STATE OF THE LAKE REPORT 2016/2017

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 in 2016 and 2017. 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 2017 sampling results were similar to those found in 2016. The lake continues to have periods of low dissolved oxygen in mid and late summer. Water clarity showed a slight decrease since 2015/16. Plant growth continues to negatively affect recreational boating. Total phosphorus (TP) levels in tributary streams were somewhat lower at most sites in 2017 than 2016. One site, near Meadow Street, exhibited higher TP levels than in 2016. The Knightly Brook and Tan Brook sites continued to produce extremely high phosphorus levels. Reduced TP was found at the UMASS Horse Farm sample site, perhaps due to best management practices implemented at the horse farm between 2012 and 2015. E. coli bacteria levels remain elevated in the Eastman Brook, Knightly Brook and the Mill River. The Friends of Lake Warner will continue the sampling program in 2018.

Introduction

The Friends of Lake Warner and the Mill River (FoLW) began a monitoring program on Lake Warner and its tributaries in 2016 and continued it in 2017. 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.

Background

Lake Warner is a reservoir of approximately 68 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 TMDL Report.

The most recent bathymetric map of Lake Warner was made by Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement (Masswildlife) in 1952. It showed a mean depth of 3.5 feet and maximum depth of 10 feet.

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.

A 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.

A 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.

A 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.

A 2015 State of the Lake Report by the Friends of Lake Warner and the Mill River documented the group's 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.

FoLW achieved the following in 2016/17:

- Removed, in conjunction with the US Fish & Wildlife Service (USF&WS) over 2,000 pounds of invasive Water Chestnut (*Trapa natans*) from Lake Warner.
- Tested for dissolved oxygen, temperature and water transparency at selected points on a bi-weekly basis.
- Sampled total phosphorus in the lake and at five tributary locations monthly.
- Collected sediment samples from four locations and tested for nutrients and metals.
- Collected E. coli bacterial samples bi-weekly from the lake and 5 tributary sites. Results were posted at the boat ramp and available online.
- Sponsored a lake cleanup day.
- Sponsored a lake appreciation day for the public.
- Sponsored an aerated composting workshop for small animal farms.
- Accepted ownership and management responsibility for the dam, water rights and a 6 acre parcel of conservation land at the north end of the lake from the Kestrel Land Trust following the fall 2017 completion of repair of the dam.

Testing/Sampling Schedule:

Table 1. Testing and Sampling Schedule

FoLW conducted the following tests/activities in 2016/17:

Survey Type/Test	Indicators	Materials/Methods	Laboratory	Sample Locations Frequency
General Lake Health	D.O, Transparency, Temperature	YSI 200 Meter, Secchi Disc		Mid-Lake, June-October, and additional sites
Nutrient Source Evaluation	Total Phosphorus	100ml brown sample bottles, lab supplied	EAL UMASS Amherst	82 samples Lake, Mill River, 5 tributaries
Primary and Secondary Contact for Recreation	E.coli bacteria	100ml clear sample bottles, lab supplied	CRWC Lab Greenfield	77 samples, Mid-lake, Mill River,5 Tributaries
Soil Nutrients/Metals	Plant Nutrient Uptake, Soil Nutrients/Metals	grab samples, stainless steel trowel	Paige Soils Lab, UMASS Amherst	3 locations in Upper Lake

Testing 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 2016 FoLW conducted 130 temperature and DO measurements throughout the lake, focusing on hypolimnetic oxygen levels and used the same mid-lake site used in the 2003/2004 study to determine trends in temperature and dissolved oxygen levels at depths of 1 meter and 2 meters throughout the summer and early fall. In 2017 FoLW conducted 65 temperature and DO measurements, focusing on the mid-lake sample site.

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 2016 and 2017 are presented in Figure 1 and 2. Although temperatures in 2016 were somewhat higher, reflecting the drought, Lake Warner generally continues to be a well-mixed warm water lake with no thermocline. 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.

Figure 1. Lake Warner Temperature 2016

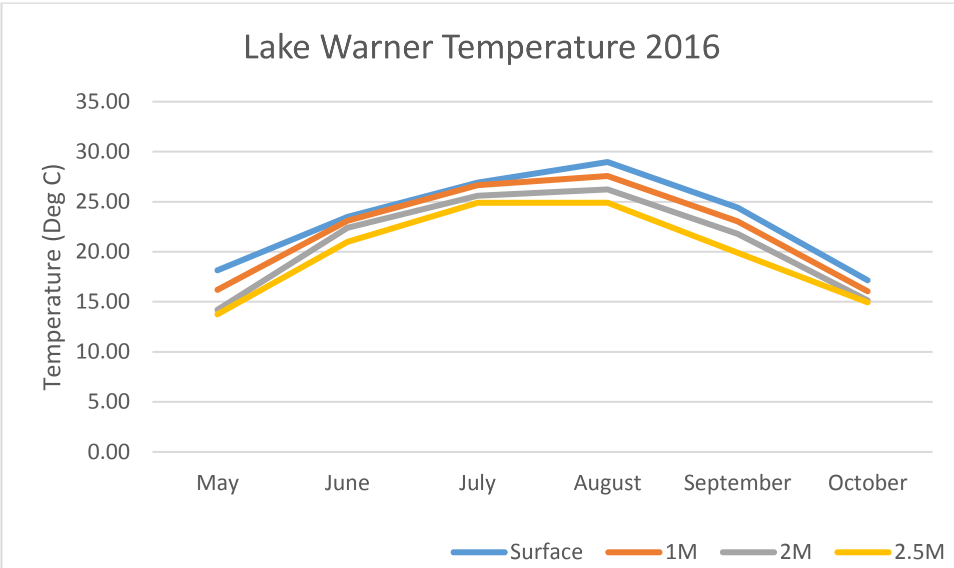
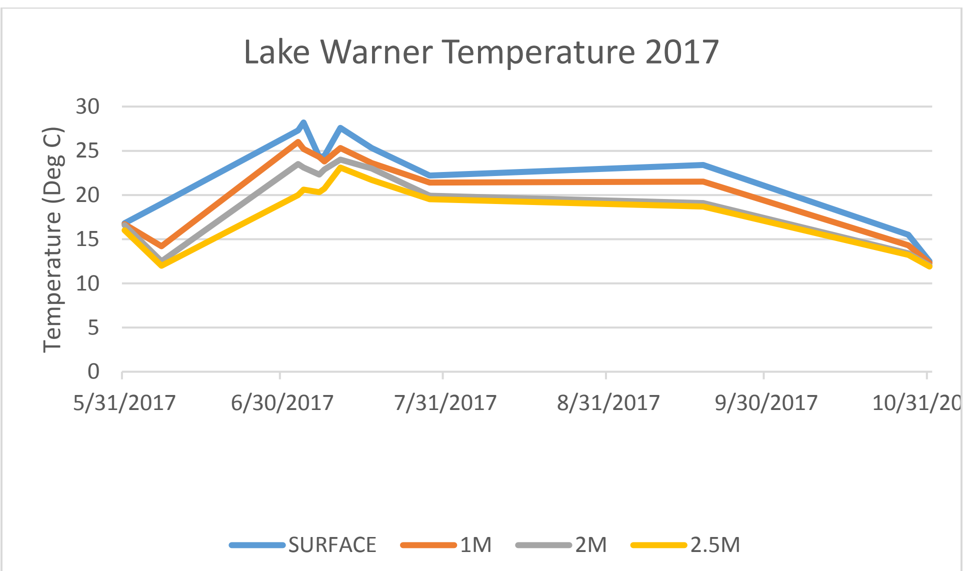


