STATE OF THE LAKE REPORT 2018 LAKE WARNER HADLEY, MASSACHUSETTS

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for the Town of Hadley, Massachusetts

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Executive Summary

The Friends of Lake Warner and the Mill River conducted a monitoring program on Lake Warner and its tributaries from 2016-2018. Study objectives were to assess general health of the lake, to identify and to assess potential nutrient sources within the watershed. Parameters sampled were temperature, dissolved oxygen, water transparency, and E. coli bacteria on a bi-weekly basis in the lake, total phosphorus on a monthly basis in the lake and total phosphorus in five tributary locations. The 2018 sampling results were similar to those found in 2016 and 2017. The lake continues to have periods of low dissolved oxygen in mid and late summer. Water clarity showed a slight increase in 2018, likely due to increased precipitation. Excessive plant growth continues to negatively affect recreational boating. Total phosphorus (TP) levels in Lake Warner were above eutrophic thresholds again in 2018. Total phosphorus (TP) levels in tributary streams were higher than in previous years. The Knightly Brook and Tan Brook sites continued to produce extremely high phosphorus levels. E. coli bacteria levels were elevated in the Mill River and exceeded the secondary contact level six times over the sampling period. The Friends of Lake Warner would like to continue the sampling program in the future, primarily focusing on water quality conditions in the lake. Outreach and education within the watershed in collaboration with municipalities and agencies are ongoing goals of the organization.

Introduction

The Friends of Lake Warner and the Mill River (FoLW) began a monitoring program on Lake Warner and its tributaries in 2016 and completed the three-year study in 2018. The program has been coordinated by FoLW, who also trained volunteers, oversaw quality control, entered data and produced reports. Financial support for laboratory analyses was provided by the town of Hadley through a Community Preservation Act grant. The study was born of area residents longstanding interest in the health of the lake. FoLW recognized that the lake suffered from a variety of problems, and that additional water quality information would be useful in developing strategies to protect, and restore as needed, the health of the water body and its watershed.

Acknowledgments

This work would not have possible without the generous support of our membership, the citizens of Hadley through the Community Preservation Grant, and through a grant from the Community Foundation of Western Massachusetts. Thanks to the expertise and assistance from the Environmental Analysis Laboratory at UMASS Amherst and the Connecticut River Conservancy Laboratory for analysis of our samples.

Background

Lake Warner is a reservoir of approximately 70 acres, located on the Mill River in Hadley, Massachusetts in the Connecticut River watershed.

The Mill River watershed covers 30.01 square miles and drains into Lake Warner. It encompasses portions of Amherst, Leverett, Shutesbury and Sunderland. The watershed is 58 percent forested, 20 percent agricultural, 14 percent rural, and 8 percent urban with high-density residential and commercial-industrial land use according the 2001 Total Maximum Daily Load (TMDL) Report.

The most recent bathymetric map of Lake Warner was made by Masswildlife in November of 2018. It showed a mean depth of 4 feet and maximum depth of 12 feet.

In 1973 and 1975 reports are produced for the Massachusetts Water Resources Commission, Division of Water Pollution Control by the University of Massachusetts that focus on phosphorus loading and lake sediments that include Lake Warner.

In 2001 a TMDL Total Maximum Daily Load for Phosphorus for Connecticut River Lakes is published that established a phosphorus load and modelled reductions that would bring the lake into compliance with water quality standards.

The Massachusetts Department of Environmental Protection (DEP) placed Lake Warner on the 303d list of impaired water bodies in 2002, 2007, 2012, 2014 and 2016 as being impaired due to nutrients (total Phosphorus), excess algal growth, organic enrichment, low dissolved oxygen, turbidity and noxious aquatic plants. The Mill River above the inlet to the lake was placed on the 303d list of impaired water bodies for excessive E. coli bacteria pollution in 2006, 2011, 2014 and 2016.

The 2002 Lake Warner Assessment Project, coordinated by DFWELE's Riverways Program, involved visual survey of the lower portions of the watershed to identify potential nonpoint pollution sources and nutrient pathways into the lake.

The 2003/2004 Monitoring Report by the Massachusetts Water Watch identified sources of nutrients and characterized the extent and type of aquatic plant growth and characterized the general health of the lake. An attempt to assess bacterial contamination was dropped from the study.

The 2011 Study by Ann Capra of the Pioneer Valley Planning Commission (PVPC) found excessive levels of E. coli bacteria in the Mill River above the inlet to Lake Warner.

The 2015 State of the Lake Report by the Friends of Lake Warner and the Mill River documented the group's initial testing and monitoring of Lake Warner and the Mill River. This was the first attempt in a decade to comprehensively measure the physical and biological parameters of the lake.

The 2016/2017 State of the Lake Report by the Friends of Lake Warner and the Mill River documented the group's ongoing testing and monitoring of Lake Warner and the Mill River.

List of 2018 Achievements

- Tested for dissolved oxygen, temperature and water transparency at selected points on a bi-weekly basis.
- Sampled E. coli bacteria weekly in the lake and river between June and October. Made results available online and posted the boat ramp to keep the public aware of water quality conditions.
- Sampled phosphorus in the lake and 5 tributaries bi-monthly between June and October.
- Coordinated volunteers to remove 648 pounds of water chestnut from the lake. FoLW sponsored and ran two public pulling events at the lake this summer.
- Produced two newsletters that were mailed or send electronically to over 200 members and supporters.
- Participated in several public events like the Sustainability Festival, the Asparagus Festival and the 5K for Farmland to educate and inform the public about the lake and our work.
- Advocated and helped advertise for workshops put on by the Hampden Hampshire Conservation District on Soil Erosion and Nutrient Management in the Mill River watershed. FoLW continues to work with the HHCD on community education and collaboration to improve water quality in the Mill River Watershed.
- Advocated and advertised for conservation workshops put on by UMASS Agricultural Extension Services in the Mill River Watershed.
- Collaboration with Hitchcock Center for a fall exploration of the lake.

Testing/Sampling Schedule

FoLW conducted the following tests/activities in 2018:

Table 1. Testing and Sampling Schedule

Survey Type/Test	Indicators	Materials/Methods	Laboratory	Sample Locations Frequency
General Lake Health	D.O, Temperature, Transparency	YSI 200 Meter, Secchi Disc		Mid-Lake, bi-monthly June-October,
Nutrient Source Evaluation	Total Phosphorus	100mL brown sample bottles, lab supplied	EAL UMASS Amherst	60 samples Lake, Mill River, 4 tributaries
Primary and Secondary Contact for Recreation	E. coli bacteria	100mL clear sample bottles, lab supplied	CRC Lab Greenfield	34 samples, weekly Mid-lake, Mill River
Vegetation	Plant Species, Dominant vegetation type, percent cover	Grab samples, sampling rake, GPS Unit		5 transects across Lake

Results

Temperature and dissolved oxygen levels are principal indicators of aquatic habitat. FoLW use a YSI200 dissolved oxygen (DO) and temperature meter to take temperature and dissolved oxygen samples. In 2018 FoLW conducted 160 temperature and DO measurements throughout the lake, focusing on hypolimnetic oxygen levels at the mid-lake site to determine trends in temperature and dissolved oxygen levels throughout the summer and early fall.

