STATE OF THE LAKE REPORT 2019
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 2019. This expanded on the monitoring from 2016-2018. Study objectives were to assess general health of the lake and to identify and assess potential nutrient sources within the watershed. Parameters sampled were temperature, dissolved oxygen, water transparency, E. coli bacteria on a weekly basis in the lake, total phosphorus on a monthly basis in the lake and eleven tributary locations, and total nitrogen and nitrate/nitrite in the lake and twelve tributary locations. The 2019 sampling results continue to confirm findings from 2016 to 2018. The lake continues to have periods of low dissolved oxygen in mid and late summer. Water clarity showed a slight increase in 2019, likely due to increased precipitation. Excessive plant growth continues to negatively affect recreational boating. Total phosphorus (TP) levels in Lake Warner are above eutrophic thresholds again in 2019. Total phosphorus (TP) levels in tributary streams are lower than in previous years with the exception of Knightly Brook. The Knightly Brook, Tan Brook, Eastman Brook and Horse Farm Brook sites continue to produce elevated phosphorus levels. Total nitrogen levels are below EPA Gold book standards in the two headwater streams of the watershed but elevated at all other tributary sites. Nitrate/nitrite levels are below EPA Gold Book standards at all sites except Tan Brook and the Mill River locations. E. coli bacteria levels are elevated throughout the season exceeding the secondary contact level fifteen times in the Mill River and twice in Lake Warner 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. This program was expanded in 2019 to include nitrogen and to expand the number of sampling locations. 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, and from donations from members of FoLW. 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 been 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 Environmental Analysis Laboratory at UMASS Amherst, the Connecticut River Conservancy Laboratory and the Vermont Agriculture and Environmental Laboratory for their expertise and assistance with 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 were 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 was 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 and 2018 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 2019 Achievements

- Tested for dissolved oxygen, dissolved oxygen saturation, temperature and water transparency at the mid-lake sample site on a weekly basis.
- Sampled E. coli bacteria weekly in the lake and river between June and October. Made results available online and also posted the boat ramp to keep the public aware of water quality conditions.
- Sampled total nitrogen, nitrate/nitrite and total phosphorus in the lake and 12 tributary sites monthly between May and October.
- Coordinated volunteers to remove 4,022 pounds of water chestnut from the lake. An estimated 18,000 rosettes were removed preventing 359,000 nuts from entering the system. FoLW sponsored and ran three public pulling events at the lake in summer.
- Produced two newsletters that were mailed or send electronically to over 200 members and supporters.
- Participated in public events like the Sustainability 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, and Soil and Water Conservation for homeowners. FoLW continues to work with the HHCD on community education and collaboration to improve water quality in the Mill River Watershed.
- Advocated for and advertised conservation workshops put on by UMASS Agricultural Extension Services in the Mill River Watershed.
- Installed an informational kiosk at the public boat ramp.

Testing/Sampling Schedule

FoLW conducted the following tests/activities in 2019:

Table 1. Testing and Sampling Schedule

Survey Type/Test	Indicators	Materials/Methods	Laboratory	Sample Locations Frequency
General Lake Health	Dissolved Oxygen, Saturation Temperature Transparency	YSI 200 Meter, Secchi Disc		Mid-Lake, weekly June-October,
Nutrient Source Evaluation	Total Phosphorus	100mL brown sample bottles, lab supplied	EAL UMASS Amherst, MA	78 samples Lake, Mill River, 11 tributary sites. Monthly May-Oct.
Nutrient Source Evaluation	Total Nitrogen Nitrate/Nitrite	100mL clear sample bottles, lab supplied	VAEL Laboratory Randolph, VT	150 Samples. Lake, Mill River 11 tributary sites. Monthly May-Oct.
Primary and Secondary Contact for Recreation	E. coli bacteria	100mL clear sample bottles, lab supplied	CRC Lab Greenfield, MA	34 samples, Boat ramp, Mill River Weekly, May-Oct

Results

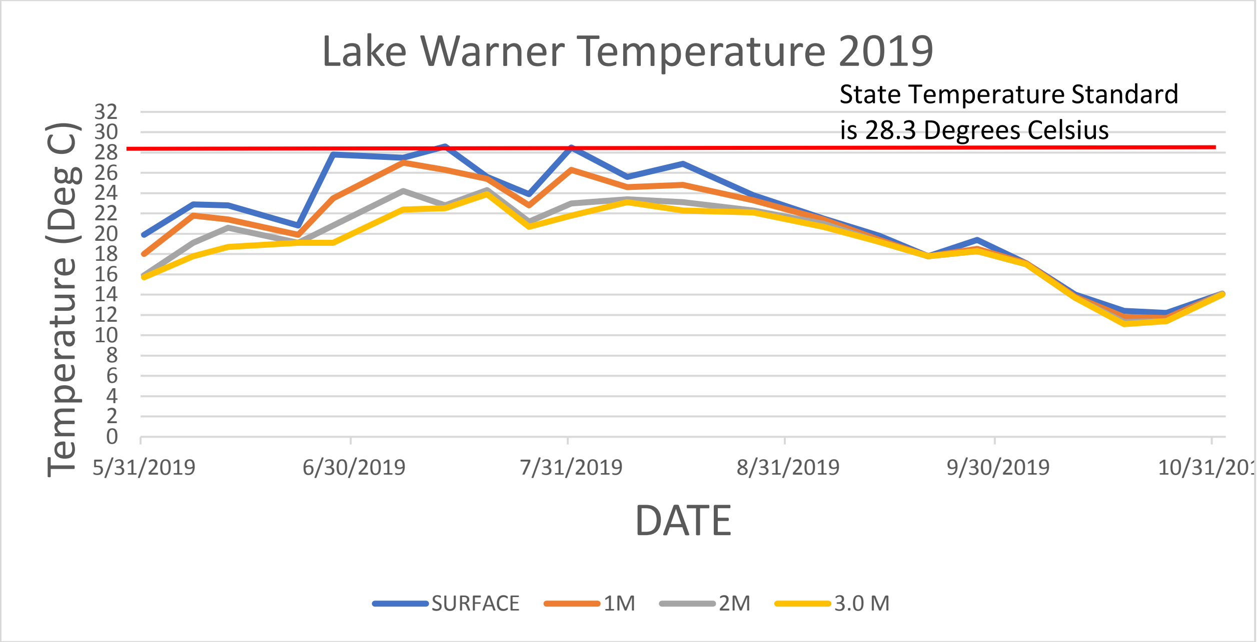
Temperature and dissolved oxygen levels are principal indicators of aquatic habitat. FoLW use a YSI200 dissolved oxygen (DO) and temperature meter to take temperature, dissolved oxygen and DO Saturation readings. In 2019 FoLW conducted 168 temperature and DO measurements, focusing on hypolimnetic oxygen levels at the mid-lake site to determine trends in temperature and dissolved oxygen levels throughout the summer and early fall.

Aquatic plants and animals have habitat preferences and limited tolerances to temperature. Temperature data from the mid-lake sample site during 2019 are presented in Table 2. and Figure 1. Although temperatures in 2019 started off warmer than average and remained higher throughout the year, Lake Warner generally continues to be a well-mixed warm water lake with no thermocline. Surface temperatures ranged from 12.2 to 28.6 degrees C, while temperatures at 3 meters ranged from 11.1 to 23.9 degrees C. The lake exceeded the State warm water temperature standard of 28.3 degrees during two measurements in July. 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. 2019 Lake Warner Temperature (Degrees Celsius) at Mid-Lake Sample Site

DATE	SURFACE	1M	2M	3.0 M
5/31/2019	19.9	18	15.9	15.7
6/7/2019	22.9	21.8	19.1	17.8
6/12/2019	22.8	21.4	20.6	18.7
6/22/2019	20.8	19.9	19.1	19.1
6/27/2019	27.8	23.5	20.8	19.1
7/7/2019	27.5	27	24.2	22.4
7/13/2019	28.6	26.3	22.8	22.5
7/19/2019	25.6	25.4	24.3	23.9
7/25/2019	23.9	22.8	21.2	20.7
7/31/2019	28.5	26.3	23	21.8
8/8/2019	25.6	24.6	23.4	23.1
8/16/2019	26.9	24.8	23.1	22.3
8/26/2019	23.8	23.3	22.3	22.1
9/5/2019	21.5	21.4	21	20.7
9/13/2019	19.8	19.4	19.2	19.2
9/20/2019	17.8	17.8	17.8	17.8
9/27/2019	19.4	18.5	18.3	18.3
10/4/2019	17.1	17.1	17	17
10/11/2019	14	13.8	13.7	13.7
10/18/2019	12.4	11.8	11.3	11.1
10/24/2019	12.2	11.7	11.4	11.4
11/1/2019	14.1	14.1	14.1	14

Figure 1. 2019 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. Summer 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 levels at the mid-lake sampling site are shown in Table 3 and Figure 2. Dissolved oxygen saturation levels are shown in Table 4 and Figure 3.

