Northeast Aquatic Research

Lake Hayward Data Review and Cyanobacteria Management Reccomendations

Prepared for the Lake Quality Improvement Committee and Property Owners Association of Lake Hayward

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Executive Summary

The Lake Hayward Lake Quality Improvement Committee retained the services of Northeast Aquatic Research to investigate the causes of the 2018 fall algae bloom. The goals of this study were to examine available water quality data and to identify any trends in the data that may have contributed to the significant algae bloom. This report also includes recommendations about water quality monitoring procedures that the Property Owners Association of Lake Hayward should adopt.

This report is divided into three sections: 1) An educational overview of harmful cyanobacteria blooms, including bloom formation dynamics and the impacts of blooms on lake biota, recreation, and human health. 2) An analytical review of past water quality and filamentous algae data, and 3) recommendations to improve current monitoring protocols, including professional advice for harmful cyanobacteria bloom management.

Introduction to Cyanobacteria

What are Cyanobacteria?

One of the most difficult issues facing lake residents is the increasing prevalence of blue-green algae, or more appropriately referred to as cyanobacteria. These photosynthetic, single-celled organisms are similar to other algae present in lakes and ponds but are instead prokaryotic bacteria, meaning that the cells neither have a nucleus or specialized organelles, like higher organisms. Cyanobacteria fossils from western Australia date back 3.5 billion years ago, making ancient cyanobacteria the beginning of life on earth (Taylor and Taylor 1993). Combined with green algae, diatoms, and dinoflagellates, these organisms make up the collective “phytoplankton” which is the base of all lake food webs.

Causes of Cyanobacteria blooms

Algae and cyanobacteria need light and nutrients to survive. Visible light and infrared radiation from the sun is in abundance during the summer season in the northeastern climate. Nutrients, primarily nitrogen and phosphorus, are used by cyanobacteria to grow and reproduce. Increasing nitrogen and phosphorus, as well as other factors like reduced grazing by zooplankton or water stagnation, increase cyanobacteria proliferation. A surface bloom can develop rapidly, appearing overnight, or it can occur over several weeks.

Cyanobacteria have distinct advantages over green algae and diatom phytoplankton that allow them to proliferate during summer months. For instance, many types of cyanobacteria are able to use atmospheric N_2 nitrogen which is unavailable to other algae. Cyanobacteria consume nitrogen gas using a specialized cell called a heterocyst (Figure 1). This allows cyanobacteria to continue to dominate when all other forms of nitrogen are not available in water.

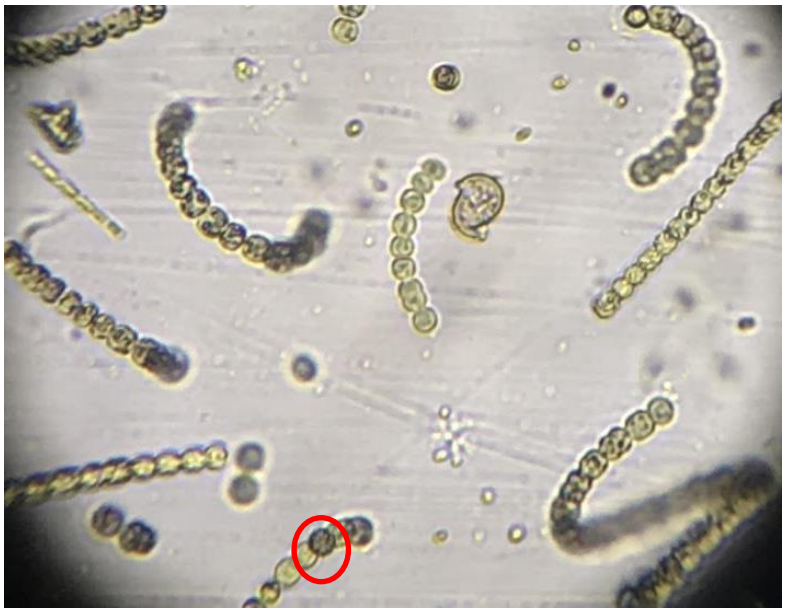

Figure 1 Example of heterocyst (red circles) on the cyanobacteria, *Anabaena*

Secondly, cyanobacteria are able to regulate their position in the water column because their cells contain gas vesicles. These structures allow cyanobacteria to stay in the upper, warmer waters to maximize light and heat exposure. The ability for cyanobacteria to regulate their buoyancy becomes increasingly necessary during calm hot summer weather when lakes are strongly thermally stratified and there is poor water column mixing. During these times, other algae sink out of the water column because they rely on temperature-driven mixing to remain afloat. Cyanobacteria have evolved to sink into the deeper waters when their vesicles collapse after prolonged photosynthesis and subsequent carbohydrate storage. When the cells sink to deeper water they use nutrients, which are more plentiful in deep water, and then rise back to the surface once they have used up their stored carbohydrates and need to revisit the light to begin photosynthesizing again.

In lakes with undisturbed, primarily forested watersheds, nitrogen and phosphorus are not normally in high enough concentrations to support dense growth. However, human development of lake watersheds has created conditions that generate greater quantities of phosphorus and nitrogen. Examples of increases in watershed disturbance include construction of roads, rooftops, driveways that do not allow water infiltration into soils, houses with septic systems, fertilizer use, and poor construction practices that exacerbate erosion and sediment transport.

All nutrients do not enter a lake directly from watershed-based sources. Lakes can also internally regenerate nutrients through a variety of processes, chief among them being chemically mediated phosphorus sediment release. When oxygen is absent in the bottom waters, a suite of chemical reactions takes place that liberates phosphorus and iron, which are bound together in sediments when oxygen is present. In no-oxygen "anoxic" environments, phosphorus becomes available for algae uptake in the water column. Ammonia, a reduced form of nitrogen is also released in oxygen-devoid water. As discussed

earlier, cyanobacteria can use nutrients released from internal loading from bottom sediments and then use their gas vacuoles to rise back to the warm, upper waters.

Impacts of Cyanobacteria Blooms

Cyanobacteria blooms can have a large impact on aquatic ecosystems by reducing water clarity, contributing large amounts of organic matter that will sink to the bottom and decompose, and the unsightly formation of surface scums. The latter interferes with recreation, as winds blow these scums into coves and shallow embayments, often where beaches are located (Figure 2).

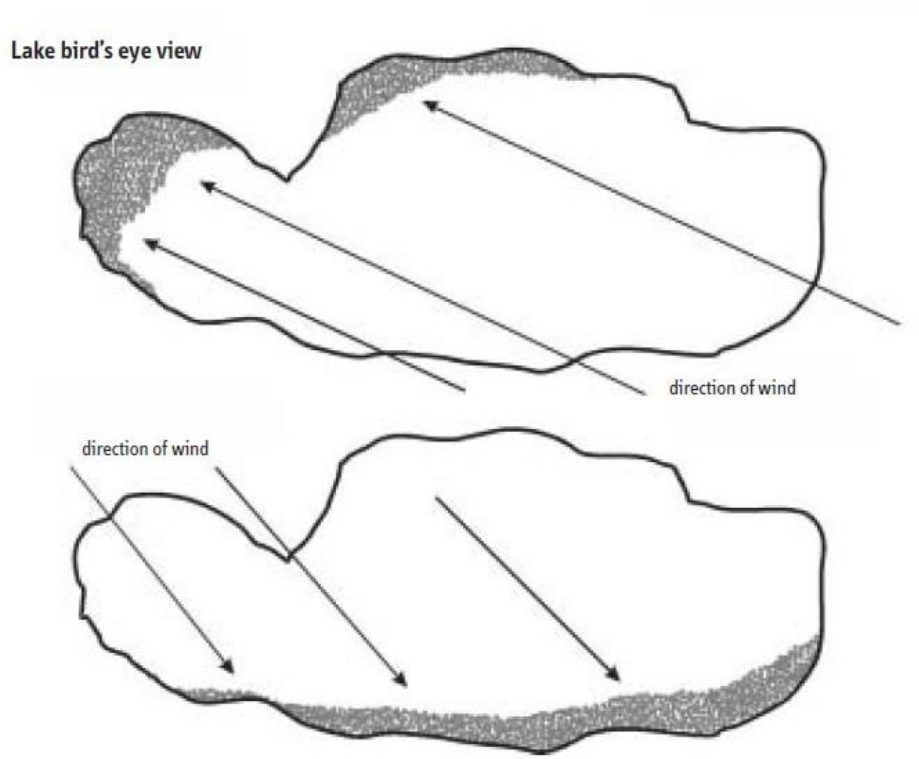

Figure 2. Illustration of the formation of cyanobacteria scums in lakes in relation to wind direction (Chorus and Bartram 1999).

In addition to the unsightly and often foul-smelling green slime observed during a bloom, many cyanobacteria produce harmful toxins (Table 1). At high levels, cyanotoxins can cause health risks for humans and animals such as skin rashes, digestion issues, and/or acute or chronic liver and nervous system damage. These health risks are increased for young children and pets. Though cyanobacteria are being heavily researched, there are still many unknowns, especially related to long-term health effects.

Table 1. Cyanotoxins that can be produced by various cyanobacteria.

Cyanotoxins	Common taxa that produce toxins
Microcystin-LR	*Microcystis, Anabaena, Planktothrix, Anabaenopsis, Aphanizomenon*
Cylindrospermopsin	*Cylindrospermopsis, Aphanizomenon, Anabaena, Lyngbya, Rhaphidiopsis, Umezakia*
Anatoxin-a	*Anabaena, Planktothrix, Aphanizomenon, Cylindrospermopsis, Oscillatoria*
Saxitoxin	*Anabaena, Aphanizomenon, Cylindrospermopsis Lyngbya*

Analysis of Lake Data

NEAR examined recent water quality and filamentous algae data In order to understand what conditions may have lead to the fall 2018 algae bloom, While Lake Hayward has an extensive data set prior(for) to 2000-2001, we did restate findings from the 2001 study (Knoecklein 2001). For the purposes of this report, we investigated algae counts, water clarity, temperature, oxygen, and total phosphorus data.

Initial Algae Bloom

The impetus for this work came from a perceived algae bloom on October 13th, 2018. Samples of this bloom were sent to Aquatic Ecosystem Research (AER) for phytoplankton identification and enumeration. Their analysis revealed 18 genera with a total cell count of 5,816 cells/mlwith90% of cells observed being cyanobacteria.

