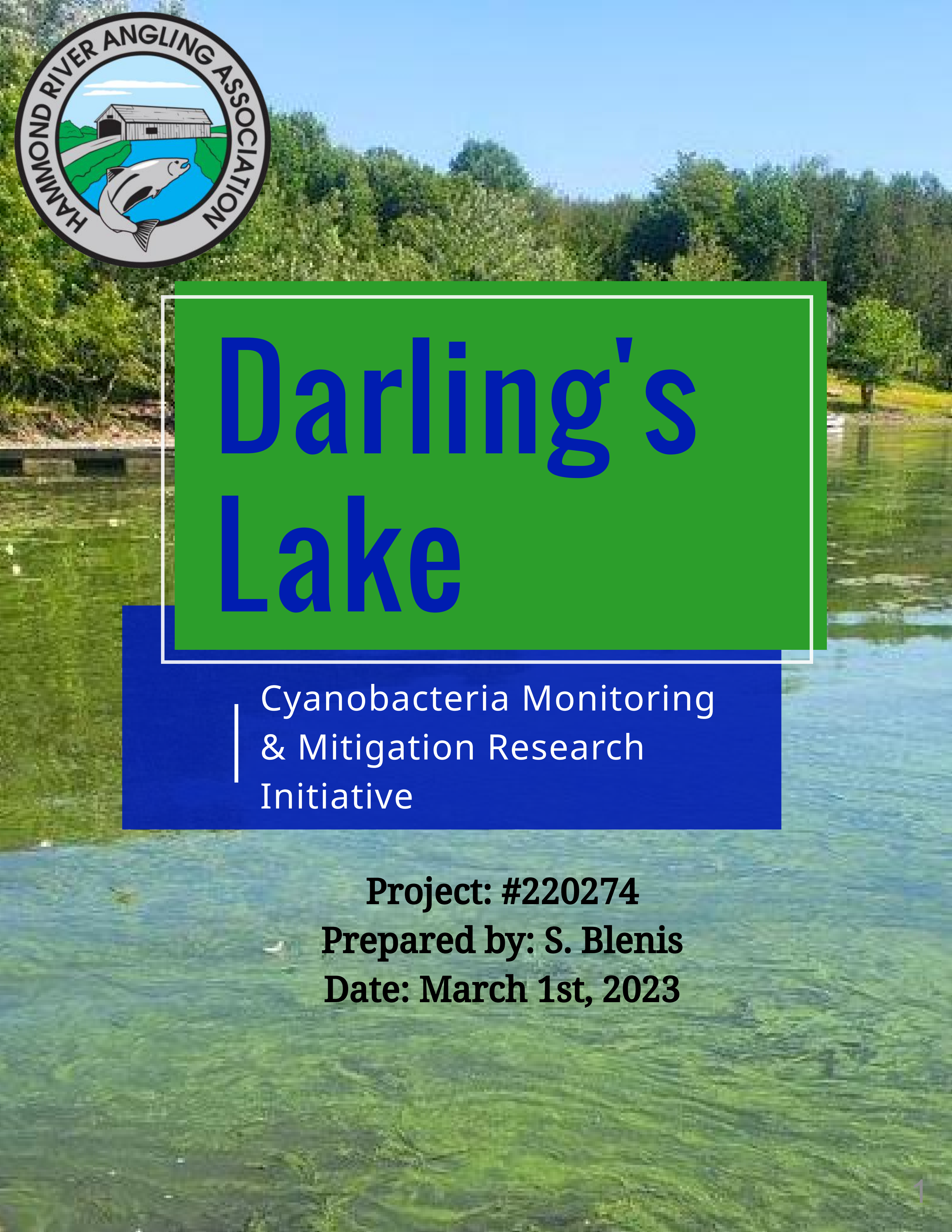


Darling's Lake

Cyanobacteria Monitoring & Mitigation Research Initiative

Project: #220274
Prepared by: S. Blenis
Date: March 1st, 2023

Executive Summary

Anywhere there is water, there is cyanobacteria; indeed, these tiny photosynthetic organisms live virtually everywhere on Earth and help create an oxygen-rich atmosphere, but it is when these organisms quickly and exponentially multiply in waterbodies that cause concern. This rapid, bloom-forming growth gives rise to potential Harmful Algal Blooms (HABs) that may contain cyanotoxins, and lead to negative environmental, social, and economic impacts.

With financial assistance from the New Brunswick Environmental Trust Fund (NBETF), the Hammond River Angling Association (HRAA) began keeping tabs on HABs.

In the summer of 2021, Darlings Lake was listed on the Government of New Brunswick (GNB)'s advisory list for a cyanobacteria bloom. Throughout HRAA's 46 years of environmental monitoring, this was the first time the organization encountered a cyanobacteria bloom within its watershed. As such, a robust monitoring plan was formulated for the summer of 2022.

Throughout 2022, HRAA worked closely with ACAP Saint John, local leaders in cyanobacteria monitoring; AquaRealTime and their team of experienced engineers to deploy two AlgaeTracker sensors; E.M. Fluids Inc, a Canadian company piloting the EMF1000 (a cyanobacteria mitigation device); GNB's skilled field team and outreach resources, and local landowners to gain as much data and insight into triggering mechanisms of cyanobacteria blooms as possible.

The bloom still occurred in Darlings Lake, despite our pilot mitigation attempt; however, we gained tremendous baseline data that will bolster our ability to take action in 2023.

-Sarah Blenis
HRAA Project Manager &
Educational Outreach Coordinator

TABLE OF CONTENTS

03 Acknowledgements

04 Introduction

06 Methods

07 Results

08 Project Deliverables

09 Other things?

11 Conclusion

12 Appendix

Acknowledgements

The HRAA acknowledges that we are on land that has never been ceded or surrendered as outlined in the Peace and Friendship Treaties. We acknowledge that this land is the Traditional Territory of the Mi'kmaq, the Wolastoqiyik and the Peskotomuhkatiyik. HRAA recognizes that more work needs to be done, on our end, to form relationships with Indigenous Communities, as they are the true knowledge keepers of this land, and we could learn so much from them. While offering a land acknowledgement is a good first step, we have so much more work to do to uphold the calls to action under the Truth and Reconciliation.

The HRAA would like to thank the NBETF for their ongoing generous financial support- without the NBETF, the vast majority of our work would not happen, and the state of our watershed would indubitably deteriorate.

ACAP Saint John and Roxanne Mackinnon- you are cyanobacteria knowledge holders, and we are so grateful for the assistance and guidance throughout project life.

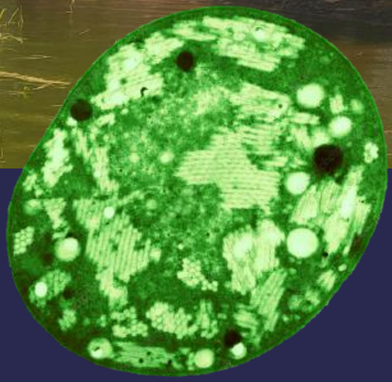
E.M. Fluids Inc., especially Dr. David Fung- thank you for allowing us to use the EMF1000 and thank you for your patience and guidance as we develop a monitoring and mitigation strategy best suited for Darlings Lake. Your support was tremendously appreciated.

AquaRealTime- hands down, the AlgaeTrackers are the way of the future for cyanobacteria monitoring. We thank you for the privilege to have been able to deploy two of these units in Darlings Lake, and we look forward to a long-term collaboration with your company.

Landowners of Darlings Lake- thank you all so much for being engaged in the project, and for providing us with access to the lake, and use of your docks, and offers of boats/canoes/kayaks. Without your support, this project would not have happened.

Introduction

What is Cyanobacteria



> "Cyanobacteria (blue-green algae) are a natural and essential part of our environment and water ecosystems, and can be found in many ponds, lakes, rivers, and wetlands in New Brunswick. Not all cyanobacteria are harmful, but some can produce toxins, which can impact the health of humans and animals- GNB"

Darlings Lake Monitoring and Cyanobacteria Mitigation Research Initiative includes a multifaceted approach to characterize the ecological system of Darlings Lake and increase our understanding of CyanoHABs dynamics within. The goal of this initiative is to identify triggering mechanisms of blooms, while investigating possible bloom remediation through deploying new technology into the lake.

This project promotes cyanobacteria awareness, including an educational unit, "Be in the Cyan-Know", designed for school-aged children, and an outreach initiative, "BloomWatch- Darlings Lake", a Facebook group for residents of Darlings Lake to document the lake's state. The results of this project may subsequently be adapted to assist in province-wide public education, monitoring and mitigation of CyanoHABs.

KEY MONITORING PARAMETERS

Based on recommendations from project partners, HRAA developed a robust set of monitoring parameters to assist in determining triggering mechanisms for cyanobacteria blooms. These parameters include precipitation, sunlight, water temperature, nutrient input, chlorophyll-a, phycocyanin, general water chemistry, as well as visual observations.

KEY WATER QUALITY DATA

Water quality data collected during this project aligns with the Canadian Council of Ministers of Environment (CCME) Guidelines for the Protection of Aquatic Life and Guidelines for Canadian Recreational Water Quality. Results were compared and ranked with the CCME's Water Quality Index calculator.

Key water quality data parameters include bacterial input, nitrogen and phosphorus, turbidity, dissolved oxygen, pH, alkalinity, total suspended solids, total dissolved solids, conductivity, salinity, true color, inorganics and trace metals.

All water quality samples collected are in accordance with GNB's water sampling protocols and were processed at the Saint John Laboratory Services, in-situ with a YSI multiprobe or the AlgaeTracker units.

Precipitation

Sunlight

Water Temperature

Nutrient Loading

Chlorophyll-a

Phycocyanin

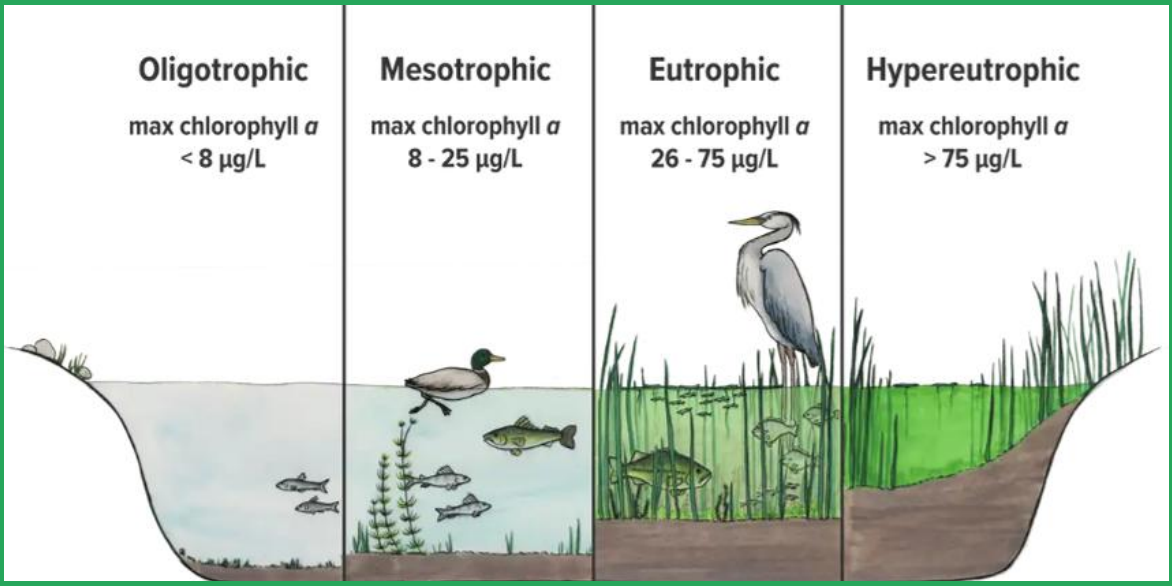
General Water Chemistry

Chlorophyll-A

Chlorophyll-A is a green pigment, present in all green plants and in cyanobacteria, responsible for the absorption of light to provide energy for photosynthesis. It absorbs light energy from wavelengths of violet-blue and orange-red light, and it reflects green/yellow light, thus resulting in the observed green color of most plants. Chlorophyll A is highly important for plants to carry photosynthesis, but Chlorophyll B is not an essential substance.

High levels often indicate poor water quality and low levels often suggest good conditions. However, elevated chlorophyll-A concentrations are not necessarily a bad thing. It is the long-term persistence of elevated levels that is a problem. Cyanobacteria are the only bacteria that contain chlorophyll A, and cyanobacteria does not contain chlorophyll-B.

Along with phosphorus, chlorophyll is often used to estimate productivity in a water body. Productivity refers to the amount of plant and animal life that a lake or river can support. Low productivity lakes are called oligotrophic, while high productivity lakes are called eutrophic.

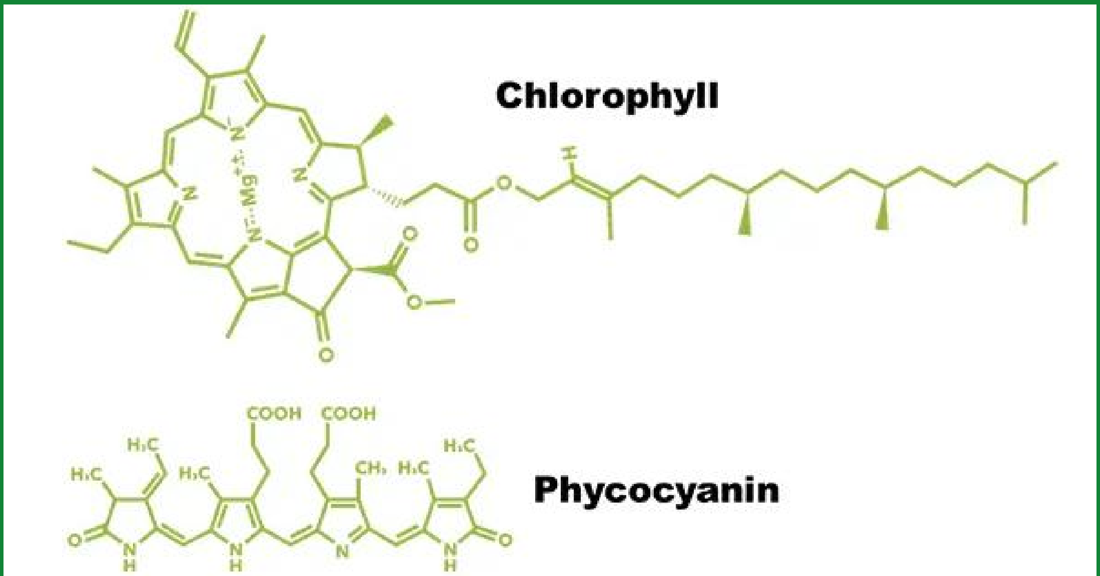


Chlorophyll is influenced by water temperature, phosphorus, at times nitrogen. Chlorophyll influences dissolved oxygen, organic carbon, and severity of cyanobacteria blooms. chlorophyll-a concentration is often used as a surrogate indicator for the growth of cyanobacterial harmful algal blooms. Additionally, chlorophyll-A has been shown to be positively associated with microcystins, (one of the cyanotoxins that we tested for as part of this project); however, phycocyanin is more closely linked to microcystin production than chlorophyll-A, given that all algae contain chlorophyll-A, For this project, we measured chlorophyll-A concentrations in-situ with the use of two AlgaeTracker units in Darling's Lake.

Phycocyanin

Phycocyanin is a pigment-protein complex that biologically functions cooperatively with chlorophyll in photosynthesis. Phycocyanin is the responsible component of the blue pigment of the blue-green color of cyanobacteria blooms ("blue-green" is phycocyanin + chlorophyll-A). Phycocyanin is a pigment, like chlorophyll, that capture light but stretching to the wider wavelength, thus allowing the plant to utilize more light for photosynthesis. It assists the function of chlorophyll especially during low light conditions. Unlike chlorophyll-A, phycocyanin is only found in freshwater blue-green algae, where chlorophyll-a is found in all of plant life.

Chlorophyll-a concentration is mostly used as an indicator of cyanobacteria biomass; however, chlorophyll-a can be found in all eukaryotic algae and aquatic vegetation. Phycocyanin, on the other hand, is a pigment found only in cyanobacteria; thus, it is used to describe the presence and abundance of cyanobacteria in water bodies. The optimal working pH range for phycocyanin is between 5.5 and 6.0 and it remains stable up to 45 °C.



The World Health Organization has formulated the evaluation criteria for cyanobacterial risk levels in lakes and reservoirs based on the cyanobacteria density in water. Phycocyanin concentrations of < 30, 30–90, and 90–303.9 μg/L are determined as levels I, II, and III risk factor for cyanobacterial blooms, respectively. Phycocyanin levels can be positively correlated to turbidity levels, and both should be quantified when developing early alert systems for cyanobacteria monitoring. This positive correlation will be discussed further in the results chapter. We collected in-situ phycocyanin data through the deployment of two AlgaeTracker units in Darling's Lake.

Other Cyanobacteria Triggering Mechanisms

Phosphorus & Nitrogen

Nitrogen and phosphorus are essential macronutrients needed to promote algal growth and they regulate metabolic activities if supplied in an acceptable form. Nitrogen additions can increase biomass and toxin production in Microcystis blooms. Generally, cyanobacteria grow until the availability of nitrogen (N), phosphorus (P) or both nutrients become limited. Phosphorus (P) is an important nutrient central to storing and the exchange of energy and information in the cell. At the same time, the availability of P in many habitats dwelled by cyanobacteria is scarce and/or fluctuating. Cyanobacteria developed a broad array of acclimations to cope with phosphorus shortages.

Bacterial Coliforms

Fecal coliform, including E. coli, are found in the intestinal tracts of warm-blooded animals, including humans and livestock. E. coli is the dominant bacteria of the fecal coliform group. Cyanobacteria blooms can be triggered by fertilizer and manure that run off of farm fields. In some areas, septic tanks and wastewater are the source of fecal coliforms in surface water. But in farm country, often the main source of such bacteria is the use of manure from livestock feedlots – known as animal feeding operations, or AFOs . Cyanobacteria can act as a barrier between radiation and bacterial organisms, allowing bacteria populations to grow unheeded.

Weather

Cyanobacteria derive energy through photosynthesis—hence the need for sunlight. Cyanobacteria microbes survive by converting sunlight into energy- when the sun sets, they take a break and rely on their energy reserves for fuel; however, some species of cyanobacteria can survive in very low light conditions. The amount of sunlight has a positive correlation on water temperatures. Growth of freshwater cyanobacteria is generally favored at higher temperatures, with well-defined thermal optima for growth at temperatures ranging between 20 and 30 °C. Changes to precipitation frequency and intensity, as predicted by current climate models, are likely to affect bloom development and composition through changes in nutrient fluxes and water column mixing. Heavy rainfall increases nutrient bioavailability, increases water column mixing, and weakens vertical stratification, all of which can trigger blooms.

KEY MONITORING DEVICES

Classic staples of water quality monitoring projects, the YSI Multiprobe collects in-situ data on pH, salinity, turbidity, TDS, dissolved oxygen, and conductivity. The HOBO Pendant logs water temperature and light in real time.

Eurofins Abraxis ELISA Assay kits are used in-house to determine presence/absence of microcystin and anatoxin-a, two common types of cyanotoxins.

AlgaeTrackers are a new technology that collect continuous data on temperature, chlorophyll-a, phycocyanin, turbidity, and light penetration and have programmable, shareable dashboards to connect with all your project partners, and allow you to set alerts when levels are reaching threshold for algal blooms.

The EMF1000 is a self-contained, solar-powered, cleantech solution that uses proprietary non-irradiating signals to stimulate the water. The device increases the gas exchange rate at the air-water boundary and in turn increases dissolved oxygen (DO) in the water column. This promotes aerobic conditions and concurrently suppresses anaerobic conditions.

