake if presented with the opportunity. One Lake-shore resident stated that he had been removing submerged macrophytes from the area around his boating dock because of the effect the vegetation had on boat engine propellers. He stated that this prevented his friends from using his dock and was unsightly. This could also potentially be a promoter of macrophyte growth. Submerged macrophytes like Eurasian Milfoil and small pondweed can reproduce asexually when they are torn apart. Structure within the plant called turions can grow on their own and if the plants are improperly removed there is a high probability that some of the plant will remain in the water and reproduce in this manner.

We also asked two fishermen during our survey of what kind of fish they had been catching. In response they told us that they had been recommended the spot for its Cod but they hadn't had the luck to catch anything at the time of inquiry.

5.0 Discussion:

In this study we identified changes to the ecological composition of Indian Lake's macrophytes. In comparing them to two earlier studies we confirmed that macrophyte growth had increased.

Based on these studies we propose causes of the advancement of eutrophication and growth of problematic submerged macrophytes. We then propose solutions to eutrophication and the control of specific problematic species, and conclude with a cost benefit analysis of each.

Internal and external causes of eutrophication

To fix Indian Lake the external causes of eutrophication should be prioritized. Storm water runoff runoff has the most direct influence on the trophic status of Indian Lake and attenuating this influx of nutrients takes precedence over providing solutions for the symptoms of eutrophication (such as increased macrophyte growth.) The best way to prevent the nutrient laden storm water from entering the Lake is by raising awareness in the community on the effects of anthropogenic activity on the quality of water. This process, however, takes time and the recreational aspect of the lake may play a large role in persuading the community to take a more active role in preventing anthropogenic deposits from entering the water system. To retain this recreational aspect of the lake we provide solutions to the overgrowth of specific macrophytes impacting this recreational value.

Furthermore, research shows that macrophyte growth can contribute 10-60% of the nutrient loading that external sources can provide. (Klein 1997) Thus controlling the growth of submerged macrophytes may also have a direct impact on the trophic status of the lakes.

For these reasons the remainder of this section is devoted to classifying additional factors contributing to general macrophyte growth and solutions towards the most common problematic macrophyte species.

5.1 Hydrodynamic encouragement of submerged macrophyte growth

The consistent documentation of submerged macrophytes on the southern side of Sears Island has been attributed to slow water velocity in the area. According to (Madsen, et al. 2001) “Current velocity can benefit aquatic macrophyte growth by enhancing CO2 and nutrient supply, or be detrimental to growth due to mechanical stress.” The study specifies that the boundary for velocities resulting in nutrient uptake and mechanical stress is .01 m s^{-1} in freshwater macrophytes. The most influential factor to current velocity in the littoral zone of Indian Lake is the underlying currents of the lake as a result of inflows and outflows. The contribution of wind to current flow in this area can be discounted as the proximity of land and structures on either side of the southern bank impedes air movement. The current velocities for the 4 inflows to Indian Lake were measured and documented by (Brown and Caldwell 2013) and can be seen under the “Flow Rate” row for each inflow location in table 5.

Sample Location:	Station 1 (Ararat Brook) Subwatershed 06				Station 2 (Shoreham Street) Subwatershed 05				Station 3 (Left Culvert) Subwatershed 04				Station 4 (Little Indian Lake) Subwatershed 12			
	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV
Field Parameters																
pH (standard units)	7.41	8.37	7.99	0.05	7.38	7.81	7.59	0.02	7.32	8.03	7.60	0.04	7.27	9.08	8.31	0.09
Conductivity (µS/cm)	217	304	262	0.14	424	535	483	0.12	235	459	380	0.26	265	290	276	0.04
Turbidity (NTU)	0.1	1.5	0.88	0.70	2.3	6.1	3.8	0.47	0.4	27.2	7.98	1.62	2.2	85.3	37.0	1.05
Flow Rate (cf3/sec)	2.45	9.60	4.87	0.67	0.30	0.65	0.43	0.44	0.18	0.81	0.56	0.55	0.27	0.60	0.43	0.35
Laboratory Analytical Results																
Alkalinity (mg CaCO₃/l)	20	24	22.5	0.09	23	37	32	0.19	33	52	43.8	0.19	32	46	38.3	0.16
TSS (mg/l)	<5.0	<5.0	2.5	0	<5.0	9.5	5.38	0.65	<5.0	7.4	3.73	0.66	<5.0	10	7.25	0.45
Color (A.P.C.U.)	20	50	30	0.58	35	50	41.7	0.18	40	50	43.3	0.13	45	70	55	0.24
Total Nitrogen (mg/l)	1.1	1.8	1.5	0.21	0.89	1.8	1.35	0.31	1.1	1.4	1.23	0.10	0.99	1.3	1.12	0.14
Nitrogen (Nitrate/Nitrite)	0.75	1.3	1.09	0.24	0.8	1.2	0.98	0.21	0.33	0.76	0.57	0.31	0.12	0.46	0.29	0.83
Nitrogen (Total Kjeldahl)	0.31	0.49	0.4	0.19	0.32	0.89	0.6	0.49	0.43	1.1	0.67	0.44	0.82	1.2	0.98	0.16
Orthophosphorus (mg/l)	0.01	0.01	0.01	0.16	0.01	0.02	0.02	0.43	0.01	0.02	0.01	0.63	0.01	0.01	0.01	0
Soluble Phosphorus (mg/l)	0.02	0.02	0.02	0.19	0.02	0.06	0.03	0.66	0.01	0.03	0.02	0.61	0.01	0.03	0.02	0.27
Total Phosphorus (mg/l)	0.02	0.23	0.08	1.20	0.03	0.11	0.06	0.66	0.04	0.11	0.07	0.43	0.08	0.27	0.14	0.58
Fecal Coliform (col/100ml)	72	440	226	0.74	23	170	111	0.57	150	21,000	6,463	1.51	10	230	78	1.32

Notes:
CV = coefficient of variation.
µS/cm = Microsiemens per centimeter
NTU = Nephelometric Turbidity Units
cm^3/sec = Cubic centimeters per second
mg $CACO_3$/l = Milligrams of calcium carbonate per liter
TSS = Total Suspended Solids
mg/l = Milligrams per liter
A.P.C.U. = Apparent Platinum Cobalt Units
col/100 ml = Colonies per 100 milliliter
Mean value for TSS Station 1 result changed from "NA" to 2.5 to allow the standard value for "less than detectable limits", which is half the detectable limit.