Cyanobacteria cell counts were done by Solitude/Act between June 2017 and August 2018 and showed a significant increase to 47,000 cells/mL in August 2018. AER analyses of lake water in October 2018 found only 5,816 cyanobacteria cells/suggesting dissipation of the cyanobacteria

Table 2. Recent cyanobacteria cell counts (cells/ml) from Lake Hayward. SOL = Solitude Lake Management, AER = Aquatic Ecosystem Research.

Date	Transect	Counter	Diatoms	Chlorophyte	Cyanophyte	Total
6/8/2017	North	SOL	123	102	500	725
6/8/2017	South	SOL	77	37	60	174
9/12/2017	North	SOL	273	74	698	1,045
9/12/2017	South	SOL	192	43	77	312
6/15/2018	North	SOL	28	55	160	243
6/15/2018	South	SOL	363	-	38	401
8/9/2018	North	SOL	58	164	350	572
8/9/2018	South	SOL	83	115	47,000	47,198
10/13/2018	N/A	AER	131	169	5,314	5,614

Cyanobacteria dominance in the late season is common in most temperate lakes, so it is not out of the ordinary to see higher counts during this time of year(it is expected really). There were also two earlier phytoplankton counts of 35,000 cells/ml, with notes indicating cyanobacteria dominance on September 26th, 2014. These numbers were similar to cell counts from Knoecklein (2001) during similar times of the year.

Water Clarity

Consistent recent water clarity data for Lake Hayward exists from 2015 to 2018 (Figure 3); before that time the only data available was collected and reviewed by Knoecklein (2001). Recent data (2015 to 2018) indicate poor water clarity during the summer months with multiple readings shallower than 4 meters. Particularly poor readings were made in 2018 (8/15: 2.59 meters, 9/23: 2.19 meters, 10/17: 2.49 meters), with the first reading occurring six days after the highest cyanobacteria count observed since 2017.

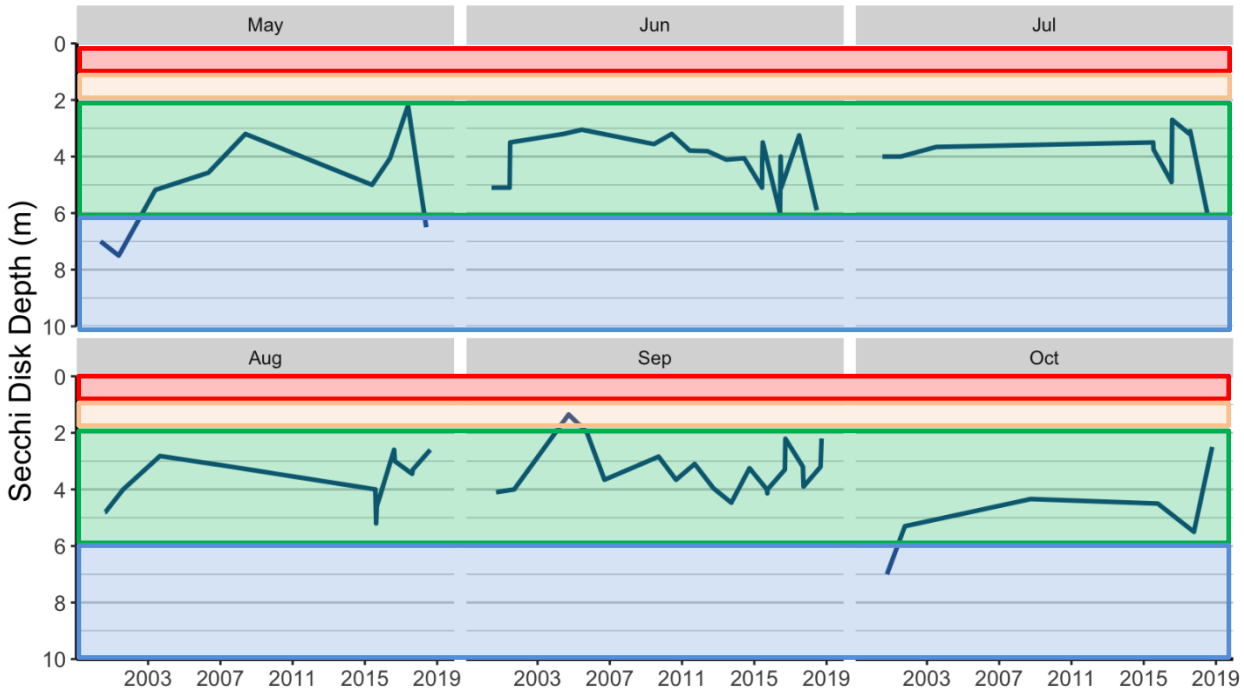

Figure 3. Annual water clarity readings grouped by month for Lake Hayward. Colored bars indicate CT DEEP trophic categories (Red = Hypereutrophic, Orange = Eutrophic, Green = Mesotrophic, Blue = Oligotrophic).

Temperature and Oxygen Profiles

Temperature profile data was only available from the north and the south sites in 2017 and 2018, collected once in early summer (June) and once in mid-late summer (August/September). Prior to this, two temperature profiles were taken at the deep spot on August 23rd, 2013 and August 9th, 2005.

Lake Hayward exhibited varying thermal profile regimes at both sites (Figure 4, 5). *these figs 4 & 5 are in shallow water consistent with the lakes Epilimnion as shown in Figure 4 Consistently, it seems that the north station is closer to full mixing (defined here as the difference in surface and bottom temperature) than the south station. Since both stations are around the same depth, we believe that the north station may be more windswept than the south station, leading to temperature conditions that are more uniform top to bottom than the south station. Temperature data from August 2005 and 2013 at the deep station show thermal stratification with a small if nonexistent hypolimnion (Figure 6).

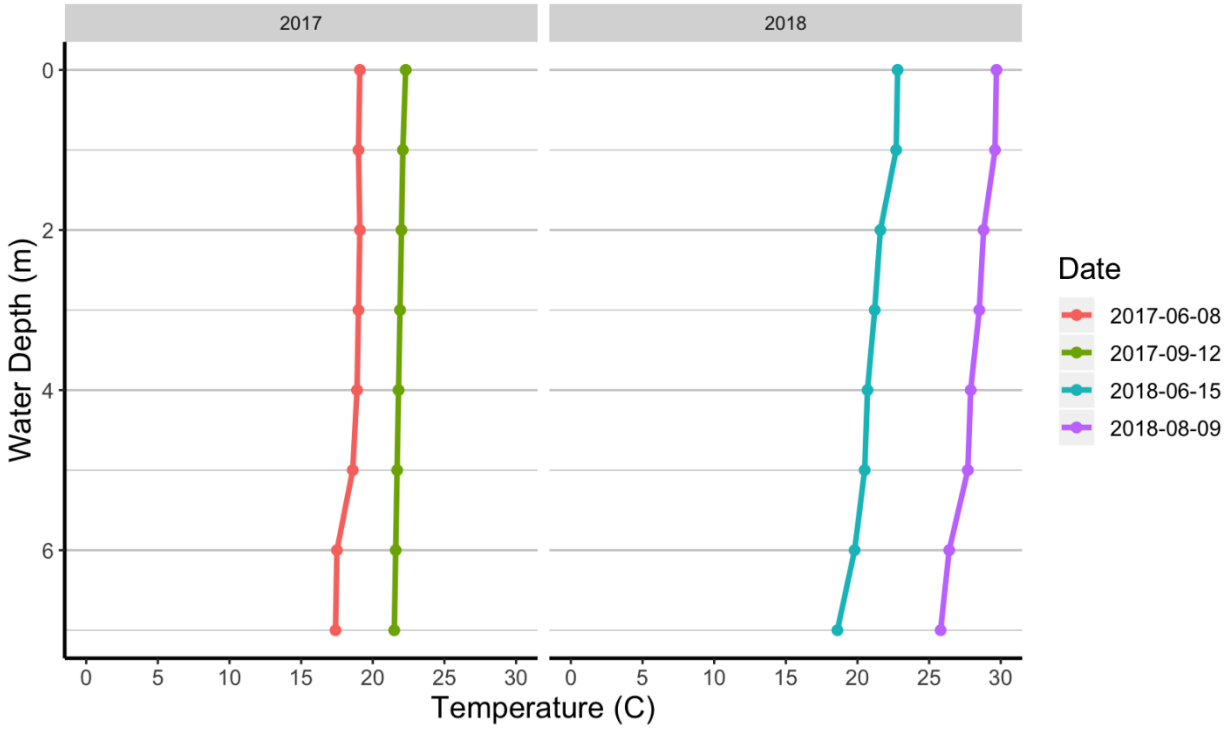

Figure 4. Temperature profiles at the north station.

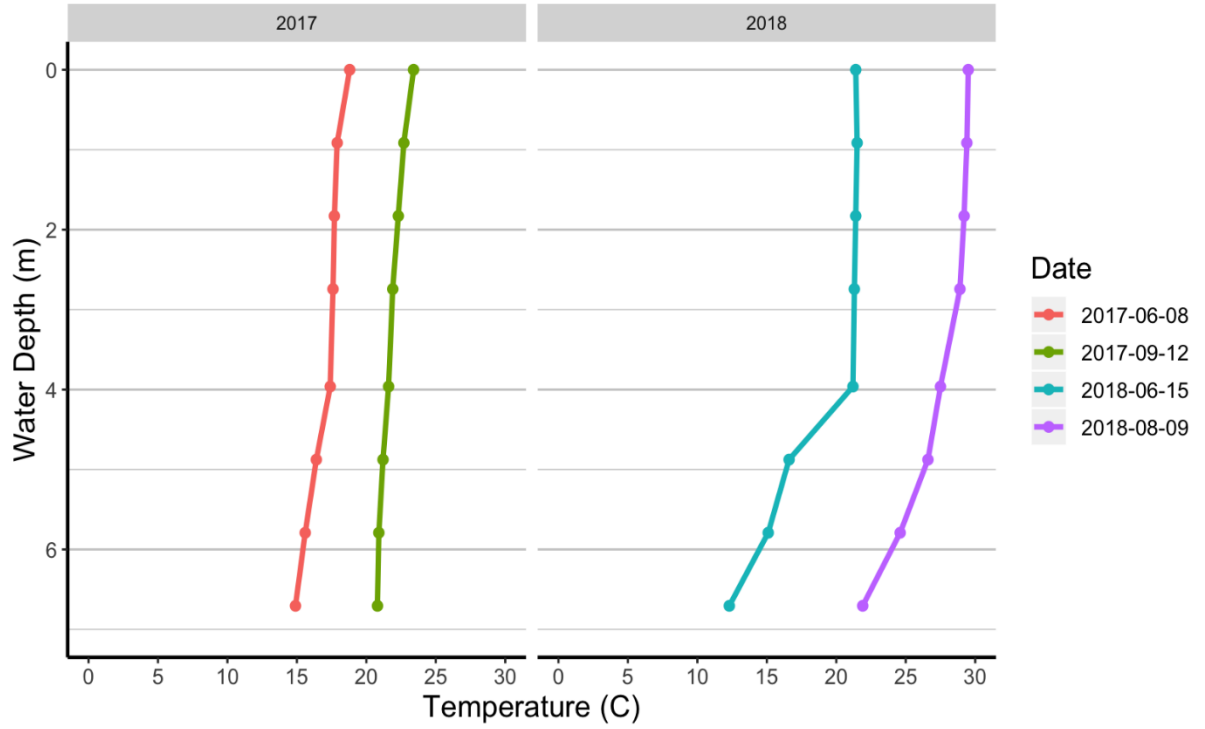

Figure 5. Temperature profiles at the south station.