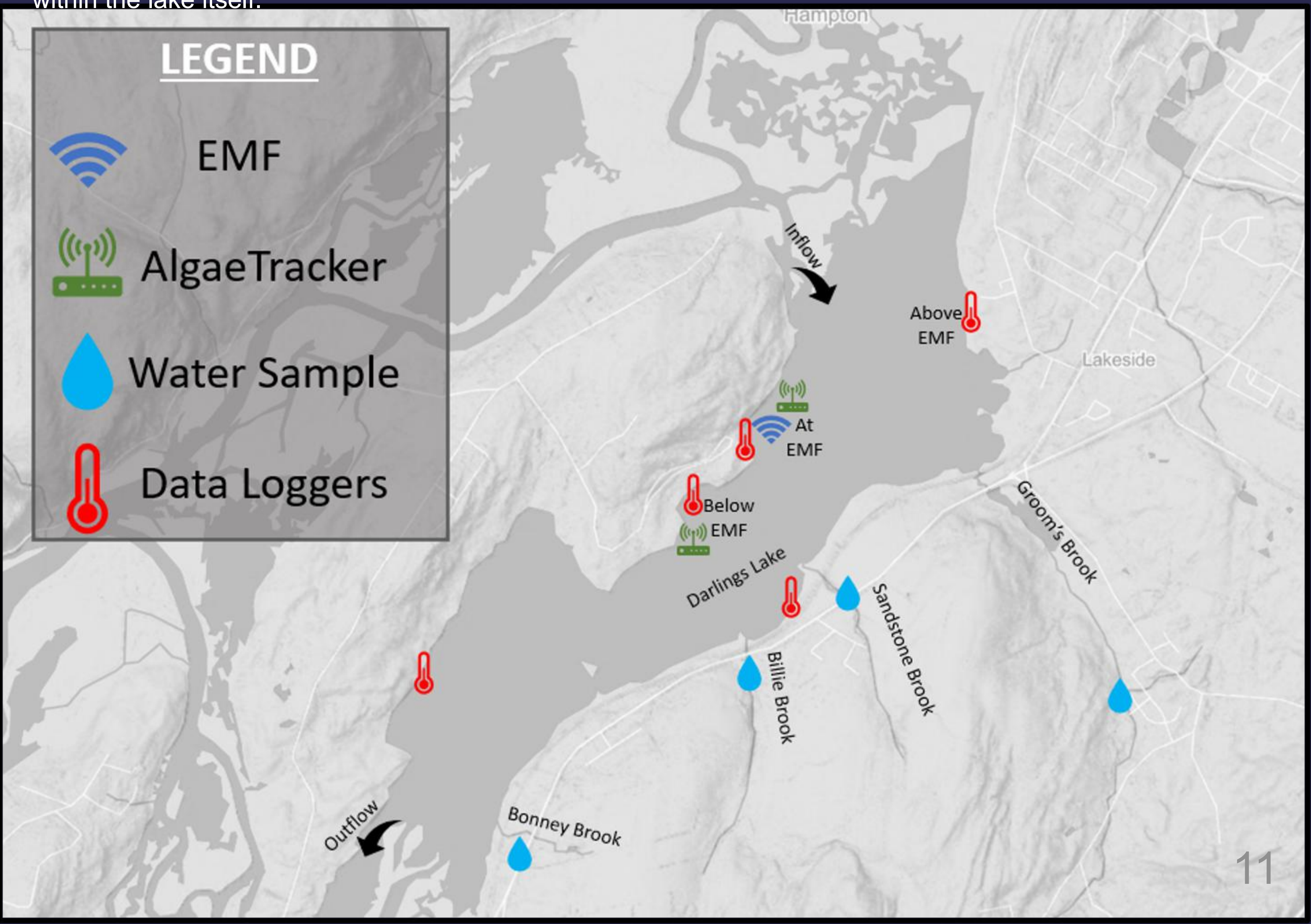
METHODS

Upon project approval, the HRAA applied for a Provisional WAWA permit for the installation of 5 HOBO data loggers, as well as landowner permission to secure HOBO data loggers on private docks. Loggers were installed at a depth of 0.5m and were installed in July and collected in October.

HRAA also secured a permit under the Canadian Navigable Waters Act for a permit for designated scientific equipment to launch two AlgaeTrackers and one EMF1000 into Darlings Lake. Buoys 15cm wide and 30cm high with reflective cautionary material and HRAA identification tags were attached to all three devices and were placed into the lake with 20lb anchors. An AlgaeTracker was stationed with the EMF1000, and one was stationed below the EMF1000. The AlgaeTracker units are self-cleaning and the landowner of the area with the EMF1000 performed bi-weekly cleaning of the device. The devices were deployed in July and collected in September.

Water quality samples were collected at each of the three lake devices once per month. Water quality samples were also collected monthly in four tributaries that feed into Darlings Lake, with additional samples collected after heavy rainfall events.

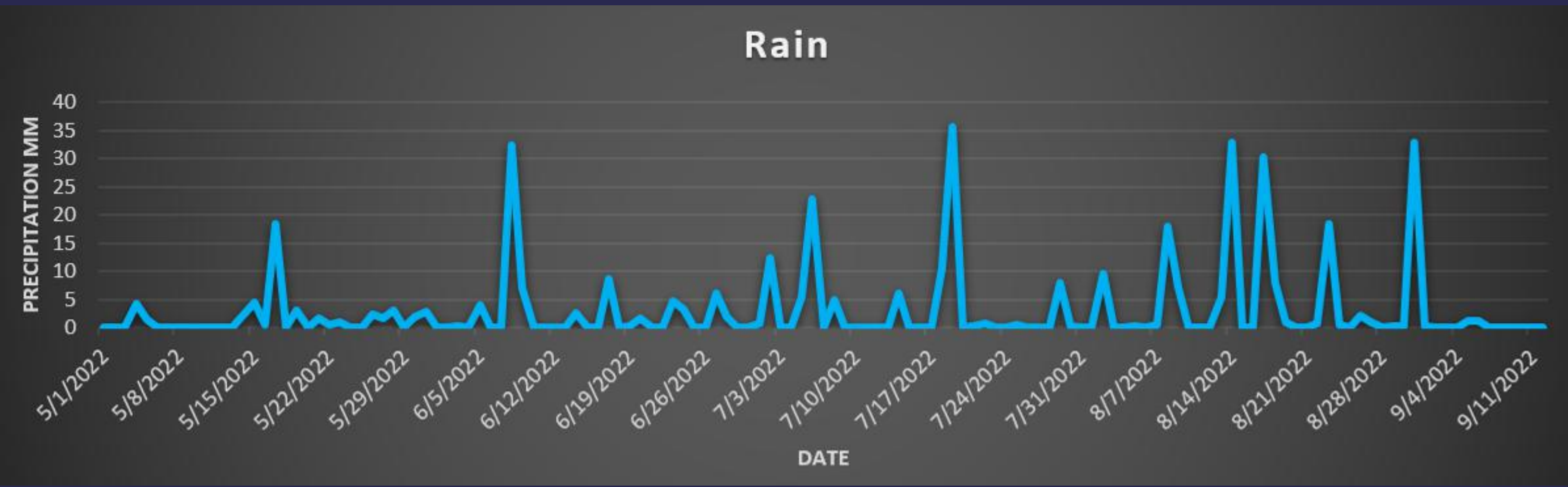
Boat surveys were completed to determine high-risk areas within the lake (i.e.: public access boat launch, public beach, swimming hotspots). Results of boat surveys indicate that the vast majority of the lake is surrounded by private access only- there are no major public access beach areas or public boat launches within the lake itself.



RESULTS

The Canadian Water Quality Index (CWQI) is an instrument used to communicate information to the public and authorities about water quality and its changes over time. To analyze our lake water quality data, we used the CWQI calculator. To summarize its capacity, data taken from the field and laboratory results are uploaded into the CWQI calculator and tested against exceedance limits specific to each parameter under a weighted evaluation scale and given a classification ranking.

Site	WQI Score	WQI Category
At EMF	68.5	Fair
Below EMF	55.5	Marginal
Groom's Brook (lower)	42.9	Poor
Bonney Brook	42.3	Poor
Billie Brook	40.6	Poor
Groom's Brook (upper)	40.5	Poor
Sandstone Brook	40.1	Poor
Above EMF	39.5	Poor



Key Heavy Rain Dates

July
5th-6th
28.2mm

July
18th-19th
45.9mm

August
8th-9th
25.3mm

August
13th-14th
38.3mm

August
17th-18th
38.2mm

August
22nd-23rd
19.5mm

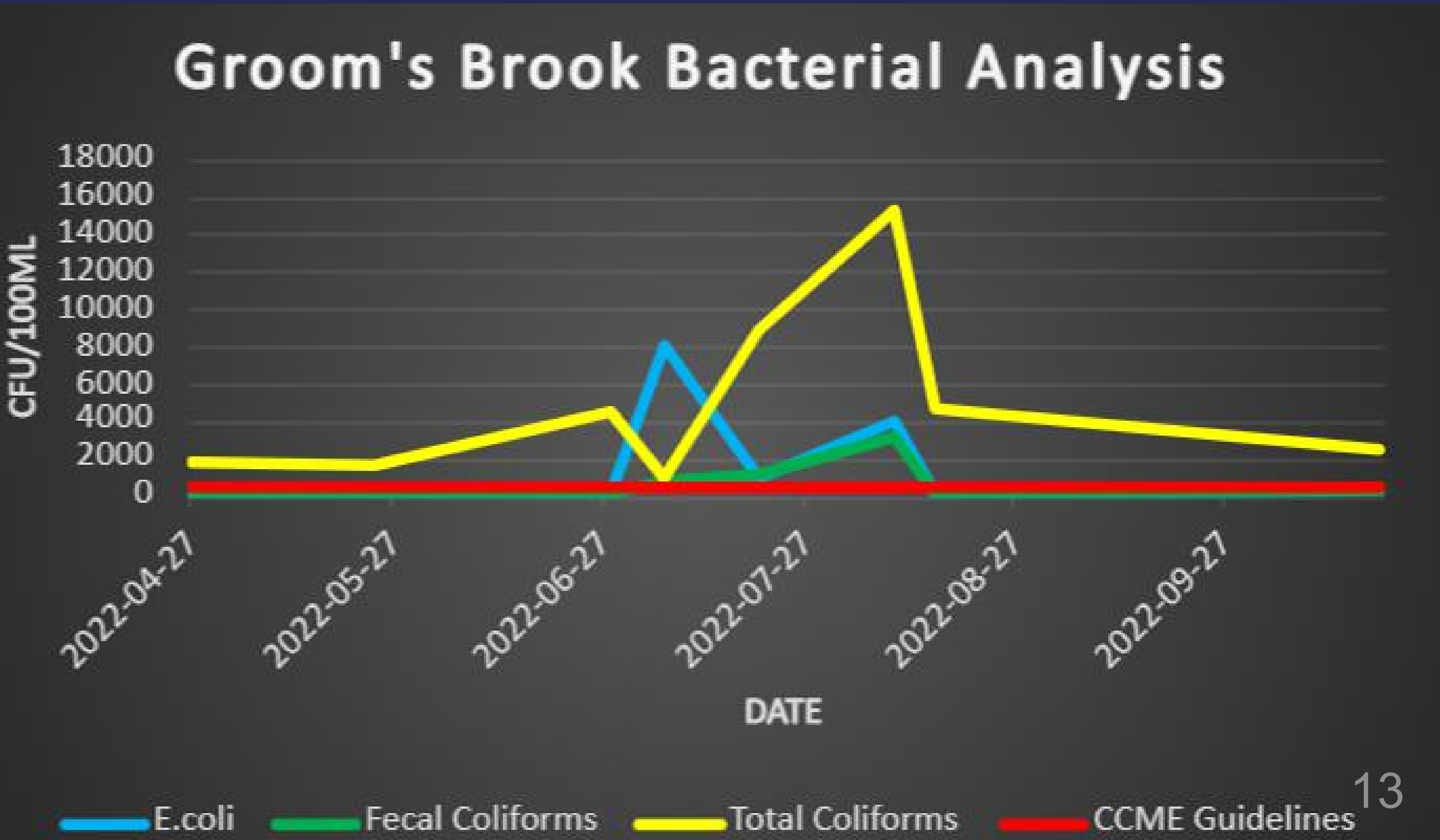
August
30th-31st
33.2mm

Tributary Results: Groom's Brook

There are four main tributaries that feed Darling's Lake, all of which pass through (or are adjacent to) agricultural fields that are treated with liquid manure. Farming activities occur along the southeast border of the lake on a fairly steep slope; additionally, there are several smaller drainage ditches running through these fields and directly into the lake.

Groom's brook feeds into a large wetland complex before entering the lake- financial constraints did not allow for additional water sampling within the wetland; however, it is recommended that HRAA include this area in the 2023 sampling program, as well as upper portions of Groom's Brook to assist in determining the complete source of the nutrient loading.

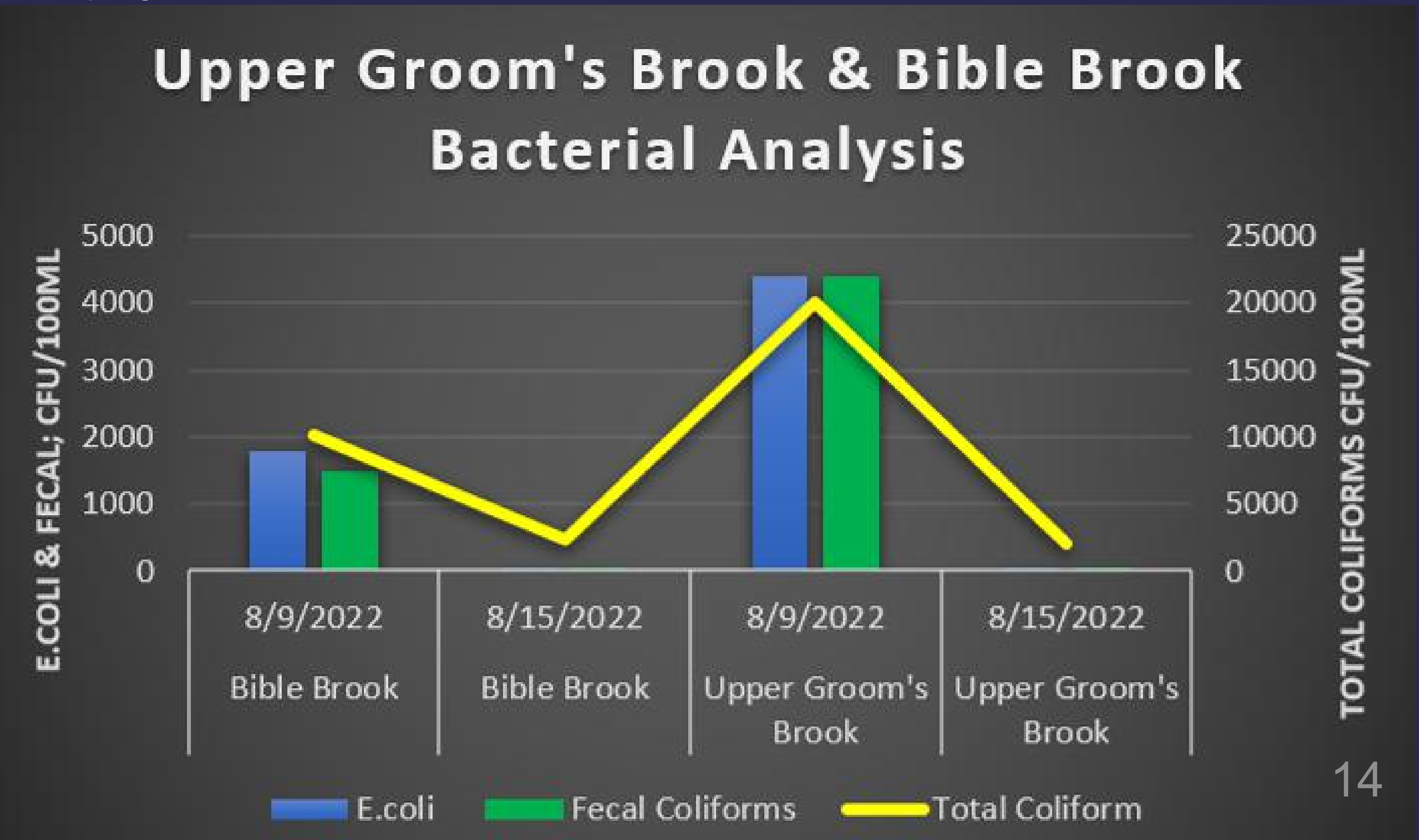
A major spike of E. coli occurred early July, reaching 7,960 CFU/100mL, exceeding CCME guidelines by 180%. In total, 8 bacterial samples were collected from Groom's Brook between April and October. In total, five samples were within guideline limits; however, three samples were well above guidelines.



Tributary Results: Groom's Brook

In addition to being adjacent to liquid manure application, Groom's Brook runs through the Bonney Subdivision, and many residents within the subdivision connect to the Town of Hampton's wastewater treatment facility. As seen in the photo above, there is a lift station that is less than 100m away from Groom's Brook. The HRAA Project Manager spoke with the Town of Hampton's wastewater treatment facility manager to determine if the lift station was overflowing, or if a blockage was occurring- this was not the case.

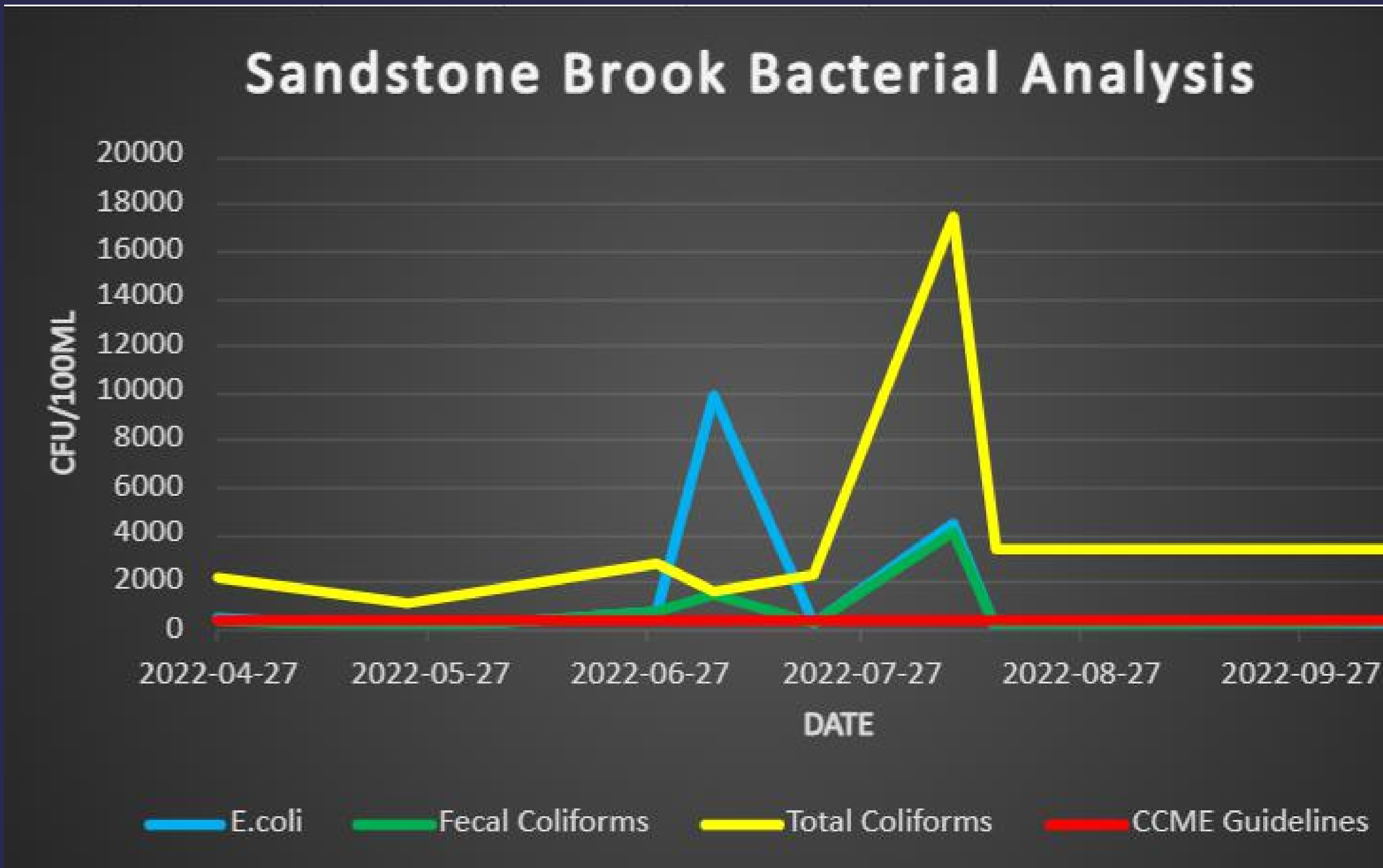
In an attempt to isolate the source of nutrient loading, HRAA field staff collected additional samples from Upper Groom's Brook, and from Bible Brook. Bible Brook is a small tributary whose headwaters is a pond on the Hampton Bible Camp Property, adjacent to their horse barn. Upper Groom's Brook and Bible Brook were not included in the original project proposal, and funding was limited to collect any further samples. It is recommended to include both brooks in the 2023 sampling season.



Tributary Results: Sandstone Brook

Sandstone Brook produced the second highest E. coli throughout the entire water sampling survey, with a peak input of 9,990 CFU/100mL in July, well above CCME guidelines. Liquid manure spreading is occurring along both the right and left bank of the brook, with <30m riparian buffer. Additionally, the left bank is completely embedded with trash- metal, bottles, and cans. From visual observations, this garbage was probably dumped in this area decades ago, and removal will be challenging, as removing the debris could cause significant erosion into the brook. It is recommended to expand the sampling parameters to include leachate, BTEX, and hydrocarbons to determine the magnitude of impact.