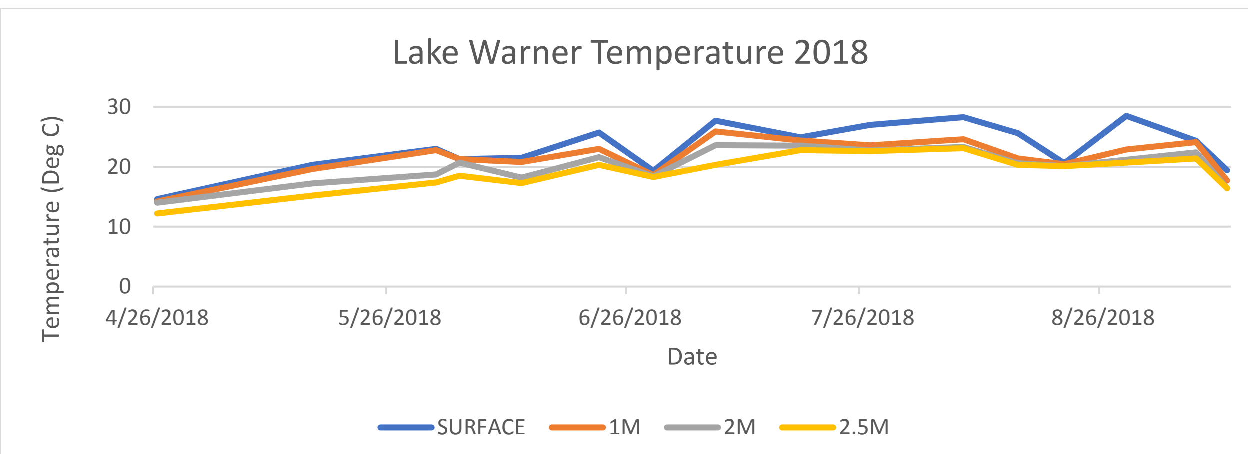
Temperature

Aquatic plants and animals have habitat preferences and limited tolerances to temperature. Temperature results from all locations are in the raw data summary in the Appendix. Temperature data from the mid-lake sample site during 2018 are presented in Table 2. and Figure 1. Although temperatures in 2018 were somewhat lower, reflecting the wet summer, Lake Warner generally continues to be a well-mixed warm water lake with no thermocline. Surface temperatures ranged from 14.6 to 28.5 degrees C, while temperatures at 2.5 meters ranged from 12.2 to 23.1 degrees C. Lake Warner appears to benefit from normal to above average snowfall during winter with above average precipitation during the spring and summer months. Above average precipitation means less water is taken from the lake and its tributaries for summer irrigation. Increased tributary inflow helps maintain lake temperatures. Groundwater may also play an important role.

Table 2. 2018 Lake Warner Temperature (Degrees Celsius) at Mid-Lake Sample Site

DATE	SURFACE	1M	2M	2.5M
4/26/2018	14.6	14.2	14	12.2
5/16/2018	20.3	19.6	17.2	15.2
6/1/2018	23	22.8	18.7	17.4
6/4/2018	21.3	21.3	20.7	18.5
6/12/2018	21.5	20.8	18.2	17.3
6/22/2018	25.7	23	21.6	20.3
6/29/2018	19.3	18.6	18.4	18.3
7/7/2018	27.7	25.9	23.6	20.3
7/18/2018	24.9	24.4	23.5	22.8
7/27/2018	27	23.6	22.7	22.6
8/8/2018	28.3	24.6	23.3	23.1
8/15/2018	25.6	21.4	20.6	20.3
8/21/2018	20.6	20.4	20.1	20.1
8/29/2018	28.5	22.9	21.2	20.7
9/7/2018	24.3	24.1	22.4	21.4
9/11/2018	19.4	17.7	16.4	16.4

Figure 1. 2018 Lake Warner Temperatures at Mid-Lake Sample Site



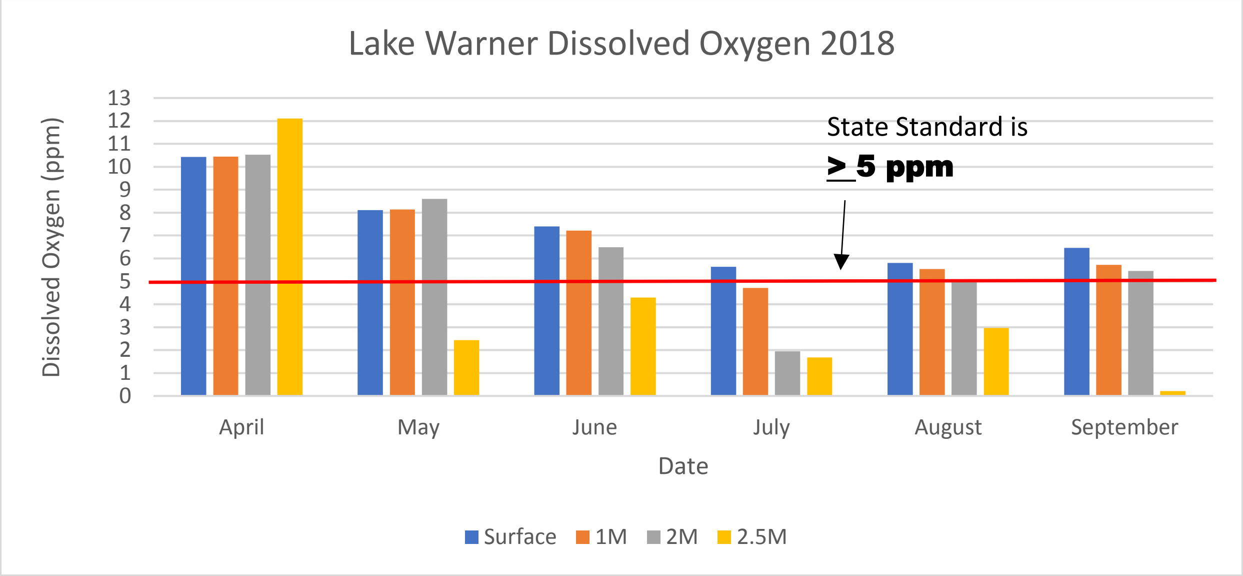
Dissolved Oxygen

All aquatic animals are dependent on dissolved oxygen (DO). The state standard for dissolved oxygen in lakes is 5 parts per million (ppm). The lake is amply oxygenated in the spring. But by mid-July DO levels at 2.0 meters in depth decrease dramatically as light is cut off by excessive plant growth. Lake Warner exhibits supersaturation of oxygen at the surface and levels well below saturation at max depth. The drop in DO is also influenced by the abundance of decomposing plant material at the peak of the growth of vegetation coupled by the reduction of highly oxygenated flow from the feeder tributaries. The intense storm events of the 2018 summer caused mixing in the lake that lowered oxygen levels in the upper layers during August. Overall these large inflows helped maintain tolerable conditions in the lake and kept temperatures down and surface DO levels up. Lake Warner, fortunately, did not experience a fish kill. Groundwater flow may also be helping to maintain tolerable conditions. Dissolved oxygen results from all locations are in the raw data summary in the Appendix. Average monthly dissolved oxygen levels at the mid-lake sampling site are shown in Table 3 and Figure 2.