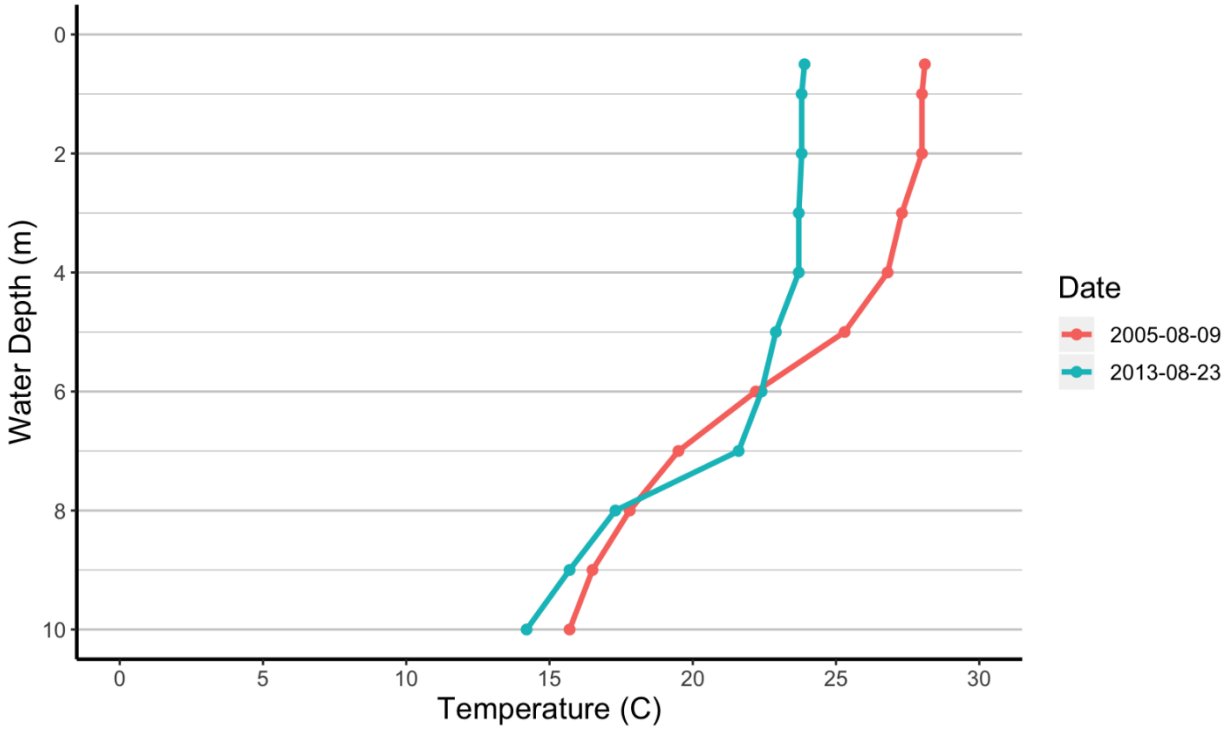

Figure 6. Temperature profiles at a deep station in 2005 and 2013.

Dissolved Oxygen

Dissolved oxygen profiles were taken on the same dates, stations, and depths at the temperature profiles previously discussed. Similar to the temperature profiles, the north station has a less severe oxygen loss from the surface to bottom than the south station (Figure 7, 8). At the deep spot in 2005 and 2013, oxygen loss was severe with anoxic conditions (D.O. > 1 mg/l) starting at 6 and 8 meters, respectively (Figure 9).

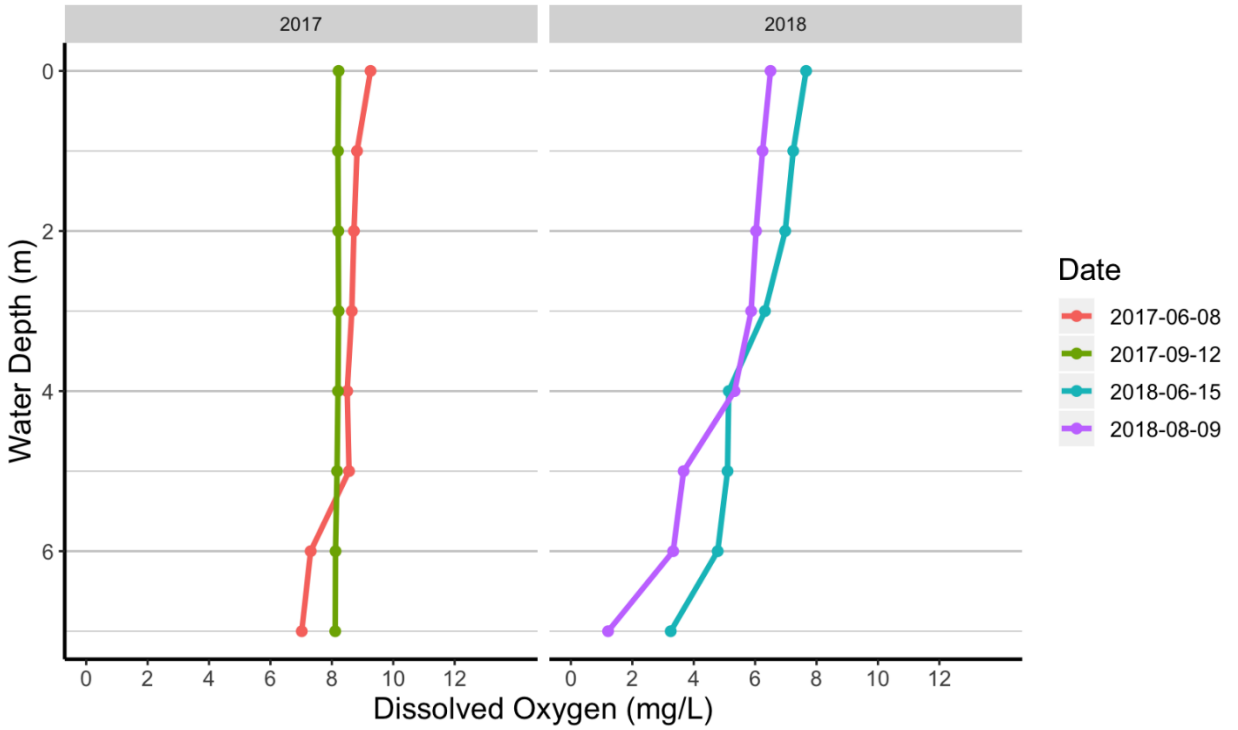

Figure 7. Dissolved oxygen profiles from the north station.

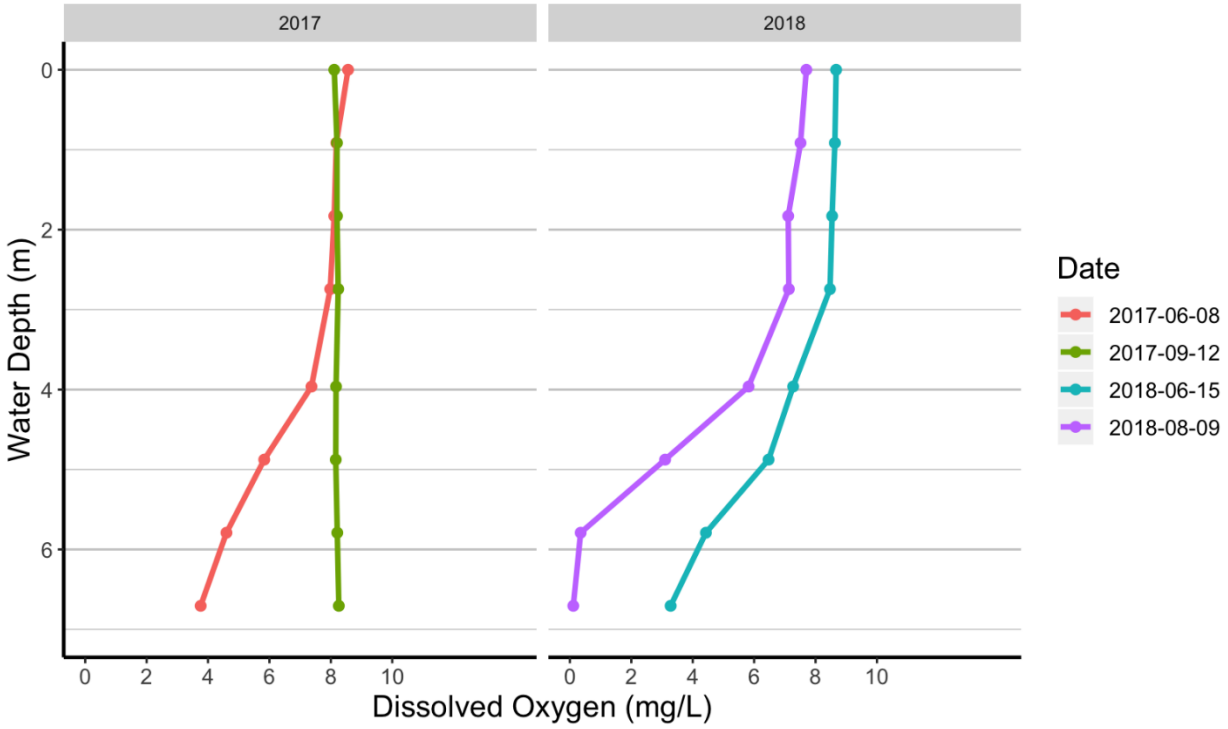

Figure 8. Dissolved oxygen profiles from the south station.