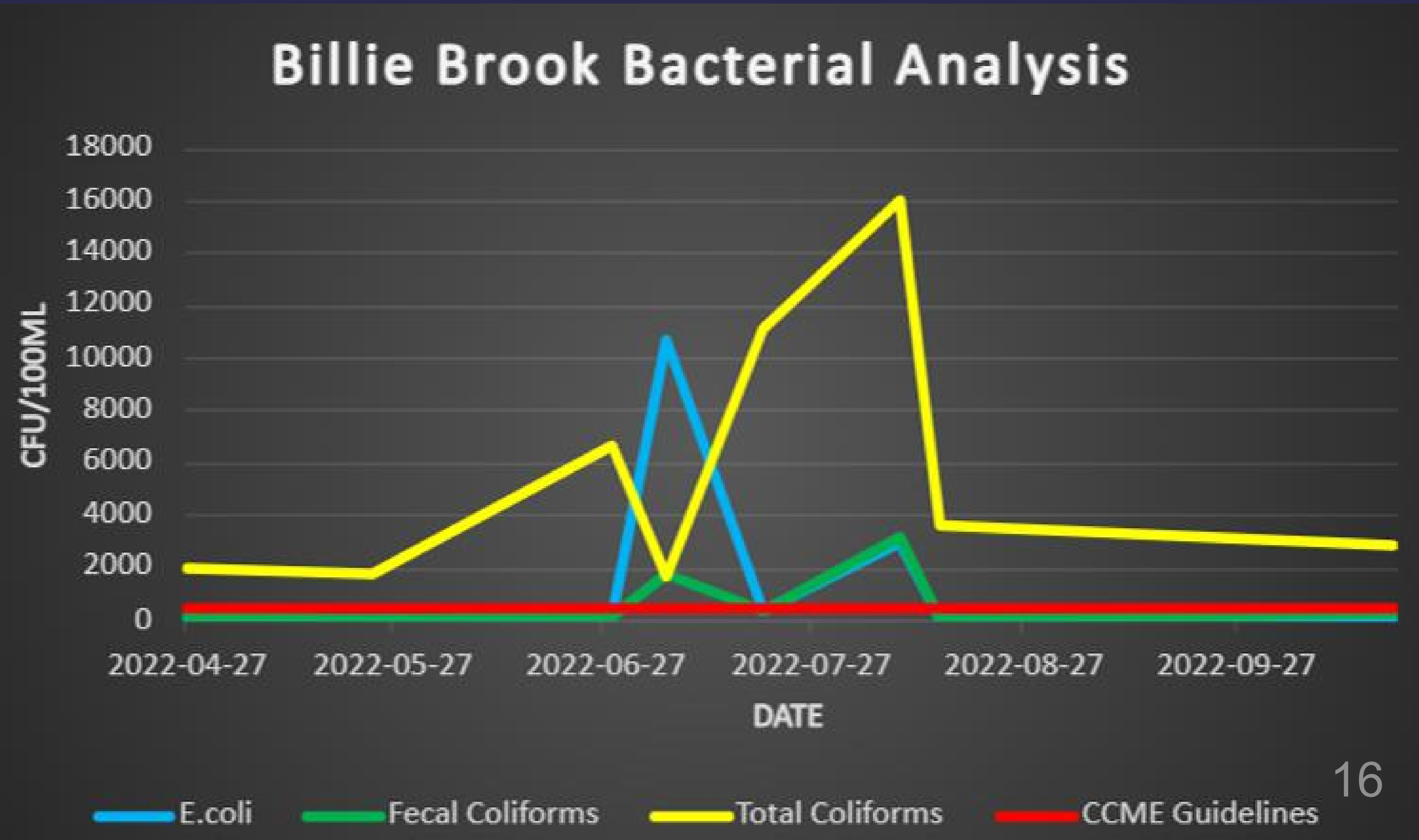
Sandstone Brook runs perpendicular to Route 100, and the current culvert does not allow fish passage to the upper stretch of Sandstone Brook. A fish habitat survey has not been completed in the upper portion, although the brook's water temperature average was 14 degrees Celsius, with dissolved oxygen readings well over 10mg/L, and may support aquatic life; albeit the nutrient loading may impact fish's ability to thrive.



Tributary Results: Billie Brook

Billie Brook produced the highest E. coli throughout the entire water sampling survey, with a peak input of 10,640 CFU/100mL in July. Both Billie Brook and Sandstone Brook are flowing into Darlings Lake in the middle portion of the lake- given the tidal influence of the lake, these bacterial exceedances are being spread over a larger area of the lake and increasing bloom severity.

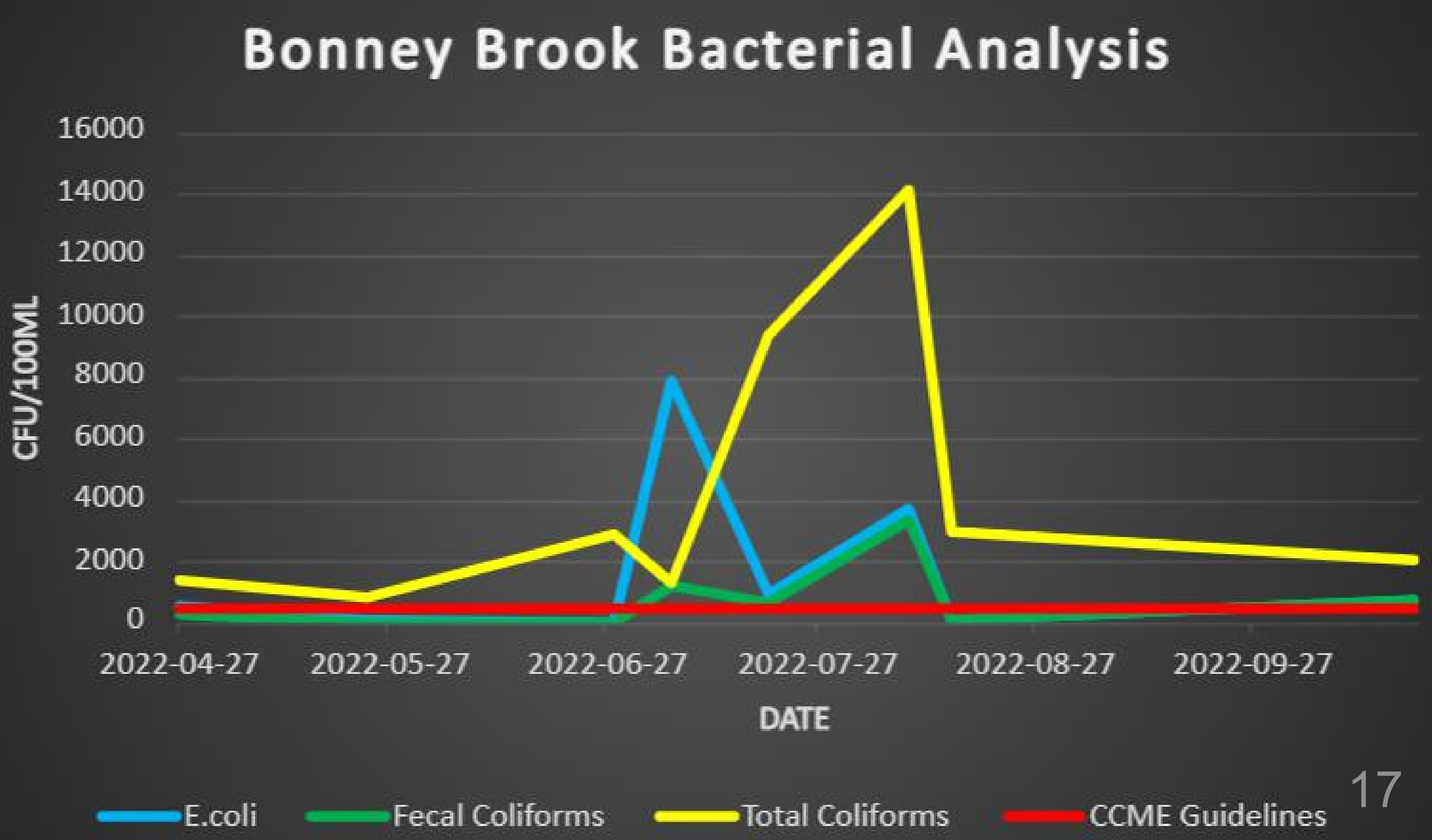
Another nutrient that may be playing a critical role in cyanobacteria bloom formation is iron, in which all four tributaries are contributing high levels of iron into the lake. Cyanobacteria have higher iron requirements, and there is therefore a tight linkage between iron and phosphorus cycling, which may explain seasonal blooms and their development even in oligotrophic and mesotrophic lakes.



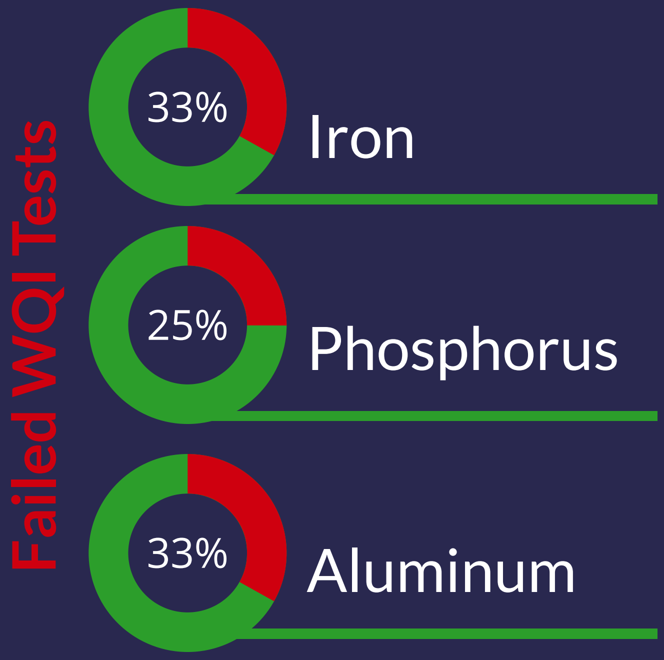
Tributary Results: Bonney Brook

Out of the four tributaries sampled throughout 2022, Bonney Brook had the lowest input of bacterial loading; however, it was still above acceptable limits. Similar to the other three tributaries, Bonney Brook contains higher levels of aluminum, which has lowered the brook's water quality index score.

Aluminum can enter the water via natural processes, like weathering of rocks. Aluminum is also released to water by mining, industrial processes using aluminum, and wastewater treated with alum, an aluminum compound; however, it is anticipated that the aluminum in these brooks is naturally occurring. Among freshwater aquatic plants, single-celled plants are generally the most sensitive to aluminum, including cyanobacteria. The acceptable levels of aluminum for the protection of aquatic fish health are 0.005 ug/L if pH is 6.5; therefore, adding additional aluminum-based algaecides is not recommended. In 2023, it is recommended to perform fish community composition surveys through electrofishing and environmental DNA analysis in all four tributaries.



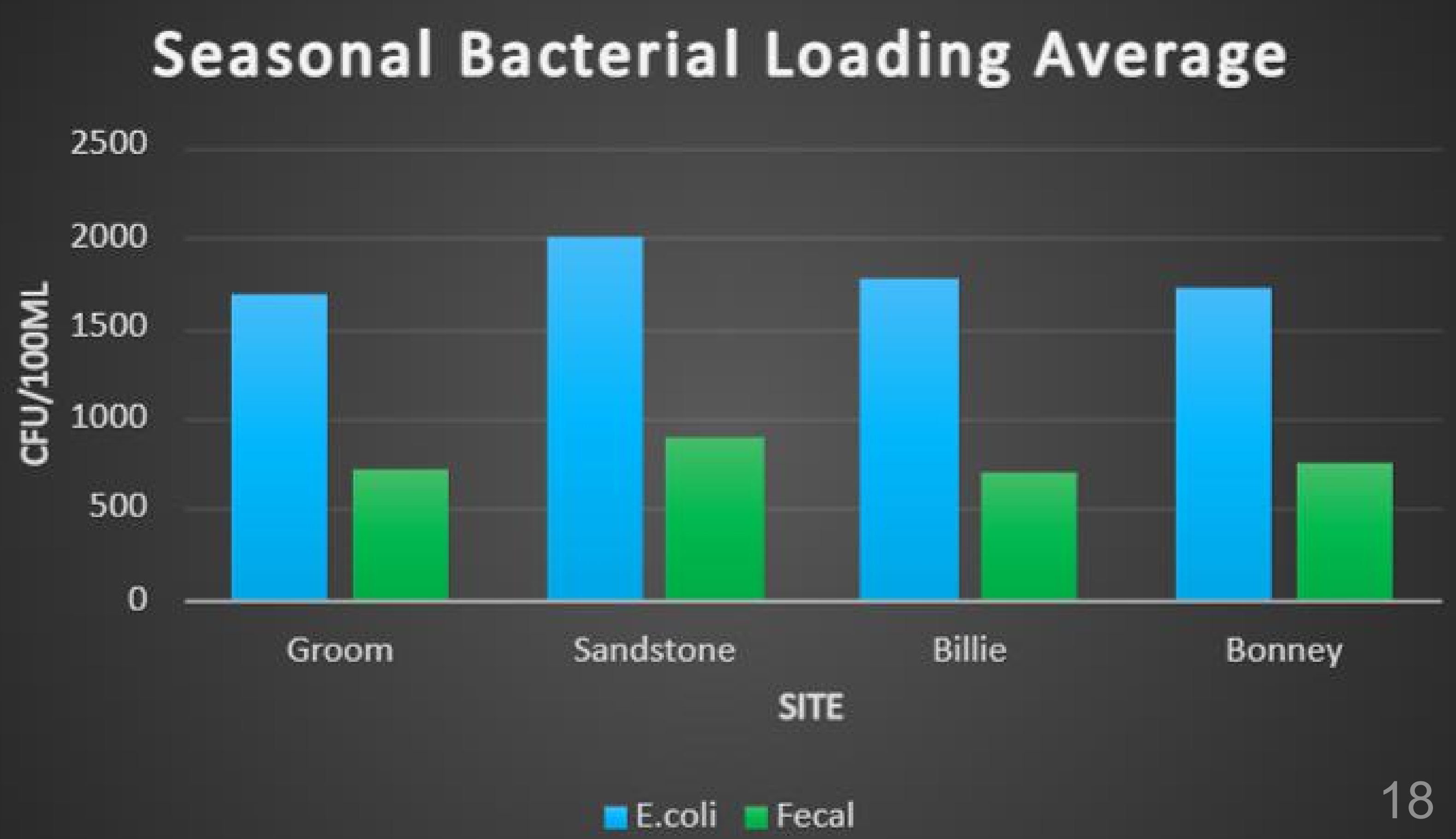
Darling's Lake Tributaries



Each of the four tributaries ranked as "Poor" on the Water Quality Index- this is due to the results from iron, phosphorus, and aluminum.

Cyanobacterial blooms have an exceptionally large iron requirement for photosynthesis. In many aquatic ecosystems, the levels of dissolved iron are so low and some of the chemical species so unreactive that growth of cyanobacteria is impaired. High levels of iron from the tributaries may be exacerbating the cyanobacteria bloom growth rate.

Phosphorus is one of the most critical drivers behind cyanobacterial abundance and dominance. Even a small increase in phosphorus input can drastically increase cyanobacterial growth.



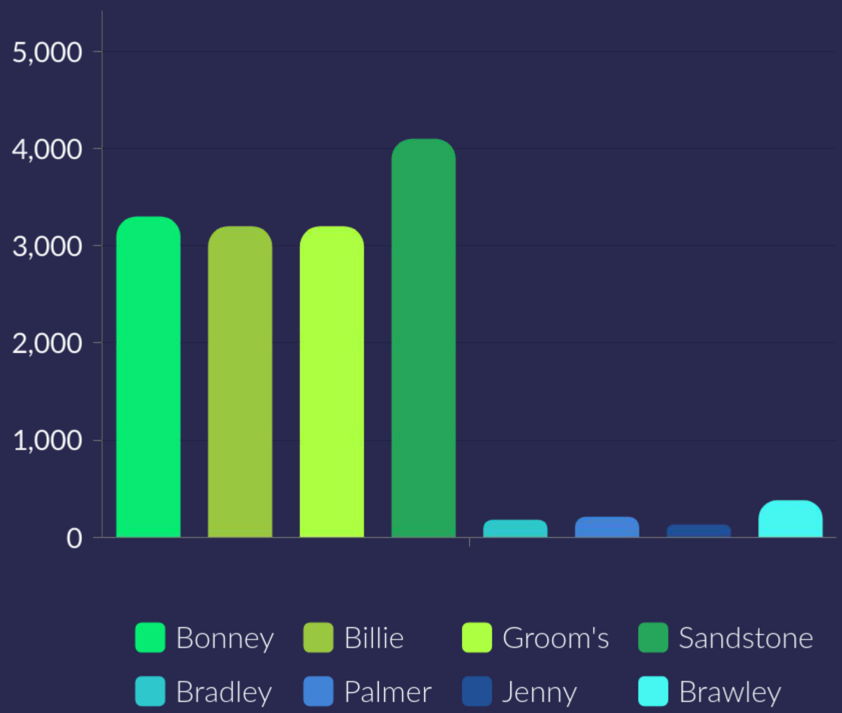
Darling's Lake Tributaries vs Other Hammond Tributaries

To gain perspective on these four tributaries, we have compared their peak fecal coliform levels and peak phosphorus levels to other tributaries throughout the watershed.

The HRAA maintains water quality on fifteen index sites- the top four contributors to each parameter have been included in this comparison.

It is interesting to note that each of these comparison sites are impacted by agriculture, albeit not to the same extent. The watershed is speckled with farming, but the survey area containing these four tributaries represents the largest agricultural undertaking within the watershed.

Peak Fecal Coliforms CFU/100mL



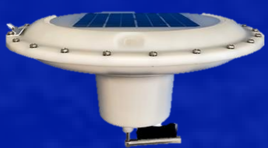
Peak Phosphorus mg/L

Despite HRAA maintaining one of the most historical water quality datasets within the province, this is only the second time water quality testing has been performed, with the last data entry occurring in 2011 as part of a stream crossing project.

Ergo, results of this current project will become an extremely valuable baseline dataset, particularly for predicting future cyanobacterial blooms in Darlings Lake.

Darlings Lake Devices

- The following are the sites in which monitoring was performed within the lake.

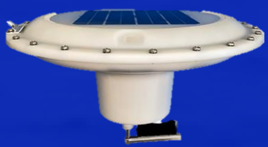


Below EMF

A HOBO light and temperature data logger attached to dock; AlgaeTracker deployed, cyanotoxin testing & water quality testing

At EMF

A HOBO light and temperature data logger attached to dock; EMF deployed, cyanotoxin testing & water quality testing



Above EMF

A HOBO light and temperature data logger attached to dock; AlgaeTracker deployed, cyanotoxin testing & water quality testing

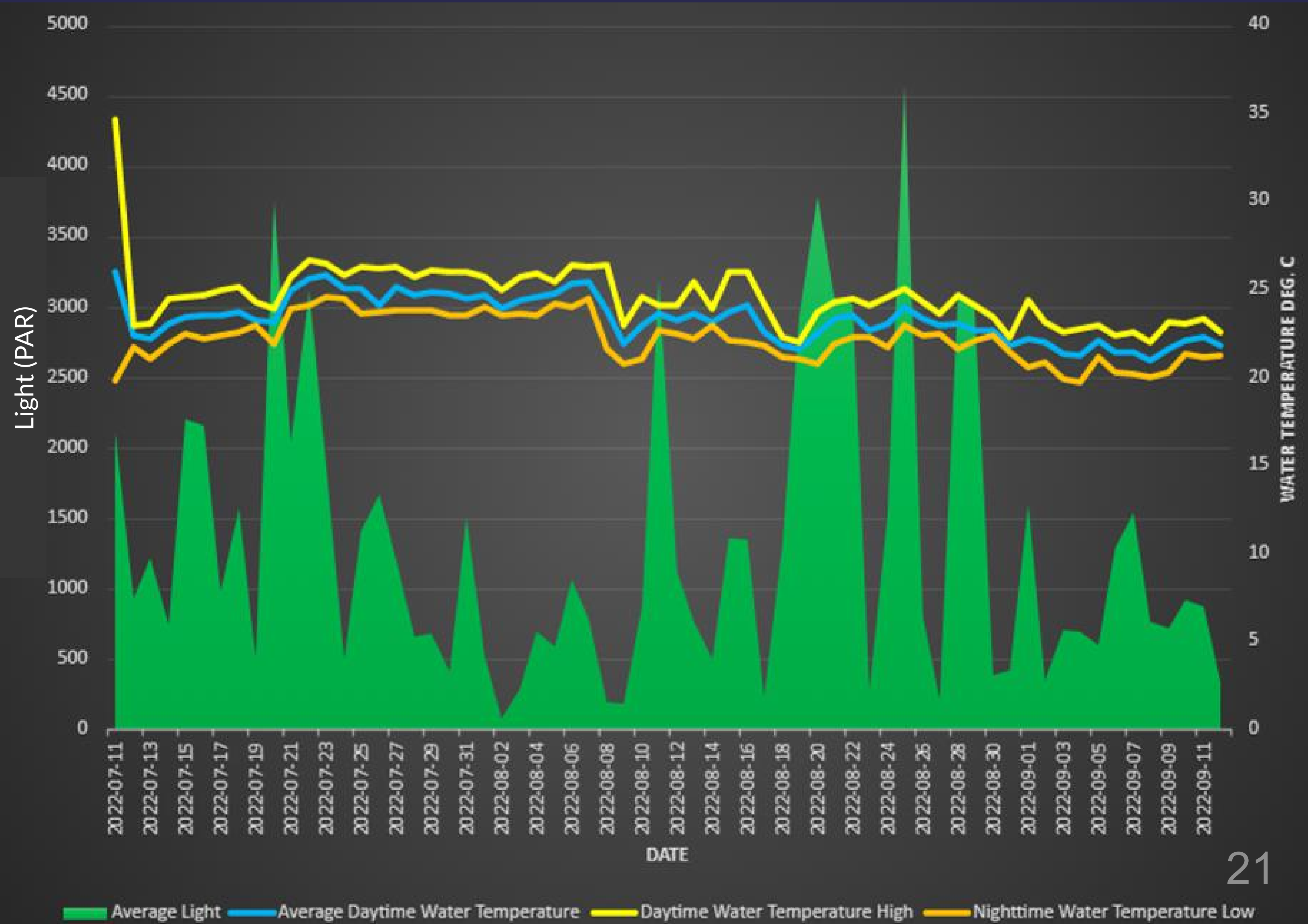
Across EMF

A HOBO light and temperature data logger attached to dock

Below EMF
Light & Temperature

Cyanobacteria are bacteria that share features of both bacteria and algae. They are similar to algae in size, possess blue-green pigmentation and are capable of photosynthesis; thus, they are often termed blue-green algae (WHO, 2003a). Most planktonic cyanobacteria, including the species found in Canadian lakes, form colonies, which can appear as irregular groupings of cells or as filamentous chains that can be straight, coiled or branched (Chorus and Bartram, 1999; Falconer, 2005). In a typical summer, a lake water sample can contain several species of cyanobacteria, along with numerous other species of algae. Cyanobacterial cells contain small gas bubbles called vacuoles, which allow them to control their buoyancy. The cells use this buoyancy control to move up in the water column to where light is the greatest and down in the water column to where nutrients are more abundant (Falconer, 2005).

