Project Abstract

M.L. 2016, Chp. 186, Sec. 2, Subd. 04b; and M.L. 2015, Chp. 76, Sec. 2, Subd. 10

For the Period Ending June 30, 2019

PROJECT TITLE: Assessing the Increasing Harmful Algal Blooms in Minnesota Lakes

PROJECT MANAGER: Miki Hondzo
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML. 2016; M.L. 2015

APPROPRIATION AMOUNT: $ 341,000
AMOUNT SPENT: $ 327,700
AMOUNT REMAINING: $ 18,300

Sound bite of Project Outcomes and Results

We designed a cyanobacterial profiler to record and display continuous data on physical and micro-algal conditions in lakes over the Internet. The data revealed an approximate seven days time-lag between the maximal cyanobacterial biomass and toxin concentrations. Spreadsheet-type models were developed for predicting cyanobacterial biomass and toxin concentration in lakes.

Overall Project Outcome and Results

Harmful algae, including cyanobacteria, have been populating a growing number of freshwater ecosystems including lakes, rivers, and wetlands in Minnesota. Excessive accumulation of harmful algal biomass and associated toxin generation is referred to the public as a harmful algal bloom (HAB). The algal toxins, called microcystins, are harmful to wildlife and humans. The overall objective of this study was to determine how lake physical processes and meteorological conditions control HABs in three Minnesota lakes. We designed and implemented a unique research station to document HABs and toxin generation. This research station provides full-depth water quality (hourly) and meteorological conditions monitoring (5 min) at the sampling site and the display of data over the Internet. The high cyanobacteria biovolume (BV) in the approximate 4 m of the lake surface water depth was observed in mid-July and persisted until late September. Two types of BV distributions were observed. The first distribution depicted BV uniformly distributed over the surface water depth, and the second BV distribution displayed local underwater BV maxima. A quantitative relationship was developed to determine the anticipation of observing a uniform or underwater peak distribution as a function of the lake physical and meteorological conditions. Toxin microcystins (MC) was observed to accumulate in the lake surface layer and had a vertical distribution similar to BV. The temporal variabilities of BV and MC were different. The maximum toxin concentration occurred on average, seven days before or after the maximum HAB concentration was established. The time-lag between the maxima of BV and MC is notable because the maximum toxin concentration could occur before the visual signs of enhanced cyanobacterial accrual are less recognizable to the public and monitoring. Our findings could have important implications for predicting toxin and cyanobacterial biomass distribution and guiding monitoring strategies for quantifying toxin concentrations in Minnesota lakes.

Project Results Use and Dissemination

Public education and outreach were an integral part of our project. We had a total of 19 separate outreach and educational activities. We held six (6) different public outreach activities conducting over 365 different individual conversations and conducted five (5) in-person workshops with over 460 participants. The project produced three (3) peer-reviewed publications (attached to this report). A new HAB focused webpage was also developed, which remains active. We also purchase, retrofitted, and set-up a mobile educational trailer to provide hands-on HAB educational activities, including demonstrating the use of drones and spectral camera in detecting and monitoring HABs.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2016 Work Plan Final Report

Date of Report: August 16, 2019

Final Report

Date of Work Plan Approval: June 7, 2015

Project Completion Date: June 30, 2019

PROJECT TITLE: Assessing the Increasing Harmful Algal Blooms in Minnesota Lakes

Project Manager: Miki Hondzo

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Location: St. Anthony Falls Laboratory (Hennepin County), Madison Lake (Blue Earth County), and South Center Lake (Chisago County), and Ramsey Lake ((Wright County)

		M.L. 2015, Chp. 76, Sec. 2, Subd. 10 Emerging Issues Account $	M.L. 2016, Chp. 186, Sec. 2, Subd. 04b Work Plan $
Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$71,000**	**$270,000**
	Amount Spent:	**$67,913**	**$254,787**
	Balance	**$3,088**	**$15,212**

Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 04b
M.L. 2015, Chp. 76, Sec. 2, Subd. 10

Appropriation Language:

M.L. 2016, Chp. 186, Sec. 2, Subd. 04b

$270,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Saint Anthony Falls Laboratory to investigate lake processes and meteorological conditions triggering algal blooms and toxin production, develop models for tracking blooms, and provide outreach on the prediction, detection, and impacts of mitigation of algal bloom events. This work must be done in cooperation with the St. Croix Watershed Research Station of the Science Museum of Minnesota and the Minnesota Pollution Control Agency. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

M.L. 2015, Chp. 76, Sec. 2, Subd. 10

$1,000,000 the first year is from the trust fund to emerging issues account authorized in Minnesota Statutes, section 116P.08, subdivision 4, paragraph (d).