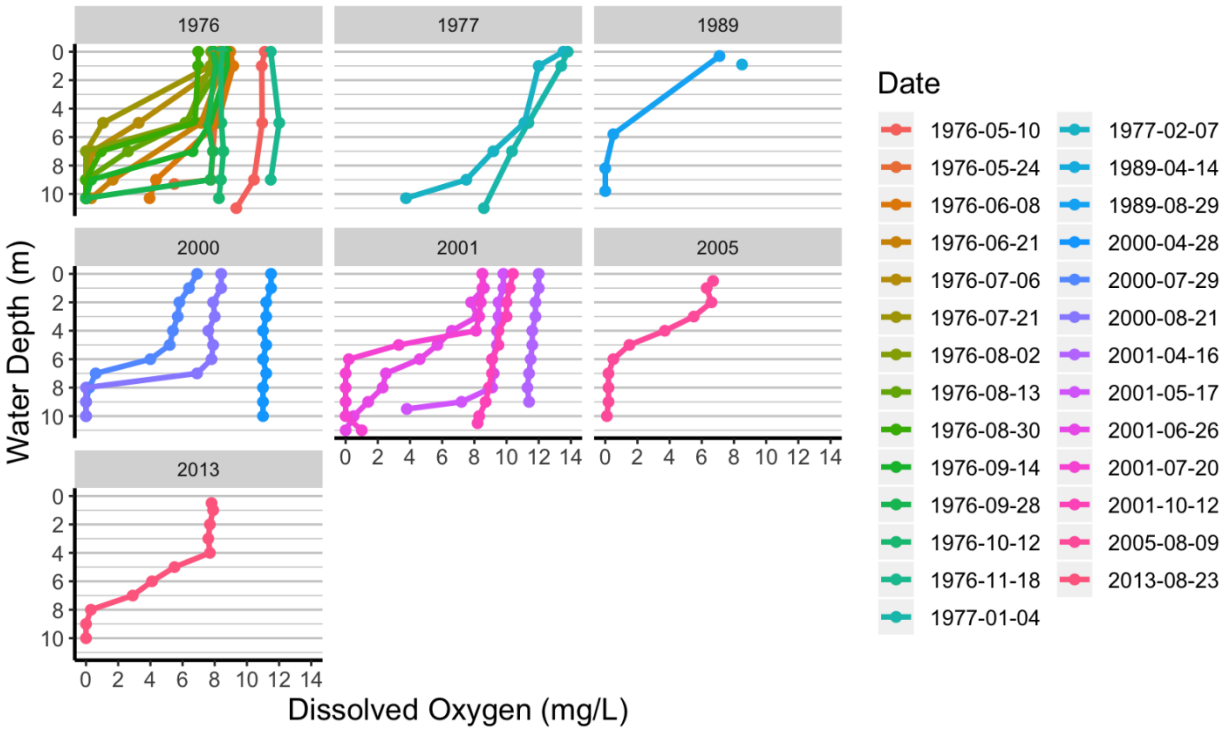

Figure 9. Historical dissolved oxygen profiles at the deep station

No dissolved oxygen data has been collected from Lake Hayward's deepwater station since 2013. Based on the historical data oxygen profiles from the north and south stations, oxygen loss is severe in Lake Hayward. Data show anoxia can overwhelm all water below 20ft (6 meters).

Total Phosphorus

Total phosphorus data was available sporadically from 2005 to 2018 from the deep station. Unlike temperature and oxygen profiles, no data was available from the north and south station. Surface phosphorus data has stayed relatively steady since 2005, averaging 12.4 µg/l (Figure 10). Bottom phosphorus values seem to be increasing, as the four highest values since 2001 were present in 2017 and 2018 (Figure 11). More discrete sampling is required to make inferences about internal phosphorus load quantities and potential entrainment to surface waters. Nutrient testing needs to be paired with dissolved oxygen and temperature testing at the deepest location in the lake.

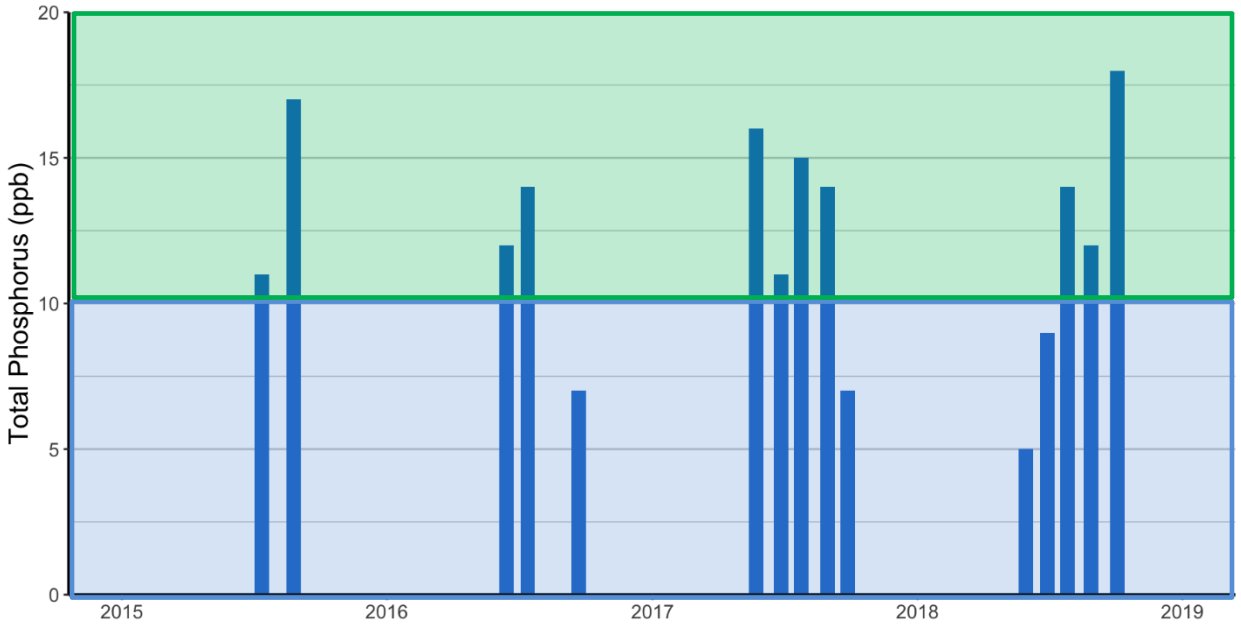

Figure 10. Surface total phosphorus data from the deep site 2015 to 2018. Colored bars indicate CT DEEP trophic categories (Green = Mesotrophic, Blue = Oligotrophic).

It is important to note that the bottom TP numbers insinuate the degree of internal loading of phosphorus from bottom sediments. The samples were taken in 2000 and 2001 show much lower bottom TP than today, which means that internal loading is rapidly becoming worse.

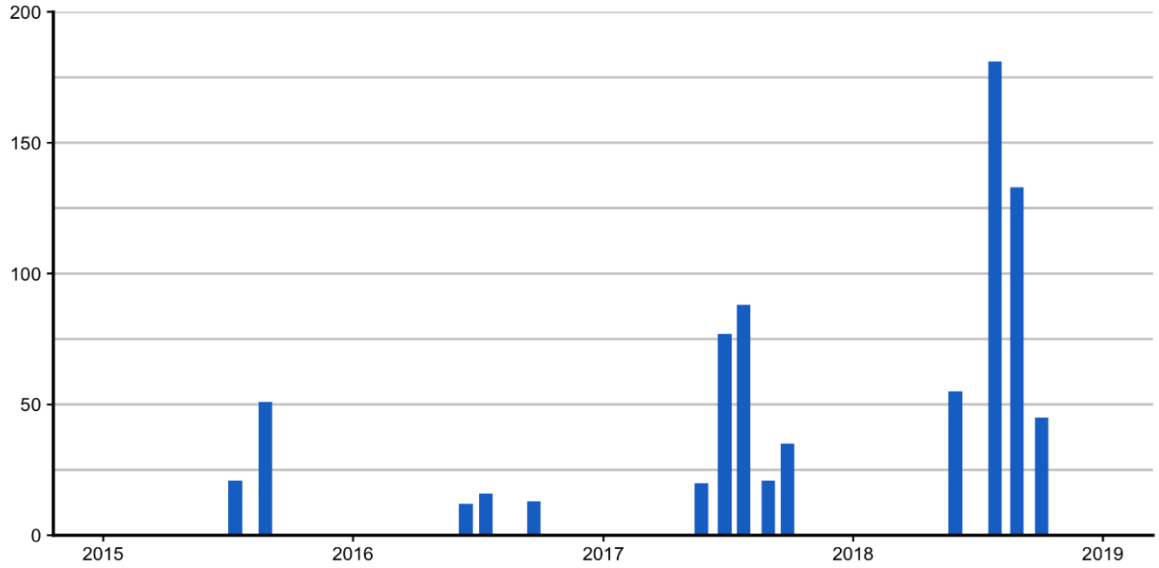

Figure 11. Bottom total phosphorus (measured in ppb) data from the deep site 2015 to 2018.

Filamentous Algae

Solitude Lake Management conducted pre and post-treatment surveys in 2016, 2017, and 2018 which contained data on filamentous algae distribution and abundance. Filamentous algae were observed most often during the May 24th, 2016 sampling (59.6% of all sites; Table 3), followed by September 12th, 2017 (37.1 % of all sites). Abundance data was not documented until 2017, but late season filamentous algae abundance seemed to be higher than early season abundance.

Table 3. Filamentous algae data from solitude surveys. No early season 2018 data available.

Date	Number of Sites Sampled	Filamentous Algae Sites (Percent of all Sites)	Trace	Sparse
5/24/2016	62	37 (59.6)	--	--
9/21/2016	62	2 (3.2)	--	--
6/8/2017	62	10 (16.1)	8	2
9/12/2017	62	23 (37.1)	11	12
8/9/2018	62	14 (22.3)	4	10

Filamentous algae were distributed throughout the lake in most years, with the most abundant growths being present on the western shore an in the southern section (Appendix B). Comparing filamentous algae distributions to the locations of lake inlets, it appears that there is an association between algae distribution and inlets W2, and W6 (Figure 12). Some of the highest total phosphorus and nitrogen concentrations have been historically observed at these locations (Knoecklein 2001). It is important to note, though, that the line intercept survey did not sample points directly in front of all inlets, meaning we may be missing other inlets that have filamentous algae growth in close proximity.