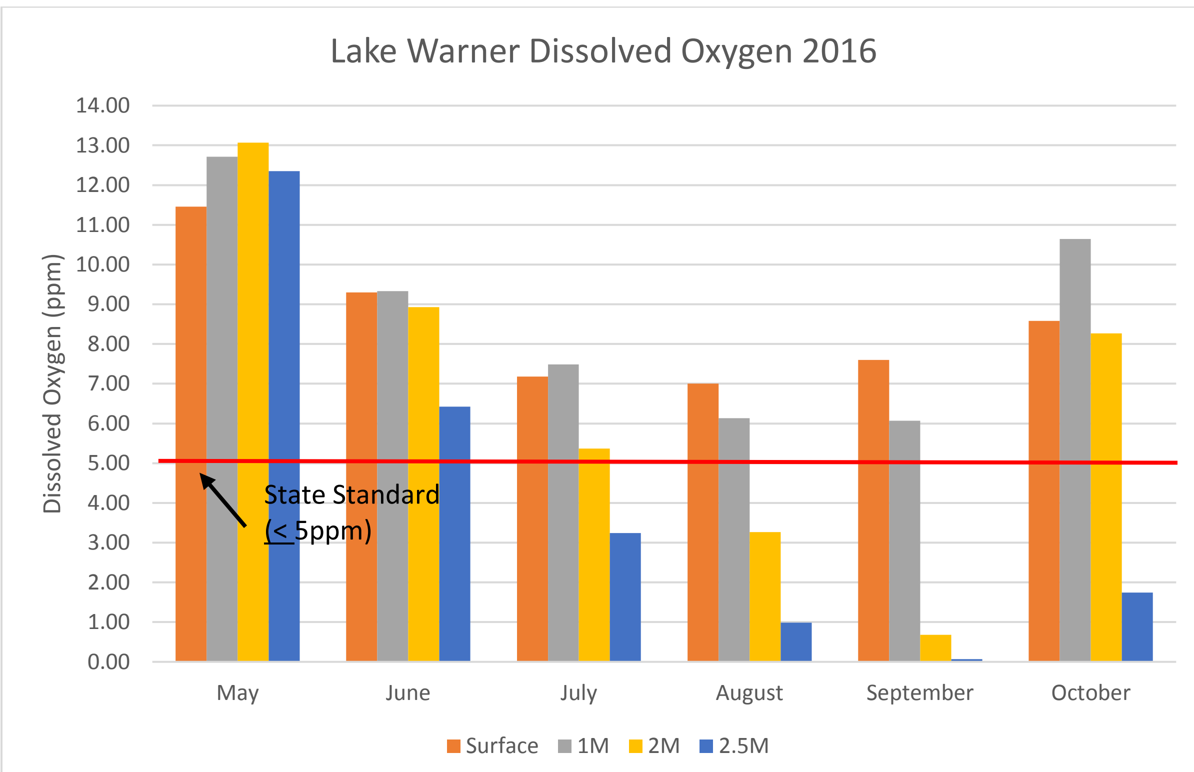
Figure 2. Lake Warner Temperature 2017



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-August 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 very dry 2016 summer created a stressful environment for aquatic organisms. Lake Warner, fortunately, did not experience a fish kill. Groundwater flow may be helping to maintain tolerable conditions. Dissolved oxygen values are shown for 2016 and 2017 in Figures 3 and 4. Dissolved oxygen values at 2 meters depth for 2016/2017 are shown in Figure 5.

Figure 3. Lake Warner Dissolved Oxygen 2016



During dam repair in 2017 booms were installed near the dam to prevent recreational users from accessing the construction area. The booms prevented floating aquatic vegetation, mainly Wolfia sp. from being flushed from the system. This created a backup of floating vegetation that extended upstream into the mid lake sample site. Excessive floating vegetation can result in decreased DO levels at depth as well as contribute to super saturated conditions near the surface. Precipitation in 2017 was above average, maintaining overall cooler temperatures and less stressful DO conditions in the lake.