Table 5 Table with flow rates for 4 inflows to Indian Lake (Brown and Caldwell 2011)

By applying a conversion factor of .01 meters to the mean flow rate at these points we see that the issue of mechanical stress as a result of current velocity arises only at station 1. At this point the mean current velocity is .487 m s^{-1} while at stations 2, 3, and 4 the mean current velocity is .043 m s^{-1}, .056 m s^{-1}, .043 m s^{-1} respectively. Thus, only the current in area one has the velocity to be a detriment to submerged macrophyte growth. This is supported within our survey by a decrease in yield of submerged macrophytes in the North-West quadrant of the lake.

Furthermore, our observations of increased growth and reduced current we experienced during our survey time at the southern bank can be explained through these finding as the inlets at stations 2, 3 and, 4, (Figure 32) have speeds under the velocity boundary condition stipulated by Madsen. These effects also explain the overgrowth of thick vegetation beds in Little Indian Lake due to the Lake's extremely slow current velocity. This information provides that a potential solution towards the growth of submerged macrophytes is to increase the current. One possible way this could be done is to increase the current velocity by improving the flow under the causeway mentioned in figure 32. It has been noted by the ILWA that this pipe is not well designed and fails to perform its function of increasing water circulation by being too elevated.

5.1 Recursive positive effects of Macrophytes on Sedimentation in the Littoral Zone

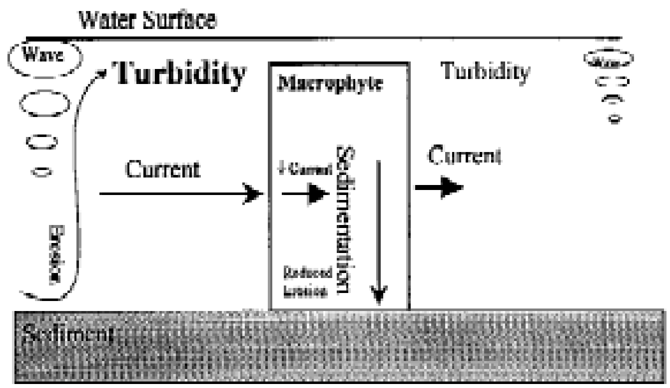


Figure 33 Resuspension of Sediments Process

Madsen, et al,, (2001) also compiled evidence of instances where submerged macrophytes increased sedimentation within littoral zones of lakes as a result of their negative effect on current velocity. (Figure 33) This has the added effect of reducing resuspension of nutrients as a result of decreased turbidity in water within thick macrophyte beds. The precursor to nutrient resuspension is the erosion of silt and soil of the lakebed. The erosion of sediments from lakebeds requires for the drag forces of current waters to overcome the frictional forces of the lakebed. This is not feasible with the relatively weak initial water currents in Indian Lake compounded with the reduction in current velocity by the mats of vegetation. The result of this was seen in the entire southern half of Indian Lake when dredging the lake bottom yielded thick black soil depositions signifying large amounts of aquatic secession and little erosion in the area. (Doyle 2000) supports this finding of increased macrophyte growth with a negative correlation between turbidity and available light concentration. This is the most likely explanation for progressing macrophyte growth in Indian Lake as nutrients accumulate in problematic areas faster than the resuspension process can remove them. This then expands the littoral zone and provides room for more growth of submerged macrophytes by eliminating the restriction of light as a result of depth.

Growth of Specific Problematic Species: Eurasian Milfoil and Small Pond Weed

Previous studies have noted that competitive exclusion is likely the cause of growth of Eurasian Milfoil in Indian Lake. The specific increase in growth of Small Pond Weed excludes the effect of competitive exclusion alone as the sole limiting factor on the biodiversity of the Lake. If the competition for nutrients or sunlight were the only factor dictating the ecology then the growth of the native species Potamogeton pusillus would be reduced. The results contradict this and the collective growth of the two species can most likely be attributed to their hardy, perennial nature. Both Small Pond Weed and Eurasian Milfoil are known to grow earlier in the spring season due to their higher tolerance of cold. For comparison Eurasian Milfoil begins growing in temperatures of 15 degrees centigrade (Department of ecology State of Washington 2016) while similar species, such as *HYDRILLA VERTICILLATA (*which have the potential to grow in the area) require temperatures of 20 degrees centigrade to begin growth. (University of Florida 2016) Similarly, some species of pondweed are able to survive and grow in snow and ice, thus demonstrating the species tolerance of cold. As such, the factor of competitive exclusion could easily be confounded with the factor of their early growth allowing for these two problematic species to establish dominance in the area. It is only once these two species have established their dominance does the role of competitive exclusion for light limit the growth of other, later growing macrophytes.

Furthermore, we speculate that the annual drawdown imposed by the ILWA has an initial negative effect on the biodiversity of submerged macrophytes by restarting the growth of all submerged macrophytes and asserting dominance of these two early growing problem species. In essence, the drawdown is providing favorable conditions specifically for these two species. By killing the majority of other weeds that could compete with these two problematic weeds in normal conditions, the Drawdown has created artificial conditions which favor the growth of early growing perennial submerged macrophytes.

The continual reappearance of both Eurasian Milfoil and Small Pond Weed can also be explained with the results of (Dugdale, Daniel Clements and Butler 2012). The study documents and contributes cases "where thick beds of submerged aquatic vegetation are exposed during a drawdown, typically only the surface stems are damaged, and these act as a blanket preventing desiccation of material lower in the mounds, resulting in subsequent rapid regrowth." The presence of large amounts of dead matter in the lake late in the growing season and also the observation of thick vegetative beds in Indian lake corroborates this finding as there are likely areas in the sediment south of Sears Island which is not being penetrated by the cold.