Percent saturation is the amount of dissolved oxygen in a water sample compared to the maximum amount that could be present (at the same temperature). For example, a water sample that is 50 % saturated only has half the amount of oxygen that it could potentially hold at that temperature. Dissolved oxygen (DO) in surface waters can exceed expected saturations when photosynthetic processes by algae or rooted aquatic plants produce oxygen more quickly than it can diffuse into the atmosphere. Algal blooms often accompany an increase in water temperature and this higher temperature further contributes to supersaturation (USEPA 1986a).

To protect aquatic life, EPA (1986a) recommends a total dissolved gas concentration in water not to exceed 110 percent of the saturation value for gases at existing atmospheric and hydrostatic pressures. Water at this level of saturation and above may lead to fish mortalities when dissolved gases in their circulatory system form emboli which block the capillary flow of blood. This condition is commonly referred to as "gas bubble disease". Studies have also shown, however, that it is high nitrogen and carbon dioxide (CO2) saturation that is potentially harmful to fish due to gas bubble disease, and not high oxygen saturation (Weitkamp and Katz 1980). Therefore, MassDEP is applying the 125% saturation level of DO as simply an additional indicator of high primary producer photosynthesis levels. However, DO saturation is not recommended as a primary variable to assess nutrient enrichment in some cases because the supersaturation may not be apparent due to surface turbulence and/or other non-nutrient-related factors (USEPA 2000a).

MassDEP Guideline: to support the designated use of aquatic life, a dissolved oxygen saturation exceeding 125% in more than one site visit during the summer growing season (April 1 to October 31) is considered an indicator of nutrient enrichment.

Table 3. 2019 Lake Warner Dissolved Oxygen Levels at Mid-Lake Site

DATE	SURFACE	1M	2M	3.0 M
5/31/2019	7.76	7.95	6.48	0.55
6/7/2019	8.98	8.92	9.32	3.31
6/12/2019	7.56	7.52	6.02	0.19
6/22/2019	5.58	3.15	0.25	0.24
6/27/2019	8.5	6.23	4.26	0.69
7/7/2019	6.68	6.52	4.24	3.8
7/13/2019	7.3	6.2	5.31	0.31
7/19/2019	5.6	5.15	2.45	0.13
7/25/2019	5.6	4.35	4.7	0.17
7/31/2019	8.4	7.25	3.4	0.15
8/8/2019	7.65	6.1	1.89	0.18
8/16/2019	9.1	9.75	6.15	1.97
8/26/2019	6.88	6.72	6.42	0.15
9/5/2019	5.55	5.94	4.39	0.21
9/13/2019	6.73	7.83	8.21	0.18
9/20/2019	7.38	7.94	7.25	2.9
9/27/2019	7.21	7.18	7.58	1.76
10/4/2019	6.44	6.44	6.35	2.2
10/11/2019	7.1	6.65	6.76	1.68
10/18/2019	6.95	6.62	6.38	2.88
10/24/2019	6.64	6.93	6.26	2.85
11/1/2019	7.66	7.06	6.93	4.9

Figure 2. 2019 Lake Warner Dissolved Oxygen at Mid-Lake Site

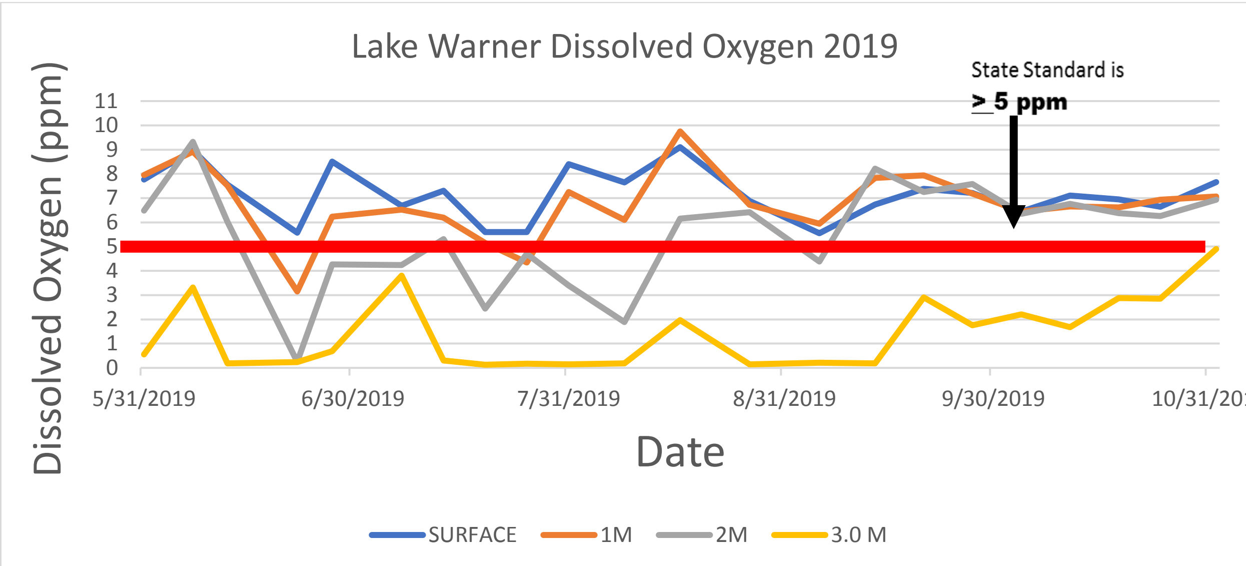
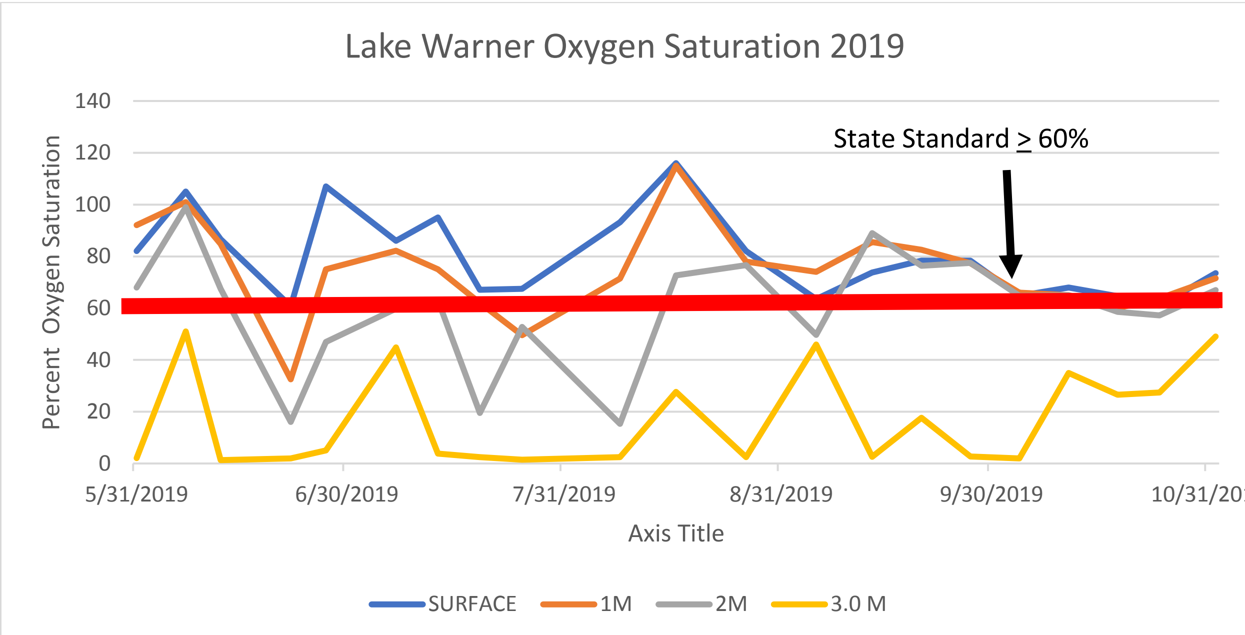