Table 3. Mean Monthly Dissolved Oxygen at Mid-Lake Site

Month	Surface	1M	2M	2.5M
April	10.43	10.45	10.53	12.11
May	8.11	8.14	8.60	2.44
June	7.40	7.21	6.49	4.29
July	5.63	4.72	1.94	1.68
August	5.80	5.54	4.96	2.96
September	6.46	5.72	5.46	0.22

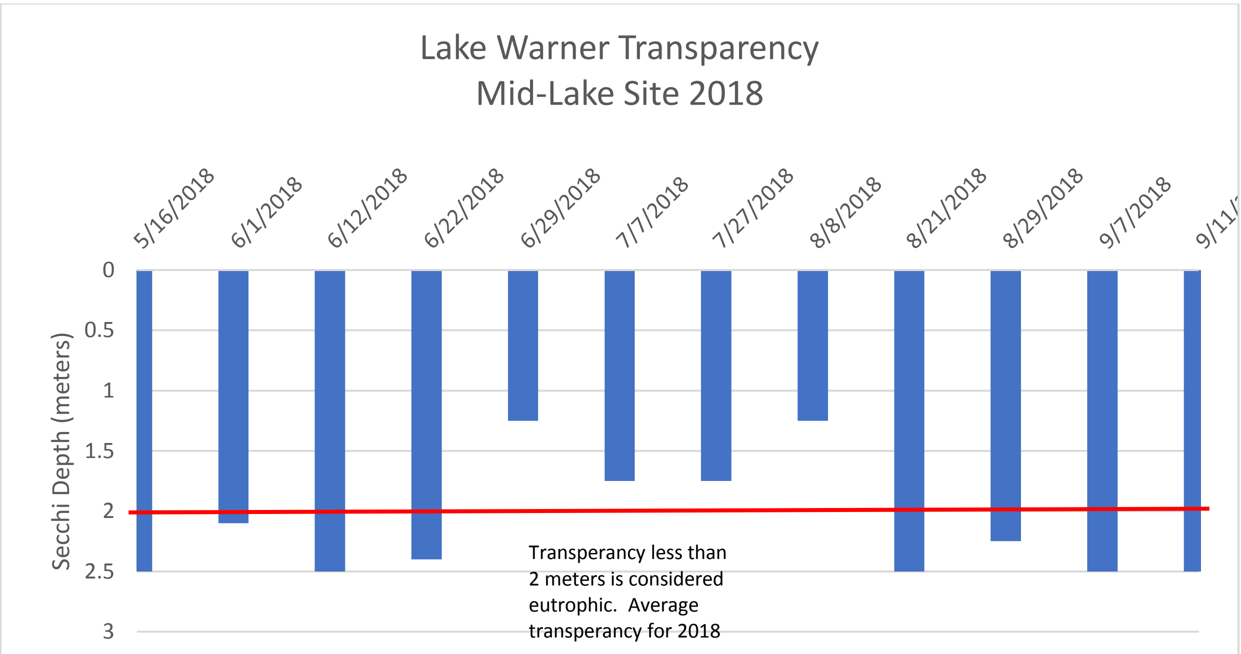
Figure 2. Mean Monthly Dissolved Oxygen at Mid-Lake Site



Transparency

Secchi disc measurements ranged in 2018 from 1.25m to 2.5m with an average of 1.94 for the season. Measurements in 2017 ranged from 1.2 meters to 1.8 meters with an average of 2.1m for the season. The range of results reflected the influxes of fresh water coming in from above average precipitation events during the 2018 season. Turbidity increased during these precipitation events but the effect on transparency the mid-lake site was brief. Floating aquatic plant density was notably reduced at the mid lake site throughout the summer. Transparency results from 2018 are shown in Figure 3.

Figure 3. Lake Warner Transparency at the Mid-Lake Site 2018



Phosphorus

Phosphorus is generally the limiting plant nutrient in lake ecosystems. Excessive amounts of phosphorous are a particularly significant pollutant because they support massive algae and lower plant blooms in the water. These blooms, in turn, change a lake or pond's ecology by creating a condition in which their decomposition robs the water of oxygen, making the lake or pond inhospitable to many higher animals like fish. This process is called eutrophication (nutrient enrichment).

Phosphorus levels were measured ten times at the mid Lake site during the 2018 sampling season. Levels in the lake were 5 times higher than the ecological threshold for lakes in our region. Levels at the mid-lake site exceeded the eutrophic threshold from 2016-2018. Trends from the 2003/2004 study of the lake and this study are presented in Figure 4. Comparisons between 2016 and 2018 are shown in Figure 5. All values are represented as geometric means.