Formation of spatial heterogeneity as a result of light limitations

The developing spatial heterogeneity between the two problem species in Indian Lake can be potentially explained by a macrophyte study conducted in Lake Pleasant, Pennsylvania. The study concluded that in nutrient rich waters a similar milfoil, called Myriophyllum exalbescens, preferred to grow in deeper, nutrient-rich waters while "shallow nutrient-rich sites were dominated by several different species of Potamogeton" (Johnson and Ostrofsky 2004).

Many studies cite that the competitive success of myriophyllum Spicatum is a result of its quick and early growth extending into the water column and thus shading the surround submerged macrophytes. A key study indicates that the growth of Eurasian Watermilfoil had significantly higher growth rates than pondweed species similar to small pondweed in zero and medium shade levels as seen in figure 34 (Zefferman 2015) In the case of Indian Lake, the retention of Small Pond Weed is likely a result of the extremely shallow waters limiting the ability of Eurasian milfoil to form a canopy over the native species and restrict its access to light.

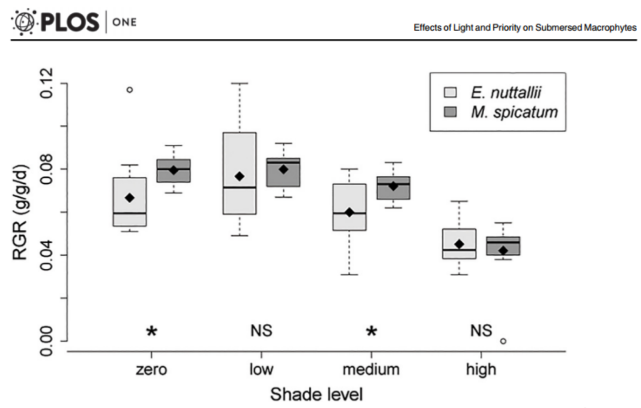


Figure 34 Shading effects on Eurasian Milfoil (Zefferman 2015)

Suggested Remedies

The factors promoting general macrophyte growth south of Sears Island are a result of hydrodynamics. The factors promoting the specific growth of Eurasian milfoil and small pond weed are a result of the combined effects of their seasonal growth pattern and their subsequent competitive exclusion for light from other species. There are several solutions to controlling these species and a cost benefit analysis has been added to appendix E. Out of these solutions, we believe that imposing a lake drawdown and installing plastic sheets down on the bottom of the lake bed to be the most effective solution in control the problematic species. A summary of the treatments and the factors contributing to this decision can be seen in table 6.

Treatment	Cost	Pros	Cons
Drawdown	Very cheap	Limits overgrowth of aquatic plants	Promoting Growth of problematic species
Dredging	• Highly expensive. • Millions of dollars	Improves water circulation and removes weeds	
Chemical Treatment	• Somewhat Expensive but cheaper than dredging • Hundreds of thousands of dollars	Effective in preventing aquatic growth by restricting available nutrients	Inserts foreign materials into lake which have the potential to disturb natural ecology
Light Screens	• Affordable • Tens of thousands of dollars	Shown to be completely effective in areas where treatment was applied	Requires reapplication of treatment every 2-3 years.

Table 6 Summary of Cost Benefit

The first part of our solution addresses the general growth of macrophytes in Indian Lake. Prior to the establishment of the annual drawdown the lake was rendered useless. The results clearly indicate that the drawdown is useful tool in managing the overall growth of aquatic life in the Lake.

The second part deals with the species that have the potential to resist the effects of cold implemented by the drawdown. This solution instead manipulates light the penetration of light to the submerged macrophytes by shielding them from solar exposure. Both species require large amounts of sunlight and this could prove to be an efficient method of treating Eurasian Milfoil and Small Pond Weed.

There are many benefits of artificial shading through the use of plastic sheets. First, is that their use is confined to specific lake areas. Specifically, the sheets are put on the very bottom of the lake and as such people still have access to the Lake as these sheets do not interfere with boating, swimming, or fishing. Furthermore, these sheets are none-toxic so their impact on surrounding wildlife is limited to their ecological responses. The sheets can be removed if the results indicate that they are causing more harm than good. These sheets also usually do not require a permit for installment.

Some drawbacks of using plastic sheets is that they are expensive and difficult to apply to large areas. Furthermore, they are also difficult to relocate and remove if necessary.

This study proposes that the benefits of applying Polypropylene sheets outweigh the drawbacks. Furthermore, studies indicate that anchored polypropelene sheets were completely effective in removing submerged macrophytes such as “Najas flexilis, Potamogeton gramineus, P. crispus, P. foliosus, and P. pusillus for 1 year in an area that previously had been drawn down and exposed to freezing.” (Cooke and Gorman 1980) The study noted that the water column above the sheets was completely devoid of all submerged macrophyte indicated a stark increase in quality of water. Furthermore, these sheets can be used in small area of the lake as a test run for their extremely localized results. To cover the problematic area south of Sear’s Island in Polypropelen would cost $2,341-$11,019 based on 2002 prices of US$14,715 per ha to $65,900 per ha. This estimate was created by evaluating the problematic area to be 18000 square feet.

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Appendix A:

System (period/ year)	N influx (mmol m^{-2} a^{-1})	P influx (mmol m^{-2} a^{-1})	Mean annual nitrogen concentration in system (μmol l^{-1})	Mean annual phosphorus concentration in system (μmol l^{-1})	Annual primary production (g C m^{-2} a^{-1})
River Rhine & river Ems					
‘background’ situation			45 ± 25 (tN)	1.8 ± 0.8 (tP)	
early 1980s					
early 1990s					
English Channel					
‘background situation			5.5 ± 0.5 (winter NO_3)	0.45 ± 0.05 (winter DIP)	
early 1930s					
early 1980s					
early 1990s					
North Sea					
‘background’ situation			9.1 ± 3.1 (NO_3) (near coast)	0.57 ± 0.13 (DIP) (near coast)	
early 1930s					
early 1980s					
early 1990s					
Dutch western Wadden Sea					
‘background’ situation			13 ± 6 (tN) ca. 4 (DIN)	0.8 ± 0.3 (tP) ca. 0.3 (DIP)	<50
early 1980s					
early 1990s					
Ems estuary					
‘background’ situation	(rivers) 315 (tN)	(rivers) 16 (tP)	(for salinity gradient) 10–45 (tN)	(for salinity gradient) 0.7–1.8 (tP)	
early 1980s	3850 (tN)	90 (tP)			
early 1990s	3850 (tN)	50 (tP)			
The Baltic Sea					
‘background’ situation (ca. 1900)	57 (tN) (rivers+AD+fix)	0.8 (tP) (rivers + AD)			80–105
early 1980s	230 (tN) (rivers+AD+fix)	6.7 (tP) (rivers + AD)			135
Narragansett Bay					
‘prehistoric’ situation	18 – 76 (DIN) (rivers + AD) 270–330 (DIN) (+ sea input)	∼ 1 (DIP) (rivers + AD) 61 (DIP) (+ sea input)			130
‘recent’ (1990s)	1445 (DIN) (rivers + AD) 1725 (DIN) (+ sea input)	73 (DIP) (rivers + AD) 140 (DIP) (+ sea input)			290
Long Island Sound					
1952	-	-			ca. 200
early 1980s	1040 (tN) (rivers + AD)	70 (tP) (rivers + AD)			300
Chesapeake Bay					
mid 1980s	290–2140 (DIN) 1430 (tN)	30 (DIP) 40 (tP)			400–600

Appendix B:

Subwatershed	Dry Weather Baseflow Pollutant Loads [kg/yr]		
	Total Phosphorus	Total Nitrogen	Total Suspended Solids
01	--	--	--
02	--	--	--
03	--	--	--
04	24	422	2,550
05	15	355	2,171
06	249	4,482	7,469
07	--	--	--
08	--	--	--
09	--	--	--
10	--	--	--
11	--	--	--
12	38	298	2,349
13	--	--	--
Total	326	5,557	14,539

Sample Location:	Station 1 (Ararat Brook) Subwatershed 06				Station 2 (Shoreham Street) Subwatershed 05				Station 3 (Left Culvert) Subwatershed 04				Station 4 (Little Indian Lake) Subwatershed 12			
	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV
Field Parameters																
pH (standard units)	7.41	8.37	7.99	0.05	7.38	7.81	7.59	0.02	7.32	8.03	7.60	0.04	7.27	9.08	8.31	0.09
Conductivity (µS/cm)	217	304	262	0.14	424	535	483	0.12	235	459	380	0.26	265	290	276	0.04
Turbidity (NTU)	0.1	1.5	0.88	0.70	2.3	6.1	3.8	0.47	0.4	27.2	7.98	1.62	2.2	85.3	37.0	1.05
Flow Rate (cf3/sec)	2.45	9.60	4.87	0.67	0.30	0.65	0.43	0.44	0.18	0.81	0.56	0.55	0.27	0.60	0.43	0.35
Laboratory Analytical Results																
Alkalinity (mg $CaCO_3$/l)	20	24	22.5	0.09	23	37	32	0.19	33	52	43.8	0.19	32	46	38.3	0.16
TSS (mg/l)	<5.0	<5.0	2.5	0	<5.0	9.5	5.38	0.65	<5.0	7.4	3.73	0.66	<5.0	10	7.25	0.45
Color (A.P.C.U.)	20	50	30	0.58	35	50	41.7	0.18	40	50	43.3	0.13	45	70	55	0.24
Total Nitrogen (mg/l)	1.1	1.8	1.5	0.21	0.89	1.8	1.35	0.31	1.1	1.4	1.23	0.10	0.99	1.3	1.12	0.14
Nitrogen (Nitrate/Nitrite)	0.75	1.3	1.09	0.24	0.8	1.2	0.98	0.21	0.33	0.76	0.57	0.31	0.12	0.46	0.29	0.83
Nitrogen (Total Kjeldahl)	0.31	0.49	0.4	0.19	0.32	0.89	0.6	0.49	0.43	1.1	0.67	0.44	0.82	1.2	0.98	0.16
Orthophosphorus (mg/l)	0.01	0.01	0.01	0.16	0.01	0.02	0.02	0.43	0.01	0.02	0.01	0.63	0.01	0.01	0.01	0
Soluble Phosphorus (mg/l)	0.02	0.02	0.02	0.19	0.02	0.06	0.03	0.66	0.01	0.03	0.02	0.61	0.01	0.03	0.02	0.27
Total Phosphorus (mg/l)	0.02	0.23	0.08	1.20	0.03	0.11	0.06	0.66	0.04	0.11	0.07	0.43	0.08	0.27	0.14	0.58
Fecal Coliform (col/100ml)	72	440	226	0.74	23	170	111	0.57	150	21,000	6,483	1.51	10	230	78	1.32

Notes:

CV = coefficient of variation.

µS/cm = Microsiemens per centimeter

NTU = Nephelometric Turbidity Units

cm^3/sec = Cubic centimeters per second

mg $CACO_3$/l = Milligrams of calcium carbonate per liter

TSS = Total Suspended Solids

mg/l = Milligrams per liter

A.P.C.U. = Apparent Platinum Cobalt Units

col/100 ml = Colonies per 100 milliliter

Mean value for TSS Station 1 result changed from "NA" to 2.5 to allow the standard value for "less than detectable limits", which is half the detectable limit.