Table 4. 2019 Lake Warner Dissolved Oxygen Saturation Levels Mid-Lake Site

DATE	SURFACE	1M	2M	3.0 M
5/31/2019	82	92	68	2.1
6/7/2019	105	101	99	51
6/12/2019	86.6	84.8	67.5	1.3
6/22/2019	60.7	32.5	16.1	2
6/27/2019	107	75	47	5
7/7/2019	86	82.2	59.8	44.9
7/13/2019	95	75	63	3.8
7/19/2019	67.1	62	19.5	2.5
7/25/2019	67.5	49.5	52.7	1.5
8/8/2019	93.2	71.4	15.3	2.5
8/16/2019	116	115	72.7	27.7
8/26/2019	82	78	76.6	2.4
9/5/2019	63.5	74	49.7	46
9/13/2019	73.8	85.5	89	2.6
9/20/2019	78.3	82.5	76.3	17.6
9/27/2019	78.3	77.4	77.5	2.7
10/4/2019	64.7	66	64.8	2
10/11/2019	68	65	65	35
10/18/2019	64.6	60.1	58.5	26.6
10/24/2019	61	63.7	57.2	27.4
11/1/2019	73.5	71.5	67	49

Figure 3. 2019 Lake Warner Dissolved Oxygen Saturation Levels Mid-Lake Site



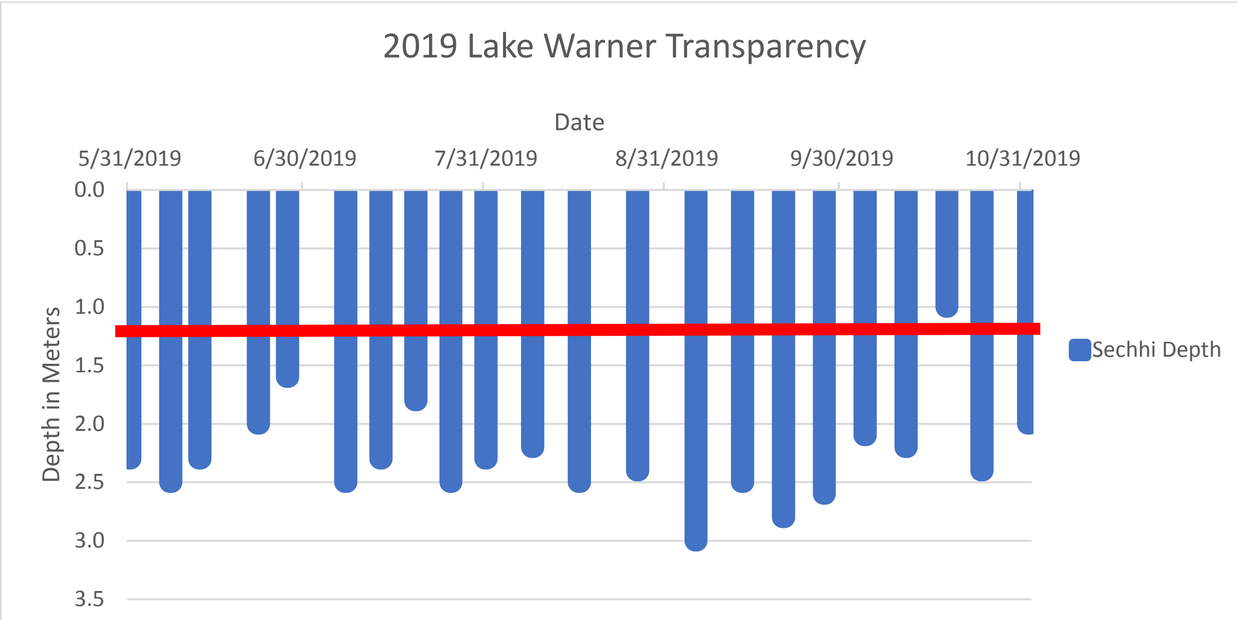
Transparency

Secchi disc measurements ranged in 2019 from 1 meter to 3 meters with an average of 2.3 meters for the season. The range of results reflected the influxes of fresh water coming in from precipitation events during the 2019 season. Turbidity increased during these precipitation events but the effects on transparency at the mid-lake site were brief. Not all precipitation events were captured during the monitoring period. Floating aquatic plant density was notably reduced at the mid lake site throughout the summer. Transparency less than 1.2 meters is considered impaired. Average transparency for 2019 is 2.3 meters. Transparency results from 2019 are shown in Figure 4.

Particulate matter suspended in the water column (total suspended solids or TSS) attenuates light and reduces transparency. The suspended matter could consist of algae, algal detritus or inorganic sediment. Surface water may also have high concentrations of light-absorbing dissolved compounds that originate from wetland areas that border the waterbody. This type of surface water is often referred to as "tea-stained".

Historically, Massachusetts has used the 1.2-meter (4 foot) transparency standard for swimming beaches to assess primary contact recreation use. This visibility standard originated from the "Green Book" (USDI 1968) which stated that ―clarity in recreational waters is highly desirable [to provide] for visual appeal, recreational enjoyment, and safety. For primary recreation, clarity should be such that a Secchi disc is visible at a minimum depth of 4 feet. This threshold was used at the Massachusetts Department of Health (MassDPH) to reduce risk of injury from swimming. Because swimming is a designated use in nearly all waters, the 1.2 m Secchi disk was selected as a screening guideline for all lakes, ponds and impoundments where swimming is a use.

Figure 4. 2019 Lake Warner Transparency at the Mid-Lake Site



Lake Nutrients

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 six times at the lake outlet during the 2019 sampling season. Levels in the lake are 4 times higher than the ecological threshold for lakes in our region. Levels at the lake exceeded the eutrophic threshold in 2019. Monthly results are shown in Figure 5. Trend data from the 2003/2004 study of the lake and recent results are presented in Figure 6. Note that 2019 results are taken from the lake outlet and not the mid-lake site.

