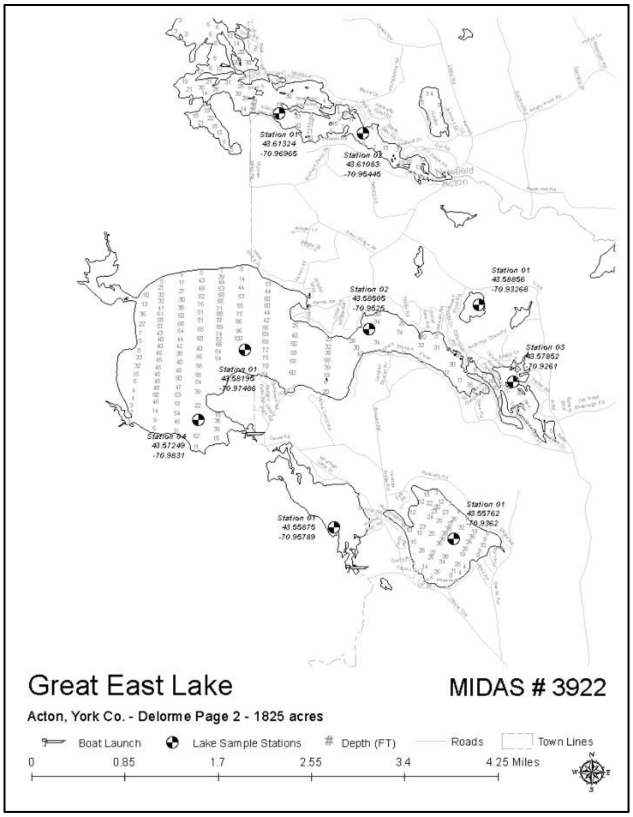
DK Water Resource Consulting LLC

Great East Lake Data Assessment



Prepared for: Great East Lake Association

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Background

Cyanobacteria have been reported in in Second Basin and Main Lake of Great East Lake several times in recent years. In response, DK Water Resource Consulting LLC was contracted by the Great East Lake Improvement Association (GELIA) to provide a water quality data review and develop future monitoring and planning recommendations supported by those data. This report represents a summary of the lake and watershed data from Great East Lake through 2022 and recommendations for a path forward for the GELIA.

Great East Lake is a 1,707-acre lake (Figure 1-1) with a watershed area of about 9,990 acres (AWWA et al 2021). within the towns of Wakefield, NH and Acton, ME. Because the lake is greater than 10 acres in size, it is categorized as a public water by the state of NH. Characteristics of Great East Lake are presented in Table 1-1. The watershed to lake area ratio is approximately 5.9. Lakes with watershed ratios greater than 10:1 can experience low water clarity, high phosphorus and algal blooms when the watershed is highly developed or has high export of nutrients. Because the watershed of Great East Lake is small relative to the lake's size, high water quality should be expected. While the shoreline of Great East Lake is highly (93%) developed, the undeveloped character of the upper watershed indicates that water entering the lake should be of relatively high quality. The slow flushing rate (0.3 times per year) of the lake suggest that the influence of watershed changes on water quality would be realized slowly but may persist longer than would be expected in a rapidly flushed lake.

The lake is naturally divided into two basins which flow into each other and out through the outlet at the southeast end of the lake (Figure 2). Despite generally favorable watershed conditions and overall high lake quality, several cyanobacteria blooms have been observed in recent years in the Second Basin and the Main Lake. Second Basin is upstream of the main body of the lake so concern for the entire lake is warranted. This effort represents an attempt to identify potential contributing factors to these blooms and elements of a plan to mitigate them in the future.

Table 1. Characteristics of Great East Lake in Wakefield, NH and Acton, ME (AWWA 2021, NHDES 1993)

Parameter	Value
Lake Area (acres)	1,707
Lake Volume (m^3)	75,589,500
Watershed Area (acres)	9,990
Watershed/lake area	5.9
Mean Depth (ft)	35
Max Depth (ft)	102
Flushing rate (times/yr)	0.3
Total phosphorus (µg/1)	2-8
Trophic classification	oligotrophic