Figure 4. Lake Warner Dissolved Oxygen 2017

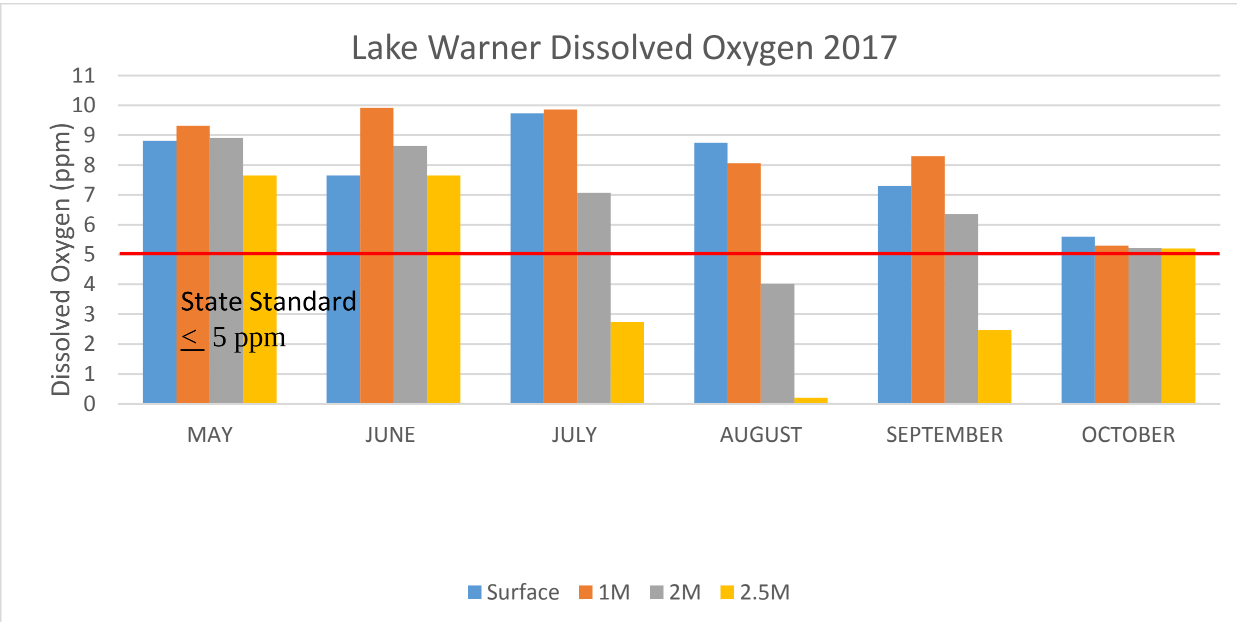
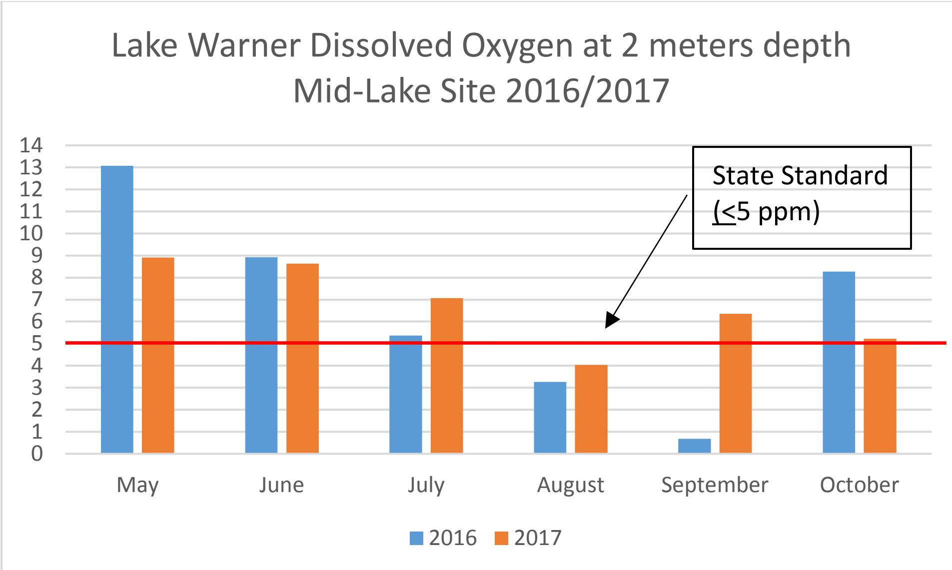


Figure 5. Lake Warner Dissolved Oxygen at 2 Meters, 2016/2017



<u>Transparency</u>

Secchi disc measurements ranged in 2016 from 1.3m to 2.6m 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 1.38 for the season. The range of results are not markedly different from the 2003/2004 sampling seasons where measurements ranged from .69 meters to 2.13 meters. However, 2017 was the first season since FoLW has been sampling that the transparency index (disc visibility) did not at any time equal or exceed 2 meters. Turbidity and decreased light, obstructed by floating aquatic plant growth may have influenced the results. Transparency results from 2016 and 2017 are shown in Figures 6 and 7.

Figure 6. Lake Warner Transparency 2016

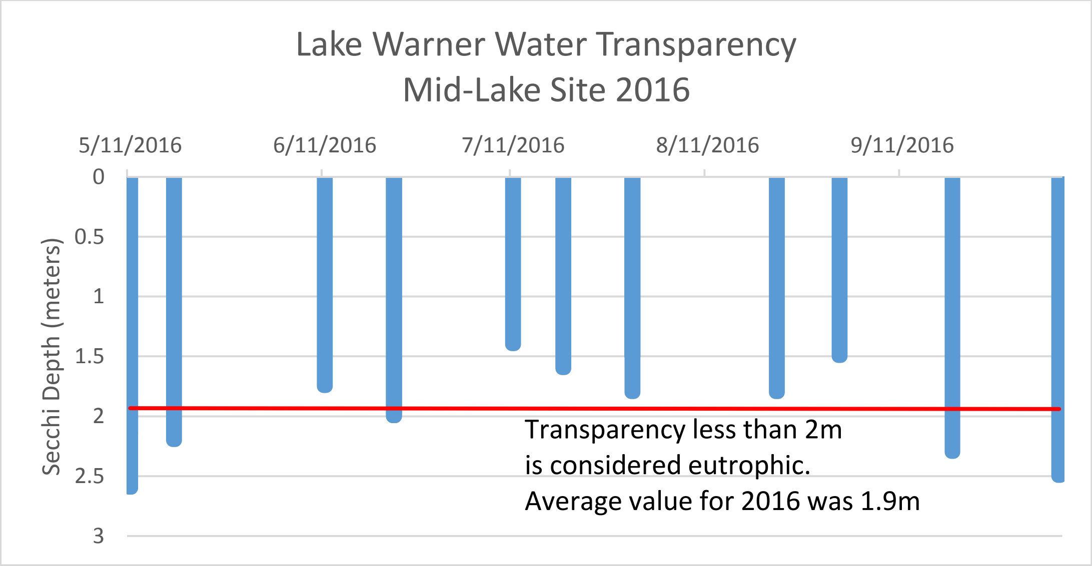
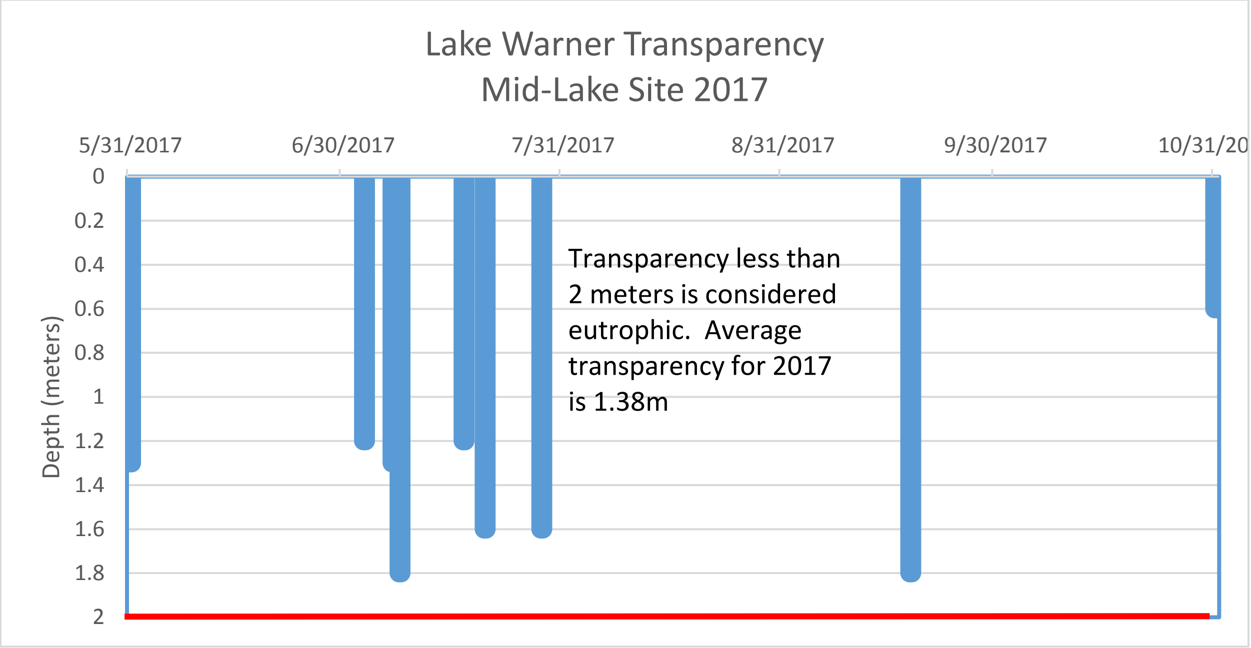