Figure 4. Total Phosphorus Trends Lake Warner 2003-2018

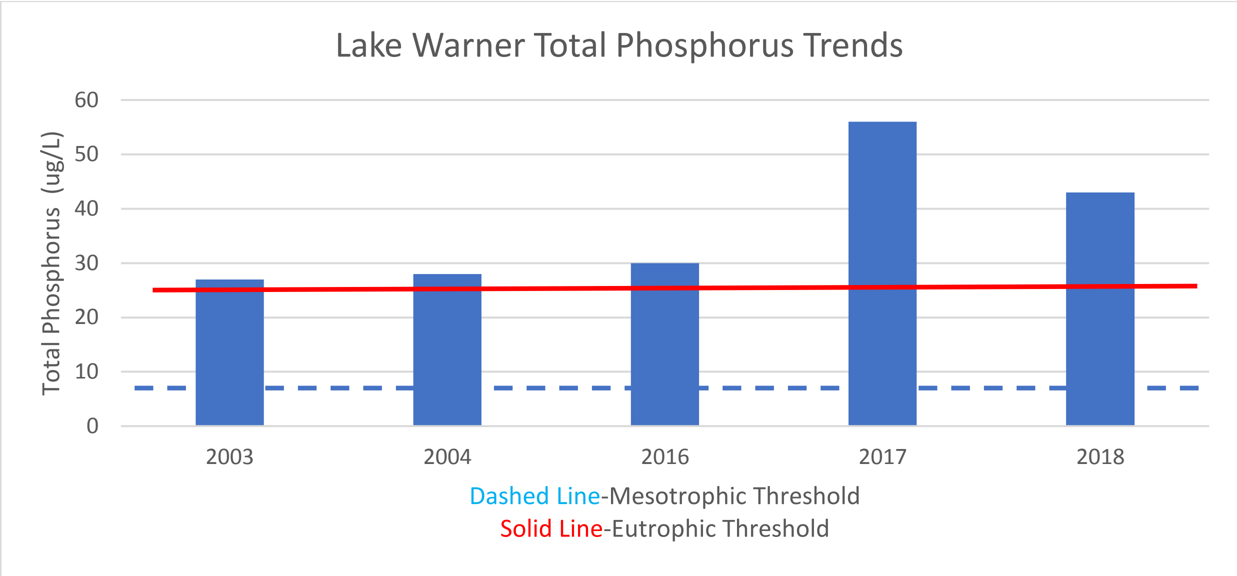
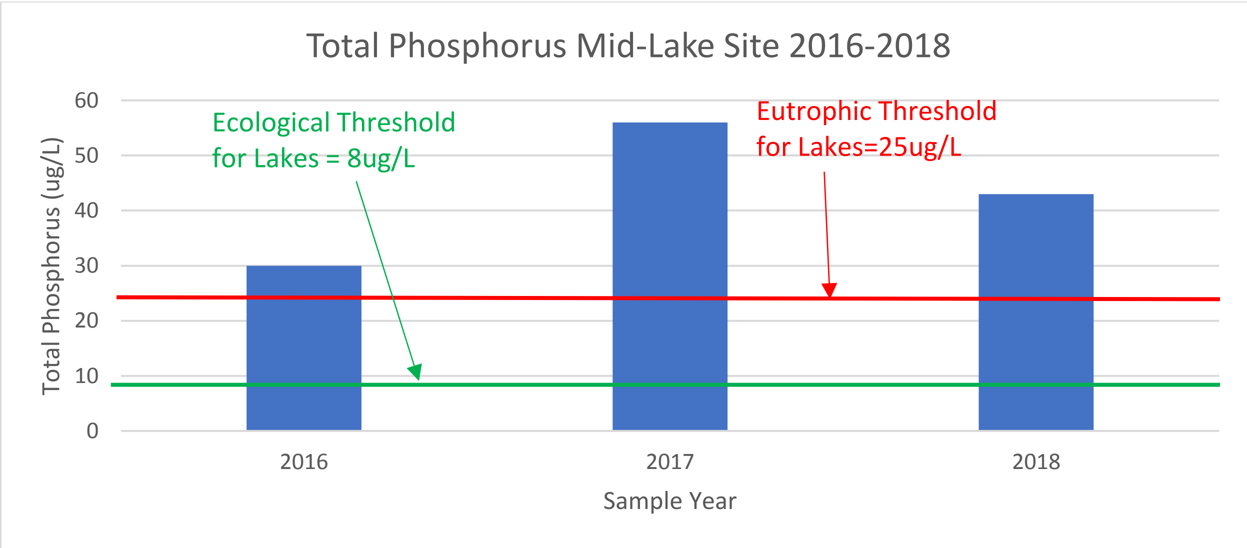


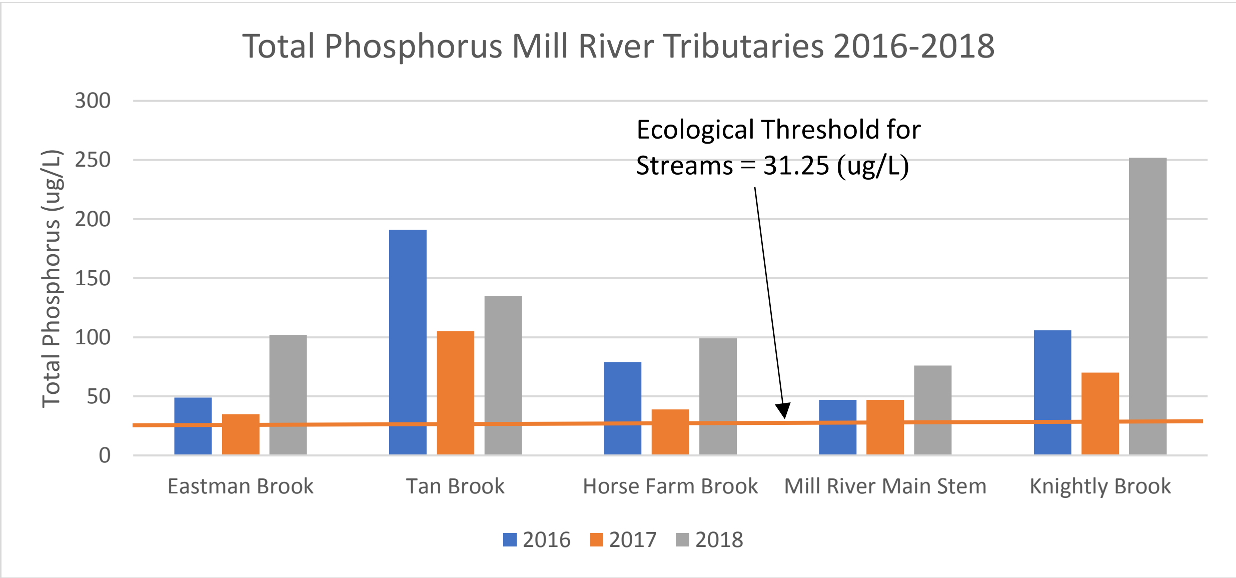
Figure 5. Total Phosphorus at the Mid-Lake Site 2016-2018



Nutrient Sources

Phosphorus levels in the Mill River and tributaries are shown in Figure 6. All values are represented as geometric means.