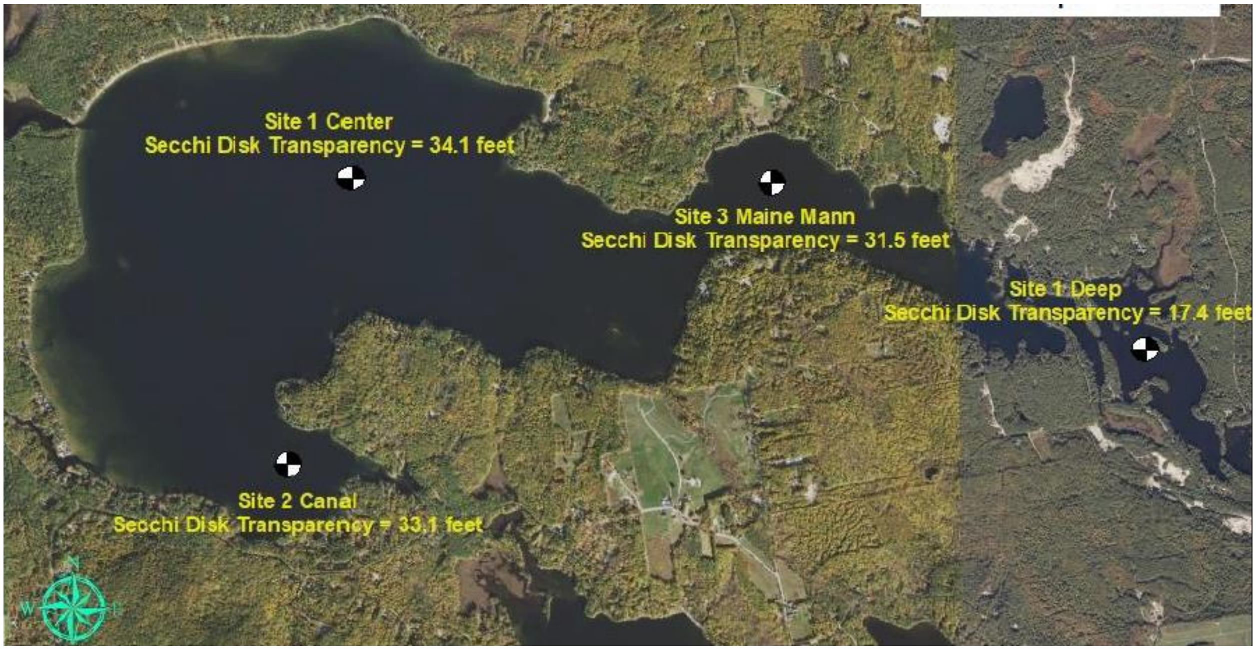
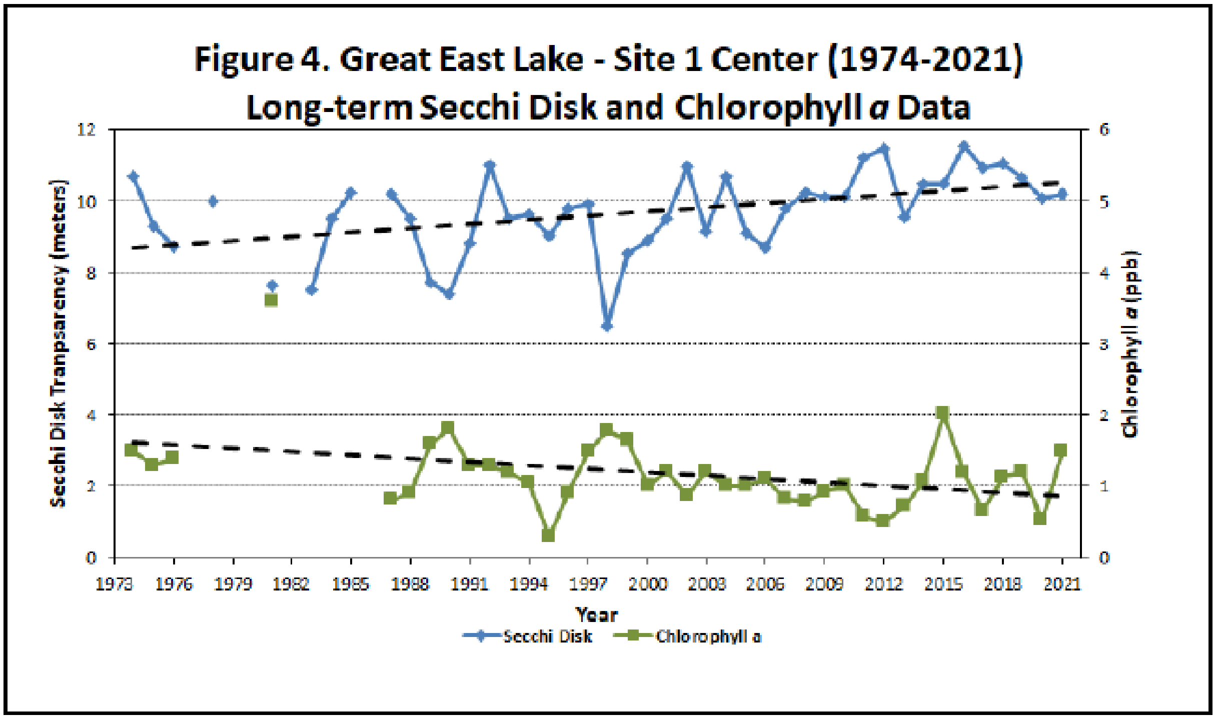