Figure 4. 2019 Total Phosphorus Lake Warner Outlet

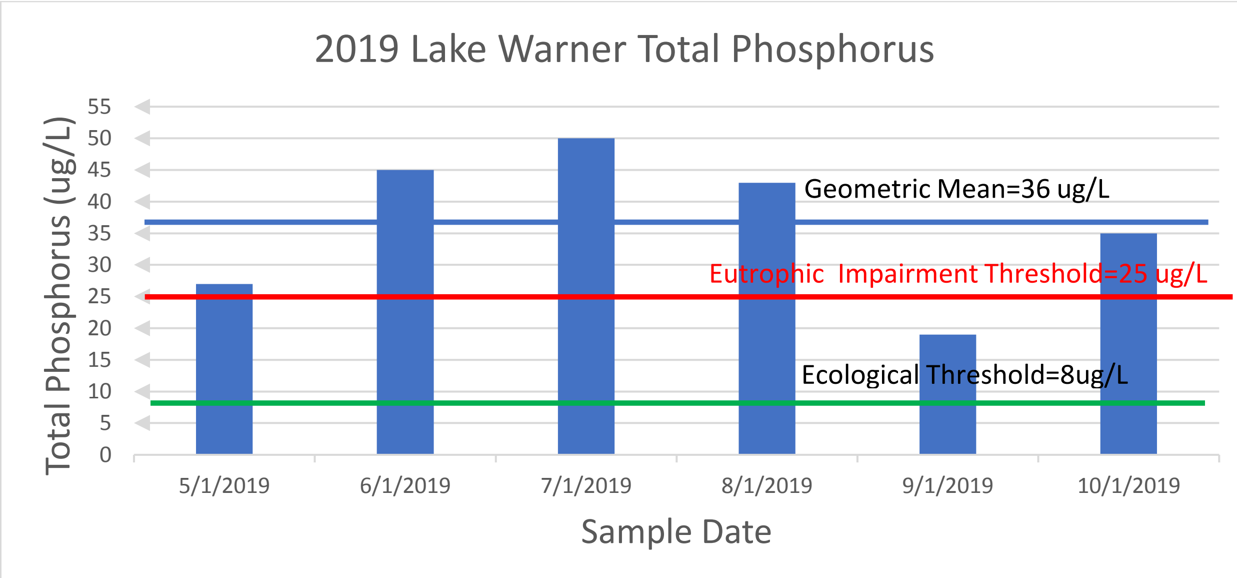
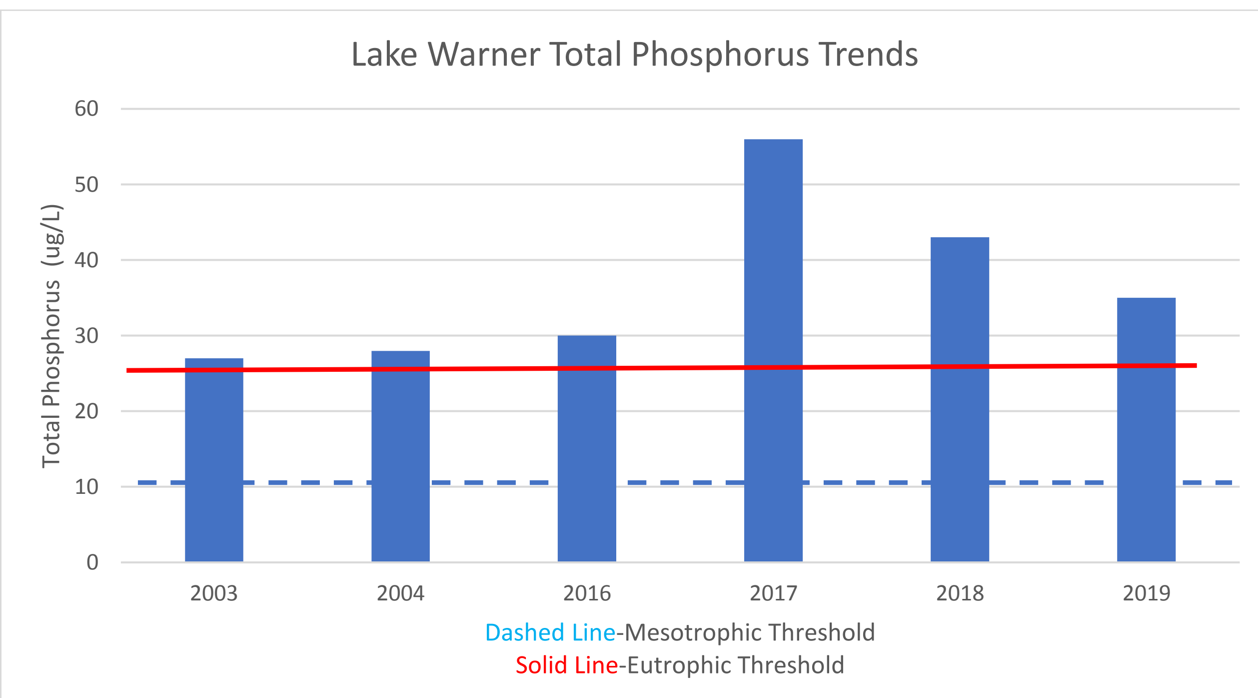


Figure 5. Total Phosphorus Trends Lake Warner 2003-2019



Nutrient criteria development status for Massachusetts is taken from the Massachusetts Consolidated Assessment and Listing Methodology (CALM) Guidance Manual for the 2018 Reporting Cycle.

Phytoplankton blooms can occur in lakes having concentration as low as 0.01 mg/l TP (Gower 1980). Relatively uncontaminated lake districts contain water with TP concentrations ranging from .01-.03 mg/l (Hutchinson, G.E. 1957). More recently, EPA guidance states that there is a general consensus that an ambient TP concentration of greater than 0.01 mg/l is likely to predict blue-green algal bloom problems during the growing season; however, because both soil enrichment and precipitation are variable across the U.S., EPA has taken an Ecoregion frequency approach to the TP criterion (USEPA 2000b). EPA recommends a TP criterion of 0.008 mg/l for lakes in both of the Massachusetts Ecoregions.

However, because many biological, chemical and physical characteristics influence whether a lake responds to certain levels of TP, MassDEP uses phosphorus concentrations as a confirming measurement when the weight of evidence points to nutrient enrichment. Specifically, when multiple biological and physico-chemical nutrient enrichment indicator thresholds are exceeded, then the seasonal average (greater than three samples) of the TP concentration data are screened against the 1986a EPA recommended "Gold Book" TP concentrations. As noted in the Gold Book, for prevention of primary producer overabundance in lakes, it is recommended that TP be maintained at 0.025 mg/l (EPA 1986a).

MassDEP Guideline: When multiple biological and physico-chemical nutrient enrichment indicator screening guidelines are exceeded, if the seasonal average for TP exceeds 0.025 mg/l for lakes, ponds and impoundments during the summer growing season (April 1 to October 31), it is considered additional confirmation of nutrient enrichment.

It should be noted here that EPA implemented a strategy to develop ambient water quality nutrient criteria by ecoregions for the US (EPA 2000a, 2000b, and 2001c). Massachusetts is encompassed by two of these freshwater ecoregions – *the Eastern Coastal Plain (Ecoregion XIV) is the region Lake Warner is located* and the Nutrient-Poor, Largely Glaciated Upper Midwest and Northeast (Ecoregion VIII) and two Estuarine and Coastal Marine Waters provinces- the Acadian Province (northern Cape Cod) and the Virginian Province (southern Cape Cod). EPA has since published their recommended nutrient criteria documents for both rivers and streams and lakes and reservoirs for each of these ecoregions. They include recommended criteria for total phosphorus, total nitrogen, chlorophyll a, and turbidity or Secchi disk depth intended to address the adverse effects of excess nutrient inputs (EPA 2000c, 2000d, 2001a, and 2001b). EPA has not yet published recommended nutrient criteria documents for either the Acadian or Virginian provinces.

Massachusetts evaluated EPA's approach along with other published literature and is using these to guide the development of its Nutrient Strategy. The ultimate goal of the state's effort is to quantitatively translate its narrative nutrient criterion with both biological response thresholds and recommended nutrient concentrations that will support Clean Water Act (CWA) goals and provide a clean and transparent process for protecting high quality waters, identifying impaired waters, and establishing associated restoration targets for degraded waters.

To evaluate a waterbody for nutrient-related impairment MassDEP analysts rely on multiple supporting indicators as evidence of nutrient enrichment. Biological indicators of nutrient enrichment (one or more of which is documented as problematic), include the presence of nuisance growths of primary producers or population changes in certain critical species. Secondly, indications of high primary productivity are often observed as changes to certain physico-chemical analytes, as well. Taken together, these biological and physico-chemical indicators are utilized for making nutrient-related impairment decisions for the Aquatic Life Use. The more combinations of these indicators are documented, the stronger the case for the Aquatic Life Use to be assessed as not supporting. It should be noted here that while total phosphorus or nitrogen concentration data alone are not currently utilized to determine impairment due to nutrient enrichment, they are used to corroborate indicator data and can help to identify potential sources (e.g., release of phosphorus from anoxic sediments).