Appendix C:

wb03
wb07
wb09
wb10
wb11
fb15
fb14
fb06
fb07
fb03
fb08
fb10
fb12
fb09
fb04
fb01
fb05
fb02
fb13
fbSTATE01
ilt01
bb45
7-21
32
7/20
34
12/12
46
7-24
39
7-23
26
74
11/29
42
1 inch = 400 feet
N
S
E
W


wb02
wb01
mb33
mb07
mb04
mb08
mb02
mb35
mb10
mb38
wb12
mb09
il07
36
mb03
mb01
il06
il05
il11
il13
il12
il14
il10
il09
il01
wab02
il03
8-7
il04
wab01
35
bb35
bb56
bb55
bb53
bb59
bb26
bb23
bb22
bb44
bb33
bb54
bb16
bb15

Appendix D:

Transect Point (line # . point #)	Date and Time	Plant collected	Longitude	Latitude	Elevation	Coverage Area (0,T,S,M,D,VD)	
1.1	Eurasian Milfoil	9/27/2015	42.29365433	-71.81145008	162.827116	D	4
1.2	9/27/2015 9:12:05	Eurasian Milfoil	42.29369549	-71.81157882	162.5901775	S	2
1.3	9/27/2015 9:11:11	Nothing	42.29371699	-71.81184386	161.9334393	(null)	
1.4	9/27/2015 9:07:23	Eurasian Milfoil	42.29373027	-71.81202063	158.8666058	D	4
2.1	9/27/2015 9:04:20	Eurasian Milfoil	42.29322958	-71.81173598	162.731657	T	1
2.2	9/27/2015 9:02:44	Eurasian Milfoil	42.29325158	-71.81173297	162.8972454	T	1
2.3	9/27/2015 8:59:34	Eurasian Milfoil	42.29325653	-71.8120814	162.0243816	S	2
2.4	9/27/2015 8:57:53	Eurasian Milfoil	42.2933284	-71.81226815	159.9966106	D	4
2.5	9/27/2015 8:56:41	Eurasian Milfoil	42.2933284	-71.81226815	161.5281048	D	4
3.1	9/27/2015 9:23:24	Eurasian Milfoil	42.29223456	-71.81215282	162.8544598	T	1
3.2	9/27/2015 9:22:09	Small Pond Weed	42.29246247	-71.81231517	162.1869793	S	
3.3	9/27/2015 9:21:36	Eurasian Milfoil	42.29253015	-71.81241718	161.3330975	S	2
3.4	9/27/2015 9:20:46	Eurasian Milfoil	42.29260291	-71.81247896	160.9427776	S	2
3.5	9/27/2015 9:19:00	Small Pond Weed	42.29273844	-71.81256705	158.4013348	D	
3.6	9/27/2015 9:16:55	Small Pond Weed	42.29280415	-71.81266772	159.6874676	D	
4.1	9/27/2015 9:34:07	Eurasian Milfoil	42.2903022	-71.81234099	161.4891033	D	4
4.2	9/27/2015 9:32:53	Eurasian Milfoil	42.29033179	-71.81251299	160.3738689	S	2
4.3	9/27/2015 9:31:09	Eurasian Milfoil	42.29058559	-71.81269311	162.4941082	S	2
5.1	9/27/2015 9:28:35	Nothing	42.29130866	-71.81394621	162.5008831	(null)	
5.2	9/27/2015 9:27:12	Nothing	42.29146133	-71.81350289	162.4637127	(null)	
5.3	9/27/2015 9:26:10	Nothing	42.29165215	-71.81283292	161.9446697	(null)	
5.4	9/27/2015 9:25:05	Nothing	42.29193646	-71.81233864	165.2552776	(null)	
6.1	9/27/2015 9:39:26	Small Pond Weed	42.29262658	-71.81378578	160.7204266	T	
6.2	9/27/2015 9:41:18	Small Pond Weed	42.292533	-71.81383188	163.179533	T	
6.3	9/27/2015 9:42:26	Small Pond Weed	42.2922416	-71.8138577	161.6367474	S	
6.4	9/27/2015 9:43:00	Eurasian Milfoil	42.29206315	-71.81396138	163.5016155	T	1
6.5	9/27/2015 9:43:54	Eurasian Milfoil	42.2917946	-71.81405987	162.5030193	T	1
6.6	9/27/2015 9:45:06	Nothing	42.29159875	-71.81424201	163.8078899	(null)	
6.7	9/27/2015 9:46:36	Nothing	42.29134776	-71.81409021	163.9217205	(null)	
6.8	9/27/2015 9:47:26	Eurasian Milfoil	42.29118641	-71.81413363	160.6519451	T	1
7.1	9/27/2015 9:55:15	Nothing	42.29157545	-71.8155754	160.6800823	(null)	
7.2	9/27/2015 9:54:37	Eurasian Milfoil	42.29180306	-71.81529234	161.4264202	T	1
7.3	9/27/2015 9:53:56	Nothing	42.29209676	-71.81499529	161.5811443	(null)	
7.4	9/27/2015 9:53:13	Eurasian Milfoil	42.29230489	-71.81488305	161.3946819	T	1
7.5	9/27/2015 9:51:08	Eurasian Milfoil	42.29252391	-71.81469941	164.4734783	T	1
7.6	9/27/2015 9:50:18	Eurasian Milfoil	42.292691	-71.81451056	165.2413006	S	2
8.1	9/27/2015 9:58:13	Nothing	42.29371074	-71.81548471	160.618742	(null)	
8.2	9/27/2015 9:59:03	Nothing	42.2936172	-71.81564111	162.1041546	(null)	
8.3	9/27/2015 10:00:16	Eurasian Milfoil	42.29356632	-71.81599516	160.5188885	S	2
9.1	10/4/2015 8:30:40	Nothing	42.29578509	-71.81432524	165.0083904	(null)	
9.2	10/4/2015 8:29:37	Nothing	42.29564067	-71.81512697	162.8934612	(null)	
9.3	10/4/2015 8:28:21	Nothing	42.29565036	-71.81560281	162.4579754	(null)	
9.4	10/4/2015 8:27:39	Nothing	42.29565568	-71.8161649	163.7236614	(null)	
9.5	10/4/2015 8:26:47	Eurasian Milfoil	42.29542442	-71.81691273	162.6432171	M	3
10.1	10/4/2015 9:50:57	nothing	42.2955403	-71.81306158	162.9002972	nothing	
10.2	10/4/2015 9:51:42	nothing	42.29570442	-71.81290794	162.2818279	nothing	
10.3	10/4/2015 9:52:13	nothing	42.29573606	-71.81273075	162.7466106	nothing	
10.4	10/4/2015 9:52:42	nothing	42.29575127	-71.81256738	165.1162395	nothing	
12.1	10/4/2015 9:48:32	nothing	42.29500046	-71.81189532	165.1880169	nothing	
12.2	10/4/2015 9:47:13	nothing	42.29481845	-71.8113137	163.901762	nothing	
12.3	10/4/2015 9:46:38	nothing	42.29478849	-71.81102755	163.6741619	nothing	
12.4	10/4/2015 9:46:22	nothing	42.29468673	-71.81068758	162.1975384	nothing	
12.5	10/4/2015 9:45:31	nothing	42.29480844	-71.8103388	162.4432049	nothing	
13.1	10/4/2015 9:45:02	nothing	42.29468413	-71.80988836	163.356535	nothing	