Figure 7. Lake Warner Transparency 2017

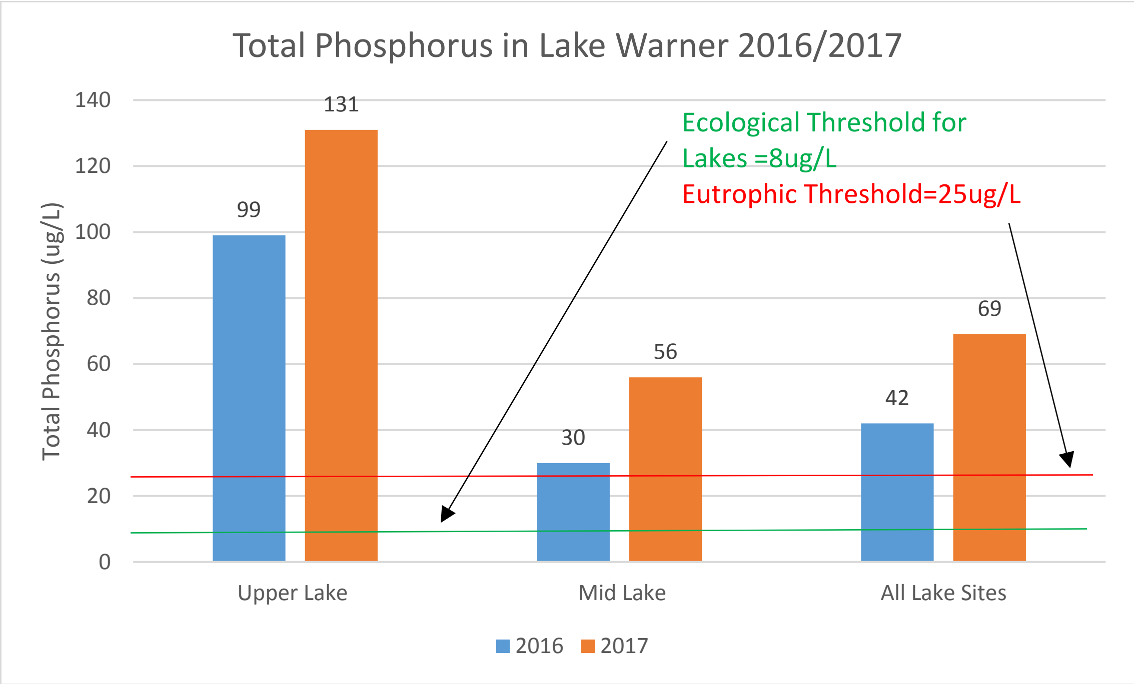


Phosphorus

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 at the mid Lake site and upstream on the Mill River and other tributaries. Levels in the lake were 4-5 times higher than the ecological threshold for lakes in our region. Levels at the mid-lake site exceeded the eutrophic threshold in both 2016 and 2017. Values for total phosphorus from all sites can be found in Table 2. Comparisons between 2016 and 2017 at different lake sites are shown in Figure 8. All values are represented as geometric means.

Figure 8. Total Phosphorus in Lake Warner 2016/2017



Phosphorus levels in the Mill River and tributaries can be found in Summary Table 2 and are shown in Figure 9. All values are represented as geometric means.

Figure 9. Total Phosphorus in Mill River Watershed Tributaries 2016/2017

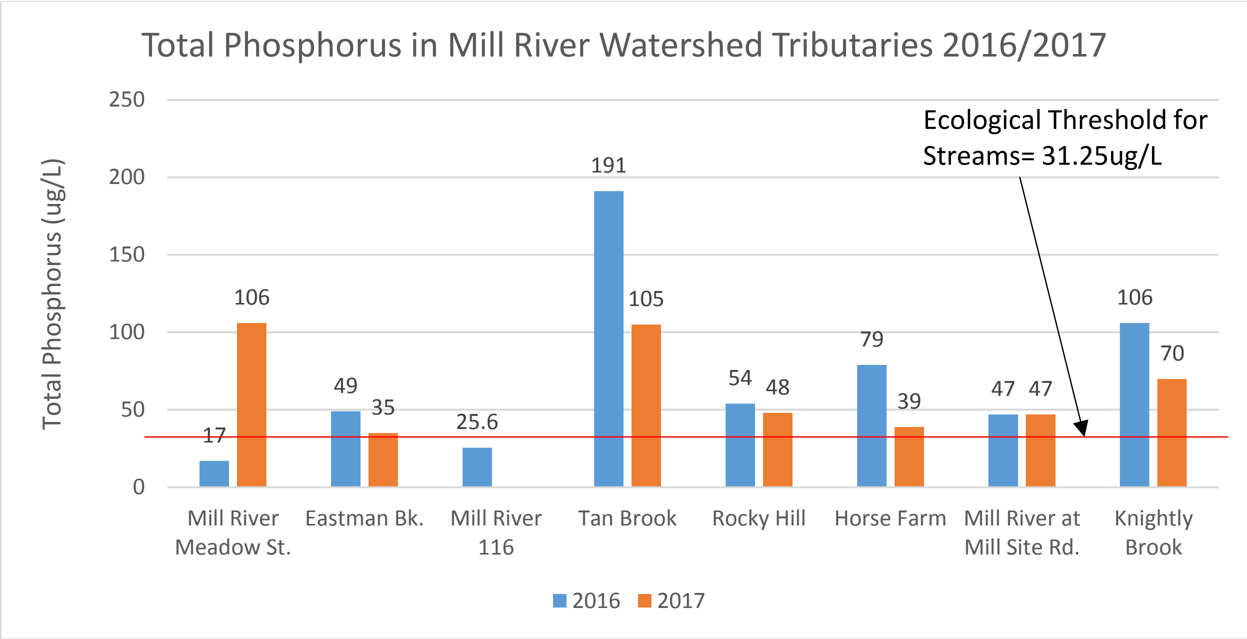


Table 2. Summary Tables- Geometric Means of Phosphorus Samples 2016/2017

Lake Warner Total Phosphorus (ug/L)