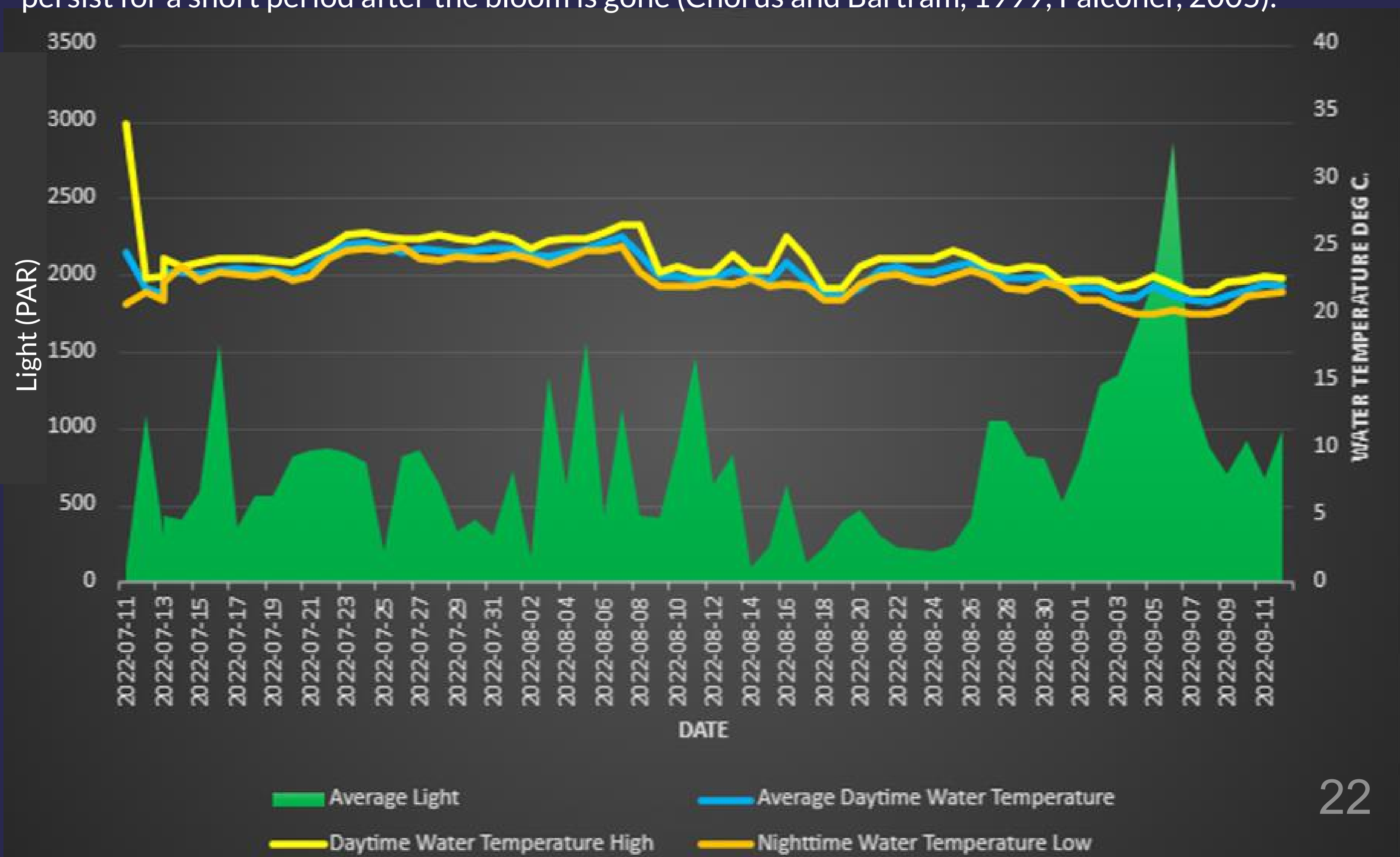
Cyanobacteria possess a number of special properties that determine their relative importance in phytoplankton communities. Cyanobacteria have lower light intensity requirements and demonstrate a greater affinity for nitrogen and phosphorus than do other algae and phytoplankton and, thus, can outcompete these organisms under conditions where these factors might be limiting (e.g., in turbid waters).



At EMF
Light & Temperature

Over 46 species of cyanobacteria are capable of producing toxins. There are several known cyanobacterial toxins that can pose concerns for recreational water users. These include microcystins, nodularins, anatoxins, cylindrospermopsin, dermatotoxins and irritant toxins. The focus on this project and cyanotoxin testing is on microcystins and anatoxin-a. Microcystins are hepatotoxins that disrupt the functioning of enzymes called protein phosphatases, and their primary target is the liver. Microcystins are the most frequently encountered cyanotoxins in cyanobacterial blooms in temperate surface waters in North America. The anatoxins (anatoxin-a, anatoxin-a(S), homoanatoxin-a) are neurotoxins that can be found in blooms produced by Anabaena (anatoxin-a, anatoxin-a(S)), Oscillatoria (anatoxin-a, homoanatoxin-a) and Aphanizomenon (anatoxin-a). Anatoxins interfere with the activity of the nerve transmitter acetylcholine, which affects the functioning of the nervous system by disrupting communication between neurons and muscle cells (Chorus and Bartram, 1999). Acute toxicity is characterized by paralysis of both the skeletal and respiratory muscles, resulting in tremors, convulsions and, ultimately, death due to respiratory failure (Rogers et al., 2005).

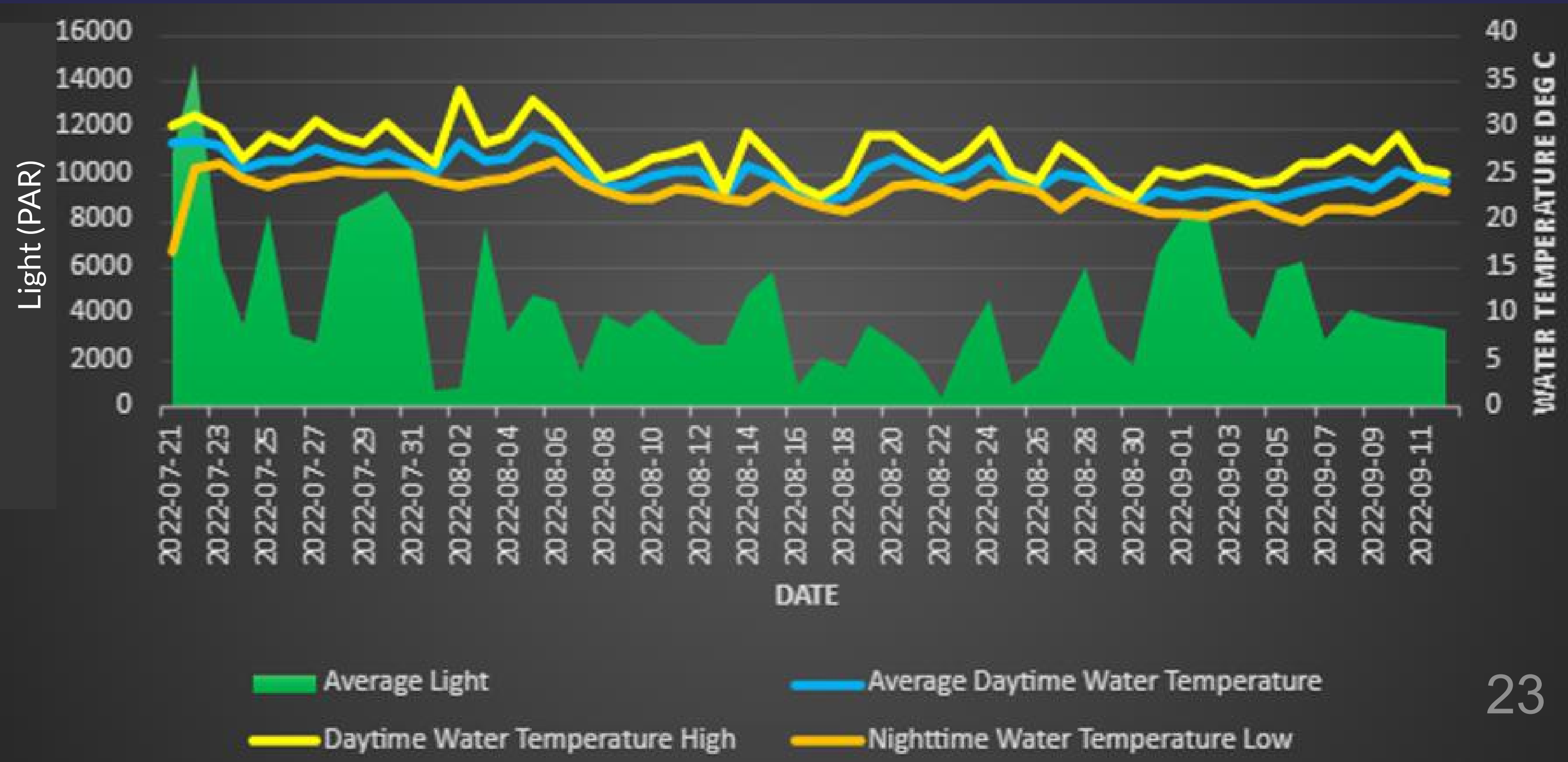
Although the conditions leading to the development of a bloom are relatively well known, the factors responsible for the dominance of toxin-producing strains are not completely understood. Consequently, toxin formation from cyanobacteria is even less predictable than the cyanobacterial blooms themselves. Lakes that have never had a problem can suddenly develop blooms that may contain toxins. Conversely, lakes that have shown toxic blooms in the past may never show it again. The bulk of the toxicity, if present, generally lasts as long as the bloom; however, some toxin may still persist for a short period after the bloom is gone (Chorus and Bartram, 1999; Falconer, 2005).



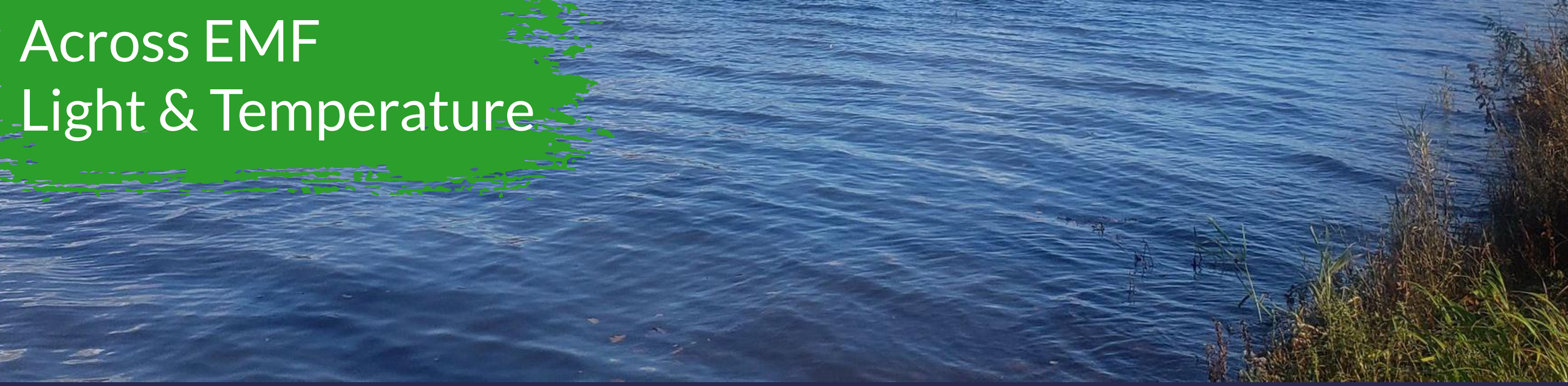
Above EMF
Light & Temperature

The occurrence of cyanobacterial blooms in recreational waters is extremely difficult to predict. Bloom development is influenced by a variety of physical, chemical and biological factors. As a result of the interplay of these factors, there may be large year-to-year fluctuations in the levels of cyanobacteria and their toxins (Health Canada, 2002). The use of algicides is not recommended as a measure to control cyanobacterial populations. The addition of copper sulphate or other algicides to mature toxic blooms may have the effect of destroying the cyanobacterial cells; however, this action may also cause the release of significant amounts of cyanotoxin into the surrounding waters if present within the cells. Jones and Orr (1994) reported that microcystin-LR could be detected up to 21 days after algicide treatment of a toxic Microcystis aeruginosa bloom that had developed in a recreational lake. Environmental concerns have also been cited as additional reasons for not pursuing this approach, as the algicides can be detrimental to the healthy functioning of the aquatic ecosystem.

The principal factors affecting the depth of light penetration in natural waters include suspended microscopic and macroscopic organisms, suspended mineral particles, stains that impart a color, detergent foams, dense mats of floating and suspended debris, or a combination of these factors. For primary contact recreation waters, it has been suggested that clarity be such that a Secchi disc is visible at a minimum depth of 1.2 m (Environment Canada, 1972). For the purpose of this project, all HOBO temperature and light data loggers were installed on docks at approximate depth of 1m. Even in low light conditions, or in turbid water, cyanobacteria have higher growth rates than other algae. Many cyanobacteria can also regulate their buoyancy, enabling them to move to more favorable positions higher in the water column. These abilities to adapt to variable light conditions gives cyanobacteria a competitive advantage over other algal species.



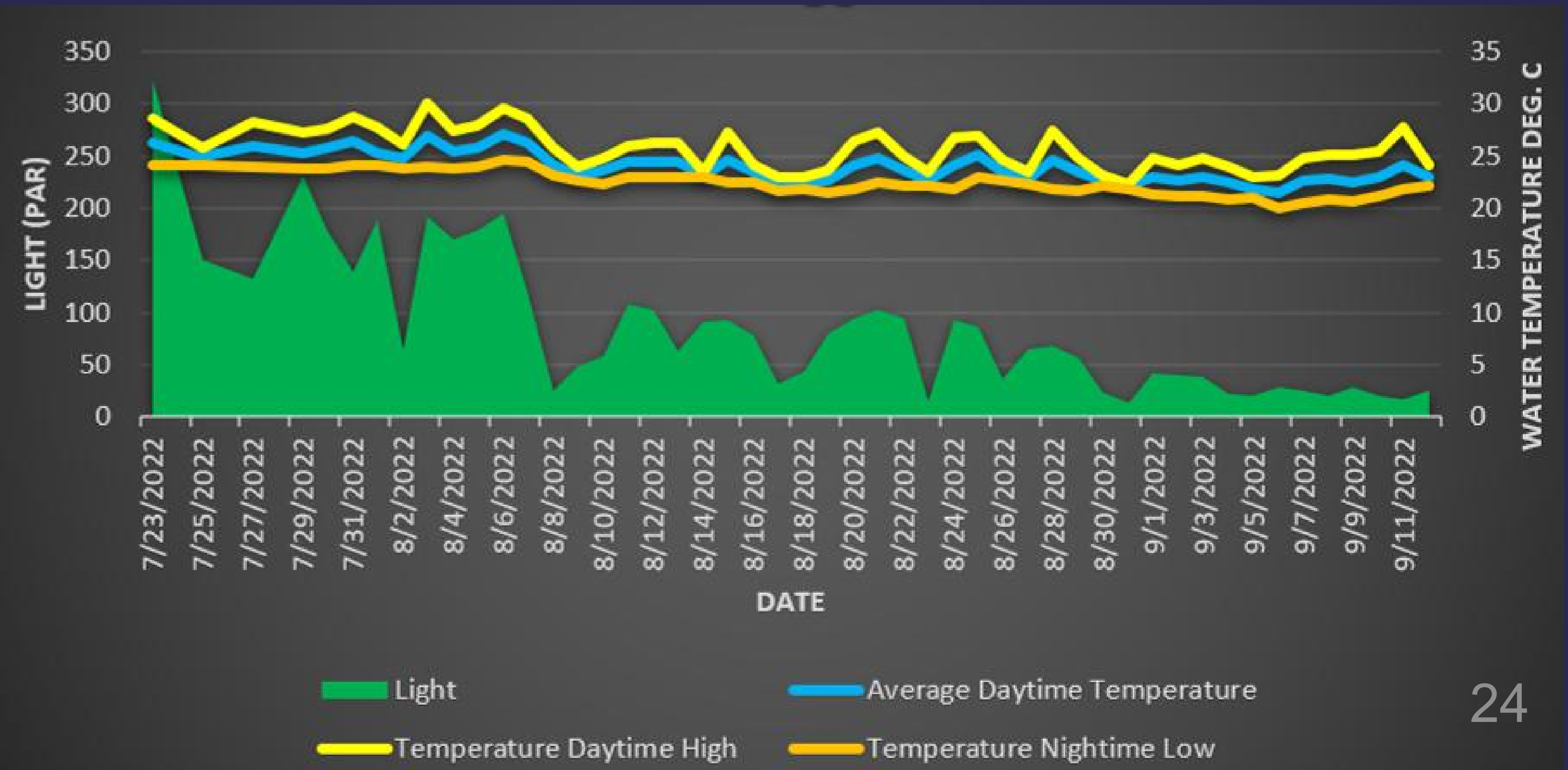
Across EMF Light & Temperature



Data collected from the loggers Above EMF and Across EMF display very similar patterns. These loggers were both installed on the southern portion of the lake, versus the other 3 loggers that were stationed on the northern portion of the lake. The density of the bloom in Darlings Lake was almost non-visible for the majority of 2022 at both the Above EMF and Across EMF locations, with the most visual bloom occurring mid-July.

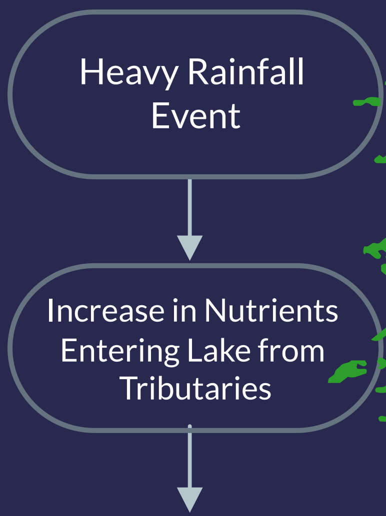
The greatest fluctuation of light penetration occurred Below EMF station, and this correlates to the severity of the bloom in this location. The station Below EMF also recorded the greatest variance between daytime water temperature highs, and nighttime temperature lows. This is interesting to note, as the Below EMF station is situated in more of an alcove than the other locations, and we were anticipating that it would have the least variance in water temperature shifts from day to night compared to the other sites that are closer to the main channel flow.

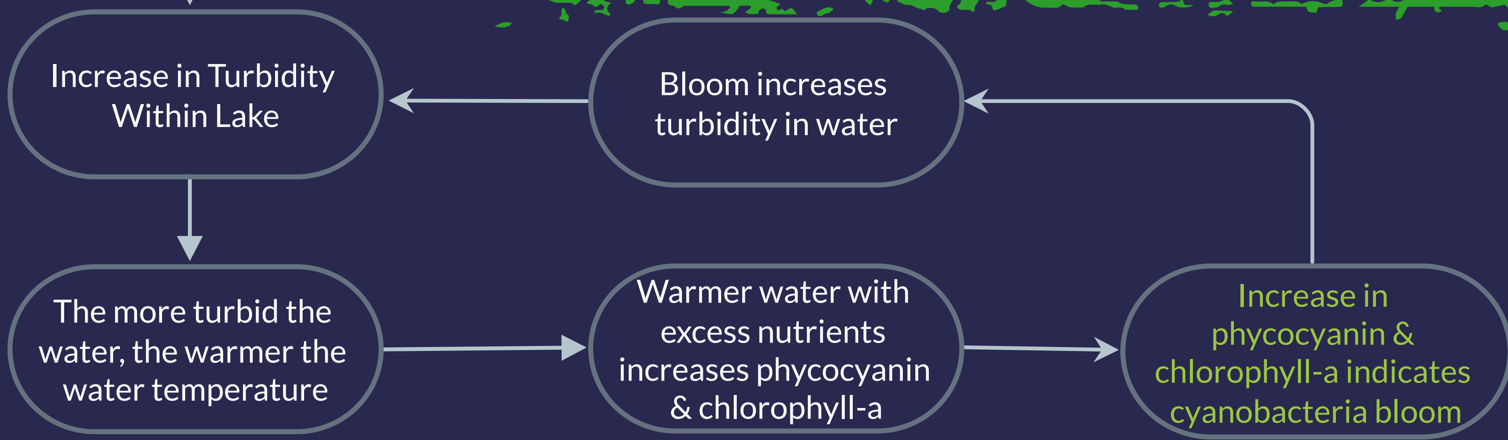
These data loggers are extremely useful pieces of water quality equipment, as we are able to see the water temperature trends at different locations, and how those readings correlate to bloom formation. Cyanobacteria thrives in water temperatures higher than 25 degrees Celsius- Below EMF and At EMF recorded consistently high-water temperatures particularly in July during peak bloom formation and began decreasing late August and into September when the bloom was dissipating. HOBOs could be influenced by local topography (shade/shadows) that may be influencing light readings, given that they are attached to docks and relatively close to shore.