Figure 1. Aerial view of Great East Lake and standard LLMP sampling locations (UNH LLMP 2021).



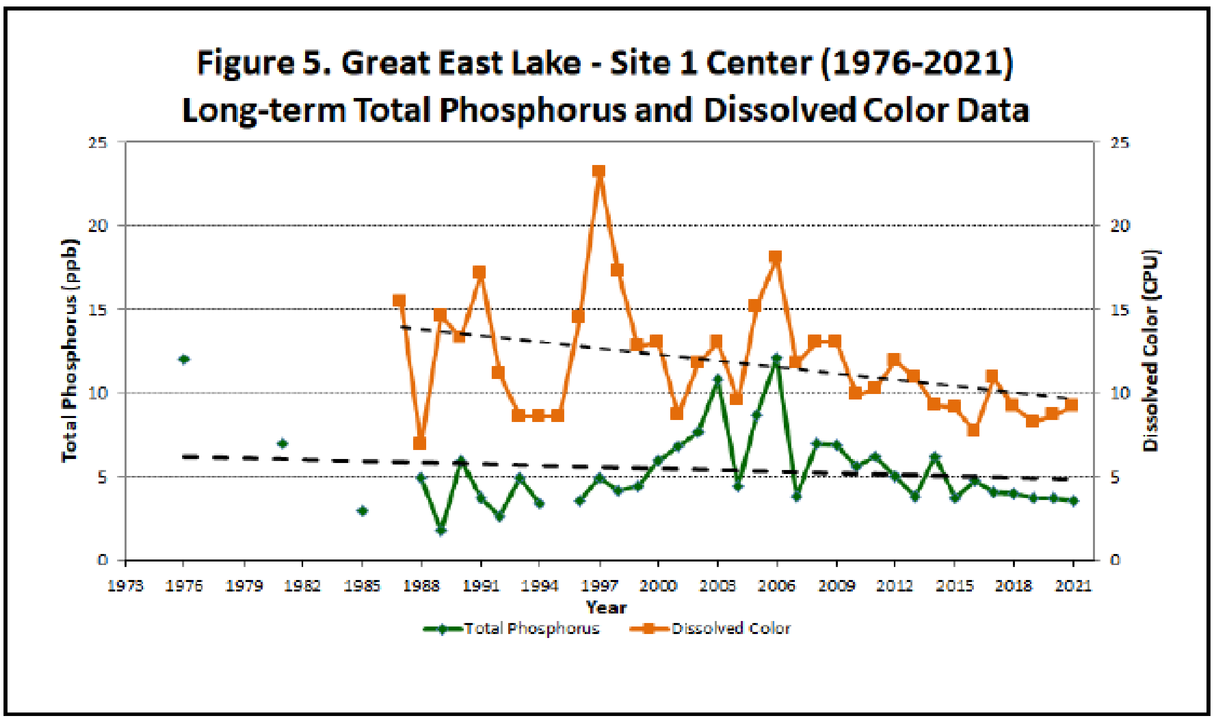


Figure 2. Long-term water quality trends in Great East Lake (UNH LLMP 2021).

Historic data

Historic water quality data were reviewed as a part of this effort. Data have been collected periodically since 1937 (NH Fish and Game 1972). The early historic monitoring focused on suitability for fish while more recent data focus on the trophic status (how much green material can grow) of Great East Lake. These data and more recent data and observations allow some insight into the ecology and overall aquatic health of Great East Lake. These observations are summarized in Table 2.