Year	Upper Lake	Mid-Lake	Boat Ramp	Below Dam	All Lake Sites
2016	99	30	75	36	42
2017	131	56			69

Mill River Watershed Total Phosphorus (ug/L)

Year	Mill R. Meadow St.	Eastman Brook	Mill R. 116	Tan Brook	Rocky Hill Road	Horse Farm Brook	Mill R. Mill Site Rd.	Knightly Brook
2016	17	49	25.6	191	54	79	47	106
2017	106	35		105	48	39	47	70

Bacteria

Bacteria samples were collected between June and September 2016 and 2017. *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. FoLW is pleased to report that the level of bacteria in the lake never in 2016 and 2017 exceeded the primary contact level that would have required warnings to be posted. The Mill River above the Lake did have levels exceeding the recreational health and safety thresholds. More analysis should be done to determine the source of these high bacteria levels. A summary of 2016 bacterial levels in the lake and tributaries is presented in Table 3. Results comparing sites throughout the watershed during 2016 and 2017 can be found in Figure 10. All values are represented by geometric means.

Figure 10. Mill River Watershed E.coli Bacteria Samples 2016/2017

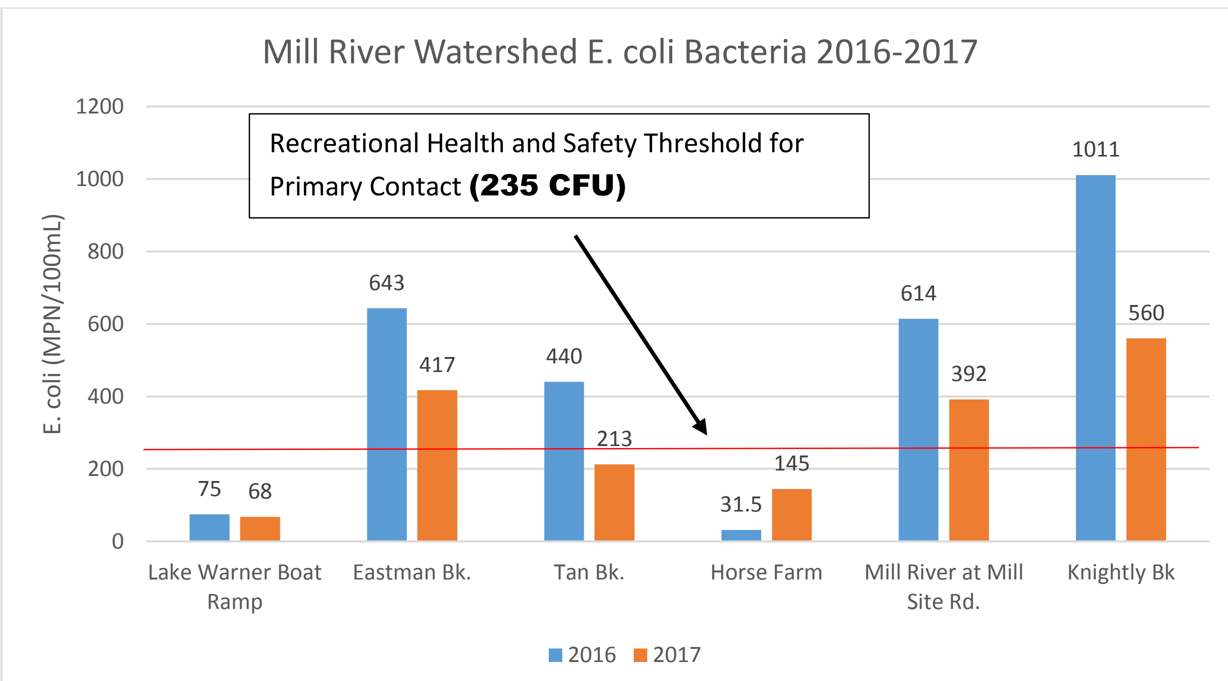


Table 3. Summary Table- Geometric Means of Mill River Watershed E.coli Bacteria (CFU/100mL)

Year	Mill R. Rte.63	Mill R. Meadow St.	Mill R. 116	Eastman Brook	Tan Brook	Mill Site Rd.	Rocky Hill Rd.	Horse Farm Brook	Knightly Brook
2016	345	1030	508	643	440	614	109	31.5	1011
2017				417	213	392		145	560

Lake Warner E.coli (CFU/100mL)

Year	Lake Warner Boat Ramp
2016	75
2017	68

Algae

Lake Warner exhibits abundant blooms of algae, mainly Anabaeana sp. and Anacystis sp. (Snow and DiGiano, 1973). Other species found during a survey by a visiting scientist from Uruguay in 2016 included Filamentous Algae: Spirogyra sp., Mougeotia sp., unknown uni-cellular Diatom possibly Osillatoria sp., and possibly Cyanobacteria, Camptocerus sp, Cyclops, Cypridopsis. The shallow, warm and nutrient rich conditions found in Lake Warner are prime for supporting cyanobacteria blooms. Under certain conditions cyanobacteria can spread quickly forming dense "blooms" on a water body's surface. These blooms are a problem because many cyanobacteria species produce toxins that are dangerous to humans and wildlife. Potential negative impacts can include; skin irritations, illness, loss of plant and animal life, loss of aesthetic appeal, loss of recreational activities, and reduction in property values. FoLW is using **bloomWatch!** a crowdsourcing App designed by a collaborative group of scientists including the Massachusetts Department of Environmental Protection for reporting possible cyanobacteria blooms. The FoLW will post educational information at the boat ramp this year and if a cyanobacteria bloom is positively identified will post warnings to recreational users to avoid the affected areas.