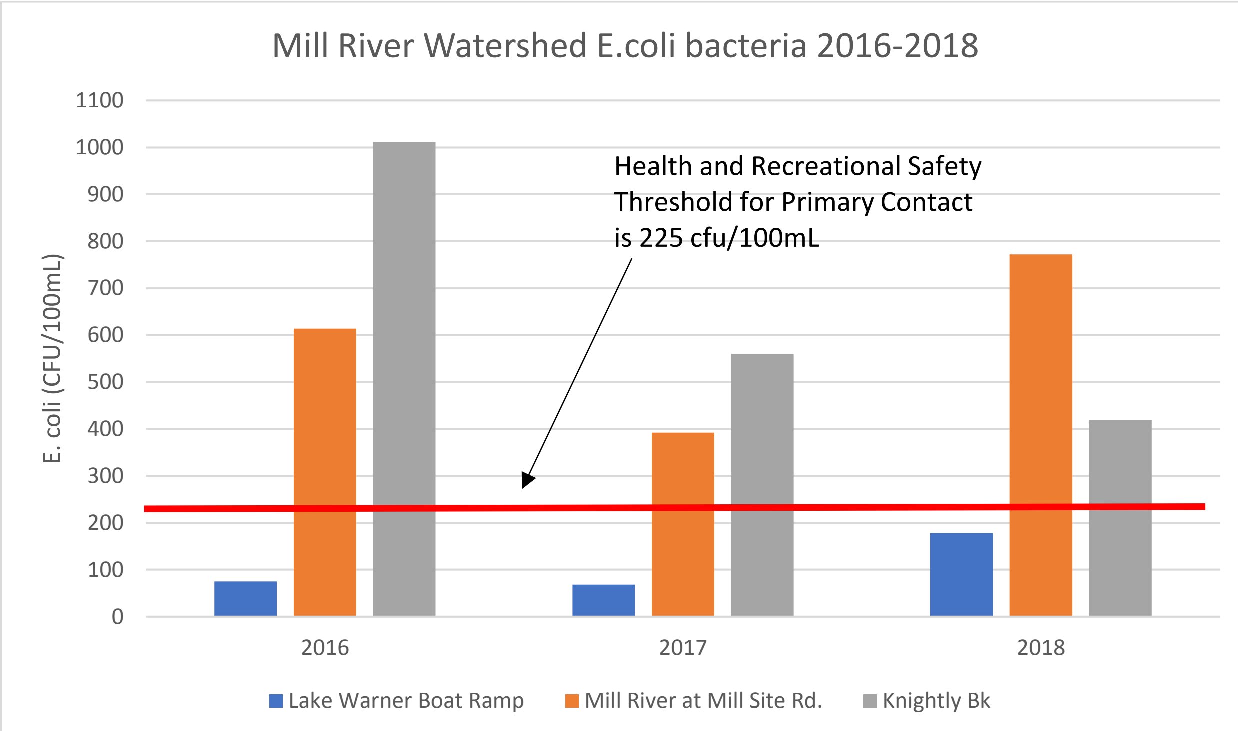
Figure 6. Total Phosphorus at Mill River and Tributaries 2016-2018



Bacteria

Bacteria samples were collected between May and October 2018. *E. coli* bacteria comes from animal waste or leaking septic systems. There are state standards for levels involving primary contact like swimming and for secondary contact such as boating. Ponds and lakes used for swimming and other recreation should have a maximum count of 235 *E. coli* bacteria per 100 mL of water (about half a cup). The Mill River and Lake Warner have previously been areas where high levels of *E. coli* have been found. The level of bacteria in the lake exceeded the primary contact level six times during the sampling season, warnings were posted at the boat ramp. The Mill River above the Lake also had levels frequently exceeding the recreational health and safety thresholds. More sampling upstream should be done to determine the source of these high bacteria levels. A summary of 2018 bacterial levels in the lake and tributaries is presented in Figure 7. All values are represented by geometric means.

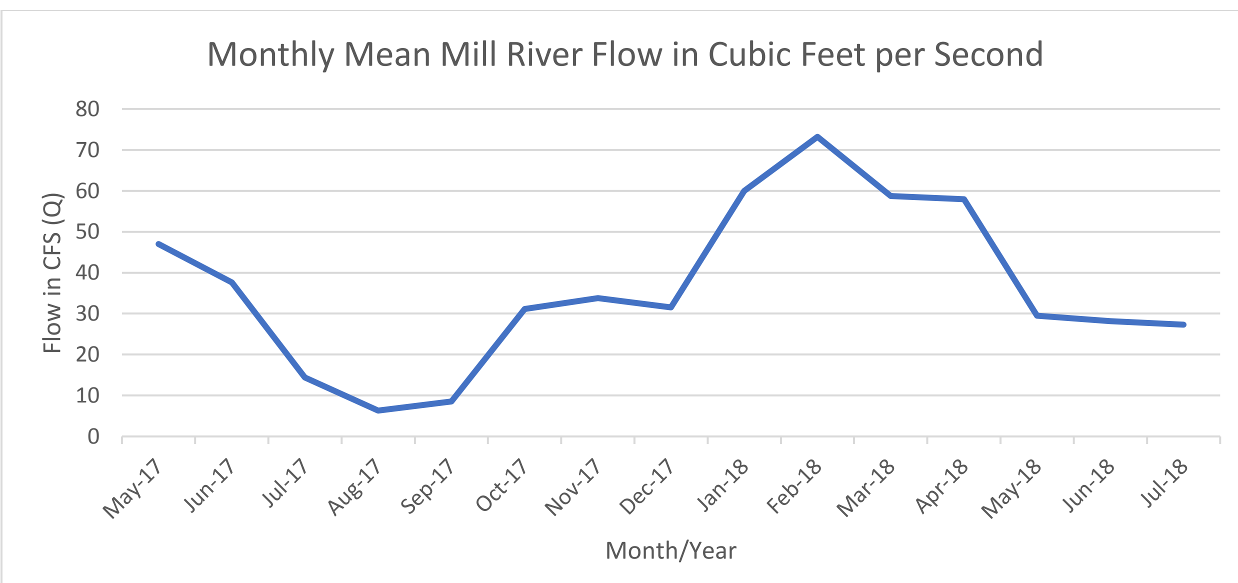
Figure 7. E. coli bacteria in Lake Warner, Mill River and Knightly Brook 2016-2018



<u>Mill River Flows</u>

With the installation of flow monitoring devices by the Mill River Monitoring Facility at UMASS Amherst on the Main Stem of the Mill River in 2017 detailed streamflow data has been collected and is available for the first time.

Figure 8. Monthly Mean Mill River Flows from May 2017- July 2018



Monitoring equipment to measure nitrogen and phosphorus are being installed at the Mill River Monitoring Facility at UMASS Amherst. When the equipment is operational it will provide real time water quality analysis combined with current flow data that will provide accurate annual loading information for the lake.

Macrophytes and Vegetation Transects

The FoLW conducted five vegetation transacts in 2018. Combined with the five transects from 2015 we now have dominant and sub-dominant species for emergent, submergent, and floating aquatic species for the entire lake. Swamp loosestrife (*Decodon verticillatus*) is the dominant emergent vegetation type followed by Pickerelweed (*Pontederia cordata*). Watermeal (*Wolffia spp*) is the dominant floating vegetation type followed by (*Lemna spp*) and White Water Lily (*Nymphaea odorata*). Coontail (*Ceratophyllum demersum*) is the dominant submergent vegetation type followed by Big leafed Pondweed (*Potamogeton amplifolius*). The complete transect results are shown in Table 4.