Table 2. Selected Historic Water Quality and Ecological Observations on Great East Lake

Date	Observer	Ecological Observations
9/6/37 through 1958	NH Fish and Game	-Repeated stocking of horned pout, smallmouth bass, lake trout and brown trout -Dissolved oxygen at depth (6.9 mg/l) -Suitable for salmonids -100% of shoreline described as wooded. -Bottom 60% rock and gravel, 30% sand and 10% muck, submerged vegetation scant
1972	MDIFW	-Alewife stocked
1978	NHDES	-Vascular plants sparse A golden-brown algae species and a diatom species were most common. -Total phosphorus 4 ug/l in winter and 7 ug/l in summer -Dissolved oxygen to bottom (5.8 mg/l) in summer -Oligotrophic classification
1992	NHDES	-Microcystis (cyanobacteria) present in summer in lake along with a diatom species and a golden-brown species. All species at very low density. -Dissolved oxygen to bottom (5.6 mg/l) in summer -Total phosphorus 5 ug/l in winter and 8 ug/l in summer -Oligotrophic classification
1990- 2022	NHDES/LLMP	-Secchi transparency improves in main lake -Smelt population established (MDIFW) -Chlorophyll a declines in main lake but becomes more variable in the past 10 years -Total phosphorus declines in main lake -Oligotrophic classification
2021-2022	NHDES/ volunteers	-Population of residents on lake likely increases during Covid-19 pandemic -Gloeotrichia, Dolichospermum and Planktothrix observed on Great East Lake in Second Basin and the Main Lake.

Historic water quality in Great East Lake has generally been excellent with occasional blooms of cyanobacteria noted recently. The lake was historically and is currently classified as a nutrient poor, clear water, oligotrophic or low productivity lake. Despite being collectively Great East Lake, the lake functionally has characteristics of a chain of 3-4 lakes. Most notably the Second Basin is isolated from the main deeper basins of the lake in a way that water and nutrients likely move in only one direction, out of the Second Basin towards the rest of the lake.

Algae and cyanobacteria are fueled by nutrients (primarily phosphorus) and reproduce, mainly through cell division, although resting cysts are an important mechanism for surviving unfavorable periods (Cooke et al 2016). When growth conditions are ideal (warm, lighted, nutrient-rich), algae multiply rapidly and reach very high densities (blooms) in a matter of weeks. As these cells and sink out of the lighted portion of the water column, they consume more oxygen than they produce through photosynthesis. Eventually the cells die and consume more oxygen as they decompose. The result can be depressed oxygen concentrations in the deeper portions of a lake. In the most extreme case, all of the oxygen is consumed in the deeper water. Under those conditions, termed anoxia, phosphorus previously deposited in the sediments can be released back into the water column potentially fueling further blooms. Resting cells, particularly of some species of cyanobacteria that can regulate buoyancy, can utilize phosphorus directly from the sediments and store it for later use when they rise into the water column. Unlike blooms that develop over a period of weeks, blooms of cyanobacteria that are not apparent one day but appear all at once at the surface are likely to have been present for some time either on the bottom or at the interface of a nutrient rich layer of the lake out of view from the surface.

Mean and median phosphorus concentrations observed over the past 10 years in the three main Lake sampling locations of Great East Lake are well below New Hampshire criteria for oligotrophic (8 ug/l for low nutrient) lakes (Table 3). Concentrations in Second Basin over the same period are higher than in the rest of the lake and slightly above that threshold (mean 8.8 ug/l, median 8.2 ug/l). Algal and cyanobacteria growth is typically limited by phosphorus in northern temperate lakes and phosphorus is typically more easily managed than other nutrients. This is why the watershed survey (AWWA 2021) puts so much emphasis on phosphorus as the best way to control algal and cyanobacteria growth. Currently, low water column phosphorus concentrations in the lower three basins are not particularly favorable for algal of cyanobacteria growth.

Phosphorus concentrations in the deeper waters of the lake are somewhat higher than those observed in the surface waters however, they are not high enough to suggest widescale release of phosphorus from the sediments at this time. In the Second Basin, phosphorus concentrations at depth are also somewhat (≈50%) higher than those observed in surface waters (Table 3, Figure 3), particularly in the past three years suggesting there may be some release of phosphorus from the sediments. Lakes with significant release of phosphorus from the sediments (internal loading of phosphorus) often show deep concentrations of phosphorus an order of magnitude higher than shallow concentrations. Based on the limited data currently available, this cannot be said for Great East Lake.