2016 Sediment Monitoring & Testing Results

FoLW conducted soil samples at four locations in the lake for toxins, heavy metals and nutrients. The results of these studies showed low levels of heavy metals, and high levels of nutrients. Phosphorus levels were within optimum ranges for agricultural soils indicating abundant available nutrients that encourage aquatic plant growth. The results are shown in Table 4, the laboratory reports are located in the appendix.

Table 4. 2016 Lake Warner Sediment Sample Results

Location	MAFW	Kestrel Peninsula	Knightly Brook	**Lake Sediment**	Optimum Range
Sample Number	LWUL COMP 1	LWUL COMP 2	MRKB	**Averages**	
Macronutrients (ppm)					
Organic Matter	8.4%	6.8%	18.9%	**7.6%**	
Nitrate (NO3-N)	3	5	7	**4**	
Soil pH (1:1, H2O)	4.6	4.5	5.5	**4.55**	
Phosphorus (P)	6.4	5.2	15.3	**5.8**	4-14
Potassium (K)	72	55	196	**63.5**	100-160
Calcium (Ca)	923	867	2340	**895**	1000-1500
Magnesium (Mg)	100	95	359	**97.5**	50-120
Sulphur (S)	386.5	452.0	225.3	**419.25**	>10
Micronutrients(ppm)					
Boron (B)	0.4	0.3	0.8	**0.35**	.1-0.5
Manganese (Mn)	110.1	91.4	283.1	**100.75**	1.1-6.3
Zinc (Z)	30	22	4.4	**26**	1.0-7.6
Copper (Cu)	1.1	1	0.5	**1.05**	0.3-0.6
Iron (Fe)	150.7	119.6	208.2	**135.15**	2.7-9.4
Aluminum (Al)	109	85	147	**97**	<75
Lead (Pb)	3.8	3.0	0.0	**3.4**	<22

Aquatic vegetation

Plant growth continues to negatively affect recreational boating and fishing. FoLW did not sample plant transects in 2016 or 2017 due to lack of volunteer help. Plant transects will be sampled in the 2018 field season.

Water Chestnut Harvesting

FoLW removed approximately 800 lbs. of water chestnut from Lake Warner in 2016. 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 2016 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 eight days were logged exclusively for scouting and removal of water chestnut. An estimated 200 volunteer hours were spent on this effort. Near weekly patrols resulted in small but consistent harvests throughout the growing season. FoLW sponsored one public volunteer water chestnut harvest in July 2016 resulting in a harvest of 367 pounds.

A total of 2,200 pounds of water chestnut was removed from Lake Warner in 2015. While it appears that FoLW removed half as much in 2016, FoLW believes that, because of the differing maturity of the plants, the overall counts were about the same. Calculations estimated the number of actual plants removed at about 16,000. "The equivalent weight of 16,000 fully mature plants is somewhere between 2,200 and 2,400 pounds. As a result of this removal an estimated 320,000 water chestnut seeds were prevented from entering Lake Warner in 2016." (Maleady, 2017)

In 2017, an estimated 1,250 pounds of water chestnut was removed from Lake Warner. The increase in volume was again linked to the timing and frequency of harvesting. The "early and often" strategy was difficult to employ because of the lack of volunteers able to commit to the 2016 level of intense scouting and harvesting. Sixteen days were logged exclusively for scouting and removal of water chestnut. Only 99 volunteer hours were documented in 2017, half as many as in 2016. Fewer volunteers meant that the time required to scout the entire lake increased. Large patches of mature plants developed rapidly in areas that were not scouted thoroughly or missed in the profusion of other plant growth in the lake. Larger plants resulted in increased overall harvest totals. FoLW believes that the 2017 total underestimates the total quantity of plants and that almost certainly all plants were not harvested from the lake this year.

As a result of the discouraging results from 2017, a more aggressive approach is planned for 2018. Four public pulling dates are scheduled and scouting will continue on a weekly basis. Hand pulling of water chestnut using volunteers will have to be permitted under the guidelines outlined in the Request for Determination with the Hadley Conservation Commission for another three years, through 2020.

Discussion

Water Quality

Water quality measurements were affected by an abnormally dry spring and summer in 2016 and unusually wet conditions during the spring and summer of 2017. The amount and timing of agricultural water withdrawn from the Mill River is still undocumented. Sample sites and methods were chosen to allow comparison and trending with earlier studies. Temperatures are normal for a shallow warm-water lake. Transparency was reduced in 2017 and may have been due to excessive turbidity due to precipitation as well as the backing up of surface vegetation caused by buoy installation at the Mt. Warner Bridge during dam repairs. Low levels of dissolved oxygen in the 2 meter level was consistent in both the 2016 and 2017 season. This indicates that overall lake health is still in a state of decline since 2003/2004 values from the same site and depth. 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.

Phosphorus

Nutrients in the lake and tributaries were sampled with increased frequency in 2016 and 2017 in order to obtain geometric means for the sample sites. However, in 2016 wet samples were difficult to obtain at some sites due to abnormally dry conditions. And in 2017 the time and effort required to collect samples as well as to attend to other components of the monitoring program affected the frequency of nutrient sampling. Two sites dried up completely in 2016. An effort to concentrate on permanently flowing tributaries was made in 2017. Tan Brook, which drains much of urban Amherst and the UMASS Campus Pond continues to have the highest phosphorus levels of any tributary in the watershed.

We are confident of the quality assurance of the sample collection process, performed by the same personnel consistently throughout the season. However, while values presented are geometric means of measurements at those sites, they cannot be taken for accurate average values for the tributaries or lake. There was considerable variability among samples, thought to result from differences in flow at sampling and duration of time taken following precipitation events. Nonetheless, the lake values are considerably higher than state and federal thresholds and exceeded the eutrophic thresholds during both 2016 and 2017. In 2016 and 2017 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 levels in the lake.

The conditions at Lake Warner are serious, and threaten the long term prospects of the site for recreational use. A broad based approach to nutrient and pollution management will be necessary to improve and preserve the health of the lake. The current monitoring project will provide a baseline status and a tool for assessment of the impact of interventions and changes in the lake and watershed.

Management Options

While mechanical harvesting is expensive and would involve some permitting requirements, it may be the most effective short term solution to the current over growth of aquatic vegetation. However, harvesting is not a substitute for addressing the fundamental problem of excessive nutrient levels, which must be approached on a watershed wide level. Vegetation management will help open up some of the congested areas of the lake that become inaccessible during the peak of the summer. This would improve fishing and recreational boating on the lake. It would have to be accepted that this would be a temporary effort to maintain the open water areas of the lake. We may develop problems with other undesirable species such as algae invading niches left by harvest of current vegetation. It is recommended that we experiment with vegetation harvest on the smallest portion of the lake that is economically feasible and monitor the results closely. A preliminary harvest plan might involve 5-10 acres of the lake a year for 2 years. The project would require fundraising, as FoLW does not have a budget for vegetation management.