Table 4. Lake Warner Vegetation Transect Results 2015-2018

Common Name	**Latin Name**	**No. of Observations**	**Freq. in Group (%)**	**Freq. Overall (%)**
Emergent Species				
Swamp Loosestrife	*Decodon verticillatus*	21	**28**	**7**
Purple Loosestrife	*Lythrum salicaria*	11	**15**	**4**
Burreed	*Sparganium erectum*	13	**18**	**4**
Arrowhead	*Sagitteria latifolia*	7	**9**	**2**
Cattail	*Typha latifolia*	3	**4**	**1**
Rushes	*Scirpus spp*	3	**4**	**1**
Sedges	*Juncus spp*		**0**	**0**
Pickerelweed	*Pontederia cordata*	16	**22**	**5**
		74		
Floating species				
Watermeal	*Wolffia spp*	47	**36**	**15**
Duckweed, Major	*Lemna spp*	31	**24**	**10**
White Water Lily	*Nymphaea odorata*	28	**22**	**9**
Yellow Water Lily	*Nuphar variegata*	16	**12**	**5**
Duckweed, Minor	*Lemna minor*	3	**2**	**1**
Water chestnut	*Trapa natans*	2	**2**	**1**
Smartweed	*Polygonum spp*	2	**0**	**1**
		129		
Submergent species				
Coontail	*Ceratophyllum demersum*	56	**77**	**18**

Pondweed1 Big-leafed	*Potamogeton amplifolius*	36	**35**	**12**
Waterweed	*Elodea canadensis*	8	**31**	**3**
Pondweed2 Curly	*Potamogeton crispus*	2	**2**	**1**
Pondweed3 Ribbon	*Potamogeton epihydrus*	1	**1**	**0**
Bladderwort	*Utricularia spp*	1	**1**	**0**
		104		
Total No. of observations		**307**		

Volunteer Invasive Plant Removal

FoLW removed an estimated 650 lbs. of water chestnut from Lake Warner in 2018. This was the lowest amount of water chestnut removed from the lake since annual harvesting began in 2002. The reduction in quantity was achieved by an "early and often" scouting and pulling strategy. During 2018 this strategy was employed with success, as indicated by effective location and harvest of juvenile plants, sometimes before they had an opportunity to reach the surface of the water. The smaller size and immaturity of the rosettes pulled resulted in reduced overall harvest weights. Twenty days were logged exclusively for scouting and removal of water chestnut. At least 122 volunteer hours were spent on this effort. Near weekly patrols resulted in small but consistent harvests throughout the growing season. FoLW sponsored two public volunteer water chestnut harvests in 2018. Small patches of water chestnut were located and pulled in September indicating that despite increased effort not all plants were collected during the 2018 effort. Increased effort and extension of effort through September will be implemented next year with a goal of completely clearing the lake of water chestnut plants and viable nuts.

Discussion

Water Quality

Water quality measurements were affected by an abnormally wet spring and summer in 2018. Sample sites and methods were chosen to allow comparison and trending with earlier studies. Results were subject to climatic conditions with regard to temperature, dissolved oxygen and transparency. Temperatures are normal for a shallow warm-water lake. Transparency was increased in 2018 due to increased inflow and the reduction of surface vegetation at the mid-lake sample site. Low levels of dissolved oxygen below the 1-meter level continue to be an issue. This season low DO levels rebounded more quickly at 2 meters, averaging above 5ppm in August and September for the first time since this study began. Low oxygen levels can impair health and growth rates of fish and other aquatic organisms. The lake remains fully saturated in the upper meter of the lake, and on average maintained oxygen levels above the 5ppm threshold. There were a few days during the sampling period where levels dipped below this threshold in the upper meter of the lake.

Phosphorus

Nutrients within the lake and tributaries were sampled with increased frequency in order to obtain geometric means at all sites. The final year of this study doubled the amount of phosphorus samples taken at the mid-lake site and at the five tributary locations. This reduced the variability of the results and increased our confidence in the levels reported. There was still variability among samples, caused by differences in flow at sampling and duration of time taken following precipitation events. We are confident of the quality assurance of the sample collection process, performed by the same personnel consistently throughout the study.

The lake levels from all three years are less than those predicted by the phosphorus model from the TMDL study of 120 ppm. We only sample five months out of the year so actual rates may be higher. The 2018 value of 43 ppm align with the range predicted by Snow and DiGiano of 25-50 ppm. While values presented are geometric means of measurements at those sites, they cannot be taken for annual average values for the tributaries or lake. Nonetheless, the lake values are considerably higher than state and federal thresholds and exceeded the eutrophic threshold during 2016-2018. Similarly, in 2016-2018 all tributary sites exceeded the ecological threshold of less than 31.25 ug/L. While these are small tributaries and actual loading rates may be low, cumulatively they are having an impact on the phosphorus loading to the lake.

The MADEP 2001 Total Maximum Daily Load study suggests that a significant source of phosphorus available for plant growth is coming from lake sediments. Internal loading of phosphorus can be a significant source of loading in shallow, eutrophic lakes. We did make an effort to obtain sediment samples during the 2015-2017 sampling seasons. A detailed analysis of phosphorus loading from the lake sediments is beyond the scope of this report. Lake sediments are going to be an ongoing source of phosphorus loading to the lake, especially under anoxic conditions.

Determining how much phosphorus loading is occurring due to loading from the sediments is beyond the scope of this monitoring effort. We can make some deductions based on the literature and other water quality data we obtained during this study.

- The sediment samples show that Lake Warner sediments contain abundant Aluminum, Iron, Magnesium and Calcium, all effective at binding phosphorus.
- Lake Warner has anoxic conditions in portions of the lake and during portions of the year, depending on inflow, light transparency, and Biological Oxygen Demand (BOD) from decomposing plant material.
- Aluminum and Iron bound phosphorus can become soluble under anoxic conditions and contribute to internal loading of phosphorus.
- Ku and Feng (1975) found in Lake Warner sediments that adsorption capacities increased with a decrease in pH and temperature but increased in redox potential. Under low redox potential the sediments released large amounts of iron into the overlying waters and the phosphate adsorption capacity was reduced accordingly.

Release rates of phosphorus under anerobic conditions in Lake Warner could be more discretely measured and understood relative to their contributing to the overall phosphorus loading in the lake. Until then the focus of lake management activities should be on improving conditions in the lake to deter anoxic conditions. Having quantified that there are significant loading issues coming from tributaries to the lake, an ongoing effort must be made to address nutrient contributions from both urban and agricultural areas.

While reduction of internal loading should not be ignored as a potential source of phosphorus to Lake Warner, recommended management strategies should focus on external loads (e.g. riparian buffer strips, on-farm comprehensive nutrient management plans, stormwater retention areas, and constructed wetlands/detention areas). These will likely have the greatest influence on reducing phosphorus loads to the Mill River and Lake Warner. Continued monitoring of all sources of phosphorus loading is encouraged to address and adapt methods to reduce eutrophication problems in the lake.