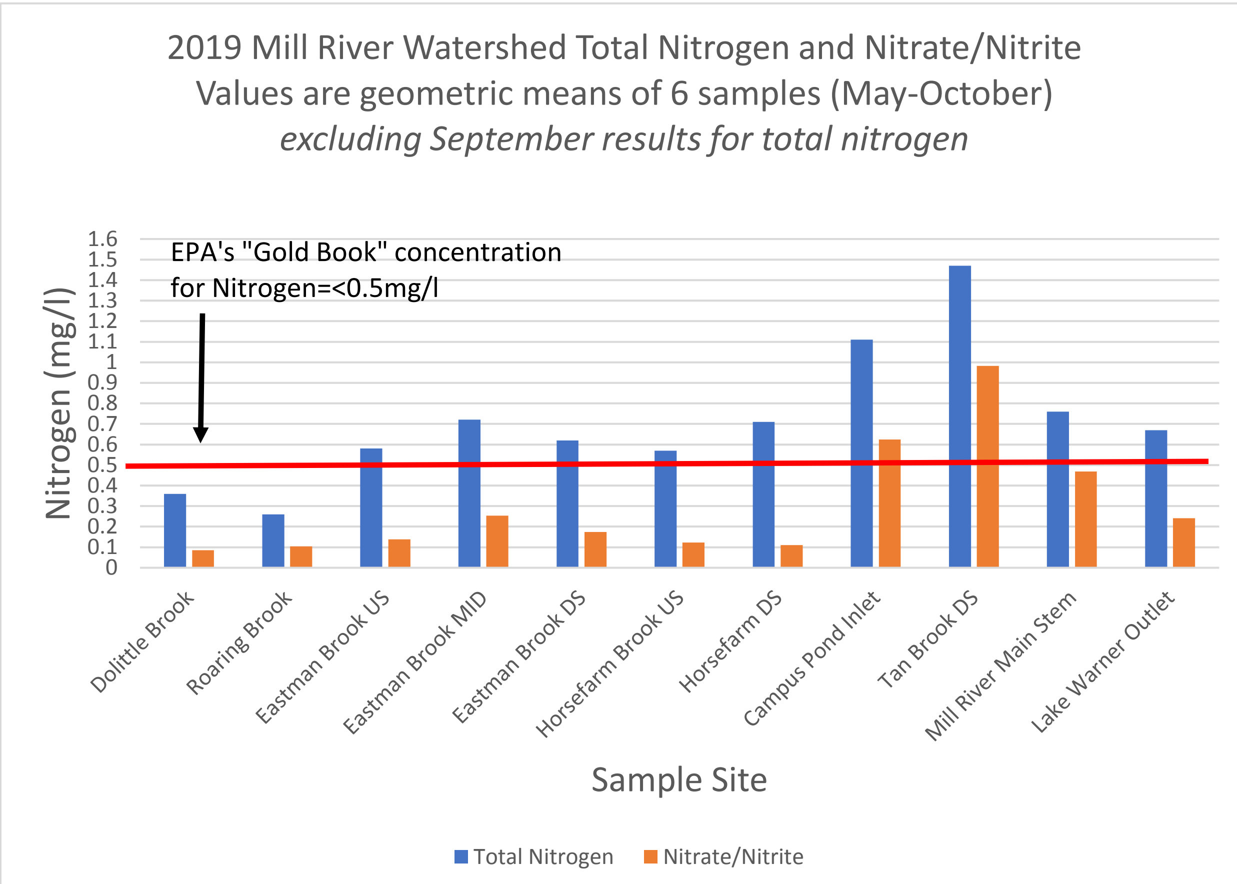
Aquatic Life Use for lakes is assessed primarily with the primary producer biological data. The use is assessed as support for lakes when the nutrient enrichment indicator thresholds based on survey data are not exceeded. The Aquatic Life Use for lakes is assessed as impaired when there is more than one nutrient enrichment indicator present more than once during the survey season (i.e., the occurrence of planktonic blooms particularly blue-greens, extensive cover of non-rooted aquatic macrophytes -- particularly duckweed or water meal covering >25% of the surface, decreased Secchi disk transparency <1.2 m, oxygen supersaturation >125%, elevated pH values >8.3 SU, and elevated chlorophyll a concentrations >16 µg/L). Total phosphorus is included as a cause of impairment if the concentrations exceed EPA"s "Gold Book" concentration.

According to the MEP critical indicators report, when total nitrogen concentrations are < 0.5 mg/l the overall health of the system is generally good to excellent except in areas of eelgrass loss that may begin to occur at somewhat lower concentrations (~0.4 mg/l) (Howes et al. 2003). Higher concentrations (>0.5 mg/l) are typically associated with systems experiencing degraded overall health.

<u>Nitrogen levels in Lake Warner</u>

Nitrogen levels were measured at the outlet of Lake Warner 6 times during the 2019 field season. In September the total nitrogen replicate sample failed the QA/QC threshold and was discarded from geometric mean calculations. Figure 6 shows the results from nitrogen sampling at the lake outlet. Total nitrogen levels exceeded threshold, nitrate/nitrite levels were below threshold. While we are confident in the results, they may be an underestimation of nitrogen in the lake, considering the sample location and that samples were only taken from May-October.

Figure 6. Mill River Watershed Nitrogen and Nitrate/Nitrite



Nitrogen Levels in the tributaries

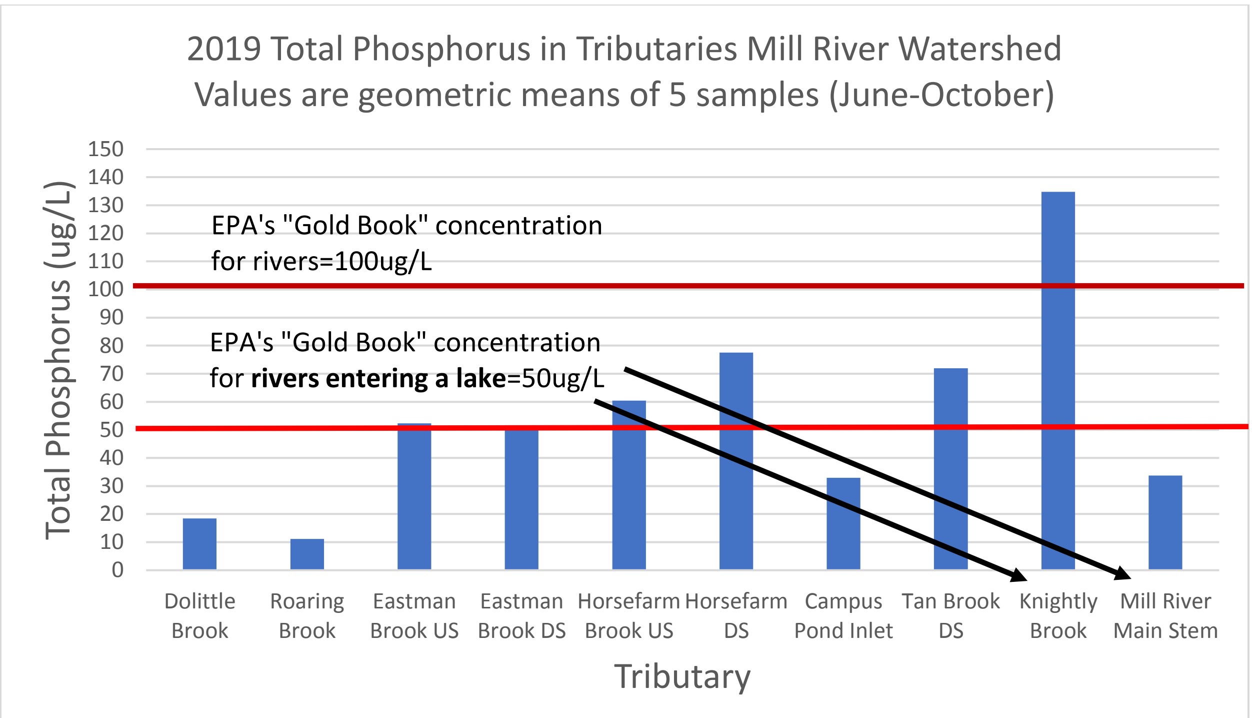
Total nitrogen levels exceeded EPA's Gold Book standards in all sites except the uppermost two tributaries of the watershed. Levels are particularly high in Tan Brook, both at the upstream location draining downtown Amherst and downstream locations past the Campus Pond, stormwater discharges and parking lot areas from UMASS Amherst. Eastman Brook, Horsefarm Brook, and the Main Stem of the Mill River all exhibited elevated total nitrogen levels.

Nitrate/nitrite levels were generally lower throughout the system, and below EPA's Gold Book threshold at most locations. Elevated levels were measured throughout the Tan Brook system.