Drawdown

A new slide gate was installed at the dam during the 2017 dam repair. FoLW would like to consider a scheduled drawdown of the pond as a management tool. Following the third year of data collection and the lake and the completion of the vegetation transects a plan will be developed. The plan will have to evaluate the benefits of drawdown on targeted plant species as well as potential drawbacks due to impacts on non-target species.

Sediment Inactivation

Sediment samples indicate that there are abundant quantities of phosphorus in the sediments of the upper lake. Inactivation of these sediments is impractical while the incoming nutrient levels remain high. Reduction of sources of phosphorus and nitrogen need to occur before other in lake treatments are attempted.

Best Management Practices Implemented in the watershed

Implementation of Best Management Practices (BMPs) at the UMASS Horse Farm between 2012 and 2015 was made possible through a 319 grant from MassDEP. These practices may be responsible for a measurable improvement in water quality at the local tributary. Phosphorus measurements from the Horse Farm Brook site were reduced by half in 2017 from 2016 levels. BMPs implemented included sacrifice areas, vegetated swales, excluding animals from wetland areas, reseeding and improving pastures and collecting manure from sacrifice areas. These improvements were made to reduce nutrient runoff and nutrient leaching, as well as nutrient/pathogen loading and runoff. Pollutant contribution reduction from the farm was calculated using a loading per Animal Unit. 3,942 lbs. of nitrogen, 1,642.5 lbs. of phosphorus, and 6.13 x10^{12} organisms of fecal coliform are now being abated annually at the UMASS Horse Farm due to the improvements there. This has resulted in a substantial improvement in water quality in the tributary running through the Horse Farm upstream of its confluence with the Mill River. Reduction in nutrient and pathogen inputs from other tributaries to the Mill River and Lake Warner are needed to improve conditions in the lake. FoLW would like to support similar efforts and improvements throughout the watershed.

Conclusions from 2016/17 Research and Monitoring

Problem Nutrients

Phosphorus, a naturally occurring element essential to all life, is especially important in aquatic ecology because it is often the primary 'limiting nutrient' for algae and aquatic plants. Its normal relatively low natural availability in a body of water limits the growth of aquatic vegetation. When phosphorous is present in excess, however, it can lead to over-abundant growth of algae and aquatic plants, along with severe depletion of dissolved oxygen as they decompose. When a pond or lake is covered with algae or duckweed it is usually because too much phosphorus is present. When a water body is starved of oxygen by over growth and decomposition of algae and vegetation many species of fish and other animals cannot survive. High levels of phosphorous are a key problem in Lake Warner.

Phosphorus levels have not decreased significantly in Lake Warner since a major study of its ecology in 1973 (Snow & DiGiano), even after elimination of a major source of phosphorus entering the Lake from the Amherst Wastewater Treatment Plant in 1979. Trends over the last decade indicate that phosphorus levels in the tributaries remain elevated above state, regional and federally established thresholds. The high levels of phosphorous adversely affect the health of the Lake, segments of the main stem of the Mill River, and several tributaries that remain unmanaged problems in the watershed.

Most lake management efforts focus on phosphorus, but other nutrients, such as nitrogen, may also affect water quality in Lake Warner. Although excess phosphorus is a driver of algae blooms, nitrogen levels may affect which algal species are present and their toxicity. Temperature may also play a role. One of the effects of climate change is the warming of shallow waters like Lake Warner. Recent regional and international research has investigated the connections between climate change, phosphorus, nitrogen and water quality. Changes in temperature and water chemistry affect the biological health of the Lake, the presence of various species of fish, plants, and other organisms, and can also trigger harmful algae blooms.

Most lake management efforts focus on phosphorus, but other nutrients, such as nitrogen, may also affect the health of Lake Warner. Where excess phosphorus is a driver of algae blooms, nitrogen levels may affect which algal species are present, including potentially toxic varieties. Temperature may also play a role. One of the effects of climate change is the warming of shallow waters like Lake Warner. Recent research exploring connections between climate change, phosphorus, nitrogen and water quality suggests that both temperature and water chemistry are factors in the biological health of the Lake, affecting the presence of various species of fish, plants, and other organisms, and triggering harmful algae blooms.

Nutrient and Pollution Load from Tributaries

The tributaries that drain into Lake Warner from its watershed continually replenish the Lake's water supply. These tributaries also deliver nutrients, including excess phosphorus, nitrogen and other nutrients, as well as toxic substances that are washed off the landscape during rainstorms.

Lake Warner's watershed extends from Hadley through Amherst and UMass up into Sunderland, Leverett and Shutesbury. The ratio of land area in the watershed to the area of the lake is 274:1. With such a large watershed draining to the Lake, the challenge of limiting nutrients and pollution input from the watershed to the lake is substantial. In addition to identifiable "point sources" of concentrated nutrients or pollutants, the watershed includes extensive "non-point sources" of nutrient enriched or pollutant contaminated runoff which make more diffuse contributions not easily traced back to an originating location.

An additional factor is the contribution of phosphorus from historical over enrichment of the Lake's sediments. This material was delivered into the Lake through sporadic slugs of sewage from the overflow of the Amherst Wastewater Treatment Plant that discharged via the Mill River from the 1930's into the late 1970's.

Management agencies have made some efforts to address these problems, with mixed success. One of the most promising techniques lies in the implementation of "Best Management Practices" to handle nutrients and pollutants before they enter the waterways.

Nutrient and Pollution Load from Developed Land Use

Land that has been built upon can be a substantial source of nutrients and other pollutants to a lake that is downstream. Lawn and garden fertilizers, detergents, small petroleum leaks and spills and similar sources can all add phosphorous and other undesirable materials. Developed lands tend to have large areas with artificial surfaces, such as building rooftops and parking lots. These surfaces shed rain very quickly and do not provide the opportunity for storm water to soak into the ground where pollutants can be trapped by the soil and naturally degrade. High storm flows can increase the erosion of stream-banks, sending enriched or contaminated sediment downstream toward the Lake. Flash storm flows, with surges of large volumes of rainwater runoff from developed lands, can increase the severity of flooding downstream. Systems and practices can be adopted to increase the amount of water that soaks into the ground during a rain, facilitating local absorption and degradation while reducing and delaying runoff to tributaries and the Lake. Investments in better-designed and more resilient roads, culverts, detention areas and "green infrastructure" higher up in the watershed could reduce the effects of these storm flows. This is especially true in areas like UMass and downtown Amherst.