Vegetation

While Lake Warner itself is absent of identification under Biomap2 the Mill River upstream of the mouth of the lake is identified as Biomap2 Core Habitat in Hadley and extends to the town line with Amherst. There are also identified Critical Natural Landscape Features within the watershed of the lake. Elements of Biomap2 Cores that fall within the Hadley portion of the Mill River watershed include Black Gum-Pin Oak- Swamp White Oak "Perched Swamp" are an unusual type of wetland found in Massachusetts in one area of the Connecticut River Valley. This Community type is dominated by red maple, with black gum, pin oak and swamp white oak. This example of Black Gum-Pin Oak- Swamp White Oak "Perched Swamp" is poorly buffered by its residential and agricultural setting, but maintains the species diversity and structure that is characteristic of this rare natural community.

Five transects were surveyed on the lake this season. FoLW was able to traverse the shallow, weed infested portions of the pond using a Jon boat with a mud motor propeller attachment. Without this specialized equipment, the surveying of the shallow sections of the lake are impossible. An effort to carry out vegetation surveys earlier in the season was hampered by weather and periodic flooding of the lake. There was more open water later into the season than in previous years. A total of 110 observations were made this year bringing the number for all ten transects to 307.

Coontail *(Certaophyllum)* is the most abundant aquatic plant in the lake, accounting for 77 percent of the submergent species sampled. It can be found anywhere there is sufficient light and nutrients for it to grow, whatever the water depth or conditions. It is frequently found intermixed with other plants such as Water Lilies, Water Chestnut or Big Leaf Pond Weed. It essentially forms a second canopy beneath many of the emergent plants. Technically a submergent, it grows so thickly in places that it pushes above the surface. It is the major hindrance to navigation, fishing and recreation in Lake Warner. It entangles propellers and clogs the cooling systems of outboard motors. It is impossible to paddle, row or pole through. It acts a nursery for Water Chestnut. It is the largest contributor to anoxic plant debris on the bottom. It is reducing the available fish habitat. If an efficient way could be found to harvest Coontail from the lake it could provide a way to remove excess nutrients from the lake. Because it is capable of reproducing via fragmentation, precautions will have to be made during management.

Big leafed Pondweed and Elodea were sampled with nearly equal frequency after Coontail. These submerged species also make it difficult to navigate boats and entangle fishing lures. The upper reaches of the lake are particularly dominated with Elodea possibly due to shallower, faster flowing water and sandy sediments. Big leafed Pondweed seems to outcompete Coontail in depths exceeding 2 meters where there is limited light.

The edges of Lake Warner are dominated by emergent species Swamp Loosestrife *(Decodon verticillatus*) followed by Pickerelweed *(Pontederia cordata)* and Burreed *(Sparganium erectum).* Purple loosestrife, a problematic terrestrial invasive is becoming more pronounced in the edges of the lake and accounted for fifteen percent of the emergent species identified.

Floating species were dominated by Watermeal *(Wolffia)* followed by Duckweed *(Lemna)*and White Water lily *(Nymphaea odorata).* Watermeal and duckweed typically invade any available space left on the lake surface by July and August. In 2018 due to precipitation and flooding events the lake surface at the mid-lake site was unusually free of Watermeal and Duckweed.

Both White Water Lily *(Nymphaea odorata)* and Yellow Water Lily *(Nuphar variegata)* are abundant in the coves and shallow areas of the lake. They get a substantial growth head start from well-established rhizomes and large leaves that block out light penetration to the water immediately beneath the plant. It is difficult to navigate through areas of thick growth. The leaves and fibrous stems inhibit rowing and paddling and fowl propellers. Water chestnut can establish within stands and can easily remain undetected until rosettes grow to maturity.

This diverse plant community provides nursery and refuge spaces for fish and other aquatic organisms. Because the plant community has never been managed, it is overgrown and a nuisance to recreational activities. Excessive plant growth also limits light penetration and photosynthesis in the lake, reducing oxygen levels that are necessary to support aquatic habitat.

Lake Warner suffers from large algal blooms every spring. Many of these persist late into the year, intermixed with vegetation. Herbicides can be effective, but are only temporary solutions, are expensive and may have negative effects on other species. A long-term solution will necessitate reducing nutrient loading from the watershed and keeping phosphorus bound to the sediments. Sediment removal via dredging is financially impractical and may not be permitted by regulatory agencies. Once nutrient loading to lake is reduced, in-lake strategies such as sediment inactivation can be explored.

Volunteer Invasive Plant Removal and Monitoring

The Friends of Lake Warner filed a Request for Determination of Applicability (RDA) with the Hadley Conservation Commission in 2018. The Conservation Commission made a negative determination, indicating that a Notice of Intent (NOI) did not need to be filed. Hand pulling of water chestnut was permitted using volunteers under the guidelines outlined in the RDA for a period of three years, through 2020.

FoLW removed an estimated 650 pounds of water chestnut from Lake Warner in 2018. FoLW advertised and sponsored two public volunteer scouting and harvests in 2018. The USFWS Conte Wildlife Refuge participated in the July effort. FoLW trained volunteers and ran an informational table at the boat ramp. FoLW coordinated for and transported canoes and a Jon boat to use as a barge/transport for bagged water chestnut and as an emergency support craft. FoLW provided personal floatation devices, bags, water, gloves and a hand washing station for the events. FoLW had approximately 23 volunteers participate at these events. Volunteers contributed over 122 hours during the 2018 season. This does not include the planning and preparation time of the Executive Director and FoLW board members.

This year removal totals were estimated due to time and volunteer participation. The 650 pounds removed in 2018 is 45% less was removed in 2017. FoLW attributes this to starting earlier in the season and continuing with an aggressive program of weekly patrols by experienced personnel into September. The reduction in quantity was achieved by an "early and often" scouting and pulling strategy. During 2018 this strategy was employed with success, as indicated by effective location and harvest of juvenile plants. The smaller size and immaturity of the rosettes pulled resulted in reduced overall harvest weights. Problems with equipment led to the early cessation of scouting and pulling efforts and subsequently some mature plants were identified later in the season and removed.

Summary/Conclusion

The FoLW has accomplished much through monitoring and identifying problems in the lake and tributaries to the lake. We established baseline and trend data of water quality parameters in the lake and major tributaries. We assessed where nutrients and bacteria are entering the system, and where more investigation is warranted. We have identified dominant vegetation species and their location in the lake. Monitoring should continue in the future to measure changes within the ecosystem.

Our research has shown that portions of Lake Warner are under extreme stress due to oxygen depletion seasonally, but conditions in the lake are dependent on environmental variables. Increased flows bring additional nutrients into the lake from the watershed, but the lake also benefits greatly from this inflow during the summer. The lake is clogged with aquatic plants and algae contributing to the low levels of dissolved oxygen. Management of the aquatic vegetation is key to extending the life of the lake. This should improve recreational experiences in the short-term.