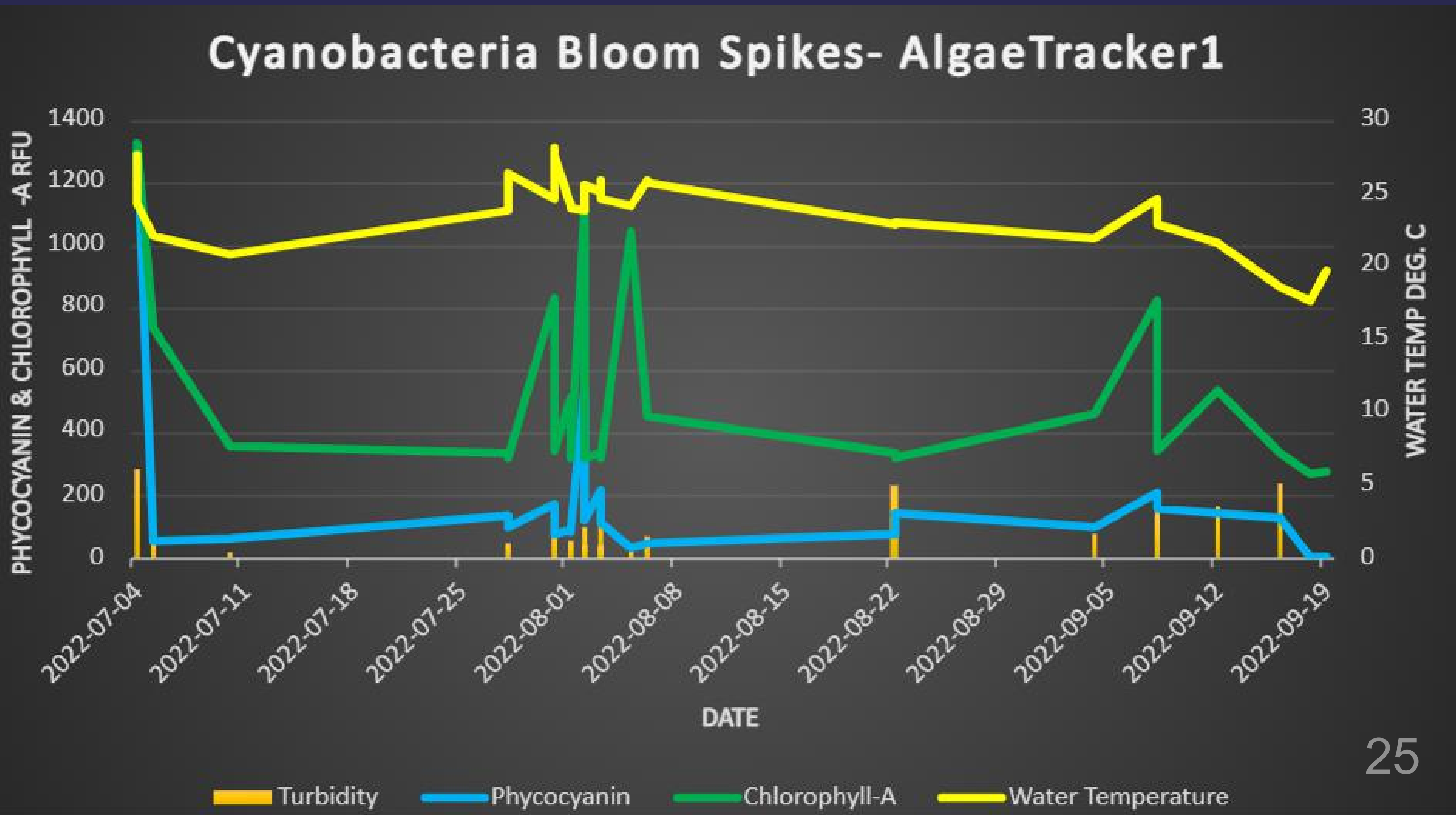


AlgaeTracker1 Below EMF

AlgaeTracker1 was deployed in the midst of an ongoing cyanobacteria bloom. The bloom decreased in severity after the July 5th/6th rainfall event, and increased in severity during the first week of August. It lingered throughout August and spiked in September, before dissipating mid-September.



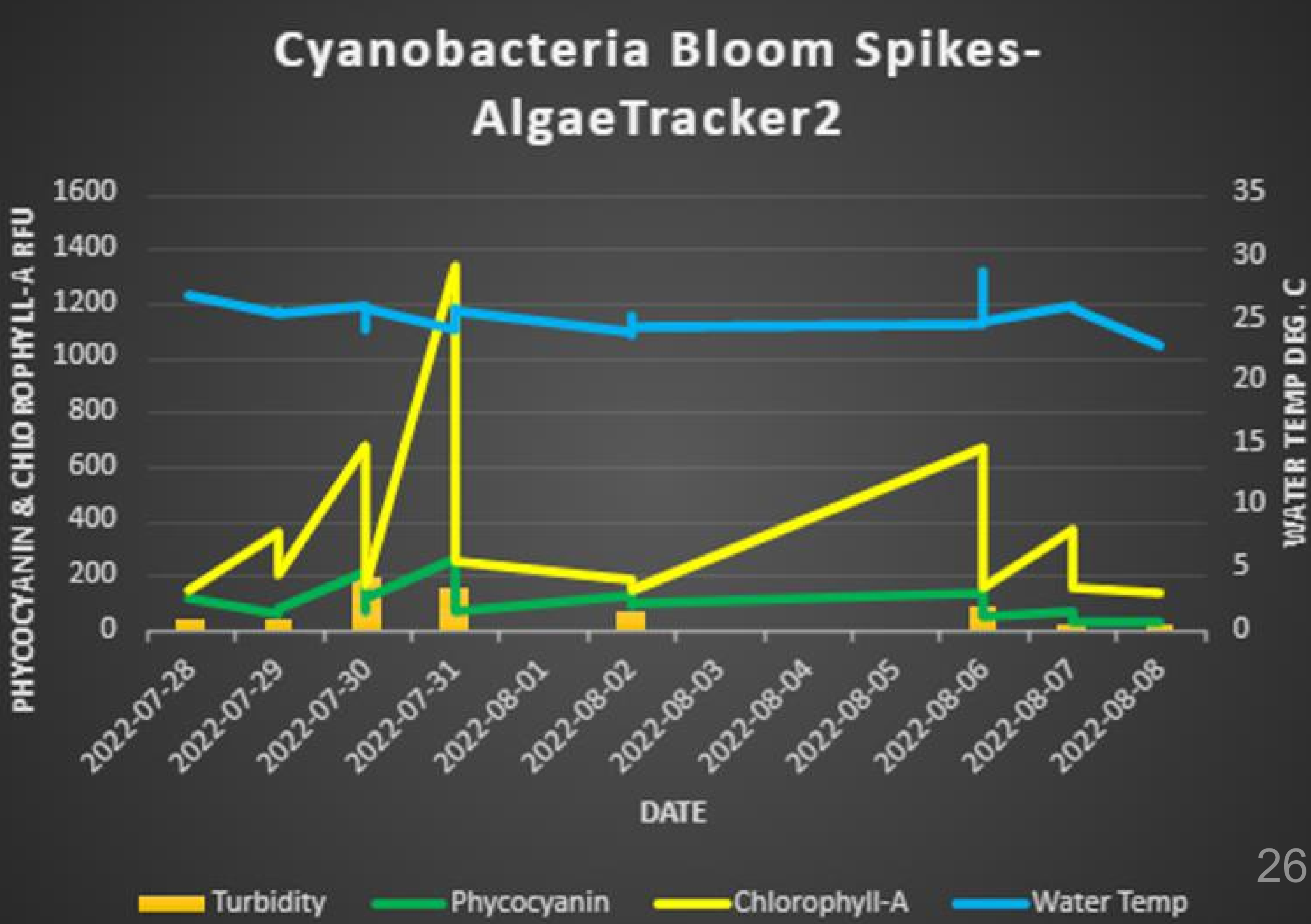




AlgaeTracker2 Above EMF

Our goal for the 2023 sampling season should be to deploy the AlgaeTrackers at an earlier date within the lake. In 2022, we deployed the trackers into a lake that was already experiencing a bloom- this is due to the delay in project approval, purchasing equipment, and then securing the necessary permits. This year, the HRAA will be applying for the necessary permits now (March), with the goal of deploying the trackers by May. Early spring deployment will allow us to collect even more baseline data in advance of a potential bloom, providing us with a greater profile of the lake.

This upcoming year, we will be able to take advantage of the devices' ability to program alerts- given what we have learned from 2022, we will set the water temperature threshold at 22 degrees Celsius (as blooms occur when the water temperature is above 25 degrees Celsius); turbidity shall be set at 25 FNU (as the blooms began occurring when turbidity surpassed 50 FNU); phycocyanin shall be set at 75 RFU (as the bloom began occurring when phycocyanin levels surpassed 100 RFU); and chlorophyll-a shall be set at 250 RFU (as the bloom began occurring when chlorophyll-a concentrations surpassed 200 RFU). By setting the alert thresholds slightly below the levels required for a bloom to occur, we will be able to begin closely tracking the trend to determine if it continues to increase, and to prepare well in advance to begin sampling for cyanotoxins, and notifying the Department of Environment and Local Government that a bloom is on the horizon.

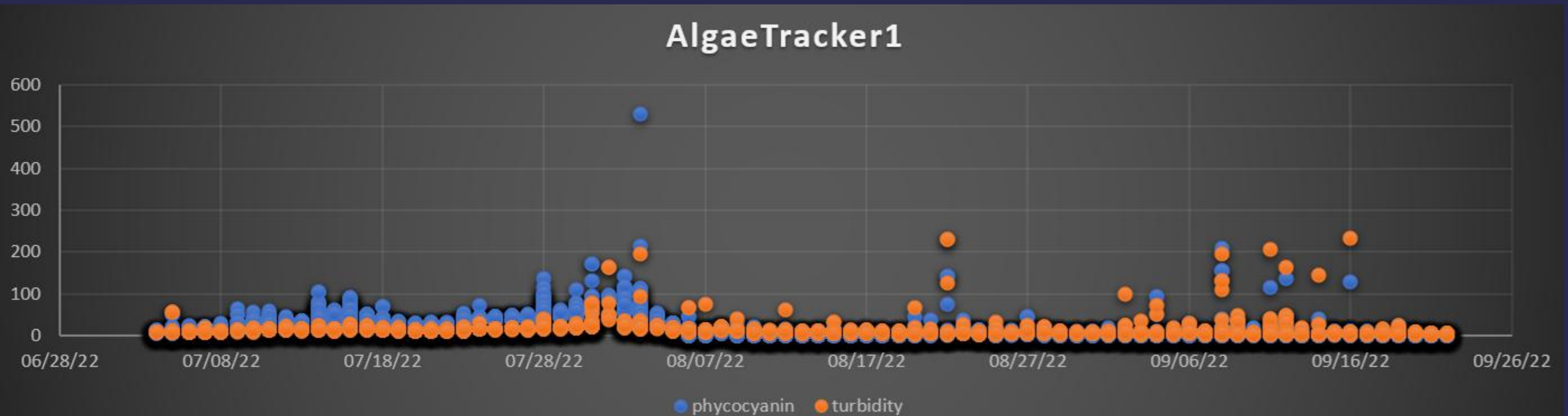


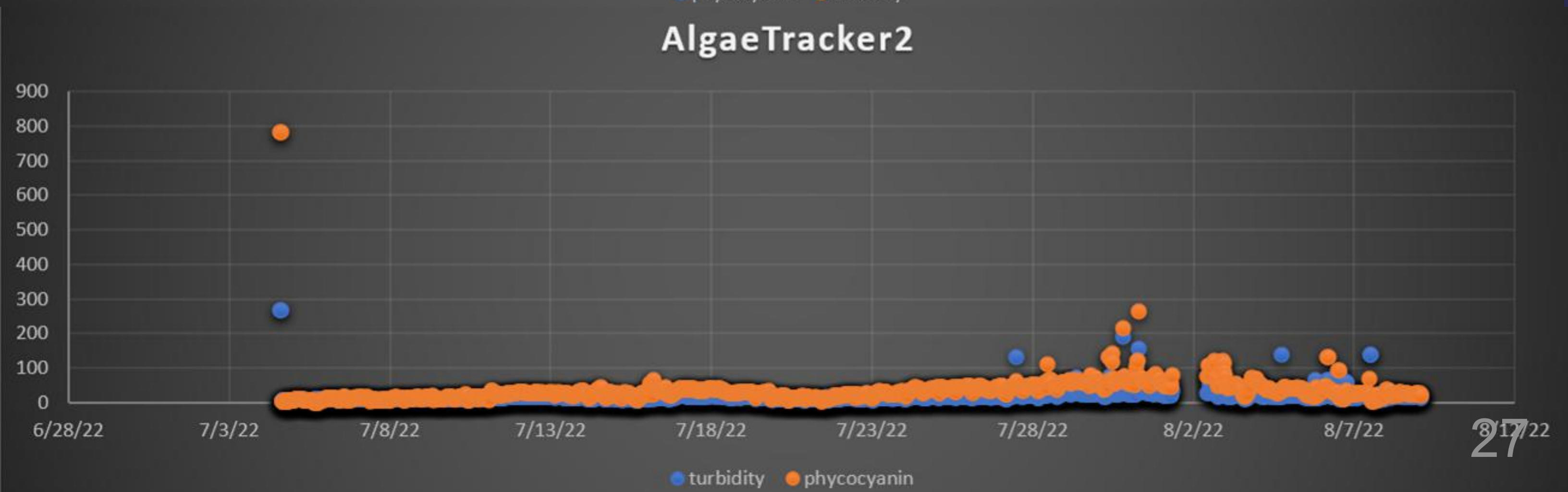
Turbidity & Phycocyanin

AlgaeTracker1 was located below the EMF1000, and AlgaeTracker2 was located above the EMF1000. These AlgaeTracker units provided the HRAA with a cost-efficient and easy method of tracking the development of cyanobacterial blooms in real time, and collected a vast amount of baseline data that will be used in 2023 to fine-tune the settings on the AlgaeTracker units to provide us instant alerts when levels of phycocyanin, turbidity, chlorophyll-a and water temperature reach threshold levels for cyanobacterial bloom formation.

As evidenced below, there is a very clear correlation between turbidity and phycocyanin levels, and both parameters assist with predicting the occurrence of cyanobacteria blooms. Their clear overlap and strong correlation demonstrate that both turbidity and phycocyanin measurements are an excellent way at predicting upcoming cyanobacterial bloom formation. As such, the HRAA would recommend that other watershed groups who are performing cyanobacterial monitoring programs (and do not have access to AlgaeTrackers), to incorporate turbidity into their monitoring parameters as an early predictive tool to track potential bloom formation.

There also exists a strong correlation between high phycocyanin levels and microcystin production. During peak phycocyanin production on July 18th, July 28th, August 20th, and August 22nd, our microcystin sampling yielded positive results, indicating that the bloom was actively producing cyanotoxins during peak phycocyanin output, and this correlation is supported by the CCME, "The presence of known microcystin producers has been shown to correlate strongly with phycocyanin concentrations" (Oh et al., 2001).





Darling's Lake Water Temperature

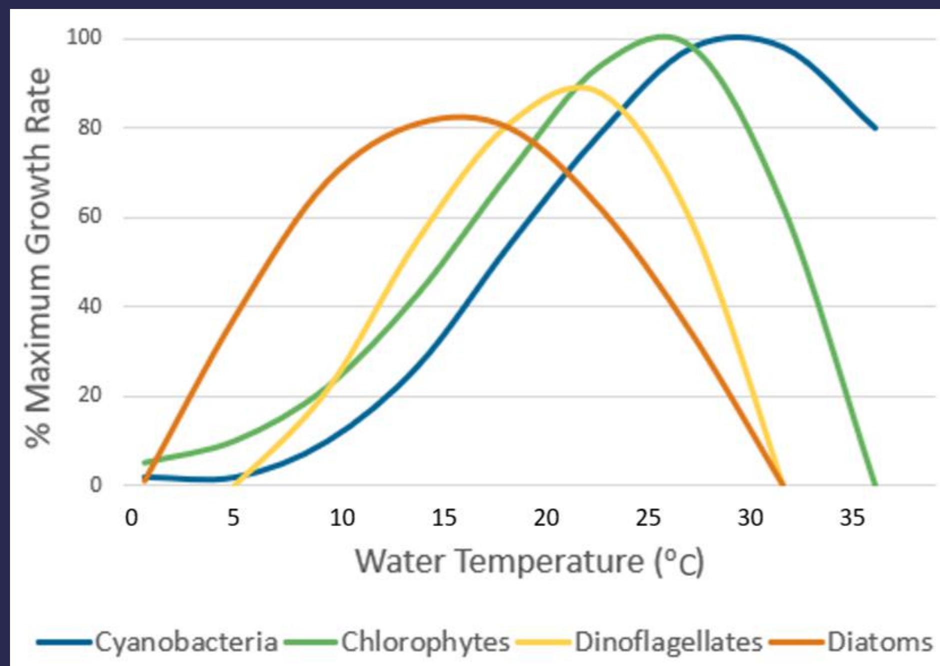
Daytime Monthly Water Temperature Averages Of All Sites

26.8 — July: Cyanobacteria Confirmed

25.5 — August: Cyanobacteria Confirmed

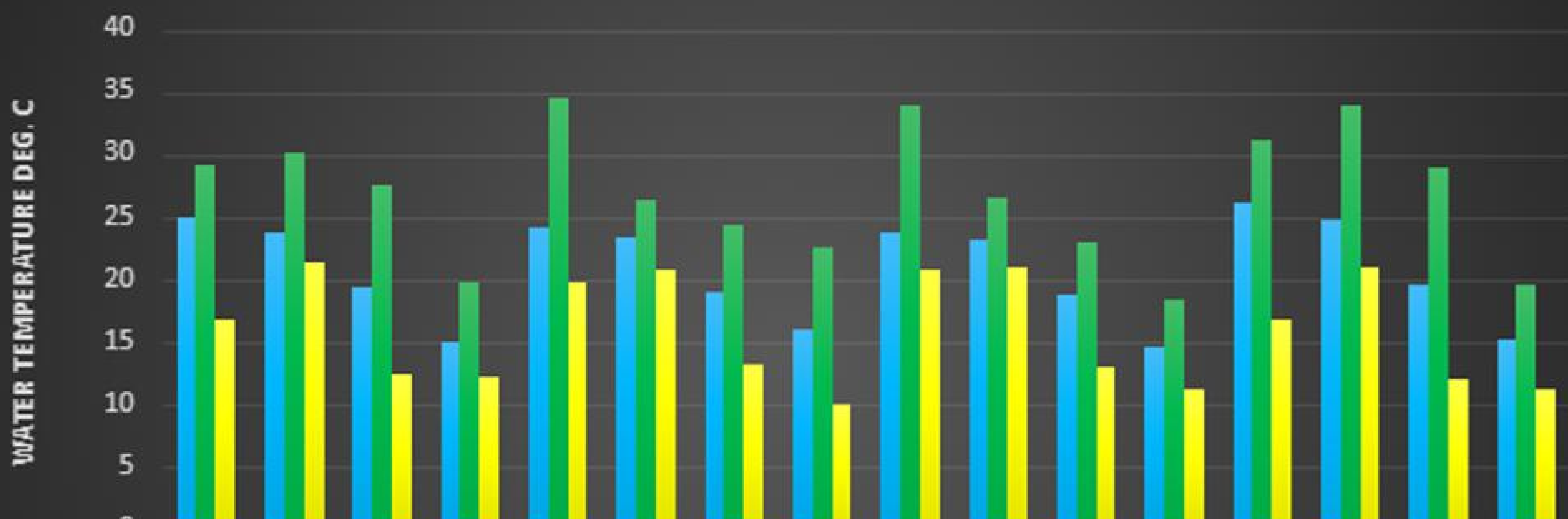
23.8 — September: Bloom Dissipating

Higher water temperatures will depress growth of many planktonic algae (for example diatoms, dinoflagellates, and chlorophytes) while encouraging growth of planktonic cyanobacteria species. Optimal cyanobacteria growth rates are generally found when water temperatures are consistently above 25 degrees Celcius.