13.2	10/4/2015 9:43:52	nothing	42.29455983	-71.8096789	164.3614788	nothing	
13.3	10/4/2015 9:43:06	nothing	42.2943297	-71.80941906	163.7519207	nothing	
13.4	10/4/2015 9:42:01	nothing	42.29425758	-71.80935888	163.1468182	nothing	
14.1	10/4/2015 9:37:52	Eurasian Milfoil	42.29535506	-71.80861398	160.3554363	T	1
14.2	10/4/2015 9:38:34	nothing	42.29535892	-71.8087682	162.2069988	nothing	
14.3	10/4/2015 9:39:30	Eurasian Milfoil	42.29534689	-71.80896652	160.4396038	T	1
14.4	10/4/2015 9:39:17	Eurasian Milfoil	42.29543272	-71.80911647	161.7917767	T	1
14.5	10/4/2015 9:39:59	nothing	42.29547174	-71.80920389	159.9278851	nothing	
15.1	10/4/2015 9:34:07	nothing	42.29607176	-71.80850727	162.8338299	nothing	
15.2	10/4/2015 9:34:34	nothing	42.29608391	-71.80874012	163.3719158	nothing	
15.3	10/4/2015 9:34:54	nothing	42.296165	-71.80897431	162.7370281	nothing	
16.1	10/4/2015 8:51:35	nothing	42.30254661	-71.8144306	161.5501995	nothing	
16.2	10/4/2015 8:51:00	nothing	42.30244682	-71.81462439	163.3432903	nothing	
16.3	10/4/2015 8:50:11	nothing	42.30226711	-71.81485028	162.2134686	nothing	
16.4	10/4/2015 8:49:42	nothing	42.30215061	-71.81515312	163.8743572	nothing	
16.5	10/4/2015 8:48:16	nothing	42.30201968	-71.81546174	168.5160809	nothing	
17.1	10/4/2015 8:53:00	Eurasian Milfoil	42.30325639	-71.81521062	164.8035564	S	2
17.2	10/4/2015 8:55:50	nothing	42.3030196	-71.81572912	164.0904217	nothing	
17.3	10/4/2015 8:57:10	nothing	42.3025275	-71.81596013	171.3621502	nothing	
18.1	10/4/2015 8:44:15	nothing	42.30111259	-71.81566014	166.6576824	nothing	
18.2	10/4/2015 8:45:43	nothing	42.30125567	-71.81502689	164.6739178	nothing	
18.3	10/4/2015 8:46:34	nothing	42.3011822	-71.81442188	165.4412518	nothing	
19.1	10/4/2015 8:41:54	nothing	42.29999604	-71.8143819	164.3279705	nothing	
19.2	10/4/2015 8:40:54	nothing	42.29981763	-71.8148056	166.9475994	nothing	
19.3	10/4/2015 8:40:18	nothing	42.29998749	-71.81524524	164.8442669	nothing	
20.1	10/4/2015 8:36:27	nothing	42.29802491	-71.81547523	163.1902752	nothing	
20.2	10/4/2015 8:37:27	nothing	42.29789327	-71.81509294	163.1173382	nothing	
20.3	10/4/2015 8:38:00	nothing	42.29780048	-71.81477451	163.030241	nothing	
21.1	10/4/2015 8:32:41	Eurasian Milfoil	42.29656947	-71.81578813	162.9738445	T	1
21.2	10/4/2015 8:33:57	nothing	42.29634216	-71.81549351	163.9465008	nothing	
21.3	10/4/2015 8:34:46	nothing	42.29619463	-71.81524314	162.6313152	nothing	
22.1	10/4/2015 9:04:48	Eurasian Milfoil	42.30296692	-71.81219154	169.4397259	M	3
22.2	10/4/2015 9:05:31	Eurasian Milfoil	42.30291198	-71.81218173	173.9976482	T	1
22.3	10/4/2015 9:06:14	nothing	42.30276651	-71.81221141	172.8012371	nothing	
22.4	10/4/2015 9:06:45	nothing	42.30252683	-71.81229539	169.5558147	nothing	
22.5	10/4/2015 9:07:42	nothing	42.30228287	-71.81242372	167.5664959	nothing	
22.6	10/4/2015 9:08:27	nothing	42.30208439	-71.81254677	167.8699017	nothing	
23.1	10/4/2015 9:11:06	nothing	42.30234012	-71.80947589	159.1601238	nothing	
23.2	10/4/2015 9:12:04	nothing	42.30216812	-71.80918931	160.1271648	nothing	
23.3	10/4/2015 9:13:00	nothing	42.30177702	-71.80880031	162.94174	nothing	
24.1	10/4/2015 9:18:45	nothing	42.30227269	-71.80708403	168.4249554	nothing	
24.2	10/4/2015 9:19:34	nothing	42.30193997	-71.80729785	167.7686443	nothing	
24.3	10/4/2015 9:20:42	nothing	42.30146731	-71.80765031	170.5602703	nothing	
25.1	10/4/2015 9:16:33	nothing	42.30080355	-71.80720339	164.4472942	nothing	
25.2	10/4/2015 9:15:28	nothing	42.30085669	-71.80744923	158.182951	nothing	
25.3	10/4/2015 9:14:55	nothing	42.3009411	-71.80769851	158.5309734	nothing	
25.4	10/4/2015 9:14:23	nothing	42.30110287	-71.8081207	157.3553143	nothing	
25.5	10/4/2015 9:13:49	nothing	42.30137079	-71.80846981	168.3013592	nothing	
26.1	10/4/2015 9:22:25	nothing	42.29979961	-71.80729517	164.3006268	nothing	
26.2	10/4/2015 9:24:11	nothing	42.29989227	-71.80748879	165.5137005	nothing	
26.3	10/4/2015 9:25:24	nothing	42.29988125	-71.80774595	163.2093182	nothing	
26.4	10/4/2015 9:26:02	nothing	42.29980279	-71.80805239	163.4393597	nothing	
26.5	10/4/2015 9:27:53	nothing	42.30007499	-71.80839144	162.7118816	nothing	
27.1	10/4/2015 9:30:31	nothing	42.29750644	-71.8081414	162.0870647	nothing	
27.2	10/4/2015 9:31:22	nothing	42.29749043	-71.80816144	161.9794598	nothing	
27.3	10/4/2015 9:32:06	nothing	42.29745842	-71.80837283	161.439909	nothing	