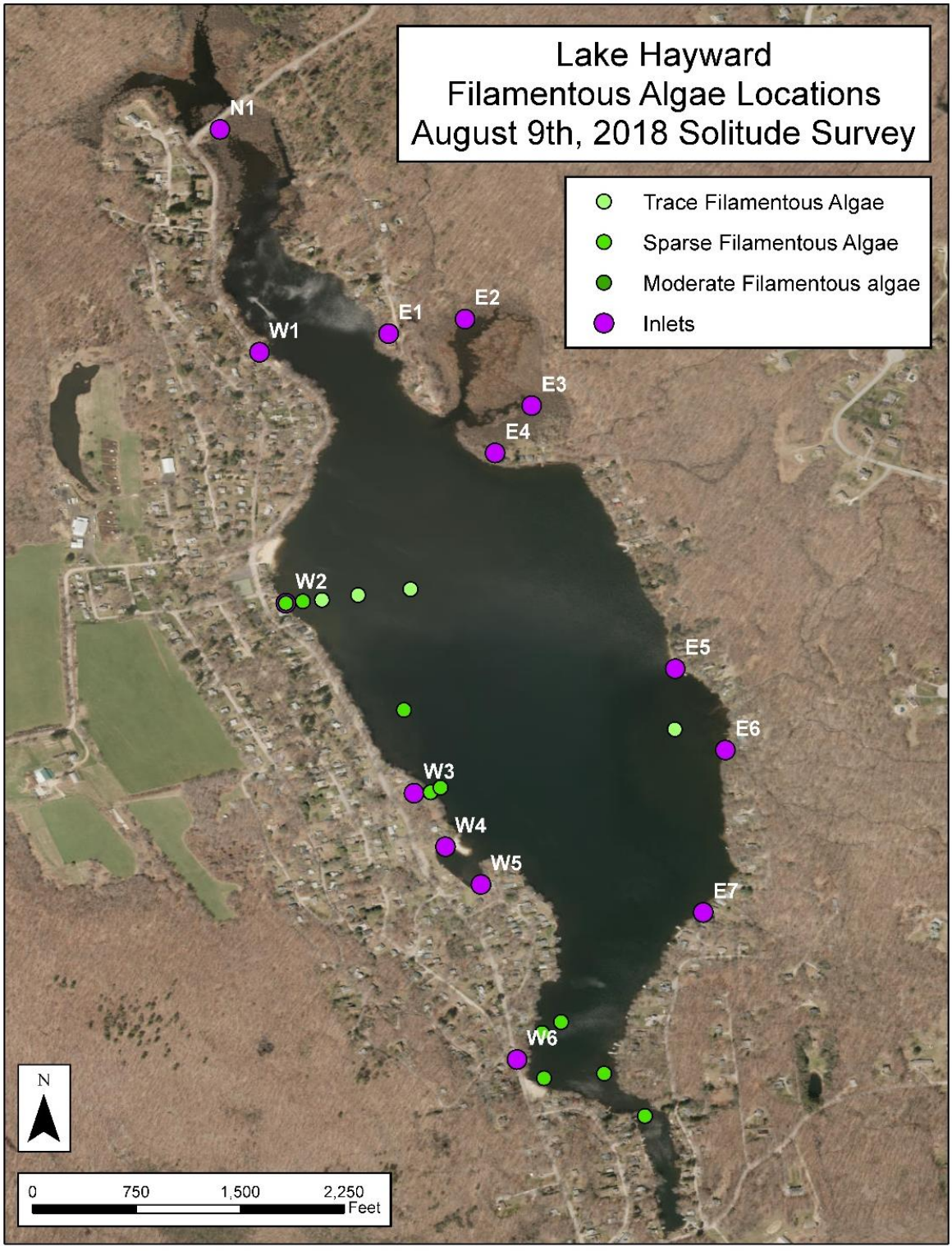

Figure 12. Distribution and abundance of filamentous algae August 9th, 2018.

Recommendations for Future Monitoring Protocols

The LQIC should completely re-vamp their monitoring program. The current data collection program makes it difficult to draw conclusions about cyanobacteria bloom-formation criteria at Lake Hayward. There is a lack of temperature and dissolved oxygen profiles at the deepest point in the lake, which means that we cannot track the extent of anoxic water to compare to historical data. Both nutrient samples and temperature and oxygen profiles need to be measured at the deepest area of the lake. Below, we have outlined a more complete monitoring program to be adopted by LQIC.

Water Clarity

Water clarity is one of the most fundamental aspects of lake health because it suggests the abundance of phytoplankton in the lake. In addition, water clarity determines the depth of warming by sunlight and drives the process of seasonal thermal stratification. To measure water clarity, an 8-inch circular Secchi disk is attached to a measuring tape and lowered into the water on the shady side of the boat. Using a view scope to shade out light in one's peripheral vision (Figure 13), the Secchi disk is lowered until it disappears from view in the water column. The average of the depth at which it is no longer visible and the depth at which it becomes visible again when lifted slightly, is recorded as the water transparency measurement.

Figure 13. Secchi disk and view scope.

Equipment needed: Secchi Disk with an attached measuring tape, View Scope

How many sampling events per season:
Minimal: Once per month (April to October)
Optimal: Bi-weekly (April to October)

Sites to sample:
Minimal: Deep spot (Station 1)
Optimal: Deep, North, and South Station

Temperature and Dissolved Oxygen profiles

[To be measured at the deep spot in the lake at one-meter depth increments from the surface to the lake bottom.]

Temperature - Water temperature in lakes and ponds in the northeast follow a seasonal pattern of warming and cooling. When the lake ice melts in early spring, Hayward Lake should be uniform in temperature from top to bottom. These combined measurements are referred to as a lake profile. As the sun's rays penetrate into the water column during the summer, the water warms; but the depth extent of this warming is dependent on how clear the water is. Clearer water allows better sunlight penetration and deeper water column warming. Thus, the depth and development of a thermocline, or the zone of rapid temperature change, is dependent on both the depth of the lake and water clarity. The thermocline influences trends in dissolved oxygen, which affect the concentrations of nutrients and metals within the water column. Cooling waters in the fall result in a weakening thermocline and eventually fall "turn-over," or when the temperature once again becomes uniform from top to bottom (Figure 14).

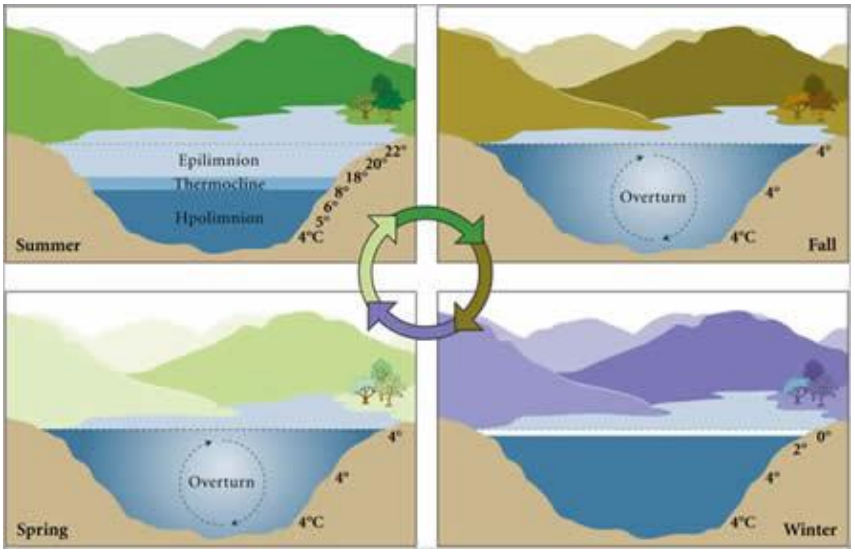

Figure 14. Diagram of lake stratification and mixing throughout the year. Photo credit: Young, M. (2004). Thermal Stratification in Lakes. Baylor College of Medicine, Center For Educational Outreach.

Dissolved Oxygen - Dissolved oxygen in a lake is essential to aquatic organisms. At the surface of the lake, the water is in contact with the air, and atmospheric oxygen is dissolved into the water as a result of diffusion. As water mixing takes place, the dissolved oxygen is circulated throughout the water column. Decomposition of rooted aquatic plants and algae by bacteria requires dissolved oxygen (Biological Oxygen Demand) and can deplete the oxygen levels in the bottom waters below the thermocline. The amount of dissolved oxygen in the water directly influences nutrient concentrations. When dissolved oxygen in the bottom water falls below 1mg/L (becomes anoxic), the process of internal loading becomes

accelerated, and meaning nutrients previously trapped in the bottom sediment are released into the water. It is critical to track the level of the anoxic boundary or the depth of water at which dissolved oxygen is depleted. Anoxic water is not suitable for organisms like fish and invertebrates.

Equipment needed: Temperature and dissolved oxygen probe. We use a Hach LDO optical dissolved oxygen probe (Figure 15), but YSI, Eureka, and In-situ sell good products as well. A 15-meter cable would be a sufficient length for collecting Lake Hayward data. The benefit of the Hach LDO is the DO sensor cap makes it so the probe does not need to be calibrated as frequently as YSI models. Membrane-based DO probes are cheaper but are more subject to user error.

How many sampling events per season
Minimal: Once per month (April to October)
Optimal: Bi-weekly Sampling

Sites to sample
Minimal: Deep Spot (Station 1)
Optimal: Deep, North, and South Station

Figure 15. Hach® Dissolved oxygen probe

Nitrogen and Phosphorus

Phosphorus and nitrogen are the two principal plant nutrients that drive aquatic plant and algae growth. Both nutrients are present in all lakes at some level. When the concentrations of these nutrients start to increase, particularly phosphorus, algae can grow rapidly and reach nuisance conditions. In freshwater systems, phosphorus tends to be the limiting factor for productivity and is more heavily monitored for the health of inland ecosystems. Low phosphorus in a water body typically equates to lower phytoplankton abundance and greater overall Secchi clarity.

Because Lake Hayward has anoxic waters in the hypolimnion, surface and bottom phosphorus and total nitrogen samples should be taken at a minimum. We would suggest to take a mid-depth sample and analyze it for total phosphorus, total nitrogen, and ammonia-nitrogen. As mentioned previously, ammonia-nitrogen increases in concentration within anoxic bottom waters, and is a preferred nutrient for algal growth. If anoxia is severe enough, we would expect to see both elevated phosphorus and ammonia-nitrogen in the middle of the water column.

Equipment needed:

Van Dorn bottle (Figure 16). The rope on it should be long enough to reach 10 meters. Our Van dorn samplers are from Wildlife Supply Company®, but other vendors sell these products. Sample bottles are also needed. Whichever lab is analyzing the samples should give recommendations on what sample bottles to use, storage and preservation.