As the Mill River Monitoring Station at UMASS continues to develop, a continuous record of phosphorus and nitrogen levels is going to be available for understanding and modelling this system. We look forward to undergraduate and graduate research using the river and lake. Maintaining a working relationship with the local academic and research community is an ongoing goal of the organization.

Collaboration with other institutions is going to be the key to success in reducing nutrient and bacterial pollution to the river and lake. Municipalities are renewing their MS4 permits, and are encouraged to support low impact development and utilize the best available technologies to improve their stormwater systems. Improving informational materials and making them easily accessible to residents and businesses is a required component of stormwater programs.

As we enter this new era of climatic uncertainty, we must work to improve the wetland functioning above the lake. Functioning wetlands are filters for stormwater and non-point source pollution coming from the urbanized portions of the watershed. Innovative design and restoration of degraded wetlands can be made to slow floodwater and retain sediments. Preparing for storms of increasing intensity and duration can help reduce future impacts to the lake and infrastructure.

Recommendations

Future monitoring recommendations

FoLW hopes to continue the monitoring program in 2019 with a few modifications. By continuing regular sampling for temperature, dissolved oxygen, transparency and total phosphorus, and by repeating aquatic plant identification and mapping, we are building a long-term database that will help document changes in conditions over time.

FoLW would like to modify the tributary sampling program to compliment any requirements by the towns of Amherst and Hadley under the new MS4 Stormwater Permit enacted this year. If nutrient and bacteria data collection are a part of their requirements, we would like to sample in the interest of addressing the nature and magnitude of the tributary and its contribution to the nutrient loading of the lake. Continuing to sample on Knightly and Horse Farm Brooks will help evaluate the improvements that are going on upstream of these sites. We would like to sample at additional sites in the watershed to evaluate other potential sources of nutrients and bacteria. We would like to continue sampling several, if not all the existing sites to document any changes in conditions. We would like to support increased sampling that includes additional parameters (e.g. nitrate-nitrogen, specific conductance, turbidity) beyond those monitored during this study period. Our ability to complete these monitoring goals will be dependent on funding and cooperation with partners.

FoLW will conduct a survey of anglers, boaters, and other lake users to collect information on the amount and seasonal variation of lake use. This survey may be used to support management activities based upon lake health and how conditions affect the use of the lake.

Management recommendations

- Develop a drawdown plan that targets the excessive aquatic plant growth at the lake's margins. A three-foot drawdown will be sufficient to address these areas of the lake.
- Hire a company to harvest aquatic plants in selected areas of the lake and pursue grant funding to accomplish this goal. This would have several positive effects on the recreational use of the lake; open channels and creating open water for boating and fishing, reducing some of the excessive plant growth from the water column, removing nutrients that are bound in the plant material and keep them from cycling back into the sediments.
- Improve the condition of the public boat ramp. The edges of the asphalt boat ramp have eroded and drop off precipitously in places. The Town is responsible for, and has been approached regarding repair of, the ramp itself. The fence separating the ramp from the adjacent property is in disrepair. The owner has been approached about repair as well as adding a kiosk to the fencing to educate the lake users about the history of the lake and expectations while using the lake. This will provide information to lake users on how they can help in keeping the lake free from invasive species, how they can contribute to

the management goals of the lake and find activities they can participate in that promote lake health.

Outreach recommendations

The FoLW is pursuing the installation of a kiosk at the boat ramp using the remaining funds from our CPA grant. The kiosk will serve as an educational tool about the historical landscape, provide information about the condition of the lake and outline basic rules for the recreational use of the lake by the public.

Complete a Lake Management Plan that will provide information and education to the local public about the conditions in Lake Warner, threats to it, the valuable assets that the lake contributes to the community's quality of life, and management practices that can be implemented to protect and restore lake health.

Work with the Hampshire Hampden Conservation District on education and outreach that will target Farmers and Forest owners, Landowners and Municipalities with information regarding soil and water management, including fertilizer use, techniques to reduce runoff, proper disposal of toxic materials and animal waste.

Work with UMASS Amherst to assess and improve stormwater runoff from the University Campus parking lots, Tan Brook and the Campus Pond. Continue to support research and projects focused on restoration of the watershed, river and lake.

Table 5. Guide to Nonpoint Source Control of Phosphorus and Erosion (MassDEP, 2001)

Type of NPS Pollution	Whom to Contact	Type of Remedial Action
Agricultural		
Erosion from Tilled Fields	Landowner and NRCS	Conservation tillage (no till planting); contour farming; cover crops; filter strips; etc.
Fertilizer leaching	Landowner, NRCS, and UMass Extension	Conduct soil P tests; apply no more fertilizer than required. Install BMPs to prevent runoff to surface waters.
Manure leaching	Landowner, NRCS, and UMass Extension	Conduct soil P tests; apply no more manure than required by soil P test. Install manure BMPs.
Erosion and Animal related impacts	Landowner and NRCS	Fence animals away from streams; provide alternative sources of water.
Construction		
Erosion, pollution from development and new construction.	Conservation Commission, Town officials, planning boards	Enact bylaws requiring BMPs and slope restrictions for new construction, zoning regulations, strict septic regulations. Enforce Wetlands Protection Act.

Erosion at construction sites	Contractors, Conservation commission	Various techniques including seeding, diversion dikes, sediment fences, detention ponds etc.

Resource Extraction

Timber Harvesting	Landowner, logger, regional service forester (DCR)	Check that an approved forest cutting plan is in place and BMPs for erosion are being followed. Provide training to local ConComms on harvesting BMPs.
Gravel Pits	Pit owner, Regional DEP, Conservation commission	Check permits for compliance, recycle wash water, install sedimentation ponds and berms. Install rinsing ponds.

Residential, urban areas

Septic Systems	Homeowner, Lake stewards, Town Board of Health, Town officials	Establish a septic system inspection program to identify and replace systems in non-compliance with Title 5. Discourage garbage disposals in septic systems.
Lawn and Garden fertilizers	Homeowner, Lake stewards, municipalities in association with MS4 permits	Establish an outreach and education program to encourage homeowners to eliminate the use of phosphorus fertilizers on lawns, encourage perennial plantings over lawns.
Runoff from housing lots	Homeowner, Lake stewards	Divert runoff to vegetated areas, plant buffer strips between house and lake
Urban Runoff	Landowner, Town or City Department of Public Works	Reduce impervious surfaces, maintain street sweeping program, catch basin cleaning, install detention basins etc.
Highway Runoff	Mass Highway Division	Regulate road sanding, salting, regular sweeping, and installation of BMPs.
Unpaved Road Runoff	Town or City Department of Public Works	Pave heavily used roads, divert runoff to vegetated areas, install erosion control and vegetate eroded ditches.
Other stream or lakeside erosion	Landowner, Conservation Commission	Determine cause of problem; install erosion controls and plant vegetation

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