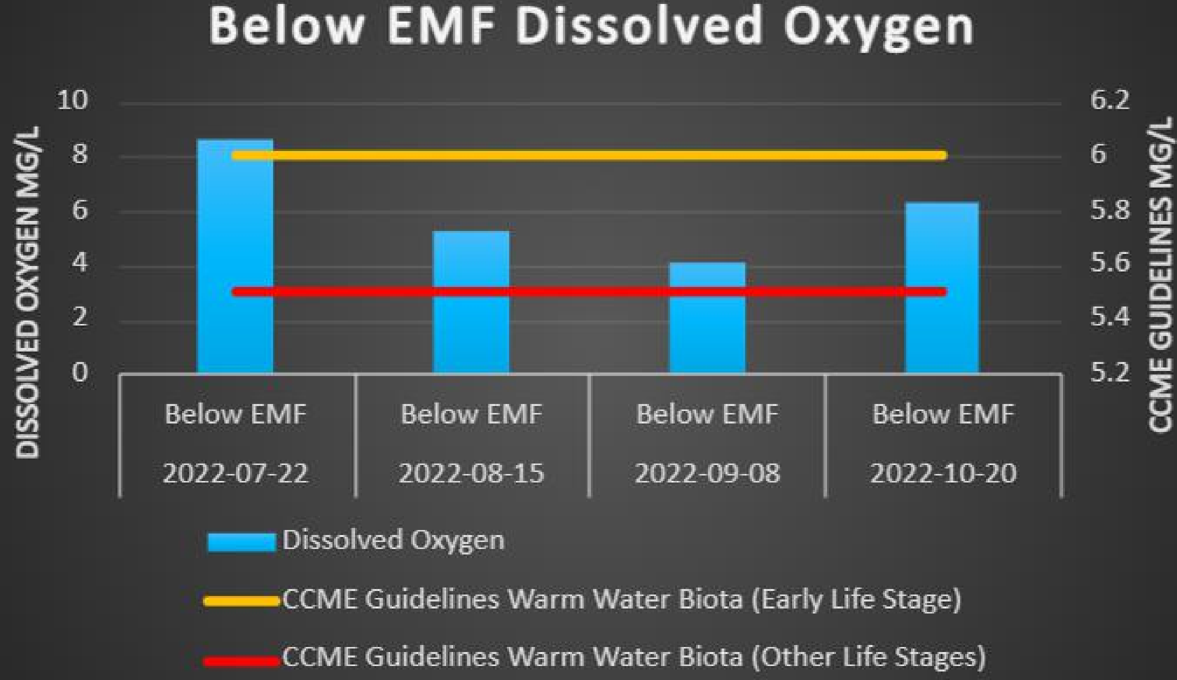


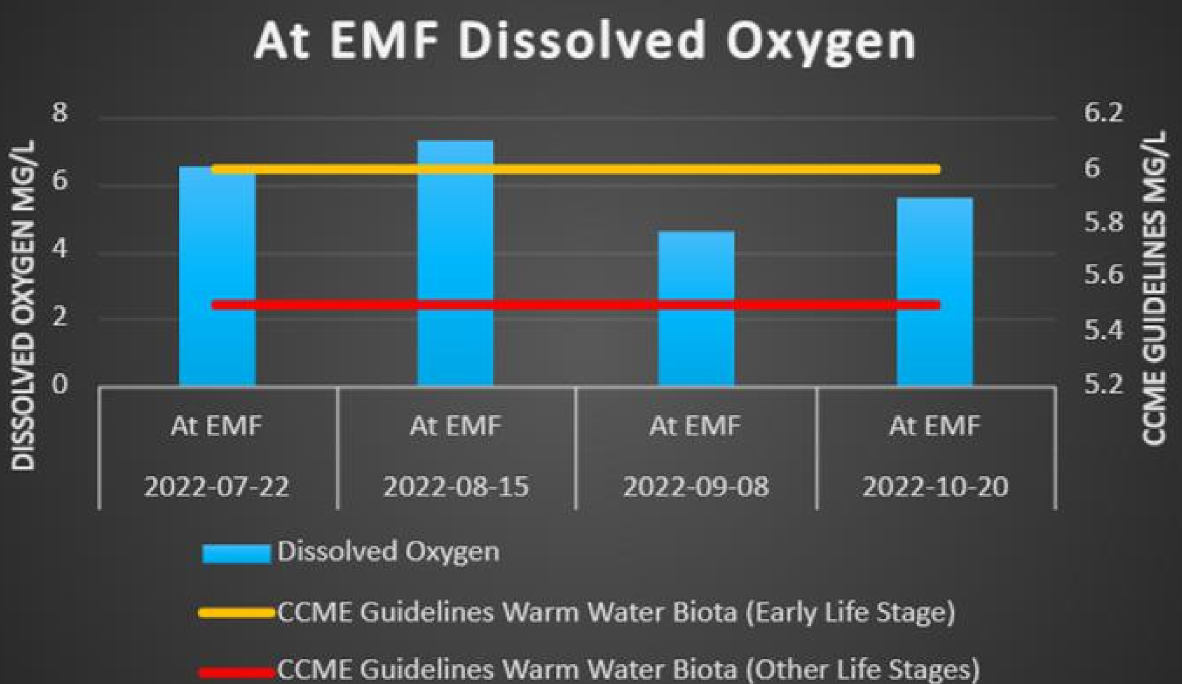
Water Temperature Trends

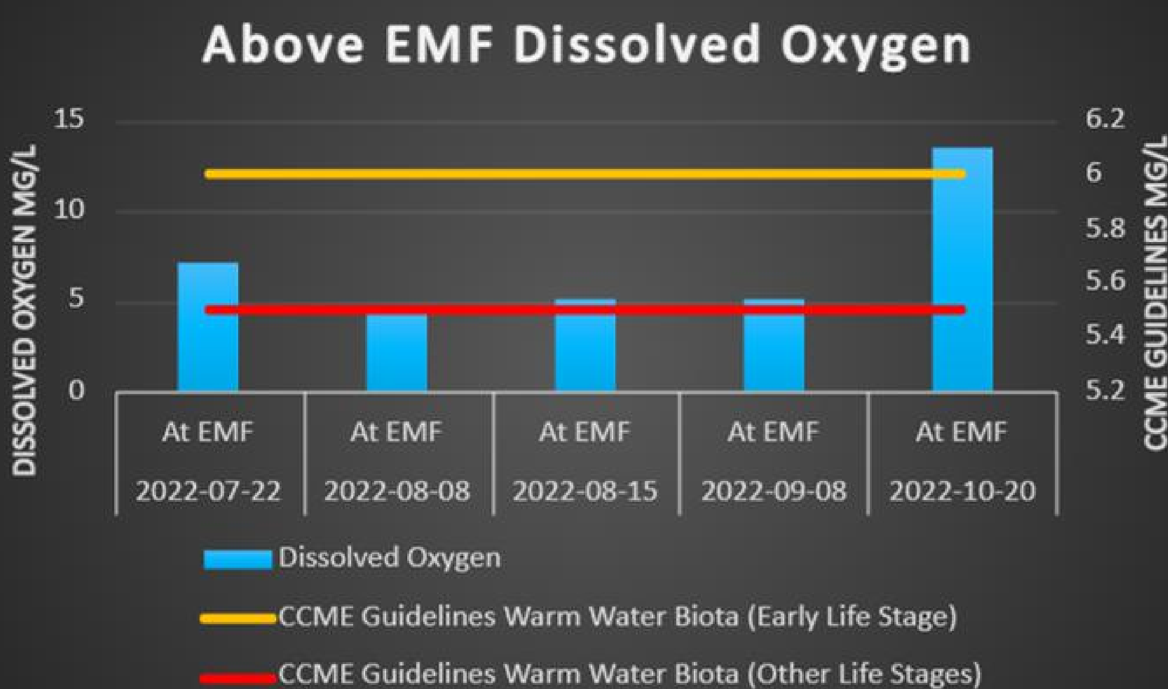
*Average includes nighttime temperatures



	Across EMF July	Across EMF Aug	Across EMF Sept	Across EMF Oct	Below EMF July	Below EMF Aug	Below EMF Sept	Below EMF Oct	At EMF July	At EMF Aug	At EMF Sept	At EMF Oct	Above EMF July	Above EMF Aug	Above EMF Sept	Above EMF Oct
Average	24.97	23.87	19.5	15.11	24.15	23.36	18.97	16.11	23.87	23.29	18.86	14.6	26.1	24.7	19.6	15.3
High	29.26	30.11	27.67	19.77	34.62	26.42	24.41	22.65	34.06	26.51	22.95	18.44	31.23	34.06	29	19.65
Low	16.81	21.49	12.35	12.14	19.86	20.8	13.25	10.04	20.72	20.98	13.08	11.15	16.77	20.93	11.97	11.19







Given Darling's Lake fish community composition is dominated by smallmouth bass, pickerel, white and yellow perch, brown bullhead, and sunfish, and is void of cold-water loving fish like salmonids, we have used the CCME guidelines for warm water biota.

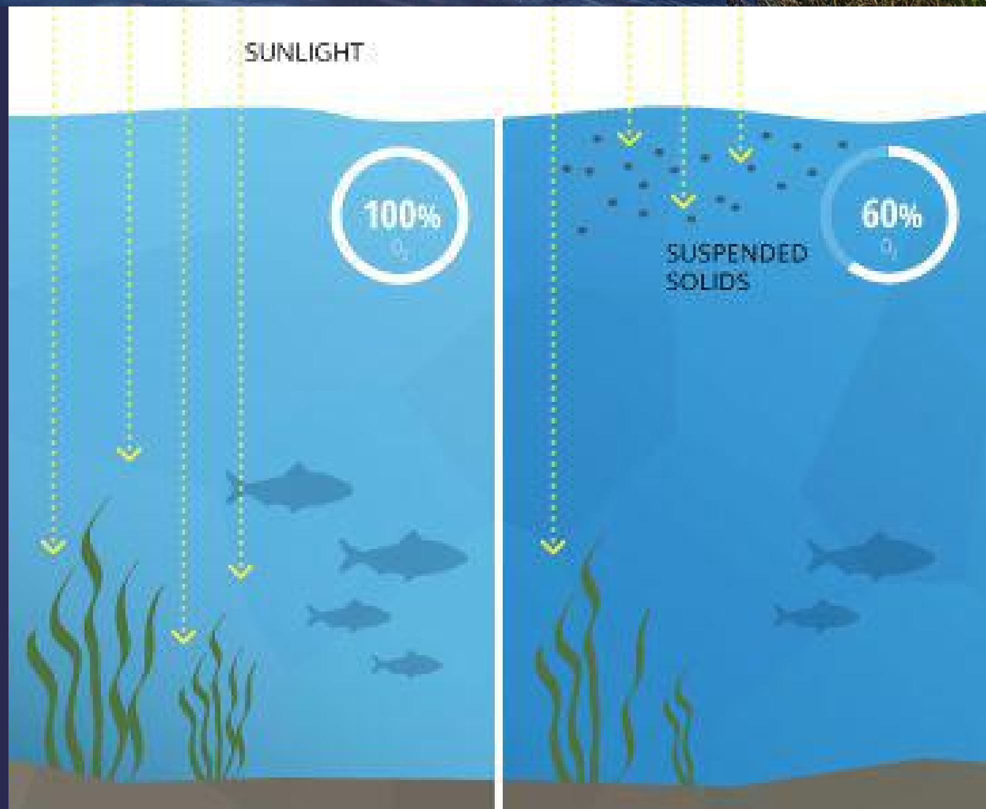
It is very interesting to note that dissolved oxygen levels remained significantly higher at the EMF1000 site than above or below the EMF1000, indicating that the EMF1000 did indeed have a positive impact on increasing dissolved oxygen levels within the lake. The tidal profile of the lake may have impacted the overall success of the EMF1000 and may have impeded its ability to deliver increased oxygen throughout the entire lake.

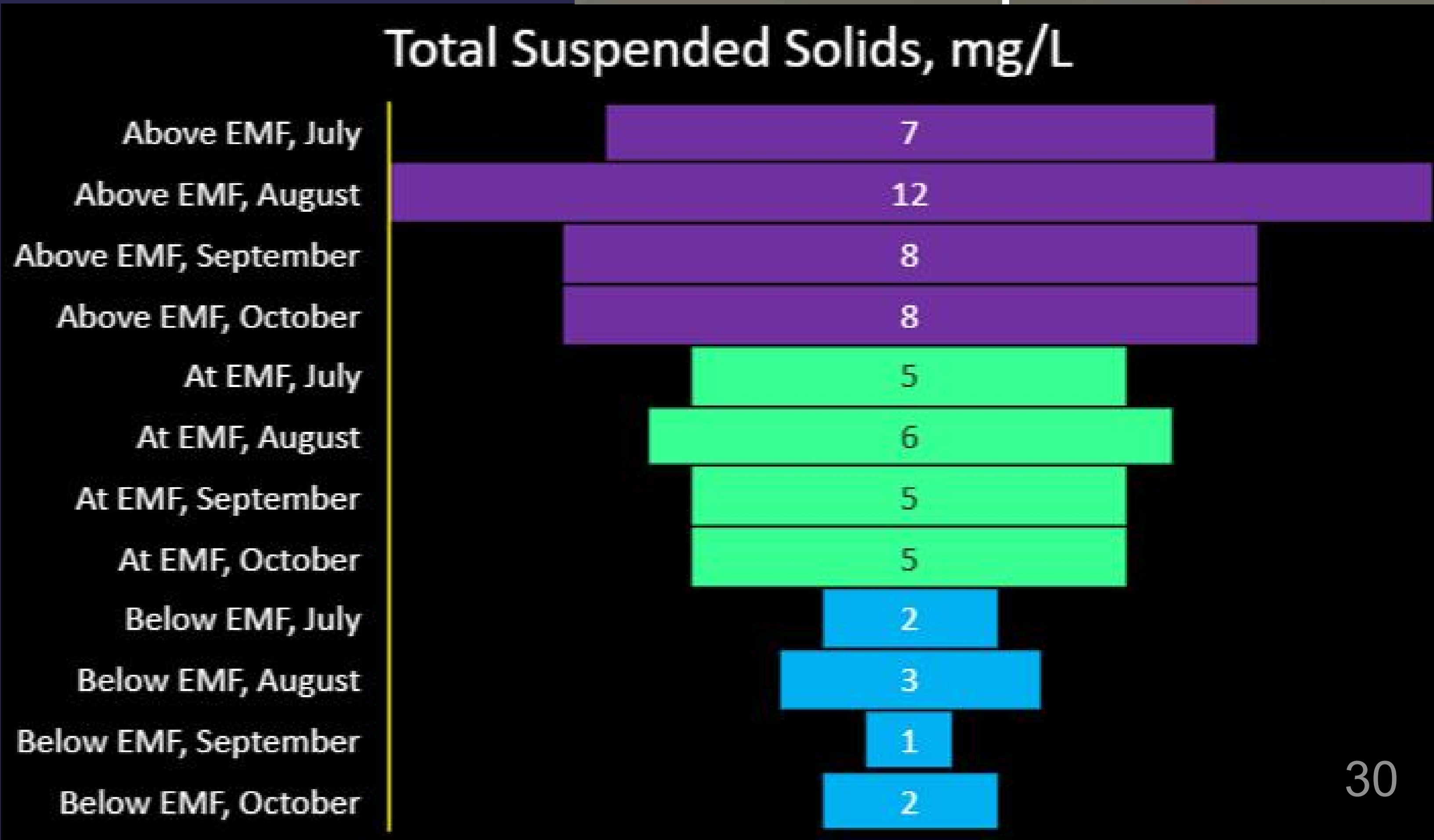
It may be worthwhile to examine the feasibility of stationing multiple submersed air circulation pumps throughout the lake, particularly closer to the shore and recessed coves to create a homogenous distribution of oxygen.

Total Suspended Solids (TSS)

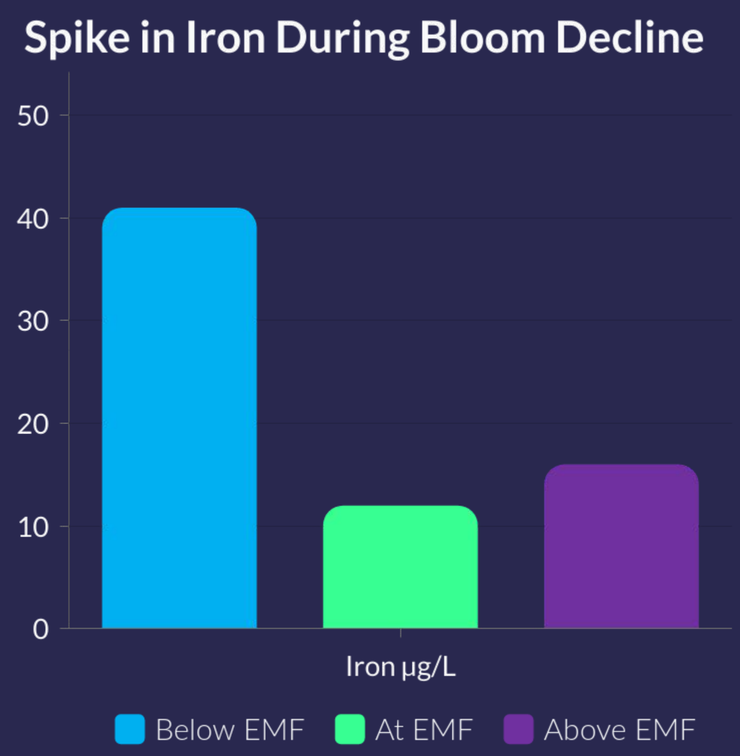
High levels of total suspended solids will increase water temperatures and decrease dissolved oxygen, as suspended particles absorb more heat from solar radiation than water molecules. Suspended solids, particularly algae, can block sunlight from reaching submerged plants, causing dissolved oxygen levels to drop, as the plants rely on respiration instead of photosynthesis.

The results of TSS monitoring positively correlate with increases in turbidity and phycocyanin at each site within the lake over the sampling season, with highest levels above the EMF.

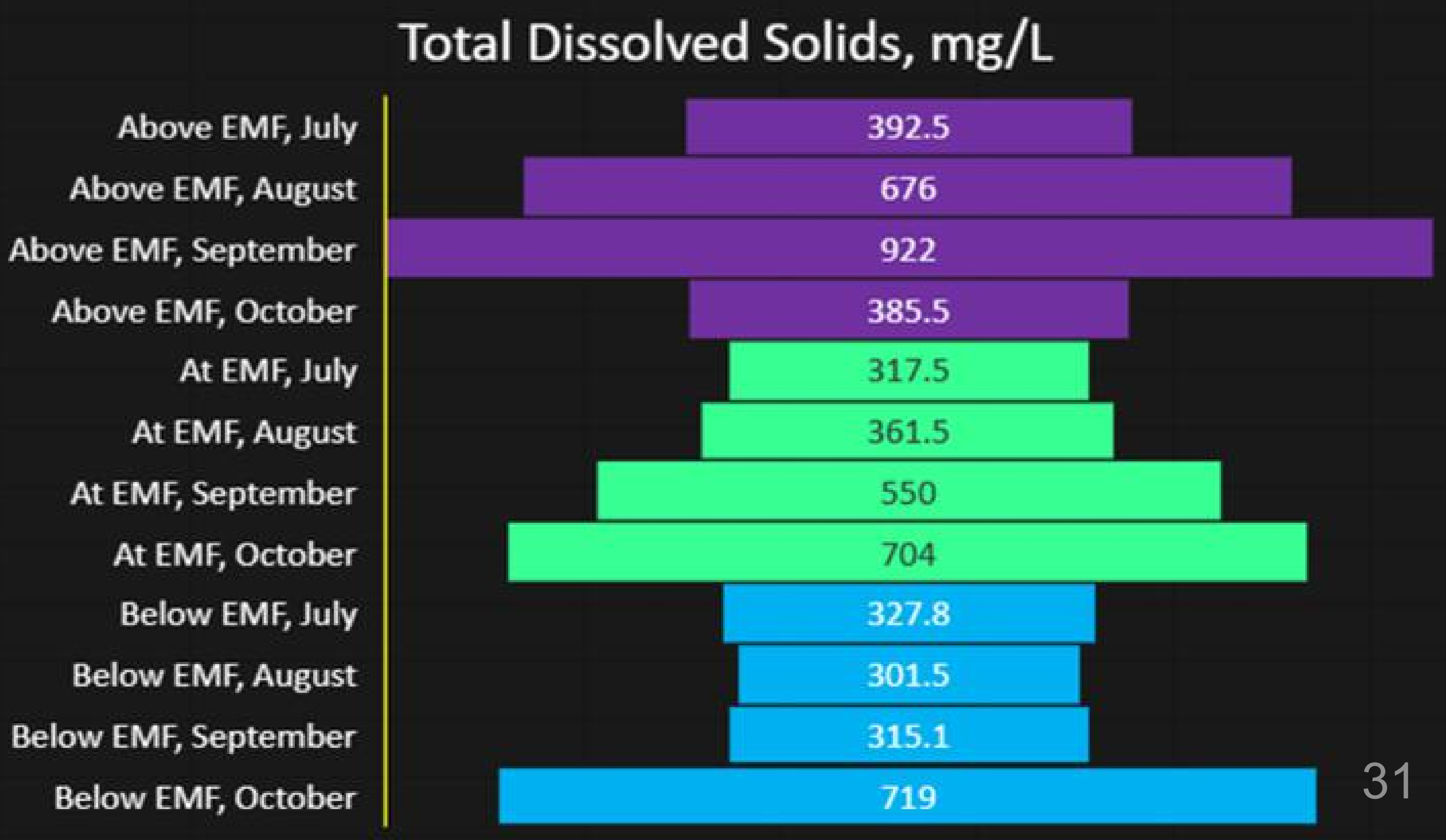




Total Dissolved Solids (TDS)



In several cyanobacterial research papers, it has been documented that iron levels spike during the bloom decline phase, and this occurrence was documented within our fall water quality sampling, with iron levels increasing at all 3 sites within the lake. As previously mentioned, cyanobacterial blooms have an exceptionally large iron requirement for photosynthesis during the active phase of the bloom, and no longer require iron input during decline phase, allowing more iron to be detected in the waterbody post-bloom. This spike is also evident in total dissolved solids readings in the fall, with higher levels of TDS happening in September and October across all three sites. Additionally, TDS may have been impacted by fall spreading of liquid manure on the agricultural fields, subsequently entering the lake; however, other conditions (light & water temperature) limited a late fall bloom.