How many sampling events per season

Minimal: Once per month (April to October)
Optimal: Bi-weekly Sampling

Sites to sample

Minimal: Deep Spot (Station 1)
Optimal: North and South Station

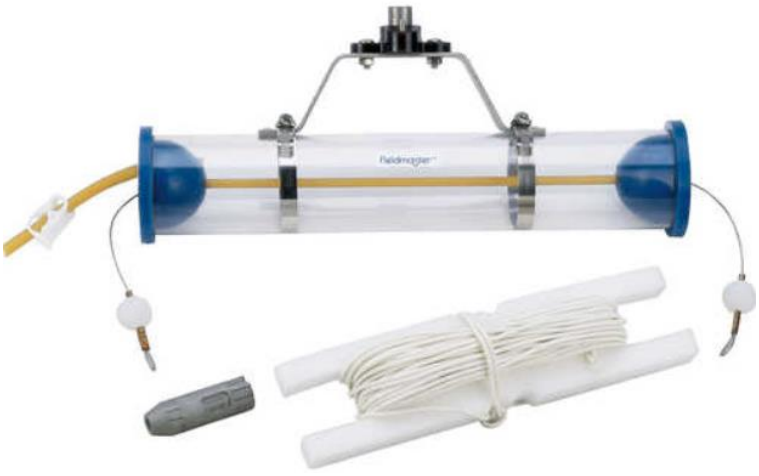

Figure 16. Van Dorn bottle for water quality sampling.

Lake Plankton

The term plankton refers to organisms suspended in the middle of the water column. The two main categories of plankton are the phytoplankton (free-floating microscopic algae) and zooplankton (microscopic animals that often graze on phytoplankton). Plankton as a group represent the beginning of the lake food chain and are essential to understanding the impacts of nutrient enrichment.

Because the LQIC is concerned with the presence and abundance of cyanobacteria, monitoring of the phytoplankton is essential. There are a few ways to monitor phytoplankton abundance, all with their

positive and negatives. Chlorophyll α, the photosynthetic pigment present in algae and cyanobacteria is an indirect measure of algal abundance, while often the cheapest method, would not be appropriate for cyanobacteria monitoring. Chlorophyll α does not tell you anything about what type of plankton is dominant, as it is an aggregate measurement. In addition, the dominant pigment in cyanobacteria is phycocyanin, meaning that chlorophyll α measurements may underestimate the abundance of cyanobacteria. We would suggest microscope cell counts as they are an actual measure of cyanobacteria abundance, rather than a surrogate like chlorophyll α. While a little is more expensive than chlorophyll α, we believe that the increased cost is worth it correctly monitor cyanobacteria.

Equipment needed:

3-meter integrated tube sampler (Figure 17). A chain or some washers are sufficient for weight to sink the tube. Our Van dorn samplers are from Wildlife Supply Company®, but other vendors sell these products. Sample vials – We use 15 ml centrifuge tubes for storage. The lab analyzing the samples can advise the LQIC on preservation and storage.

How many sampling events per season

Minimal: Once per summer month (June to September)
Optimal: Bi-weekly summer month sampling (June to September)

Sites to sample

Minimal: Deep Spot (Station 1)
Optimal: Deep, North, and South Station

Figure 17. The 3-meter tube used for algae sampling.

Optional Analyses

The above recommendations should be the base of Lake Hayward's monitoring program, however, there are some additional analyses that we deem optional, but can have some utility in a monitoring program.

- Cyanotoxin sampling – monitoring the potential toxins in algae bloom can be important for understanding the risk of exposure for lake users. This is not something that needs to be monitored frequently, but any time there is a visible blue-green paint scum, a toxin test could be useful.
- Zooplankton - Zooplankton are larger, animal members of the plankton populations that are present in all lakes. Their populations are influenced by predators such as small fish, and certain genera can regulate phytoplankton populations through grazing. An understanding of lake plankton allows for a better interpretation of water quality data.
- pH – pH is a unitless scale of acidity; it tells how many hydrogen ions are present in the water. As the pH number increases, the amount of hydrogen ions in the water decreases. Measuring pH in water is highly useful when understanding the impacts of environmental change such as acid rain, or evaluation of management techniques such as aluminum sulfate and aeration.
- Regular Stream Sampling – The tributaries leading into Lake Hayward have not been sampled since Dr. Knoecklein's work in the early 2000s. During a few of his visits, some nutrient measurements were alarmingly high, indicating a potentially large source of nutrient pollution. While it may not be financially feasible at this time, we would suggest some follow-up investigation. A good starting point would be to sample streams W4, W1, W2l, W2u, E5 once during the spring and once during the summer.

Recommendations for Cyanobacteria Management

Cyanobacteria management to reduce prevalence and intensity of blooms can be broken down into two broad categories: short term, direct cyanobacteria reduction, and longer term nutrient management. It is important to acknowledge both strategies as part long term management,

Short Term Management

Short term cyanobacteria reductions are defined as annual actions that a lake association can take to reduce the abundance of algal cells directly. These techniques are often used to give relief to lake homeowners for the season, to open beaches to swimming and for other forms of contact recreation.

Algaecides

Algaecides are registered pesticides that are used to control nuisance algal growth. They are applied either as a liquid or a solid into the water. Algaecides act on contact with the algae, penetrating the cell wall and

interfering with processes such as electron transport and photosynthesis along with causing a host of other issues for the cell. The most commonly used algaecide in the nation are ones containing copper as the active ingredient.

Copper-based algaecides have been around since the early 1900s and are the most widely used aquatic algaecide/herbicide in the nation. Their attractiveness comes from a relatively low cost and effective ability to kill cyanobacteria. One of the most common formulations, copper sulfate is particularly effective on cyanobacteria; concentrations as low as 0.0625 parts per million of copper are able to control most types of algae and cyanobacteria.

Copper itself can be toxic to fish if not used correctly, and all algaecides must be applied by a certified pesticide applicator. Water hardness (amount of dissolved calcium and magnesium) impact the toxicity of copper-based products; as hardness decreases, toxicity to fish and zooplankton increases. There is also significant concern about copper buildups in sediments, and the impacts that may have on the biota over long periods of annual copper use.

Hydrogen peroxide-based algaecide products are relatively new to the industry compared to copper but offer an alternative treatment. Hydrogen peroxide destroys the cell membranes of algae and breaks down into water and oxygen in solution, eliminating the potential long term buildup of chemical residues in the environment. Endothall, a common active ingredient used in aquatic herbicides can also be used for algae control (Hydrothol® 191). Hydrothol can be effective, but also has fish and invertebrate toxicity issues. Often, Peroxide and Hydrothol are mixed together for a synergistic effect. Both products are normally more expensive than treatment with copper.

Longer Term Management

Long term in-lake nutrient management can be done by artificial circulation or destratification, aeration, oxygenation, Alum treatments, Phoslock treatments, or hypolimnetic withdrawal. We will briefly explain each type and how they are supposed to work, but for Lake Hayward, we believe that Alum would be the most cost effective and successful at reducing large quantities of phosphorus that cause cyanobacteria blooms.

Artificial Circulation

Artificial circulation is the process of physically increasing water turbulence to reduce cyanobacteria advantage during summer lake thermal stratification. Circulation affects cyanobacteria in a few different ways:

- Circulation increases the time cyanobacteria spend in the deeper waters, reducing light exposure.
- Turbulence negates the advantageous effects of cyanobacteria buoyancy.
- Zooplankton may increase due to decreased vulnerability to feeding fish, increasing the number of potentially available grazers on algae.

Artificial circulation works well in small ponds (less than 1 acre), but it does not work as well in larger water bodies. Under-sizing of artificial circulation units is the single greatest reason they fail in larger systems. As the size of the lake increases, the complexities in lake morphometry, internal phosphorus release mechanisms, and physical water movement increase as well. There is a plethora of detailed information needed to properly size an aeration unit for a waterbody the size and depth of Lake Hayward, information that goes beyond the scope of the proposed monitoring contained within. Undersized systems may not produce enough energy to overcome thermal stratification during heat waves, which could then cause a rapid mixing of poor quality bottom-water into the surface, periodically increasing algae abundance.

Alum

Aluminum sulfate, commonly known as alum is used to remove available phosphate from the water column and sediment. Some of the more successful treatments can reduce in-lake phosphorus for a decade or longer, but the longevity of success is dependent on the dosage and proper application. Alum treatments can be applied both on the surface or injected, usually as a liquid slurry, into the deep water. When aluminum sulfate dissolves in water it forms hydroxides $Al(OH)_3$. This compound falls through the water column, biding reactive phosphorus as it sinks to the sediment-water interface, where it further binds with any reactive phosphates. These phosphates are now unable to be released under anoxic conditions.

There is a significant amount of pre-study and monitoring, similar to large-scale aeration in order for an alum treatment to be successful. Information needed includes detailed pH, alkalinity, oxygen, phosphorus (not just total, but other fractions especially for sediment-locking treatments) and biotic (phytoplankton and zooplankton) measurements.

Phosphorus Loading and Nutrient Budgets

Before any in-lake nutrient management techniques are undertaken, a detailed understanding of the nutrient loading dynamic of Lake Hayward is needed. In-lake nutrient management is usually more successful when the internal load is overwhelmingly the largest source of nutrients entering the waterbody on an annual basis. We do not yet know that to be the case at Lake Hayward. Nutrients enter lakes both through internal and external sources, and techniques such as aeration and alum do nothing to address external loads. In fact, many in-lake techniques fail to achieve measurable cyanobacteria reductions because of improper assessment of nutrient loads. We suggest that lake Hayward first understand where the largest sources of nitrogen and phosphorus are coming from before undergoing large-scale in-lake remediations. It does not make financial sense to spend an exorbitant amount of capital on reducing nutrients from a source that may not be the main driver of poor water quality. That kind of inefficient allocation of resources is what leads to failed projects and decreased public support for future endeavors.

The way managers quantify the relative contribution of nutrient sources into a lake is most often a modeling approach. While there are many different models that can examine relative nutrient

contributions, tributary, and in-lake data collection is needed to increase the utility of models. Models are only as strong as their inputs, so having detailed lake data to confirm the validity of models is important. Information such as stream nutrient concentrations, in lake phosphorus mass, days of anoxia, the anoxic boundary, outlet flows and nutrient concentrations help increase the utility of modeling.

With that said, Lake Hayward should not wait around for a full year of water quality data and a modeling approach to being remedial actions. There are smaller scale issues that can be handled now in the absence of such detailed analyses, particularly in the watershed. Those have been laid out in detail within the upcoming watershed management plan, so we will not discuss them in too much detail here. Improving storm water practices by encouraging green infrastructure, porous pavement, rain gardens and barrels, education about proper shoreline and lake property management, and septic system education/enforcement are all relatively affordable projects that the POA can start in concurrence with improved in-lake monitoring.