27.4	10/4/2015 9:32:30	nothing	42.29767383	-71.80843519	161.8713055	nothing
28.1	10/4/2015 9:00:18	nothing	42.3033283	-71.81680092	167.1507854	nothing
28.2	10/4/2015 8:58:59	nothing	42.3032004	-71.81682782	173.6927166	nothing
17.6	10/12/2015 17:40	Yellow Lily	42.3035539	-71.81710258	145.6429729	N/A
17.5	10/12/2015 17:38	Yellow Lily	42.30376873	-71.81646371	172.9720135	N/A
30.1	10/12/2015 17:36	Yellow Lily	42.30391206	-71.81690837	171.1386395	N/A
17.4	10/12/2015 17:35	Yellow Lily	42.30353903	-71.81688289	169.0169964	N/A
30.2	10/12/2015 17:22	White Lily	42.29508449	-71.81701558	163.6938763	N/A
9.5	10/12/2015 17:21	Yellow Lily	42.29497247	-71.81700996	166.6086102	N/A
30.3	10/27/2015 17:51	White Lily	42.28835098	-71.81508506	144.7293377	N/A
31.1	10/27/2015 17:47	Yellow Lily	42.28864975	-71.81458013	163.4939251	N/A
31.2	10/27/2015 17:47	Yellow Lily	42.28887786	-71.81504885	157.2555218	N/A
31.3	10/27/2015 17:45	Yellow Lily	42.28890364	-71.81437519	169.0522137	N/A
32.1	10/27/2015 17:42	Yellow Lily	42.28950713	-71.81473553	161.207365	N/A
32.2	10/27/2015 17:38	Yellow Lily	42.28942977	-71.81468071	148.5680218	N/A
32.3	10/27/2015 17:36	Yellow Lily	42.28975582	-71.81448424	156.978178	N/A
33.1	10/27/2015 17:34	Yellow Lily	42.28973441	-71.81494248	166.9543743	N/A
33.2	10/27/2015 17:30	White Lily	42.2901921	-71.81508279	166.1965618	N/A
33.3	10/27/2015 17:30	Yellow Lily	42.290146	-71.81456479	163.262907	N/A
34.1	10/27/2015 17:27	Yellow Lily	42.29014093	-71.8145813	166.3957806	N/A
34.2	10/27/2015 17:25	Yellow Lily	42.28998746	-71.81438115	167.7037029	N/A
34.3	10/27/2015 17:23	Yellow Lily	42.2903229	-71.8152506	165.7173138	N/A
35.1	10/27/2015 17:20	Yellow Lily	42.29044536	-71.81455557	167.5143719	N/A
Shoreline	10/12/2015 16:57	Canada Rush	42.29296945	-71.81403807	139.3866253	N/A
Shoreline	10/12/2015 17:49	Cattails	42.30284475	-71.81054986	151.0236492	N/A
Shoreline	10/12/2015 17:48	Cattails	42.30297321	-71.81063402	164.4657269	N/A
Shoreline	10/12/2015 17:47	Cattails	42.30244607	-71.81344723	164.2284832	N/A
Shoreline	10/12/2015 17:44	Cattails	42.30290146	-71.81455624	163.5887127	N/A
Shoreline	10/12/2015 17:43	Cattails	42.30295217	-71.81464316	167.075346	N/A
Shoreline	10/12/2015 17:37	Cattails	42.30412211	-71.81649246	172.5259075	N/A
Shoreline	10/12/2015 17:34	Cattails	42.30312207	-71.81685523	167.3098431	N/A
Shoreline	10/12/2015 17:33	Cattails	42.29563489	-71.81675926	165.3102093	N/A
Shoreline	10/12/2015 17:23	Cattails	42.29515582	-71.81699135	162.8840618	N/A
Shoreline	10/12/2015 17:13	Cattails	42.29049976	-71.81261449	162.0107098	N/A
Shoreline	10/12/2015 17:11	Cattails	42.29028502	-71.81266914	164.1242962	N/A
Shoreline	10/12/2015 17:04	Cattails	42.29386128	-71.81204251	165.0158367	N/A
Shoreline	10/12/2015 17:04	Cattails	42.29369314	-71.81217184	161.4549236	N/A
Shoreline	10/12/2015 17:02	Cattails	42.29292452	-71.81368184	163.7502117	N/A
Shoreline	10/12/2015 16:46	Cattails	42.29390591	-71.80891464	167.4615765	N/A
Shoreline	10/27/2015 17:50	Cattails	42.28833253	-71.81478951	165.2395916	N/A
Shoreline	10/27/2015 17:49	Cattails	42.28862129	-71.81452104	165.7678509	N/A
Shoreline	10/12/2015 17:36	Reeds	42.3036671	-71.81683746	167.0937176	N/A
Shoreline	10/12/2015 17:16	Reeds	42.29147734	-71.8158256	160.3274212	N/A
Shoreline	10/12/2015 17:15	Reeds	42.29125497	-71.81560373	162.2538738	N/A
Shoreline	10/12/2015 17:09	Reeds	42.29367734	-71.81190002	164.7602215	N/A
Shoreline	10/12/2015 16:59	Reeds	42.29303042	-71.81386381	162.4394817	N/A
Shoreline	10/12/2015 16:55	Reeds	42.29133929	-71.81520274	65.00778008	N/A
Shoreline	10/12/2015 16:41	Reeds	42.29390591	-71.80891464	167.4482708	N/A
Shoreline	10/12/2015 16:38	Reeds	42.29434391	-71.80912871	164.0072308	N/A

Appendix E:
Solutions for eutrophication of Indian Lake:

Prepared 2/22/16 for the Indian Lake Watershed Association by Mikhail Khibkin, Dylan Martel, Parsant Jotikashira

Drawdown

Basic Mechanics of Treatment:

The drawdown exposes aquatic plants to prolonged freezing in order to limit their growth.