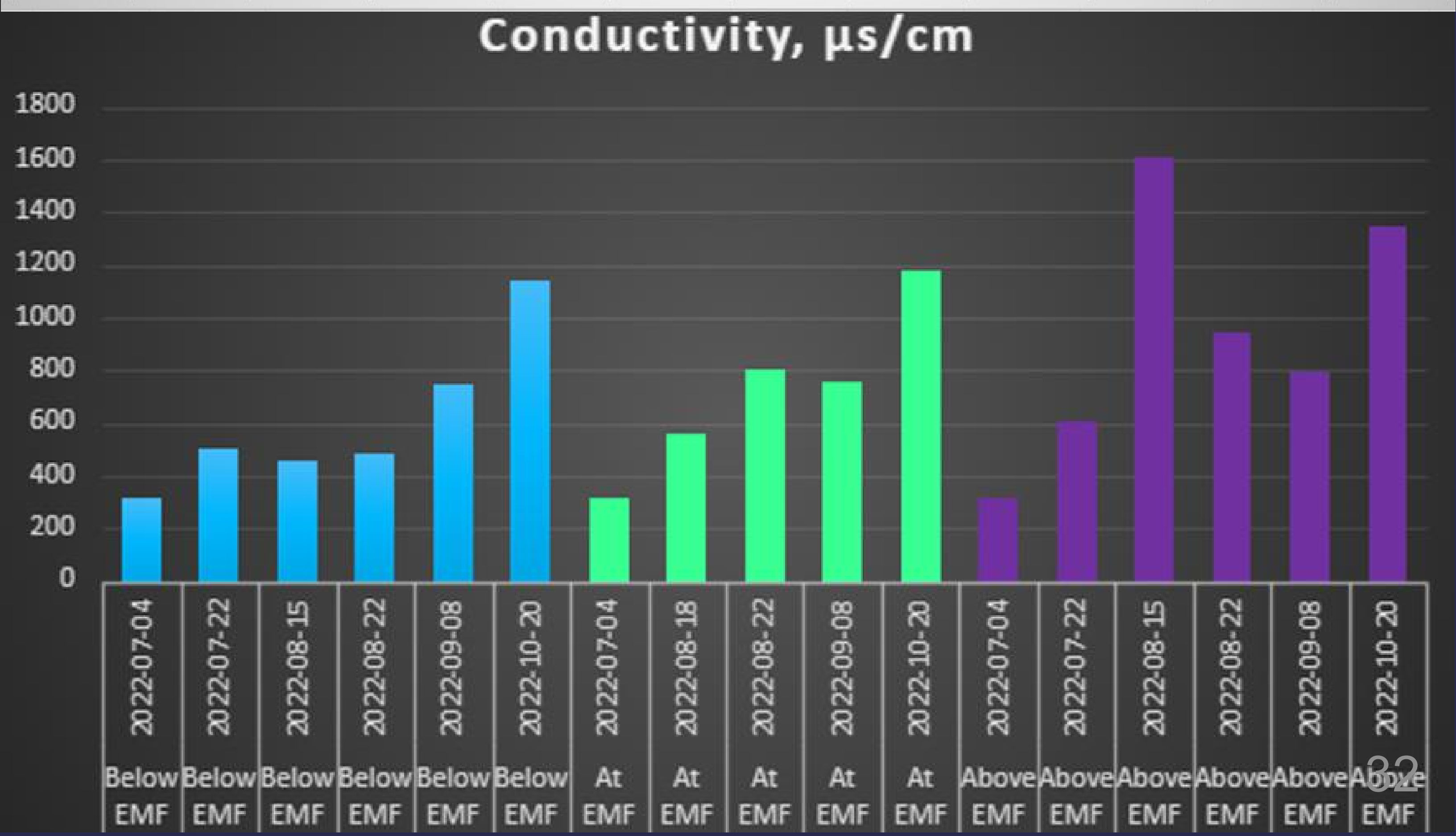


Conductivity & Salinity

As demonstrated by the following charts, conductivity levels were lower in the summer, and increased in the fall. Monitoring conductivity levels is useful because lower conductivity levels, such as is characteristic of freshwater systems, is favorable to cyanobacterial growth; indeed, the inverse is also true: conductivity will increase during the bloom decline phase. September and October also had several days of heavy rainfall events, which also contributed to higher levels of conductivity within the lake. In general, cyanobacteria blooms tend to thrive in lower conductive waters, as these waterbodies tend to contain lower levels of salinity. High salinity inhibits cyanobacterial growth rates and may stress cyanobacterial cells to rupture and leak cyanotoxins into the water. This may account for the positive microcystin tests we collected in October, during bloom decline phase.

September
18th-26th
114.5mm

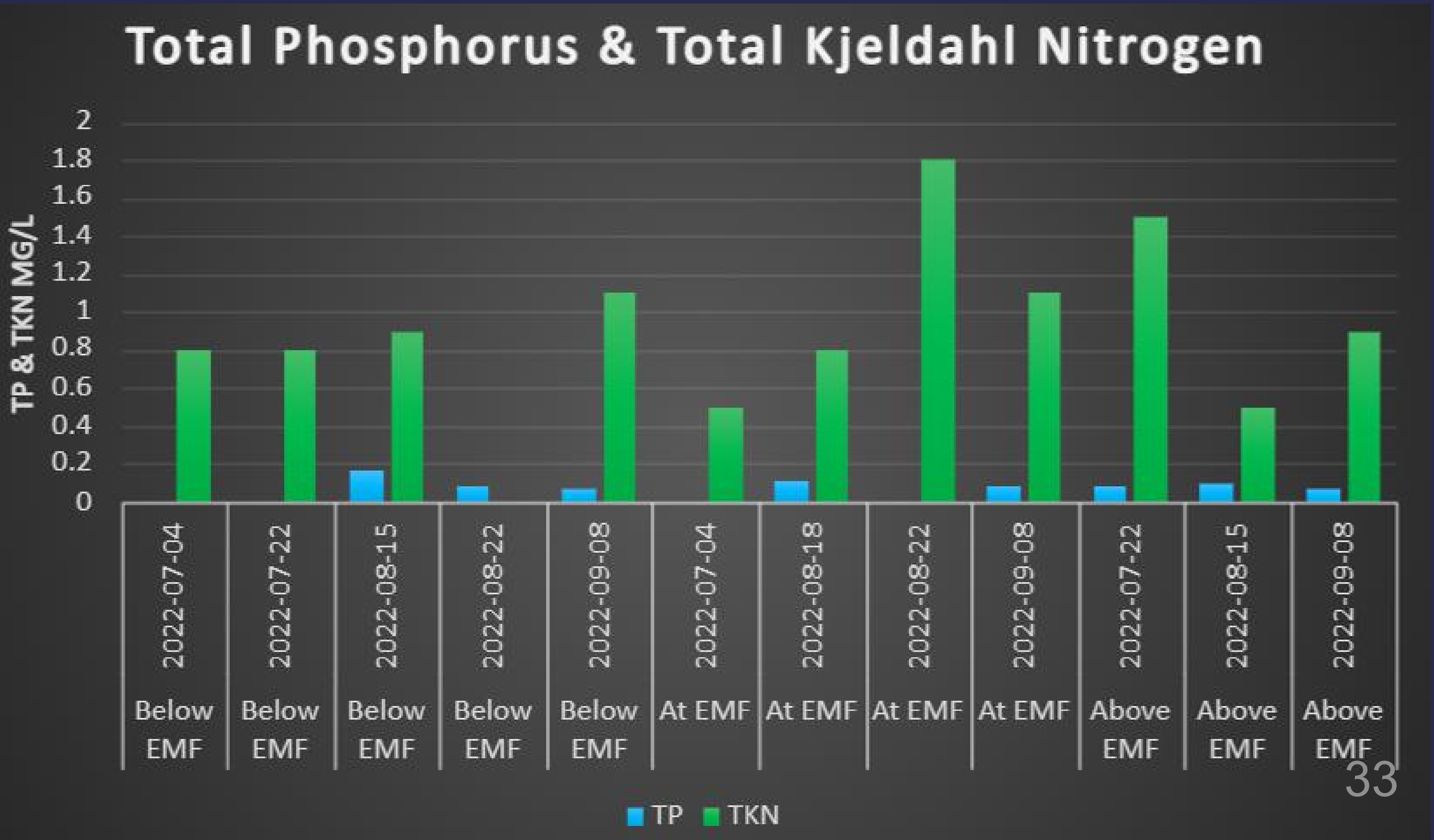
October
14th-27th
129.7mm



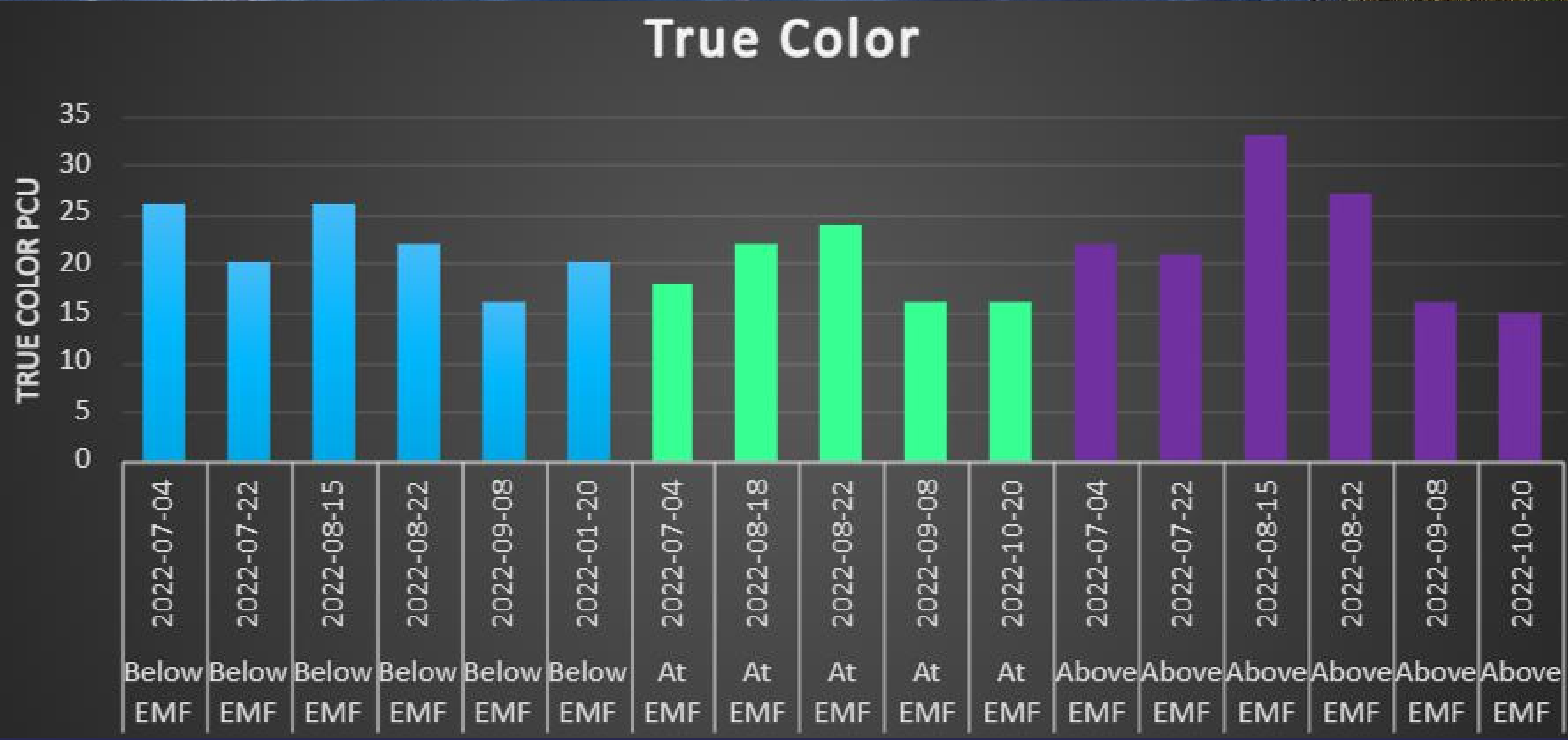
Total Phosphorus & Total Kjeldahl Nitrogen

Nutrient enrichment and eutrophication of surface waters by nitrogen and phosphorus substantially increase the amount of cyanobacteria that can occur and thus, has had a significant impact on the frequency and severity of cyanobacteria blooms. The most effective component of a long-term strategy for reducing the incidence of cyanobacterial blooms is to control the input of nutrients into the water body, specifically the input of phosphorus and nitrogen as their availability controls cyanobacterial growth. Where nutrient inputs are the result of external influences, one way in which nutrient control can be achieved is through effective control of agricultural, municipal sewage, and residential waste disposal practices in the watershed. Nutrient input via wastewater and industrial effluent, and runoff from urban or agricultural/ deforested areas can be influenced by rainfall events. As a result, a nutrient control strategy that addresses the connection between climate change and nutrient loading will be important. Although phosphorus is considered the main element regulating cyanobacterial biomass, nitrogen concentration, and more specifically the availability of different N forms, may influence the overall toxicity of blooms, particularly microcystin production; however, further research is required to fully quantify and understand the link between nitrogen levels and cyanotoxin production.

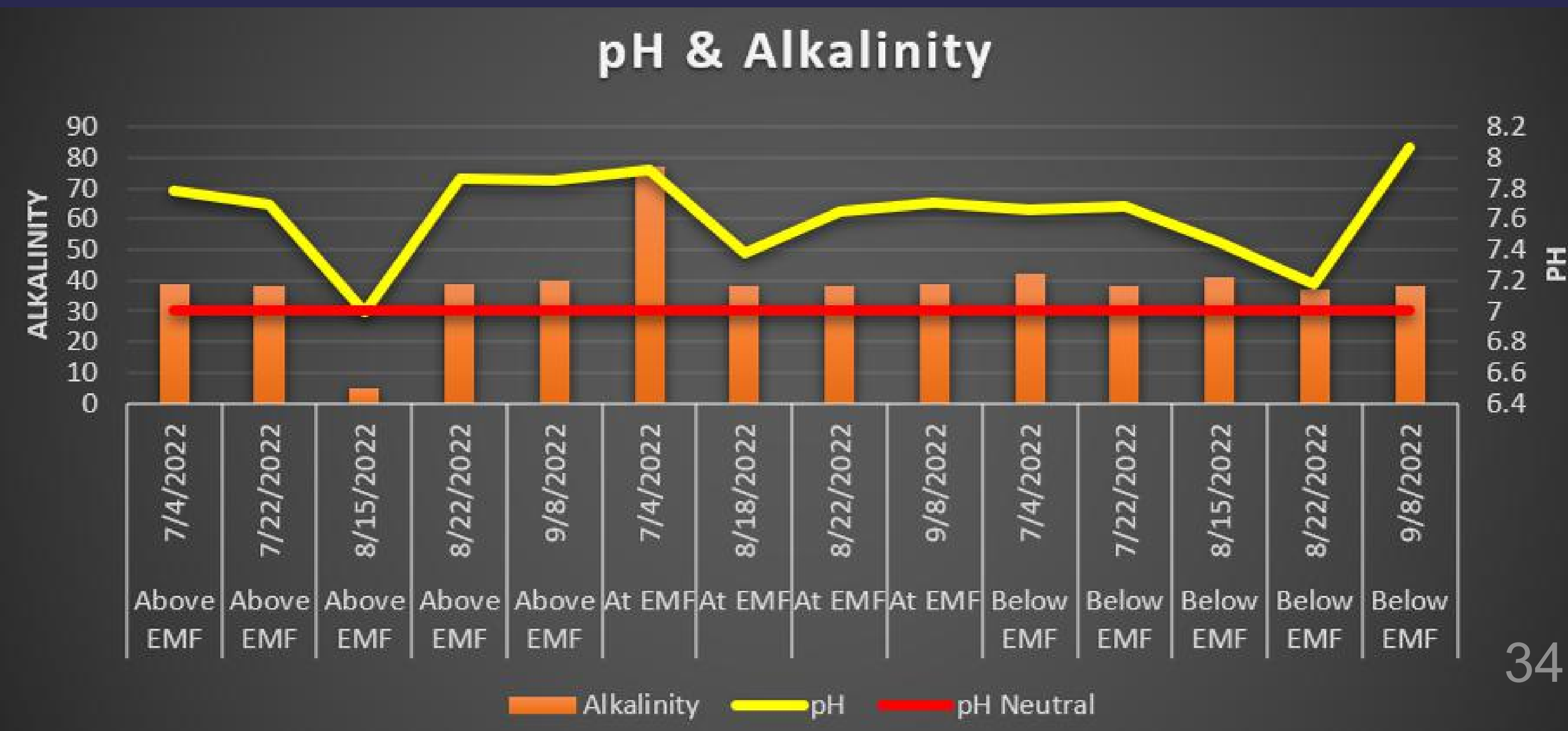
Total phosphorus concentrations greater than 0.03 mg/L (or 30µg/L) can cause algal blooms in lakes and reservoirs, while 0.500 mg/L for total kjeldahl nitrogen can cause algal blooms.