Conclusions

After reviewing water quality data, the most likely culprit for the fall algae bloom that occurred in 2018 was the internal loading of phosphorus, which is the most obvious source of phosphorus based on the data available. Currently, the data collection regime is not sufficient enough to fully quantify the severity of internal loading and its direct impacts on cyanobacteria abundance throughout the season. If data is collected on a monthly basis during the summer season, at at least one consistent deep-water location, we can start to draw meaningful conclusions concerning water quality. A strong, scientifically robust monitoring program will be instrumental if Lake Hayward eventually does need to undertake one of the large-scale in-lake remediations. When cyanobacteria blooms occur, it means that the lake is on a trajectory towards blooms becoming more frequent in future years.

Literature Cited.

Chorus, I. and Bartram, J., 1999. *Toxic cyanobacteria in water: a guide to their public health consequences, monitoring, and management*. CRC Press.

Knoecklein G. 2001 Diagnostic/Feasibility Study of Lake Hayward, East Haddam, Connecticut. 156 ppg.

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Appendix A

Volunteer Monitoring Program

Getting Started

1. Use a GPS waypoint to reach the sampling location. Do not rely on memory or location markers to reach the sampling location. If it is your first time sampling and you have not yet created a waypoint, make a waypoint on a GPS or use your phone to make a pinpoint on Google Maps. Return to this same exact spot each time you conduct water monitoring.
2. Drop the anchor and release ample anchor line. You should release 5-7 times as much anchor line as the depth of the water. You may need to release even more anchor line if it is especially windy.
3. On your data sheet, record your name, the names of all other monitors on the boat, the name of the lake, the name of the station at which you are monitoring, the date, and the weather, including temperature, wind speed, cloudiness (sunny/partly cloudy/overcast, etc), and water turbulence (waves/ripples/calm).

Water Clarity

You will determine water clarity using the Secchi disk and view scope.

1. Take off your sunglasses.
2. Place the Secchi disk in the water on the shady side of the boat, keeping tight hold of the handle.
3. While looking through the view scope, slowly lower the Secchi disk until it completely disappears from sight. Move the disk up and down slightly, bringing it in and out of view, and note the exact depth at which the disk disappears.
4. On your data sheet, record the depth at which the Secchi disk disappears.

You can practice taking Secchi readings using the Maine Volunteer Lake Monitoring program's virtual Secchi reading simulator: http://www.mainelakedata.org/recertify/disk.php

Temperature and Dissolved Oxygen (DO)

Record the temperature and dissolved oxygen at the surface of the water and then every meter down until you reach the bottom of the lake.

1. Turn on the DO meter and allow it to fully load.
2. Lower the probe into the water so that about half of the probe is underwater. Press the green button on the monitor.
3. Hold the probe steady, keeping the tip underwater, and allow the meter to finish stabilizing.
4. Once the meter has stabilized, record the DO and temperature (in degrees Celsius) on your data sheet.
5. Lower the probe to the one-meter mark. Again press the green button on the monitor and allow it to finish stabilizing. When it has locked in, record the DO and temperature on your data sheet.

6. Lower the probe again and repeat step 5 at every meter until you have reached the bottom of the lake. (Note: Be sure to not record DO when the probe is in the sediment on the lake bottom, as this can result in faulty data. Sediment on the lake bottom can be very loose and the probe can easily be lowered down into the sediment. You will know you have reached the bottom if you feel a light suction on the probe's cord while pulling the probe up).

Water Samples

Before going out to conduct lake monitoring, be sure that you know at which depths to gather water samples. Make sure that you have one bottle for each sample you will be gathering.

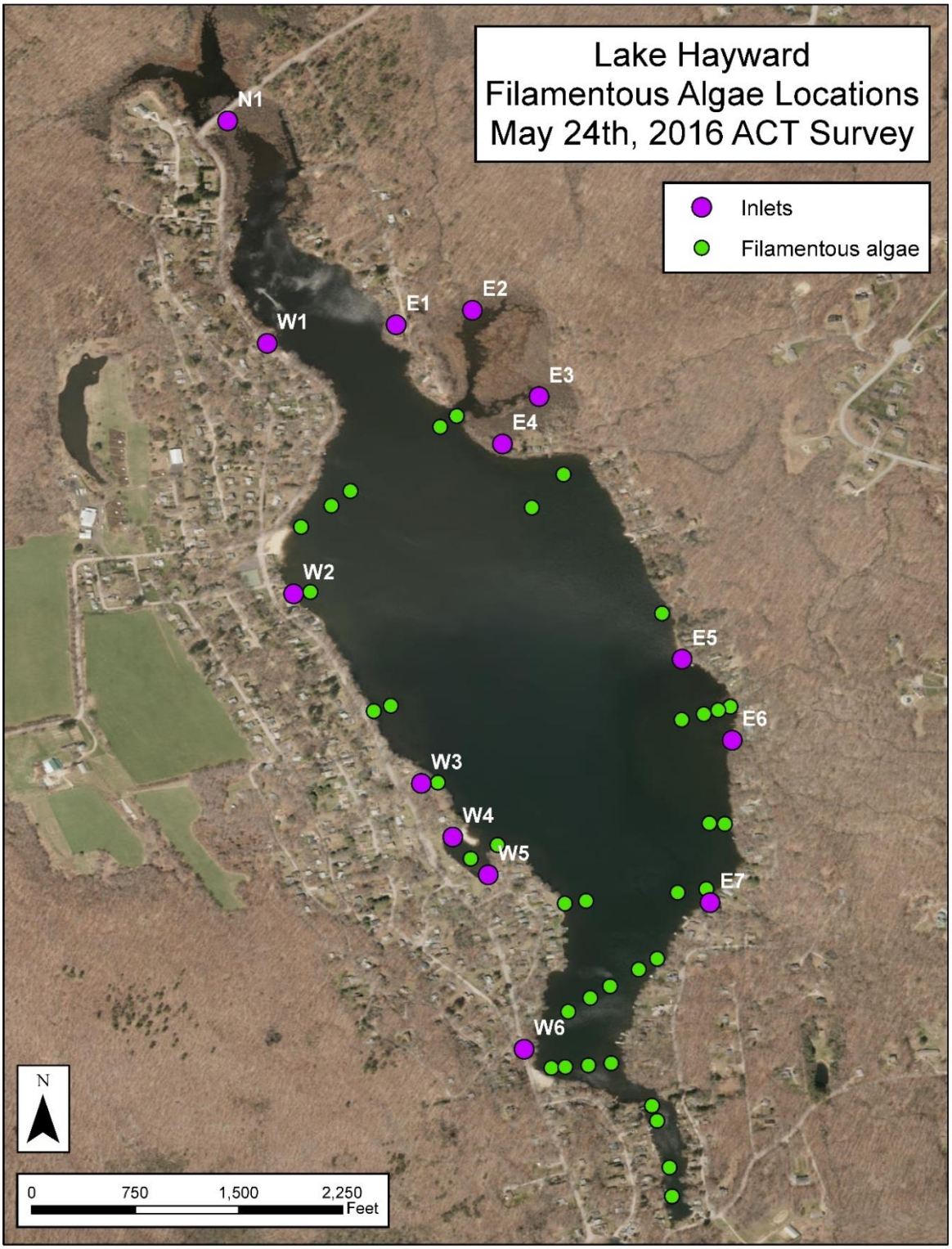
1. Label each of your bottles with the date, the lake name, the station at which you are gathering the sample (if data is only gathered at one location on the lake, label the location "Station 1"), and the depth at which the water sample will be collected.
2. Carefully open the sides of the water sampler. Lower the sampler until you reach the correct depth. Move the water sampler horizontally through the water using long, slow strokes to ensure that the sampler is filled with water from that depth.
3. Drop the messenger down the string to close the sides of the sampler. You should feel and/or hear the sides snap shut. Pull up the sampler.
4. Open the bottle that is labeled with the depth at which you just took the sample. Do not touch the inside of the bottle or the bottle cap, as this could contaminate the sample.
5. Fill the bottle about halfway with water from the sampler's spigot, shake the bottle vigorously, and then pour the water out. Do this three times to clean out the bottle.
6. Fill the bottle a fourth time, this time filling it completely, and screw on the cap. Place the bottle in the cooler.
7. Repeat steps 2-6, gathering a sample at each required depth.