Upon the recommendation of the Legislative-Citizen Commission on Minnesota Resources, the research teams of University of Minnesota (St. Anthony Falls Laboratory; Proposal 038-B) and the Science Museum of Minnesota (Proposal 037-B) had a meeting at the LCCMR office on November 10, 2015. To facilitate collaboration, eliminate duplicate efforts, and amplify synergistic discoveries related to harmful algal blooms, the researchers established a working agreement on where and when to sample harmful algae in Minnesota lakes.

I. PROJECT TITLE: Assessing the Increasing Harmful Algal Blooms in Minnesota Lakes

II. PROJECT STATEMENT:
Harmful algae, including cyanobacteria, are photosynthetic organisms that have been populating a growing number of freshwater ecosystems, including lakes, rivers, wetlands, and stormwater ponds in Minnesota (Lindon and Heiskary, 2009). Change in land use and agricultural practices have been contributing to the degradation of water quality in Minnesota aquatic ecosystems. Such human-induced activities along with the increasing summer lake water temperatures have been establishing fertile environmental conditions for triggering harmful algal blooms.

The blooms are classified as harmful because the algae (e.g., *Microcystis*) release cyclic heptapeptide hepatoxins, called microcystins, which are harmful to wildlife and humans. Quantifying intra-cellular toxin production and extra-cellular toxin concentrations in Minnesota lakes, under variable meteorological and lake physical conditions, is crucial for understanding, predicting, and mitigating harmful algal blooms. The excessive growth of harmful algae and toxin production presents a risk to public health (drinking water supply and recreational activity), has economic importance (water quality and transparency) and has ecologic significance (wildlife survival). The biological and chemical processes that trigger excessive growth of harmful algae have been studied extensively, but the meteorological conditions and corresponding lake physical processes that produce, sustain, and destroy algal growth and toxin production have received relatively little attention.

The objective of this study is to determine how lake physical processes and meteorological conditions control *Microcystis* growth and toxin production in Minnesota lakes. Quantifying intra-cellular toxin production and extra-cellular toxin concentrations under variable meteorological and lake physical conditions is very important for understanding, predicting, and responding to *Microcystis* blooms in Minnesota lakes. In collaboration with the Minnesota Pollution Control Agency and the Science Museum of Minnesota, we propose laboratory and field investigations on harmful algal blooms to 1) develop and deploy a cyanobacterial profiler with wireless data transfer and real-time data assessment over the Internet; 2) asses *Microcystis* and toxin concentration levels in Minnesota lakes before, after, and during blooms, 3) reproduce in the laboratory lake physical and meteorological conditions able to generate high *Microcystis* growth and toxin concentrations, 4) develop predictive models based on field and laboratory measurements, and 5) establish state-wide education outreach and training programs.

Lindon M., and S. Heiskary (2009). Blue-green algal toxin (microcystin) levels in Minnesota lakes, *Lake and Reservoir Management*, 25, 240-252.

III. OVERALL PROJECT STATUS UPDATES:

Project Status of July 1, 2016:
The proposed objectives have not changed. We developed and deployed the cyanobacterial profiler with wireless data transfer and real-time data assessment over the Internet. The profiler was installed in the Madison Lake (Blue Earth County; ID 07-0044) on June 14, 2016.

Project Status as of January 1, 2017:
From June 14 to October 25, 2016, we collected water temperatures, dissolved oxygen concentrations, microcystin concentrations, pH, and photosynthetically active radiation levels in Madison Lake. Weekly water samples were collected at the location of the buoy for the analysis of cyanobacterial algal species, phycocyanin, and nutrient concentrations. Since November, we have been analyzing the data to observe correlations between the concentration of cyanobacteria and driving environmental parameters.

Project Status as of July 1, 2017:
From January 1 to June 30, 2017, we analyzed the data of Madison Lake and submitted a manuscript for the publication in the Water Resources Research journal. The title of the paper is "Investigating Abiotic Drivers for Vertical and Temporal Heterogeneities of Cyanobacteria Concentrations in Lakes Using a Seasonal In-situ Monitoring Station," and the authors are A. A. Wilkinson (graduate student on this project), M. Hondzo (PI), and M. Guala (Co-PI). The key points are:
• Cyanobacteria bloom in Madison Lake in 2016 was observed to be driven by prolonged warm surface water temperatures and strong thermal stratification stability. This biomass persisted throughout the season, with high concentrations observed below the surface.
• A strong correlation was quantified between cyanobacteria vertical heterogeneity, thermal stability, and surface water temperature.
• The depth of maximum cyanobacteria biomass shows diurnal patterns, following the thermocline depth and light conditions, with sub-surface maxima localized at depths where photosynthetically active radiation is approximately ten μE/m2 s.