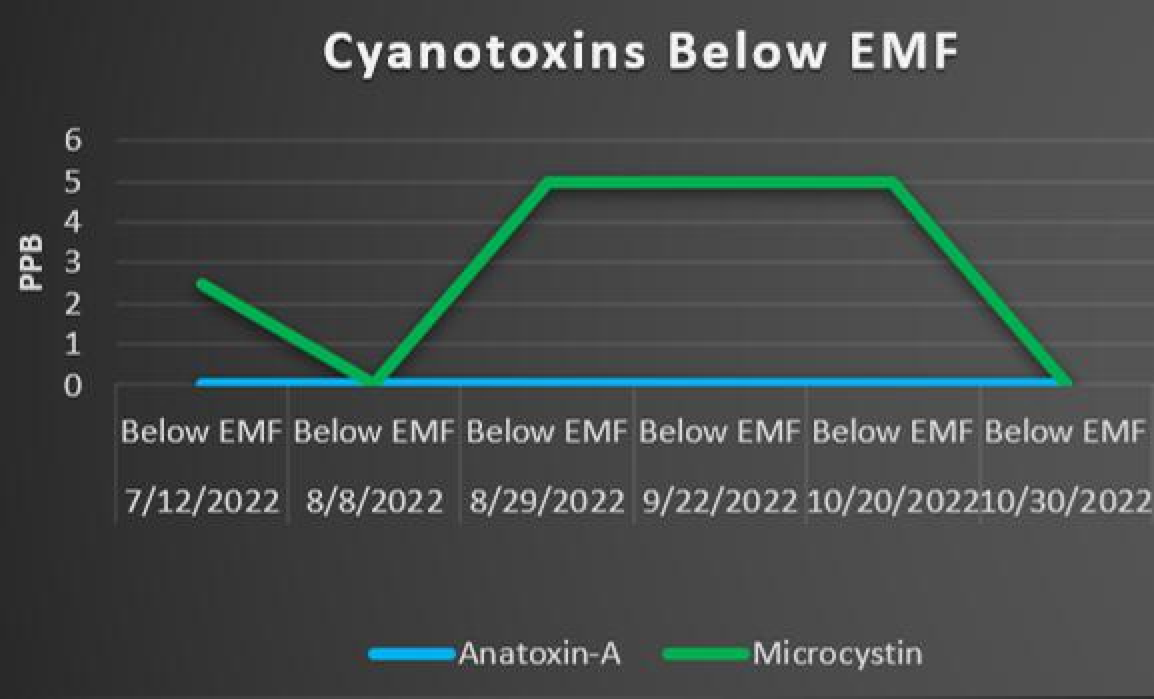


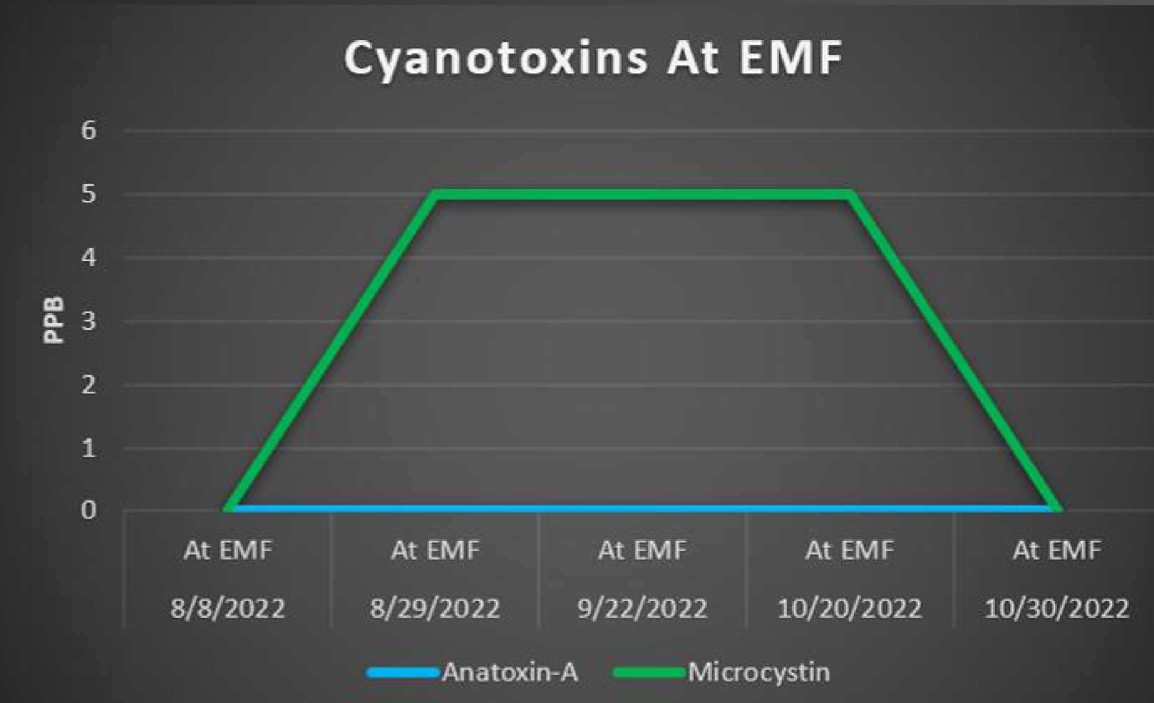
Alkalinity, pH & True Color

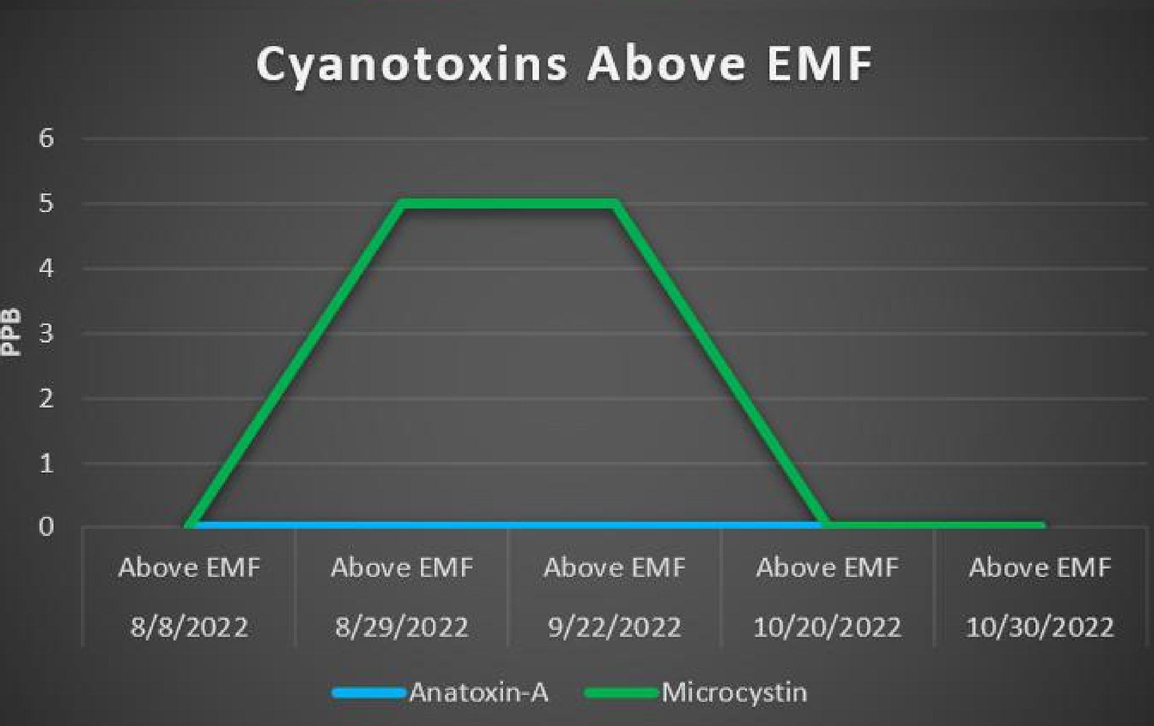


Color measured in water that contains suspended matter is defined as "apparent color"; "true color" is measured in water samples from which particulate matter has been removed by centrifugation. The true color of a given water sample is substantially less than its apparent color. In 2023, it would be interesting to expand our monitoring to include a comparison between true color and apparent color. True color is the result of dissolved organics, minerals, or chemicals in water, and changes in pH can change the true color of water. As a result, pH is always measured along with color during color testing. Cyanobacteria prefer pH levels of 7, or neutral, and their increased carbon dioxide consumption during photosynthesis can spike pH levels to 9-11 during peak blooms; however, this was not observed in 2022, but should be noted for future monitoring.









Throughout the sampling season in 2022, HRAA collected samples to be processed in-house for two different types of cyanotoxins: microcystin and anatoxin-a.

While the visible bloom declined in August, and was no longer visible by October, we still collected positive results for microcystin in October at the Below EMF and At EMF sites. Positive microcystin samples ceased occurring Above EMF in September.

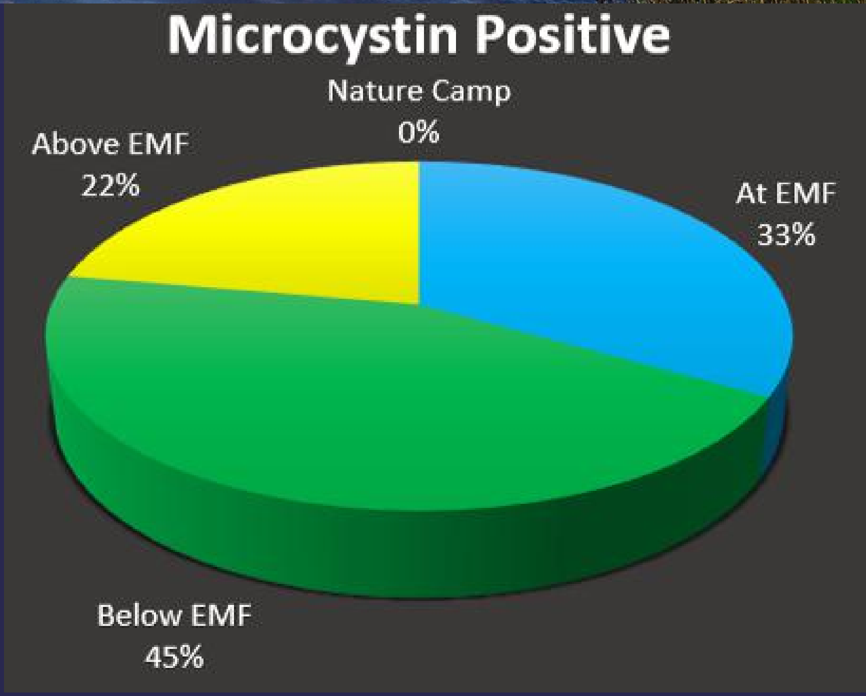
The earliest production of microcystin occurred Below EMF starting in July, when the bloom first began to form. The other sites began producing cyanotoxins in August.

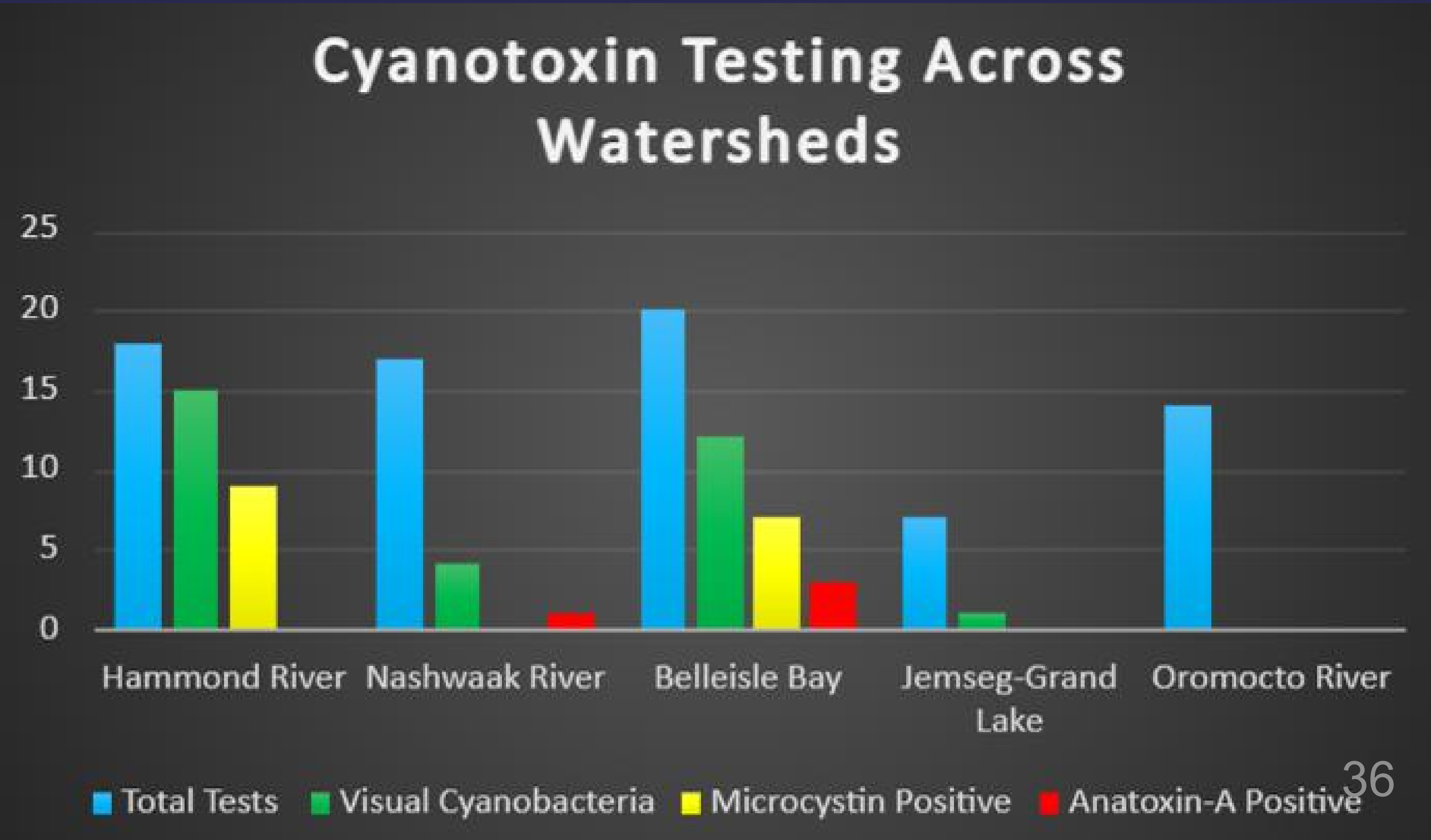
Throughout the sampling season, all samples collected were negative for the presence of anatoxin-a.

To ease parents' concerns for the safety of their children at the HRAA Nature Camp, samples for both toxins were collected in the main stem river at the Conservation Center; however, all samples tested negative for both types of toxins.

Cyanotoxin Results

In total, the HRAA collected 18 samples to determine presence/absence of microcystin and anatoxin-a. This cyanotoxin monitoring program was performed in collaboration with ACAP Saint John, who acted as Team Lead for cyanotoxin testing. This monitoring program also included collaboration with the Nashwaak Watershed Association, the Kennebecasis Watershed Restoration Committee (not shown on chart, as they did not have any positive samples in 2022), the Belleisle Watershed Coalition, Oromocto River Watershed Association and Jemseg-Grand Lake Watershed Association. While all results tested negative for anatoxin-a in the Hammond watershed, both Nashwaak and Belleisle collected samples that did indeed test positive for anatoxin-a. The site Below EMF contained the highest density of positive results for microcystin, followed by At EMF, and then Above EMF respectively. All samples in 2022 were negative for cyanotoxins at the HRAA Nature Camp. In comparison with other watershed groups, Belleisle Bay could most certainly benefit from deploying AlgaeTrackers throughout the bay to assist in early detection of cyanobacterial bloom growth.





Cyanobacteria Monitoring with ACAP Saint John

ACAP Saint John are leaders in cyanobacteria monitoring strategies, and the HRAA field staff gained a wealth of knowledge and experience through this partnership! This is our third year working with ACAP Saint John, and we are looking forward to collaborating again in 2023!

Cyanotoxin testing kits are a new tool in our arsenal of cyanobacteria monitoring devices and are a worthwhile investment for all watersheds that contain lakes. The HRAA created a YouTube video demonstrating how to use these new kits, which provided some reassurance to the general public that toxin testing is indeed occurring!

LES AMI(E)S DE LA FRIENDS OF THE KOUCHIBOUGUACIS

After the release of our cyanotoxin testing demonstration video, the Friends of the Kouchibouguacis reached out to the HRAA. While Kouchibouguacis did indeed have testing kits for microcystin, they did not have access to anatoxin-a testing kits. As a result, HRAA decided to send Kouchibouguac the supplies needed to perform two rounds of anatoxin-a samples within their watershed. This gesture of collaboration incurred an unforeseen cost within the originally proposed budget- shipping. It cost approximately $62 dollars in shipping to send Kouchibouguac the supplies they needed to perform the testing; however, we believe that this was a worthwhile endeavor, and we trust that the NBETF will not take issue with this adjustment to the originally proposed project spending!

BloomWatch NB

HRAA's New Communication Strategy for all things Cyanobacteria

Upon project approval, the HRAA created a secondary Facebook page for the specific purpose of communicating and sharing our cyanobacteria monitoring and research, entitled BloomWatch NB. This page allowed us to share GNB's updated cyanobacteria educational outreach, as well as ACAP Saint John's educational materials. This page also offered a safe and inclusive space for residents of Darling's Island to share pictures, questions, and concerns. The page outreach was substantial- we began receiving pictures and questions from residents in Saint Andrews, Washedemoak, and the Nerepis rivers, looking for assistance in determining if their waterbody was experiencing a bloom. HRAA and ACAP Saint John were able to investigate several of these additional requests, and other requests were forwarded to the Department of Environment. Our goal for 2023 is to continue to grow the outreach of the BloomWatch NB page, and continue to educate the public on cyanobacteria!

331 Page Members Joined in 2022

Post Impressions	Post reach	Post Engagement
24,685	22,554	1,469
10,320	9,503	826
1,346	1,180	207

- Our top 3 most popular posts reached 33,237 people!
- We educated the public on how to properly document and report potential cyanobacteria blooms.
- We shared all of GNB's cyanobacteria advisories on the page, increasing public awareness on what areas were experiencing blooms.

When the cyanobacteria bloom occurred in Darling's Lake in 2021, many parents with children in HRAA's Nature Camp expressed concern for their kids' wellbeing using the water at the Conservation Center (even though the Conservation Center is approximately 2km upriver from Darling's Lake). Several parents removed their children from Nature Camp that summer because they were concerned about cyanobacteria exposure, resulting in a negative economic impact for HRAA.

In conjunction with regular cyanotoxin testing at the Conservation Center, HRAA created an educational presentation called "Be in the Cyan-Know" to help educate youth on how to identify cyanobacteria, and what steps they can take to make sure they are safe when accessing their favorite waterbodies. This presentation including highlighting GNB's and ACAP Saint John's cyanobacteria graphics, while changing the wording to be more understandable to youth. Part of this presentation included emphasis on "look before you leap" (which applies to more than just cyanobacteria!). This presentation was provided once a week for eight weeks, reaching over 300 youth, and they also had the opportunity to watch experienced HRAA staff collect and process samples for cyanotoxin testing! We also installed 2 large GNB cyanobacteria signs in local area.

Don't Drink the Water!

Look Before You Leap!

Shower or Rinse Off When Done!

Project Deliverables: Protecting our Environment

Priority Area Measures:	Management Actions	Delivered
Protecting Our Environment	WMP Goal 2 Action 12: Water Quality Testing	115 Water Quality Samples
	WMP Goal 2 Action 17: Pamphlets on Livestock Diversion from Streams	200 Pamphlets
	WMP Goal 2 Action 19: Pamphlets on Nutrient Reduction	200 Pamphlets
	WMP Goal 2 Action 29: Identify New Sites for HOBO Data Loggers	5 HOBO Data Loggers Deployed
	WMP Goal 2 Action 32: Increase Cyanobacteria Education Outreach	Created BloomWatchNB
	WMP Goal 4 Action 65: Identify & Survey Undocumented Tributaries	4 Tributaries Documented
	WMP Goal 4 Action 66: Perform Lake Health Assessments	1 Survey of Darling's Lake
	WMP Goal 4 Action 67: Investigate New Monitoring Tools/Tests	5 New Tools
	WMP Goal 4 Action 68: Increase Drone Footage of Watershed	1 Drone video of Darlings Lake
	WMP Goal 7 Action 115: Promote Agricultural Best Practices	2 Social Media Posts
	Strategic Plan 1.2: Increase Environmentally Educational Programs	Creation of "Be in the Cyan-Know"
	Strategic Plan 1.3: Broaden Relations with other Organizations	Collaborated with 8 Organizations

In our original proposal, we had listed that we would undertake 449 Management Actions; however, at the time of writing the proposal, we did not clearly understand how the NBETF quantified Management Actions (i.e.: we counted each individual sample and each individual survey as 1 action). Additionally, many of the actions that we undertook during this project are not currently listed as part of either HRAA's Watershed Management Plan or HRAA's Strategic Plan (i.e.: performing boat surveys to identify potential public access hotspots for safety concerns). In total, HRAA undertook 12 Management Actions that are currently listed in our Watershed Management Plan and/or Strategic Plan, and we apologize for the inconsistency in the number of actions originally proposed!

Project Deliverables: Increasing Environmental Awareness

Priority Area Measures: Increasing Environmental Awareness	Activity	Engaged
	Active Learning: Training on Cyanotoxin Sampling	6 HRAA Staff Trained
	Active Learning: Meetings with ACAP Saint John	4 Meetings/15 Participants
	Active Learning: Participation in BloomWatch NB	331 Members
	Active Learning: Meeting with Town of Hampton	1 Meeting/5 Participants
	Active Learning: Be in the Cyan-Know Presentation	8 Presentations/320 Participants
	Observing: Video Creation on Cyano Monitoring	1 Video/32 Views
	Observing: Social Media Outreach & Education	22 Posts/>40,000 People Engaged
	Observing: Installation of 2 Large GNB Cyanobacteria Signs	2 Signs Installed

In our original proposal, we had stated that the HRAA would host a community meeting to discuss the results of our findings from the survey; however, due to the overwhelming amount of data collected, it has taken longer to properly and fully analyze the results of the survey, and a community meeting has yet to happen. Now that we have successfully compiled and analyzed all of the results, and have published the findings in this final report, our upcoming plan is to release this final report to our project partners for feedback, and then begin to develop and promote a community meeting to discuss the findings within this report. Our proposed activity duration for Increasing Environmental Awareness was 52 hours; however, the creation of BloomWatch NB increased these hours substantially, as we received messages outside of working hours, so it became difficult to track the exact level of engagement; however, we are very pleased with the community's engagement level and did not mind in the least in responding to inquiries outside of our working hours!

Conclusion

First and foremost, the results discovered in the water quality sampling are not meant as a harsh criticism towards the local farmers who use liquid manure on their multiple properties- farmers are the backbone of our community, and without their services, we would be bereft of sustenance.

The results within this survey should highlight a growing need for collaboration between the agricultural and environmental sectors. To date, there lacks a substantive riparian buffer along all 4 tributaries surveyed (as well as multiple drainage ditches that lead through the agricultural fields and into the lake) as well as a strong riparian buffer around the lake itself. Increasing vegetation should be one of the top recommendations moving forward to decrease nutrient input.

While the cyanobacteria bloom was not as colossal as the bloom that occurred in 2021 within Darling's Lake, there was still indeed a bloom of smaller magnitude in 2022, and it allowed the HRAA to collect extremely valuable data. To date, the HRAA did not house any substantial water quality data on the 4 tributaries surveyed, nor within the lake itself. This project provided us with an in-depth look on the triggering mechanisms of cyanobacteria blooms, and we feel much more confident in our abilities to predict potential bloom occurrence in the future.

While the deployment of the EMF1000 did not stop the bloom from happening, it did indeed boost dissolved oxygen levels within a small radius. Investigation into other tools to increase dissolved oxygen is warranted. The deployment of the AlgaeTracker units was of extreme value- the HRAA highly encourages the Government of New Brunswick to invest in this technology and deploy it throughout the province. With this baseline data in hand, we will be able to program our trackers in 2023 to provide us with early alerts to signal bloom formation.

Many thanks to the NBETF, Darlings Island residents, and all our project partners!

-Sarah Blenis, HRAA Project Manager

WORKS CITED

Atlantic DataStream. *Water Quality Guidelines and Explanations.* 2022.

Blenis, Sarah., Kelly, Josh. *Hammond River Watershed Management Plan.* Hammond River Angling Association. 2020.

Canadian Council of Ministers of the Environment. *Canadian Environmental Guidelines for Aquatic Fish Health*. 2014.

Canadian Council of Ministers of the Environment. *Canadian Environmental Guidelines for Recreational Water Quality*. 2012.

Canadian Council of Ministers of the Environment. *Canadian Environmental Quality Guidelines*. 2017.

Department of Environment and Local Government New Brunswick. *A Water Strategy for New Brunswick 2018-2028.*

Government of New Brunswick. Get to Know Cyanobacteria. 2022.

Health Canada. *Guidelines for Canadian Recreational Water Quality*. 2021.

Health Canada. *Cyanobacteria and Their Toxins*. 2022.

Jiang, Hai-Bo et al. *New Insights into Iron Aquisition by Cyanobacteria*. 2014.

Jones, Bill. *Interpreting Lake Data - Indiana Clean Lakes Program*. 2003.

Lingling, Wan et al. *Phosphorus Strategy in Bloom Forming Cyanobacteria*. 2019.

Lurling, Miguel et al. *Response of Natural Cyanobacteria to a Nutrient Pulse and Elevated Temperatures.* 2018.

NBDELG. *The State of Water Quality in New Brunswick's Lakes and Rivers*. 2019.

Pettersson, Anette et al. *Aluminum Effects on Uptake of Phosphorus on Cyanobacterium*. 1988.

Rastogi, Rajesh et al. *Bloom Dynamics of Cyanobacteria and Their Toxins: Environmental Health Impacts and Mitigation Strategies.* 2015.

Sachidananda, Mishra et al. *Quantifying Cyanobacterial Phycocyanin in Turbid Productive Waters*. 2013.

US Environmental Protection Agency. *Managing Cyanotoxins in Recreational Waters.* 2022.