Nutrient and Pollution Load from Agricultural Land Use

Agriculture is an important part of the economic landscape in much of the Pioneer Valley, and particularly in Hadley and Amherst, which have some of the best farming soil in the world. Farmers throughout the Mill River watershed often draw water to irrigate their crops, and may require a high degree of water quality for the productivity of their crops and for the health of the eventual consumer.

Many farming practices, both conventional and organic, require the application of fertilizer to increase crop productivity. Cattle and other animal-based farms generate large amounts of manure that must be disposed of. Farmers spread manure on their fields to recycle those nutrients back into their crops and pastures. Runoff and erosion from barnyards, laneways to pastures, and animal congregation areas can carry excessive pollution into nearby waterways. Most conventional farms also rely in part on commercial fertilizers and feed additives that are imported into the watershed. A portion of these nutrients inevitably washes off the land and into the closest waterway.

Agricultural practices have steadily improved over the years as our understanding of nutrients and pollution has increased. Many or most farmers in Massachusetts now coordinate the spreading of manure fertilizer so as to avoid imminent rainstorms that can wash away large portions of the fertilizer, wasting its benefits and spoiling streams and lakes. Likewise, many farmers have developed an appreciation of the ecological importance of riparian or stream-side buffer zones that prevent managed animals from damaging stream banks and leaving their 'deposits' in fresh water. However, small farmers often lack the time, staff and resources to research, pay for and implement practices that are beneficial to waterways. Much more can be done for the Lake and its tributaries in this regard.

The Hampden Hampshire Conservation District (HHCD) is taking an active role in outreach and education to promote best management practices that reduce non-point source pollution of water resources. The Friends of Lake Warner are working with the HHCD and other organizations to support farmers in the watershed, increase our knowledge of local ecology and encourage best management practices for the land and waters.

Action Needed

Portions of Lake Warner are effectively dead during the heat of late summer due to overgrowth of nuisance species supported by an excess of plant nutrients. These areas are in the late summer so choked with weeds and rotting vegetation that they have none of the dissolved oxygen required by fish and other forms of higher life. In these areas the weeds are so thick they are virtually un-navigable three or more months of the year- half of the recreational summer season.

The good news is that the lake is still beautiful and is providing habitat to many species of fish and wildlife.

Changing land use issues will continue to affect the Mill River watershed. The loss of forests, wetlands, increasing urbanization and development are all putting pressure on the water quality of the tributaries of the Mill River.

It will be necessary to address point source and non-point source pollution and surges of storm water runoff with controls and best management practices, or increasing nutrient and pollutant loads will cause further deterioration of the quality and health of the Lake to deteriorate further.

Efforts must also be made to support and improve wetland functioning along the Mill River above the Lake. This wetland complex is a critical filter for the storm water and non-point source pollution coming from urbanized portions of the watershed.

We look forward to working with the towns of Hadley and Amherst to improve the monitoring, assessment, and planning for better management of nutrients and pollution from non-point sources and storm water in the watershed. Addressing the impaired portions of the Mill River, reducing bacteria levels and working toward meeting nutrient loading standards for Lake Warner should be goals that we can all work together to achieve.

Additional Surveys by other entities

The Mill River downstream of Warner Dam was sampled by staff of the US Fish and Wildlife Service on August 8, 2016. Twenty-five American Eels, with a mean length of 260 mm, were sampled, demonstrating the use of this tributary by anadromous species. FoLW is supportive of efforts to improve the ecological condition and connectivity between the lower river and lake. Establishment of flow conditions and management to promote a healthy aquatic ecology are long term goals of the organization.

Sources

Biodrawversity LLC. 2010. Zebra Mussel Phase II Assessment. Physical, Chemical, and Biological Evaluation of Waterbodies in the Connecticut River Watershed of Massachusetts. Prepared for the Massachusetts Department of Conservation and Recreation Lake and Ponds Program. 30 pages.

BSC Group. 2003. Mill River Flood Study Report. Central Heating Plant Project. University of Massachusetts at Amherst. Project Number 22917.00

Hashemi, M. 2016. Minimizing Nonpoint Source Pollution from Two Horse Facilities through BMP's Massachusetts Department of Environmental Protection. Project No. 12-03/319

Maleady, Peter. 2017. 2016 Water Chestnut Report to the Hadley Conservation Commission.

Massachusetts Department of Conservation and Recreation. A Guide to Aquatic Plants in Massachusetts. 32 pages.

Massachusetts Department of Environmental Protection. 2001. Total Maximum Daily Loads of Phosphorus for Selected Connecticut Basin Lakes. 58 pages.

Massachusetts Department of Environmental Protection "Years 2002, 2007, 2012, 2014 Integrated List of Waters". 2002, 2007, 2012, 2014.

Massachusetts Riverways Program. 2003. Department of Fisheries, Wildlife and Environmental Law Enforcement. Watershed Survey Final Report & Action Plan Lake Warner / Mill River Watershed.

Schoen, J. 2004. Lake Warner 2004 Monitoring Report. Massachusetts Water Watch Partnership. 19 pages.

Snow, P.D., and F.A. DiGiano. 1973. Relationship between Trophic State and Chemical Parameters in Sediment-Water Systems of Selected Western Massachusetts Lakes. Division of Water Pollution Control. Massachusetts Water Resources Commission. Report No. EVE 32-73-3. 94 pages.

Sprankle, K. 2016. Eel backpack electrofishing survey, Lower Mill River, North Hadley, MA.

USEPA. 2000. Ambient Water Quality Criteria Recommendations
Information Supporting the Development of State and Tribal Nutrient Criteria for Rivers and Streams in Nutrient Ecoregion XIV. Report EPA 822-B-00-022. 84 pages

USEPA. 2001. Ambient Water Quality Criteria Recommendations
Information Supporting the Development of State and Tribal Nutrient Criteria for Lakes and Reservoirs in Nutrient Ecoregion XIV. Report EPA 822-B-01-011.123 Pages

USEPA. 2003. Bacterial Water Quality Standards for Recreational Waters (Freshwater and Marine Waters) Status Report. EPA-823-R-03-008. 32 pages

Appendices

1. **1.** Lake Warner-Mill River Watershed Map
2. **2.** Monitoring Sites Map 2015-2017
3. **3.** Raw Water Quality Data
4. **4.** E. coli Bacteria Reports, Connecticut River Conservancy Lab
5. **5.** Phosphorus Reports, Environmental Assessment Laboratory, UMASS Amherst
6. **6.** Soil Nutrients and Metal Reports, Paige Laboratory, UMASS Amherst