Phosphorus Levels in the tributaries

Total phosphorus levels exceeded EPA's Gold Book standards in Knightly Brook. Total phosphorus was elevated in 3 of the other tributaries to the Mill River, but did not exceed the Gold Book standard. The Mill River mainstem at 34 ug/L has slightly elevated levels above the 31.25 ug/L impairment threshold, but is still under the Gold Book threshold of 50 ug/L threshold for rivers entering a lake. Total phosphorus from the tributary sites are shown in Figure 7.

Figure 7. 2019 Total phosphorus Mill River Watershed



Precipitation levels were minimal during the majority of the sampling sessions. A table of precipitation from the NOAA Amherst, MA field station is presented in Table 5.

Table 5. Precipitation measured at the NOAA Amherst Field Station

Date	Ppt(in)	Date	Ppt (in)	Date	Ppt (in)	Precipitation Total 48 Hrs prior
5/27/2019		5/28/2019		5/29/2019	0.44	**0**
6/24/2019		6/25/2019		6/26/2019	0.79	**0**
7/22/2019		7/23/2019	2.21	7/24/2019	0.12	**2.21**
8/26/2019	0	8/27/2019	0	8/28/2019	0	**0**
9/24/2019	0.06	9/25/2019		9/26/2019		**0.06**
10/29/2019		10/30/2019	0.03	10/31/2019	0.1	**0.03**

Bacteria

Bacteria samples were collected between May and October 2019. *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 twice during the sampling season, warnings were posted at the boat ramp. Samples were not taken between August 22 and September 26 because a cyanobacteria advisory was issued for the lake. The Mill River above the Lake had levels that consistently exceeded the recreational health and safety threshold.

More sampling upstream should be done to determine the source of these high bacteria levels. Water quality grant opportunities geared at increasing the capacity for bacteria monitoring are becoming available to non-profit organizations. The grants only provide funding until June 30 of the sample year, but prefer to have samples taken through October. FoLW could not obtain the support necessary to meet the grant goals this year. An effort will be made again in 2021. There is a possibility to utilize the Amherst Wastewater Treatment Plant to analyze samples that would reduce costs, making a watershed-wide bacteria sampling effort more feasible. A summary of 2019 bacterial levels in the lake are presented in Figure 8, and the Mill River in Figure 9. A graph showing trends for geometric means for E. coli bacteria at these sites from 2016-2019 is shown in Figure 10.

Figure 8. 2019 E. coli bacteria in Lake Warner, Hadley, MA

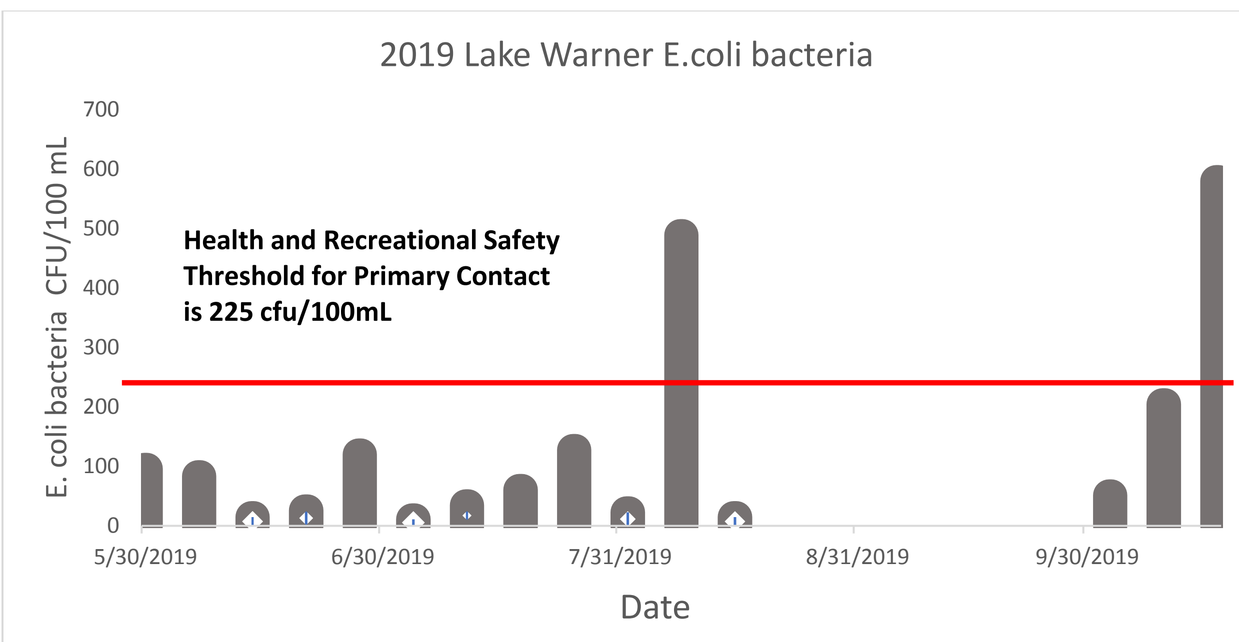


Figure 9. 2019 E. coli bacteria in Mill River, Hadley, MA

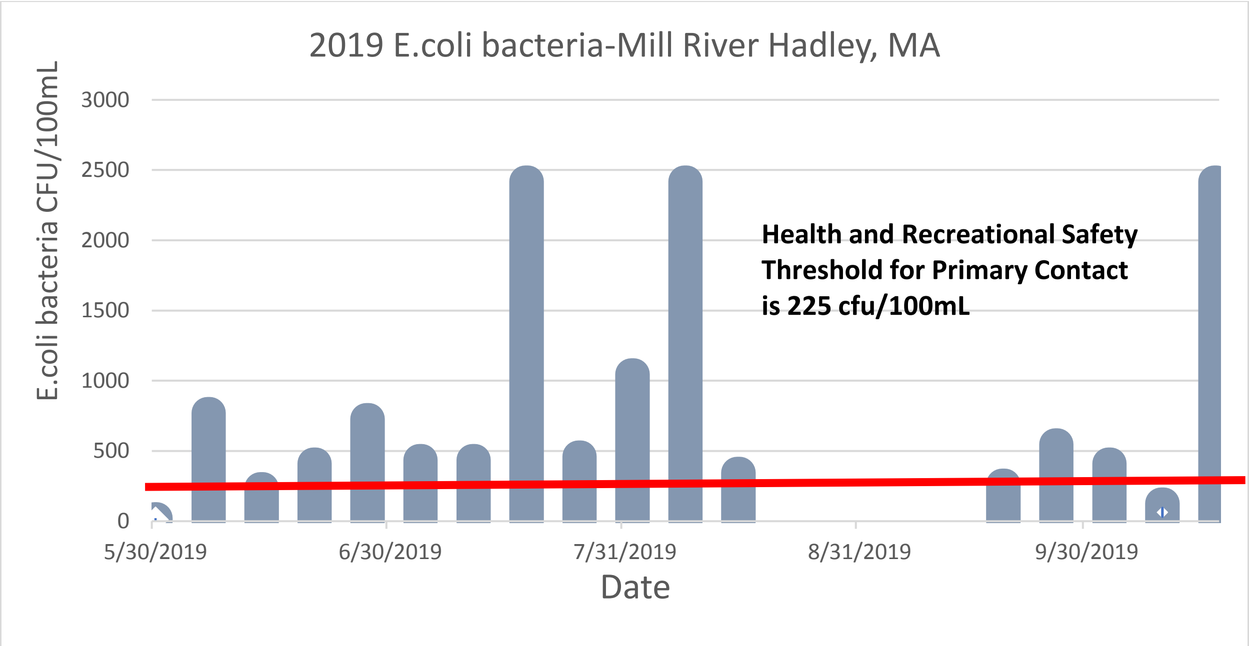
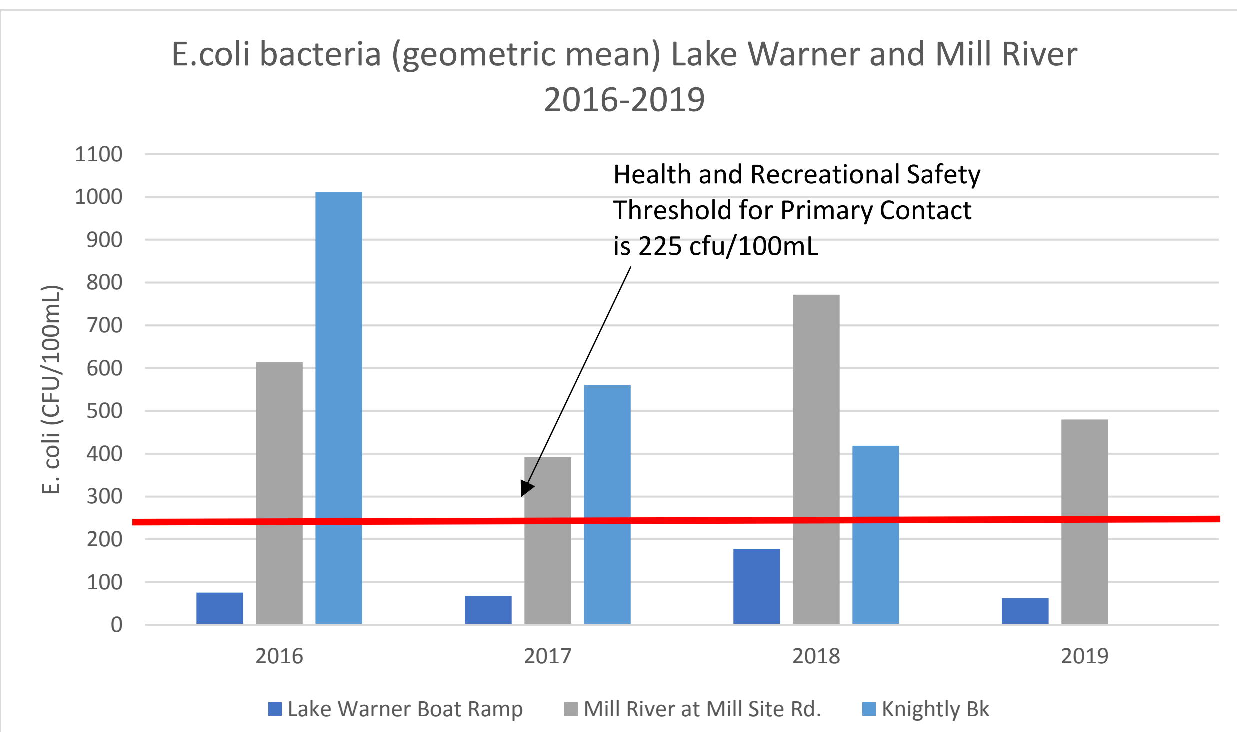