Chlorophyll *a* is the photosynthetic pigment found in all species of freshwater algae. Because phosphorus is presumed to control the amount of algae and cyanobacteria that can grow we would expect chlorophyll *a* to be higher at stations with higher phosphorus concentrations. Likewise, transparency should be lower where chlorophyll *a* is higher. Chlorophyll *a* and Secchi transparency data support that contention as chlorophyll *a* is higher in the Second Basin and Secchi transparency is lower (Table 3).

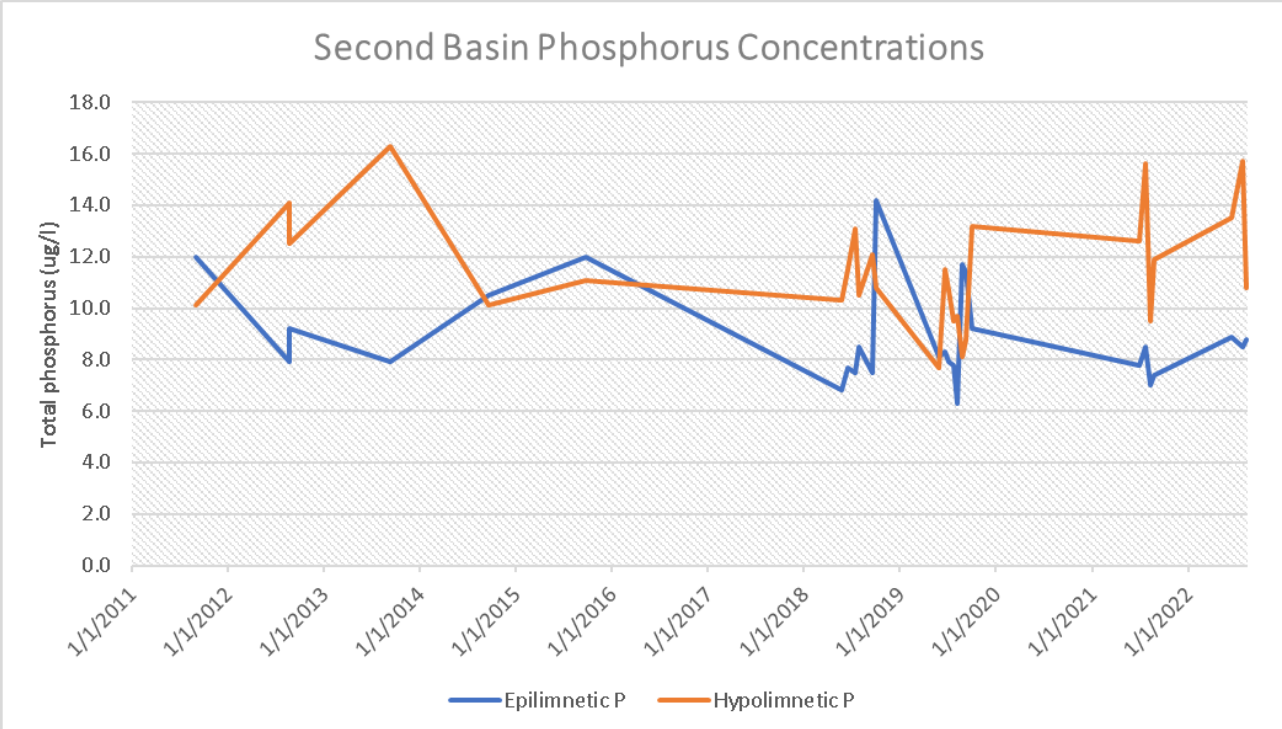


Figure 3: Epilimnetic (surface) and Hypolimnetic (deep) total phosphorus concentrations observed in Second Basin, Great East Lake 2011-2022 (UNH LLMP data).

Table 3. Selected water quality data for Great East Lake 2013-2022.