Pros:

- Inexpensive
- Can significantly reduce presence of submerged aquatic vegetation

Cons:

- Drawdowns can cause algal and cyanobacteria blooms.
- Food web may be affected. Fish in particular

Cost:

Case by case basis. If water structure is in place then the only cost could be for that of the permit ~ $200

Chemical Treatment:

Chemical Precipitant	Calcium Carbonate (Lime)	Ferrous Chloride	Aluminum sulfate
pH level	>9	5-7	6-8

The use of algaecides was not considered due to their health concerns rendering the lake unusable

Basic Mechanics of Treatment:

The chemical is used to precipitate phosphorous out of water and make it unusable by organisms. As the chemical settles to the bottom of the lake it also forms a protective seal on the lake bottom preventing phosphorous from being released by nutrient-rich sediments. Reduces nutrients in water available for aquatic life. Particularly useful in combating harmful cyanobacteria.

Pros

- Chemicals are non-toxic so it has no adverse effects towards humans
- Prevents internal recycling of phosphorous
- No adverse effects on fish with concentrations below 50 micro g/L

Cons

- Treatment is expensive
- Not guaranteed to precipitate phosphorous; especially if chemical treatment affects pH level in water causing phosphorous to become soluble again.
- Requires for treatment of external phosphorous loading before this can be an effective solution

Cost of Treatment:

Alum:

Average cost of $450 per acre. This depends on dosage requirements and cost of equipment mobilization.

Total for Indian Lake = $102,600

Calcium carbonate:

Typically use 1-2 (1.5 AVERAGE) tons per acre of surface area

Cost = $10-50 (30 AVERAGE) per ton

Total = 10,260

Ferric Chloride:

Typically higher than alum treatment because of its required aeration process. Chemical price is similar.

Dredging:

Types: Grab Bucket, hydraulic, pneumatic

Basic Mechanics of Treatment common to all 3:

Removes sediment phosphorous on the surfaces of the lakebed. In lakes this typically equals 10% of total external load. In some cases, however, lake sediments account for 60% of total loading. This process can also remove macrophytes which contribute to internal phosphorous loading. Able to change depth contour for navigation purposes in boats.

Grab Bucket:

Specific Mechanics of Treatment:

A crane with a grab bucket, with a clam shell design, removes sediment from lake. A silt curtain is used to contain the silt that is disturbed by dredging and reduce turbidity in the remaining parts of the lake. The sediment is then dumped onto the ground or hauled away by trucks.

pros:

- Able to work in confined areas

Cons

- Increase in turbidity levels
- Uneven bottom contour
- Inefficient dropping, lifting, and unloading process by the bucket

Hydraulic dredges:

Specific Mechanics of Treatment:

This type of dredging uses a component called the cutter boom to loosen soil sediments. These sediments are then suctioned off by a pipe to be deposited on land or on a barge to be hauled away.

Pros:

- Keep depth contour levels consistent
- Can keep water turbidity levels low if use properly
- More efficient than grab bucket

Cons:

- Suction pipeline requires many controls and improper use will cause high turbidity levels in the lake

Pneumatic Dredges:

Specific Mechanics of Treatment:

Similar to hydraulic dredges. This type of dredging, however, use hydrostatic forces to remove sediments via the suction pipe. Dredging should be used when the flux of nutrients due to external sources has been controlled. Dredging is also reported to increase diversity of fauna such as fish. Beneficial to fisherman who report the effect of drawdown on fish.

Pros:

- Does not unnecessarily remove water. Thus, this dredging targets the problematic solids and is more efficient than drop bucket and hydraulic dredges.

Cons:

- Increased turbidity of water.

Cost:

Costs of dredging vary based on many factors. The department of Energy and Environmental in Massachusetts cites that the average cost is $10 per cubic yard of material removed.

Underwater Artificial Shading:

Basic mechanics:

The photosynthetic nature of submerged macrohpytes can be abused to reduce the growth and development of plants by restricting sunlight. When providing artificial shading on the lake with a gradient of over 50% submerged macrophytes are shown to have a severe decline in biomass.

Pros:

- Their use is confined to specific lake areas.
- Screens are usually out of sight and thus create no disturbance on shore.
- They can be installed in places where harvesters or sprayer boats cannot gain access.
- No toxic substances are released.
- They usually require no permit or license.
- They are easy to install over small areas.
- They can be removed.

Cons:

- They fail to correct the cause of the problem.
- They are expensive.
- They are difficult to apply over large areas or on sites with obstructions.
- They may slip on steep grades or float to the surface after trapping gases beneath them.
- They can be difficult to remove or relocate.
- They may rip during application.
- Some materials are degraded by sunlight.

Polyethaline:

- Effects/complications:
- It is difficult to apply over an irregular bottom or over a high density of weeds.
- Gas forms under the sheets, even with 1.2 cm holes.
- It is not feasible to move and relocate the sheets.
- It slides down steep inclines.
- It is deteriorated by sunlight (about 1 year in direct sun).
- Its buoyancy makes it difficult to handle.

Macrophyte control was achieved in 2 years at Marion Millpond Wisconsin (10 ha)
By comparison Indian Lake is 92 ha.

Cost:
$371 per ha
Total= $34,000

Polypropelene:
Effects:

- Completely effective in controlling ***m. spicatum**,* Najas flexilis, Potamogeton gramineus, P. crispus, P. foliosus, and ***P. pusillus***
- Some growth on sediments trapped on surface of sheets
- Gas permeable

Cost:
To treat problematic area south of Sears Island: $2,341 - $11,019
(Cost derived from considering problem area to be extended 20 feet from Sears Island for roughly 900 feet)