Figure 10. E. coli bacteria geometric means in Lake Warner, Mill River and Knightly Brook (a small tributary directly flowing into Lake Warner) 2016-2019



Discussion

Water Quality

Water quality measurements were affected by a warm spring and relatively dry summer in 2019. 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, only breaching the State Standard of 28.3 degrees Celsius twice during the sampling period. Transparency increased in 2019 due to consistent 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. Similar to last year, low DO levels rebounded more quickly at 2 meters, averaging above 5ppm in August and September. 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 was only one period in late July during the sampling season where levels dipped below this threshold in the upper meter of the lake.

Nutrients

Nutrients within the lake and tributaries were sampled in order to obtain geometric means at all sites. Quality assurance and quality control measures were implemented, including replicate and blank samples to ensure data quality. This resulted in one set of samples having to be discarded due to an issue with the blank. We are confident in the levels reported. There was some variability among samples, caused by differences in flow at sampling and duration of time taken following precipitation events. All samples, with the exception of September are above eutrophic threshold levels indicating the lake is in a eutrophic state. 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 four years of analysis are less than those predicted by the phosphorus model from the TMDL study of 120 ppm. We only sample six months out of the year so actual rates may be higher. The 2019 value of 36 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 2016-2019. Similarly, in 2016-2019 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 MassDEP 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. During the 2019 sampling effort the levels between the mainstem Mill River above the lake inlet were 34ug/L and the levels at the Lake Outlet were 36ug/L possibly indicating that the amount of available phosphorus coming from the sediments may be limited during the sample period.

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 and sediment 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 Management and Algae

Lake Warner supports a diverse and productive aquatic plant community comprised of twenty-one species documented during plant surveys over the last three years.

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.

The FoLW is pursuing a permit from the Hadley Conservation Commission in 2020 to manage these species using a combination of innovative techniques. This will be the first effort to manage native nuisance aquatic species in this water body. A vegetative management plan is being developed to describe the scope of the activities, monitoring and evaluation of the activity. Harvesting and removal of excess vegetation will help open up some of the submerged aquatic habitat currently being overrun by the dominant plant Coontail *(Ceratophyllum demersum)*. Some level of nutrient remediation will be made through these efforts. Testing of the nutrient content and heavy metals present in the harvested vegetation will be made.

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.

Mats of non-rooted vegetation ("scums") may form on lakes, ponds, and impoundments as a result of high nutrient concentrations. These scums may be due to floating, non-rooted macrophytes such as duckweed (Lemna sp. or Wolfia sp.) or may be due to algal scums formed by either green algae or bluegreen algae (cyanobacteria) or some combination of the above. Impairment may be aesthetic or recreational, if for example, the lake is oligotrophic or mesotrophic, and duckweed cover is not expected nor desired. Some waterfowl such as ducks and geese use naturally eutrophic ponds, impoundments and wetlands as important feeding sites, and as such, the presence of duckweed or patches of floating algae on such waters is not necessarily an impairment.

Dense continuous (100 percent) cover of duckweed is known to inhibit the growth of algae and submersed plants and may result in anoxia (Wolverton, 1986; Landolt 1986, cited in Ozbay, 2002; Leng et al., 1995). The minimum percent oxygen saturation in waters is known to be correlated negatively with percent cover of floating unattached plants and one study (Gee et al., 1997) suggests a coverage of 25% or less is associated with relatively high oxygen saturation. Impairment to aquatic life support may occur if the scum significantly inhibits oxygen exchange across the water surface and results in low dissolved oxygen.

MassDEP Guideline: to support the designated uses of recreation and aesthetics, if nonrooted vegetation exceeds 25% surface coverage in more than one site visit within the index period April 1-October 31, it is considered an indicator of nutrient enrichment.

Note: Impairment of uses may occur at levels lower than 25 percent coverage if the lake is a coldwater fishery (typically oligotrophic), or if swimming is impaired or if the scum consists of toxic bluegreen algae (cyanobacteria) in which case the waterbody could be considered impaired under the existing narrative standard. In the case of cyanobacteria blooms, swimming and contact recreation may be impaired if surface scum is present in the area of contact. The aesthetic screening guideline may be exceeded in some site-specific cases where duckweed accumulates on the downwind shorelines.

Cyanobacteria

On August 21st, 2019 the Friends of Lake Warner was informed by the Hadley Board of Health that the presence of algae had been confirmed in toxic concentration by the Massachusetts Department of Environmental Protection (MassDEP) and the Department of and Public Health (MassDPH) within Lake Warner. The Hadley Board of Health (BOH) immediately issued an advisory notice. The advisory notice was posted on the information board at the lake, town hall, and other conspicuous locations on August 22nd 2019. The notice was also posted on the Hadley town health department page, Friends of Lake Warner webpage, and social media platforms. Friends of Lake Warner are required to maintain a permanent copy of the advisory up at the boat ramp kiosk until the advisory is lifted via MassDEP, MassDPH, and Hadley BOH. There has been some encouraging news coming from the state regarding increased available funding for testing and possible future aid with resolving the issue in cases like this for the town and Friends of Lake Warner.

Further inquiry by The Friends of Lake Warner determined that the advisory was given even though initial sampling of questioned bodies of water were not performed. The assessment typically is done "via pictures", and descriptions are sent to MassDPH/MassDEP and responses are based on that assessment. The lake was reassessed in November visually and then information was sent to MassDPH/MassDEP. If the departments determine that the lake has visually cleared of the algae then MassDPH/MassDEP will assist with sampling of the water. For the lake advisory to be lifted, the samples need to come back twice at a low enough level. This did not happen this fall, though the Hadley BOH concurred that their concerns had abated with the reduction in visible algae.