Epilimnion	Total Phosphorus			Chlorophyll *a*			Secchi Transparency		
	Number	**Mean**	**Median**	**Number of**	**Mean**	**Median**	**Number**	**Mean**	**Median**
	N	**µg/l**	**µg/l**	**N**	**µg/l**	**µg/l**	**N**	**m**	**m**
Oligotrophic criteria		<8	<8		<3.3	<3.3		>4	>4
Second Basin	24	8.8	8.2	24	3.3	3.1	24	5.2	5.4
Maine Mann Station	23	4.3	3.8	23	1.5	1.4	23	9.2	9.5
Center Station	25	4.2	4.0	25	1.4	1.3	24	10.6	10.8
Canal Station	23	4.4	4.0	23	1.5	1.5	22	9.9	10.1

Hypolimnion	Total Phosphorus		
	Number	**Mean**	**Median**
	N	**µg/l**	**µg/l**
Second Basin	24	11.4	11.0
Maine Mann Station	22	5.2	5.0
Center Station	25	6.2	5.6
Canal Station	22	6.8	6.8

The lake thermally stratifies strongly at the Center, Maine Mann and the Canal stations of the Main Lake however, oxygen is present throughout the water column in those basins. While neither temperature nor oxygen preclude the presence of warm water fish, the presence of cool water refugia allows the lake to support cold-water species such as trout.

Stratification in the shallower Second Basin is much weaker (Table 4). This stratification persists into September based on historic LLMP data. Typically, the lowest concentrations and maximum extent of dissolved oxygen depletion would be expected in mid-September near the end of the stratification period. Dissolved oxygen concentrations are depressed in the deeper waters during this stratification, but waters only become or approach anoxia (no oxygen) within a meter or two of the bottom. Based on the bathymetry of Second Basin, areas this deep are small. Unfortunately, the most recent September profile data for Second Basin is from 2016. As a result, relating the potentially negative effects of low oxygen on recent Second Basin water quality and cyanobacteria blooms is difficult to determine. Should future data suggest the anoxic area is expanding and lasting longer (which would be more likely with increases in phosphorus), potential impacts on water quality will become more likely.

Table 4. Dissolved Oxygen and Temperature in Second Basin August 12, 2022 (UNH LLMP data).

Depth m	Temp °C	DO mg/l
0.1	26.8	7.6
0.5	26.7	7.6
1.0	26.6	7.6
1.5	26.5	7.6
2.0	26.4	7.6
2.5	26.3	7.5
3.0	26.3	7.5
3.5	26.3	7.5
4.0	26.0	7.4
4.5	22.9	4.8
5.0	20.2	2.1
5.5	17.4	1.0

In recent years, the lake as a whole has had excellent water quality for swimming and was generally clear (UNH LLMP 2021). However, blooms of cyanobacteria were noted in the past two years in Second Basin. None of the observed blooms were officially documented and thus did not elicit an advisory from the state with the exception of August of 2022. Nonetheless, these blooms are concerning. The species observed were *Gloeotrichia, Dolichospermum and Planktothrix.* Historically*, Microcystis* has been observed in the lake. While blooms associated with these species are often non-toxic, all four species can produce toxins that have resulted in contact advisories for affected waterbodies throughout the region. Selected characteristics of these species are presented in Table 5. While only two of the four species can fix (use) atmospheric nitrogen, all respond to phosphorus and nitrogen in the lake and all four would be expected to be less prevalent with less phosphorus available.

It is likely that recent blooms were a result of a combination of current external loads of phosphorus from the watershed and septic systems and possibly internal loads from the sediments either from anoxic release or from direct utilization of phosphorus at the sediment surface. Phosphorus in the sediments is largely an artifact of loading from the past. Phosphorus can be transported from the sediments to the overlying water through anoxic release, transport into the water column by cyanobacteria cells that take up phosphorus from the sediment surface or disturbance and resuspension of phosphorus rich sediments. At present there are insufficient data to fully implicate any particular pathway however, future data collection efforts can help to differentiate the sources.

Because the Second Basin is the most upstream basin of Great East Lake, the watershed is much smaller than the watershed of the lake as a whole and sources may be more easily identified and managed. Second Basin discharges to the other basins so poor water quality in Second Basin has the potential to impact the entire lake making action more imperative.

Table 5. Relevant characteristics of cyanobacteria taxa reported in Great East Lake (iNaturalist 2023, UNH CFB 2023, USEPA 2023).

			Potential toxin production (partial list)				
Taxa	Nitrogen fixer	Gas vesicles	Anatoxins (nerve)	Microcystins (liver)	Lipopoly-saccherides (skin irritant)	BMAA (nerve)	Saxitoxins (nerve)
Gloeotrichia	no	yes		yes	yes	yes	
Dolichospermum	yes	yes	yes	yes	yes	yes	yes
Planktothrix	yes	yes	yes	yes	yes	yes	
Microcystis(hist)	no	yes	yes	yes	yes	yes	

Monitoring recommendations

The following recommendations were developed to improve the current monitoring program in light of recent changes in water quality. They can be implemented at once or over time.