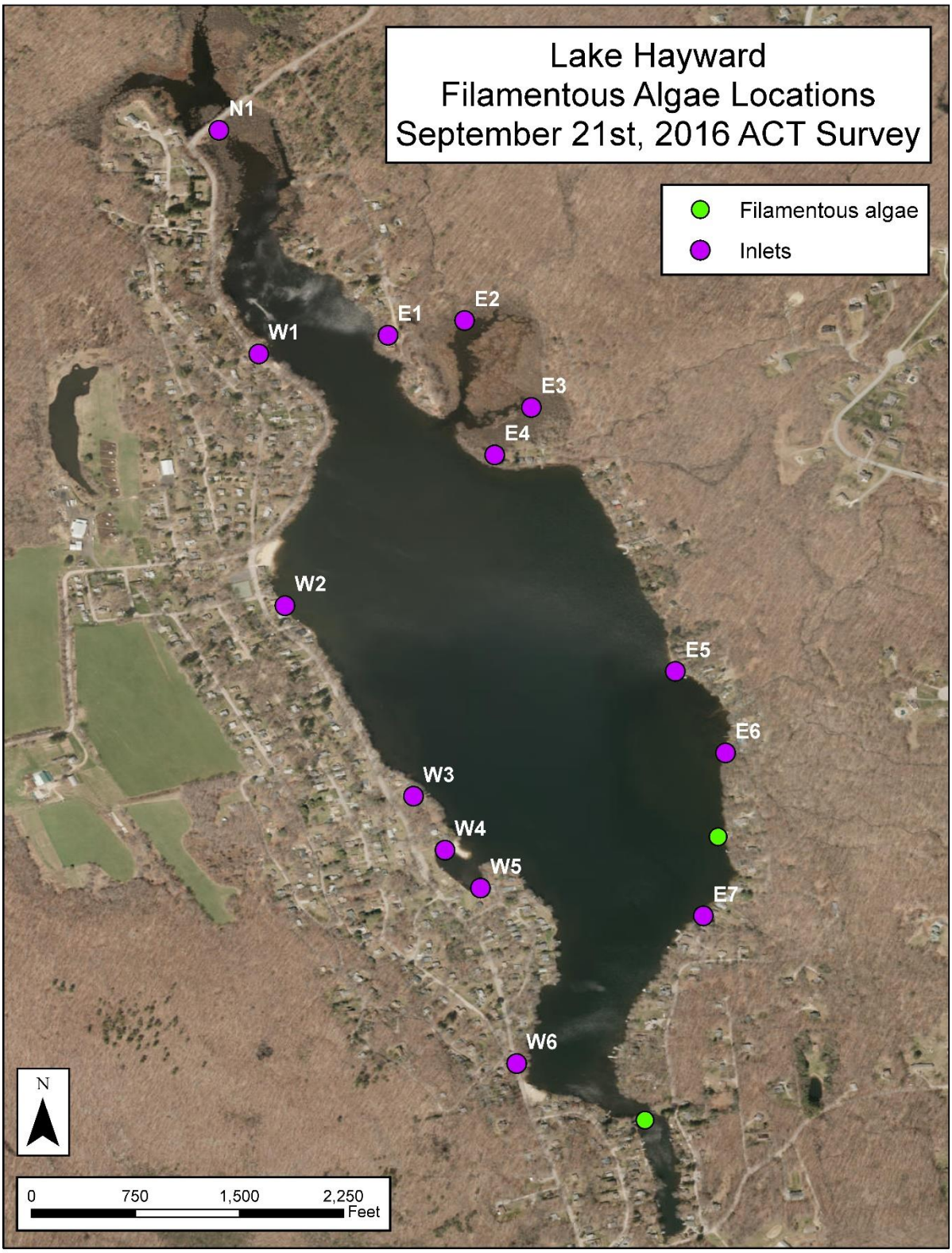
Inlet Sampling

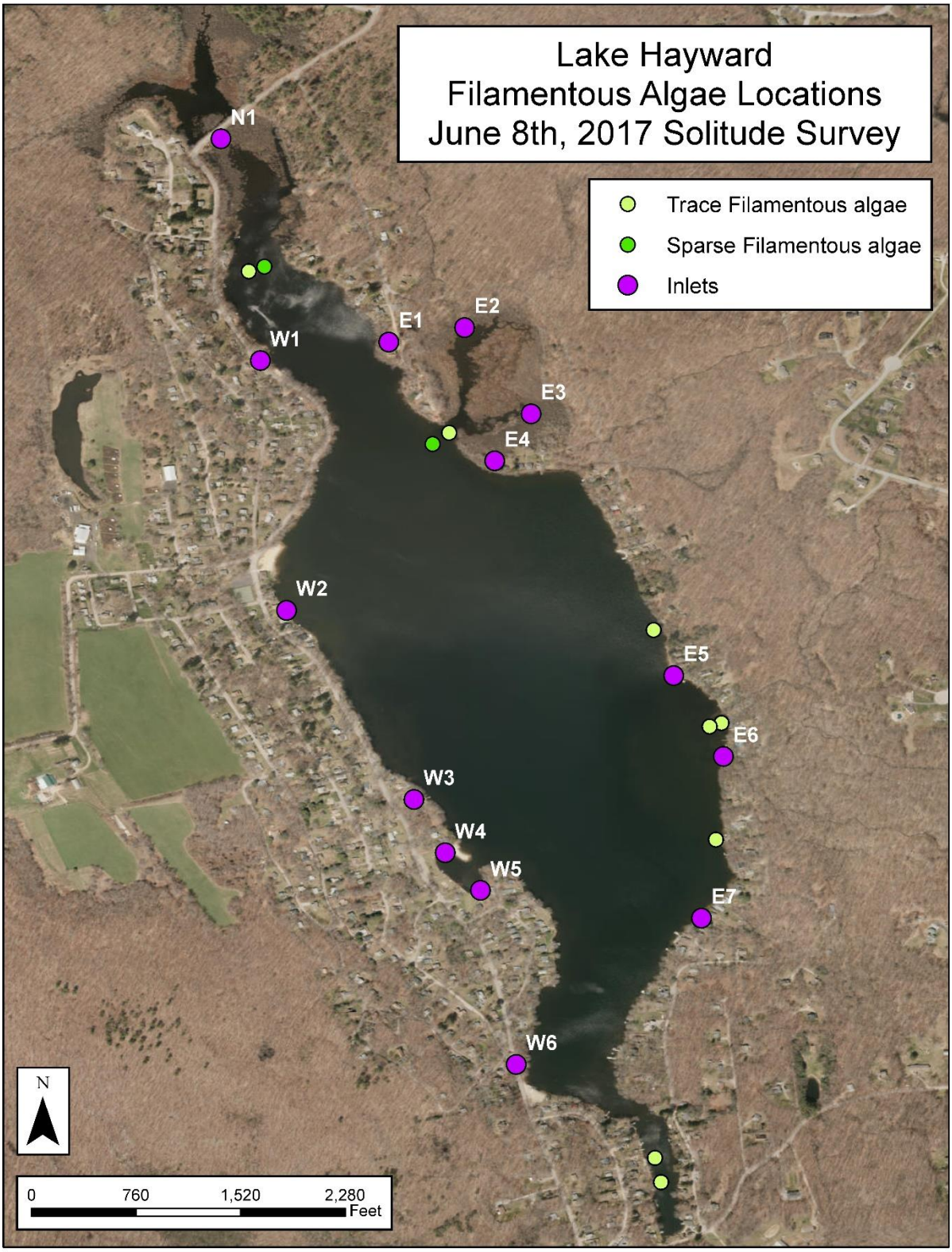
1. For each inlet that you will be sampling, label a bottle with the date, the name of the lake, and the name of the inlet.
2. Open the bottle, making sure to not touch the inside of the bottle or the bottle cap. Place the bottle in the inlet with the opening facing upstream so that water will flow into the bottle. Do not step in or put your hand in the inlet upstream of where you are taking the sample, as this could contaminate the sample.
3. Close the bottle and place in the cooler.

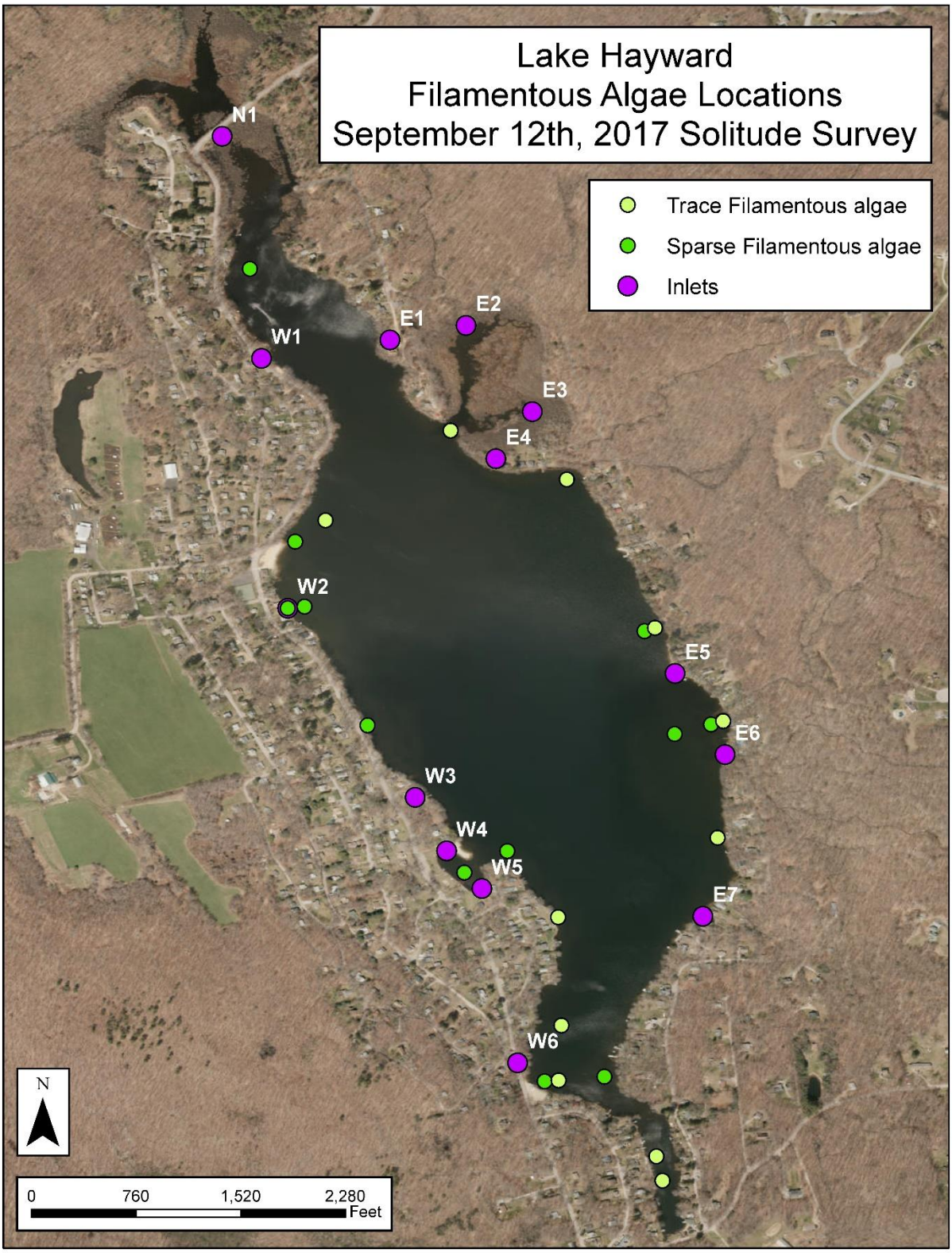
Appendix B

Filamentous Algae Maps




Lake Hayward
Filamentous Algae Locations
September 21st, 2016 ACT Survey
Filamentous algae
Inlets
N1
W1
E1
E2
E3
E4
W2
E5
E6
W3
W4
W5
E7
W6
N
0
750
1,500
2,250
Feet


Lake Hayward
Filamentous Algae Locations
June 8th, 2017 Solitude Survey
Trace Filamentous algae
Sparse Filamentous algae
Inlets
N1
W1
E1
E2
E3
E4
W2
E5
E6
W3
W4
W5
E7
W6
N
0
760
1,520
2,280
Feet


Lake Hayward
Filamentous Algae Locations
September 12th, 2017 Solitude Survey
Trace Filamentous algae
Sparse Filamentous algae
Inlets
N1
W1
E1
E2
E3
E4
W2
E5
E6
W3
W4
W5
E7
W6
N
0
760
1,520
2,280
Feet