The EPA has a mobile testing van that is going to be travelling around the region testing selected waterbodies. The FoLW has obtained testing kits for cyanobacteria and the Hadley BOH is applying for funding from the Community Preservation Act to pay for analysis in 2020. The Friends of Lake Warner will continue to communicate with MassDEP and MassDPH to stay informed with up to date information regarding Harmful Algal Blooms and will keep the public informed via the boat ramp kiosk, our newsletter, and through our webpage at friendsoflakewarner.org

MassDEP does not provide a specific numerical screening guideline for detection of cyanobacteria blooms within surface waters. Instead, MassDEP tracks the frequency of cyanobacteria advisories placed on surface waters by the Massachusetts‟ Department of Public Health (MDPH). In 2007 MDPH issued a guidance document outlining monitoring procedures for cyanobacteria and/or the toxins they produce designed to prevent adverse health effects before they reach levels of concern.

Cyanobacteria blooms occur most often in late summer or early fall. The most common types of blooming cyanobacteria are Microcystis and Anabaena, which may produce toxins called microcystin and anatoxin, respectively. If these cyanobacteria are ingested, the cell walls break down and the toxin may be released.

MDPH guidelines are designed to encourage action to be taken prior to exposure, thereby mitigating possible health concerns. The guidelines recommend various combinations of three monitoring methods, while cautioning that the measurement of the toxin is less feasible than conducting cell counts: 1. Observation of visible algae layer; 2. Total cell count of cyanobacteria (units of total cells/mL water); and/or 3. Concentration of cyanobacteria toxin (units of µg toxin/L of water).

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 4,022 pounds of water chestnut from Lake Warner in 2019. FoLW advertised and sponsored three public volunteer scouting and harvests in 2019, one had to be cancelled due to the cyanobacteria advisory. 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 25 volunteers participate at these events. Volunteers contributed over 119 hours during the 2019 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. Subsamples of each harvest were counted and weighed to provide more accurate estimates of total daily harvests. The 4,022 pounds removed in 2019 is six times the amount was removed in 2018. This totaled just under 18,000 individual rosettes, preventing an estimated 359,000 nuts from entering the lake. FoLW attributes the increase to starting earlier in the season and continuing with an aggressive program of weekly patrols by experienced personnel into September. The "early and often" scouting and pulling strategy was confounded by excessive mid-season and widespread growth in the mid-lake areas, delaying the ability to harvest the upper lake areas until late in the season. Compounding this was the cyanobacteria advisory eliminating our ability to utilize volunteers during late August. Consequently, rather than the effective early location and harvest of juvenile plants, we were faced with larger patches of mature plants. The larger size and maturity of the rosettes pulled resulted in increased overall harvest weights.

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, and evaluate management techniques.

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 in the process of complying with their MS4 permits, and are encouraged to support low impact development and utilize the best available technologies to improve their stormwater systems. Monitoring outfalls within the system is going to require data gathering in upcoming years to provide compliance with these plans. 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. FoLW monitoring data is being used to complete a Watershed Based Plan, a necessary component for 319 grant funding for nutrient and sediment mitigation projects in this watershed.

Recommendations for future action

Continue lake monitoring of temperature, dissolved oxygen and transparency to document trends over time.

Continue to collaborate on nutrient monitoring in the lake and watershed to better understand trends in background levels, quantify sources and be able to support modeling efforts that help coordinate strategies for mitigation.

Support the Hadley Board of Health to monitor and publish bacterial levels in the lake for recreational health and safety of lake users. Explore funding mechanisms to sample tributaries upstream in the watershed to identify sources and seek remediation.

Support the testing of the lake for cyanobacteria to be able to accurately inform the public regarding the possibilities and risk of exposure to Harmful Algal Blooms (HAB's).

Support best management practices by municipal stormwater programs that reduce sedimentation and urban stormwater flow to the lake.

Continue to manage water chestnut both by hand pulling and mechanical methods. Expand management activities to include native nuisance species. Utilize these techniques to harvest the aquatic vegetation to remove accumulated nutrients from the lake and reduce internal nutrient loading.

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.

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.

FoLW's ability to complete these monitoring and management goals will be dependent on funding and cooperation with partners.

Table 6. 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

References

Biodrawversity. 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

Dodds, W. K. Jones, J. R. and Welch, E. B. 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. Water Resources. 32. pp.1455-1462.

Gee, J.H.R., B.D. Smith, K.M. Lee, and S.W. Griffiths. 1997. The ecological basis of freshwater pond management for biodiversity. Aquatic Conservation: Marine & Freshwater Ecosystems 7:91-104.

Gower, A.M., 1980. Ecological Effects of Changes in Water Chemistry. Water Quality in Catchment Ecosystems. John Wiley & Sons Ltd. 1980. pp. 145-171

Hutchinson, G.E. 1957. A Treatise on Limnology, v. 1. Geography, Physics and Chemistry. Wiley. 1015p.

Ku, Wen-Chi and Tsuan Hua Feng. 1975. Equilibrium Adsorption of Inorganic Phosphate by Sediments. Report for Division of Water Pollution Control. Massachusetts Water Resources Commission. Contract Number 73-07 (3). Environmental Engineering Program. Department of Civil Engineering. University of Massachusetts Amherst. 191 pages.

Landolt. E. 1986. The family of Lemnaceae – a monograph study. Vol. I Morphology, karyology, ecology, geographic distribution, systemic position, nomenclature, descriptions. pp. 1-556. Zurich: Veroff Geobot. Inst. ETH, Stiftung, Rubel.

Leng. R.A. Stambolie, J.H., and R. Bell. 1995. Duckweed – a potential high-protein feed resource for domestic animals and fish. Livestock Research for Rural Development. Volume 7, Article#5. Retrieved September 2, 2015, from http://www.lrrd.org/lrrd7/1/3.htm.

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.

MADPH. 2007. MDPH Guidelines for Cyanobacteria in Freshwater Recreational Waterbodies in Massachusetts. Massachusetts Department of Public Health. Boston, MA

Massachusetts Division of Watershed Management Watershed Planning Program. 2018 Massachusetts Consolidated Assessment and Listing Methodology (CALM) Guidance Manual for the 2018 Reporting Cycle. CN 455.0. 131 pp

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

Ozbay, H. 2002. An Experimental Approach to Examining the Effect of Water Depth and Lemna minor L. on Algal Growth. Turk. J. Bot. 26:5-11.

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. Report for Division of Water Pollution Control. Massachusetts Water Resources Commission. Report Number EVE 32-73-3. Contract Number 15-51-452. Environmental Engineering Program. Department of Civil Engineering. University of Massachusetts Amherst. 91 pages.

US Department of the Interior (USDI). 1968. Water Quality Criteria, (the Green Book), Federal Water Pollution Control Administration, Report of the National Technical Advisory Committee to the Secretary of the Interior.

USEPA. 1986a. EPA Quality Criteria for Water, (the "Gold Book")1986. EPA 440/5-86-001.

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. 2000a. Nutrient Criteria Technical Guidance Manual. Rivers and Streams. EPA-822-B-00002 Environmental Protection Agency, Washington DC.
USEPA. 2000b. Nutrient Criteria Technical Guidance Manual. Lakes and Reservoirs. First Edition. EPA-822-B-00-001 Environmental Protection Agency, Washington DC.

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.

Weitcamp, DE., and Katz, M. 1980. A Review of Dissolved Gas Supersaturation Literature. Transactions of the American Fisheries Society L0 9:659-702. Copyright by the American Fisheries Society 1980. pp. 659-702.

Wolverton, B.C. 1986. Aquatic Plants and Wastewater Treatment (An overview). Chapter I. Proceedings of a Conference on Res. And applications of Aquatic Plants for Water Treatment and Resource Recovery. Orlando FL. NASA-TM-108066. 18 pp.

Zurr, B. 1992. Water quality Guidelines #1: Guidelines for the Control of Undesirable Biological Growths in Water. New Zealand Ministry for the Environment. Wellington.