Baseline

In-lake monitoring following UNH LLMP protocols (UNH LLMP 2010) should occur at each of the four in-lake stations as soon as practicable after ice-out and monthly from mid-May through mid-October. The intermittently sampled station in the narrow area between the small eastern basin of Second Basin and the larger Basin of Second Basin should be sampled regularly. After mid-October, monitoring should occur include one event after turnover before the lake freezes. It is estimated that this will result in 7-8 lake monitoring events over the course of a typical year. If the station is stratified, even weakly, phosphorus samples should be collected both by epilimnetic core and near the sediments (within 1 meter) otherwise, epilimnetic core samples are sufficient. These data can be used to assess the variability of water quality in Great East Lake and detect seasonal change which is not currently possible. Periodic monitoring of the phytoplankton community of Great East Lake in Second Basin at a minimum is critical to understanding the dynamics of the various groups of phytoplankton and the implications for designated uses of the lake.

A recommended schedule is presented in Table 6 and a list of parameters is presented in Table 7. It should be noted that both the location and frequency of monitoring should be reevaluated at least annually and can be adjusted over time in response to changes in field conditions, evaluation of data and management priorities.

Tributary monitoring should be conducted at major tributaries a minimum three times each year. If resources are scarce, monitoring at the tributaries to Second Basin should be a priority. Monitoring will target three (3) separate runoff events roughly coinciding with spring, summer and fall depending on precipitation patterns. Since flow in many of the small tributaries is primarily storm related, monitoring will occur as soon as practicable after a rainfall of at least 0.25 inches or a period of snowmelt. One event should occur in spring prior to leaf-out. The second event will occur in the mid-summer and the third event will occur in the mid-fall. Sample analyses will be performed by LLMP. This monitoring is expected to be shore based with grab sample collection. Locations are the same as have been traditionally monitored which represent the major surface tributaries to the lake. Tributary samples should be collected as close to the point of discharge to the lake as possible without sampling water from the lake. A schedule is presented in Table 6 while parameters are in Table 7. Consistently high readings of one or more parameter may trigger additional investigation upstream in the tributary to identify the source of the high readings.

Table 6. Recommended Baseline Monitoring Schedule

Target Period	Frequency	Target Conditions	Location
Within 2 weeks of ice out	Once/yr	Spring turnover-well mixed	Deep station (2 depths if stratified)
Spring	Once/yr	Pre leaf-out spring runoff	Tributary stations
May through mid-October	Monthly	Growing season	Deep station (2 depths if stratified)
Summer	Once/yr	Summer rain event	Tributary Stations
Late fall	Once/yr	Fully mixed pre-winter	Deep station (2 depths if stratified)
Late summer/early fall	Once/yr	Fall runoff event	Tributary Stations

Table 7: List of Parameters Recommended for the Great East Lake Baseline Monitoring Program

Laboratory Parameter	Field Parameter
Lake Deep Station	
Chlorophyll *a* (chlor a) (epilimnetic core only) Dissolved color Total phosphorus as P (TP) Alkalinity Phytoplankton identification (epilimnetic core)	Temperature (T) (profile) Dissolved Oxygen (DO) (profile) pH (from epilimnetic core) Secchi transparency Specific Conductance (profile)
Tributary Stations	
Total phosphorus as P	Stage (if gages are installed)

Potential Special Investigations

In addition to the routing monitoring program outlined above and the recommended actions in the Watershed Survey Report (AWWA 2021), there are a number of special data collection efforts that would further inform specific aspects of the management of Great East Lake. These are not presented in any order of priority. Priority should be informed by goals set by the association, future planning efforts, available funding and data collected as a part of the routine monitoring program outlined above.

1. Sediment phosphorus characterization. Sediment phosphorus characterization would involve collection of 6-8 sediment samples at variety of depths and analysis of those samples to establish the likelihood of phosphorus release to the water column. Parameters might include: total iron, total aluminum, loosely bound phosphorus, iron bound phosphorus, labile organic phosphorus and aluminum bound phosphorus as well as grain size, water content and bulk density. This is not particularly time sensitive as sediments change very slowly over time. The estimated cost for a sampling and analysis program with 8 sampling stations would be approximately $7,500.

2. Nearshore septic surveillance. Nearshore areas can be evaluated by specific conductance or fluorometry to identify large septic failures or malfunctions. Because breakout is often related to immediate use, such a survey should be completed in conjunction with or immediately after high use periods. Use of dye tablets may increase the ability to quantify septic outbreak. A specific conductance survey could be conducted for approximately $1,000 if completed by a contractor or at no cost if completed by volunteers.

3. Flow gaging. Having a way to quantify flow from tributaries allows the calculation of loads of substances to Great East Lake. Initial actions might include the installation of staff gages in the major tributary streams to Great East Lake and recording of water levels in conjunction with sample collection. Loads are much more informative than concentrations and can be calculated by multiplying the concentration by the flow. Tributaries where such gaging could be accomplished would be identified during a reconnaissance field survey. Flow gaging at selected appropriate locations can be accomplished through installation of staff gages and development of calibration curves for each gage. This typically requires gaging flow at 4-5 different levels in each tributary and developing a curve. Installing gages and calibrating each gage (assuming 6) would cost approximately $7,000.

4. Contingency sampling. If bloom conditions or other atypical conditions are encountered, the frequency of routine sampling may be adjusted to include more frequent in-lake sampling (e.g. biweekly). Toxicity screening may also be considered if cyanobacteria are present. Additional locations near points of contact may also be considered (nearshore where cyanobacteria accumulate, and contact is more likely). Costs for contingency testing could range from no cost for the typical NHDES testing up to $10,000 for repeated rapid response toxicity and identification through the life of a major bloom.

Management Recommendations

Based on the review of the historic and current water quality data and observations made while at Great East Lake as well as the preliminary modeling completed as a part of this review, I make the following recommendations for the future management of the lake.

Watershed issues and solutions are presented in some detail in AWWA et al (2021) and are critical to source identification and mitigation as well as preservation of long-term water quality. The watershed recommendations presented in that document are an essential part of the future protection of Great East Lake. Restoration of the specific sites identified will reduce the likelihood that cyanobacteria blooms occur in the future. Institutional recommendations will help minimize the number of new problem sites. An over-arching principle of watershed management for Great East Lake is to minimize the nutrient and sediment footprint of existing and new development.

Reduction of nutrient concentrations but primarily phosphorus to lower the likelihood of future blooms may require action in both the watershed and in the lake itself. A definitive plan of action requires a commitment to water quality monitoring to identify sources and evaluate progress.

1) Continue and expand the existing monitoring program using current LLMP protocols. Details on a recommended program are presented above. Optional monitoring tasks also presented. Overarching goals should be to quantify portions of the nutrient budget that are currently uncertain (i.e. tributary and internal loading).

2) Continue aggressive watershed management efforts outlined in AWWA (2021) including but not limited to:

    - Mitigate phosphorus export from identified sites.
    - Maintain vegetated buffers around the lake to slow runoff and take up nutrients.
    - Maintain and upgrade septic systems. Where possible, move them further from the lake.
    - Do not use fertilizers or detergents/soaps that contain phosphorus.
    - Encourage infiltration of runoff from impervious surfaces including rooftops, roads and parking areas. Infiltration allows phosphorus to be captured by soil particles while water returns to the lake as groundwater.
    - Discourage waterfowl from using nearshore areas by not providing food or allowing egress from the lake to lawn areas by using natural buffers or

barriers/deterrents.

- Properly dispose of all pet waste away from the lake.

- Evaluate gravel roads and have a plan for implementing best management practices on them.

3) Continue AWWA programs for assisting individual homeowners with BMPs..

4) Continue education and outreach efforts to inform residents, local officials and other stakeholders.

5) Develop water quality goals for Great East Lake or portions of the lake (Second Basin). The goals should be the product of local input with guidance from NHDES, UNH, AWWA and other stakeholders.

6) Continue protection of the as much as possible of the watershed in a natural state. Because the watershed is small, disturbance could have immediate, adverse impacts to the lake. Consider permanent watershed protection through conservation easements or other permanent protection over the portions of the watershed that are not currently under conservation.

Evaluation of water quality data collected since 1937 suggests that while there have been modest fluctuations in water quality throughout the time period, the quality of Great East Lake remains excellent in most years and historically has been representative of a low nutrient or oligotrophic system. Careful attention to sources of nutrients to the lake can reverse the recent downward trend in water quality in the Second Basin. The undeveloped nature of the watershed is particularly important to success in reversing the trend. The high level of interest and active stewardship around Great East Lake speaks to a high likelihood of success.

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