Project Status as of January 1, 2018:
From July 1 to October 31, we monitored physical, chemical. Meteorological, and algal biological conditions in the South Center Lake (Chisago County; ID13-0027). The monitoring stations were removed from the lake and stored at the St. Anthony Falls Laboratory on October 31, 2017. Since November, we have been working on the analysis of data.

Project Status as of July 1, 2018:
From Jan 1 to Jul 1, we analyzed physical, chemical, and algal conditions in the South Center Lake. The data were compared with the analysis in Madison Lake. On May 17, 2018, we deployed the cyanobacterial profiler, and meteorological station in the Ramsey Lake (Wright County, ID 8601-2000). The monitoring station will be removed from the lake in October, 2018.

Amendment approved by LCCMR Jan 28, 2019 (requested in November of 2018)
We request to redistribute (re-budget) available resources in Activity 4: Education and public outreach:

1) Increase personnel from 20,895 to 21,320
2) Decrease Equipment/Tools/Supplies from $10,000 to $4,300) and add a trailer to the list of non-capital equipment to be purchased.
3) Eliminate printing costs - $1,000 to $0
4) Reduce travel costs from $8,625 to $1,200
5) Add a line item for $13,700 capital equipment to allow us to purchase a spectral camera and ancillary equipment.

The reason for this change is: we spent less than anticipated in Activity 4 due to in-kind contribution of St. Anthony Falls Laboratory (not charging the usage of the auditorium for the meetings and workshops), and Water Resources Center – Extension (covering the cost of invited speakers at the workshop); and rapid change in the technology of the detection of harmful algal blooms have led us to believe we need to purchase new detection equipment to demonstrate as part of our outreach efforts.

The objectives and outcomes for Activity 4 have not been changed about our original proposal. Based on our phone conversations with Mr. Michael McDonough, we revised Activity 4 and updated the budget.

Project Status as of January 1, 2019:
On October 18, 2018, we removed the cyanobacterial profiler and meteorological station Ramsey Lake (Wright County, ID 8601-2000). The monitoring station successfully collected meteorological and lake data from May 17 to October 18, 2018. Each day, the monitoring station collected 12 vertical profiles.

Project Status as of July 1, 2019
The data for Ramsey Lake have been analyzed and compared with the data of Madison Lake and South Center Lake. We have been working on the predictive models of thermal stratification, cyanobacterial biomass distribution, and microcystin occurrence in the selected three lakes. The prediction models range from simple spreadsheet type predictors to three-dimensional models.

Overall, Project Outcomes and Results:
We proposed field and laboratory measurements of harmful algal blooms in three Minnesota lakes. The field measurements were conducted in Madison Lake, South Center Lake, and Ramsy Lake. The objectives of the project, results, and outcomes are summarized below.

Objective 1: Develop and deploy a cyanobacterial profiler with wireless data transfer and real-time data assessment over the Internet. **Results:** The proposed cyanobacterial profiler was developed and successfully deployed in Madison Lake, South Center Lake, and Ramsey Lake from May to October with sampling interval every 2 hours. The profiler is equipped with wireless data transfer equipment and can be displayed over the Internet in real-time. **Outcomes:** The profiler generated for the first time continuous data on physical, chemical, and cyanobacterial biomass conditions and revealed the importance of meteorological and hydrodynamic lake conditions on the formation of cyanobacterial blooms and high toxin concentrations (Wilkinson et al., 2019a).

Objective 2: Asses *Microcystis* and toxin concentration levels in Minnesota lakes before, after, and during blooms. **Results:** Cyanobacterial and toxin concentrations were collected in three selected lakes at multiple depths approximately weekly from May to October. **Outcomes:** The data revealed a time-lag between the maximal cyanobacterial biomass and toxin concentrations in all lakes. The maximum microcystin concentration occurred before the maximum cyanobacterial biomass and specifically, during the onset of significant biomass growth in Madison and South Center Lakes. In Ramsey Lake, the time-lag occurred after the maximum cyanobacterial biomass was established. This observation is notable because the maximum toxin concentration could occur before the visual signs of enhanced cyanobacterial accrual are less recognizable to the public and monitoring efforts (Wilkinson et al., 2019b).

Objective 3: Reproduce in the laboratory lake physical and meteorological conditions able to generate high Microcystis growth and toxin concentrations. **Results:** Under laboratory conditions, we designed bioreactors which enabled good growth and colony formation of Microcystis Aeruginosa. The laboratory setup generated temperature and turbulent flow conditions comparable to field values in three selected Minnesota lakes. **Outcomes:** The results revealed that small-scale turbulence mediates the metabolism of Microcystis aeruginosa measured by the net oxygen production, oxygen uptake, and inorganic carbon uptake. Furthermore, small-scale turbulence marginally influenced Microcystis growth rate (Wilkinson et al., 2016; You et al., 2018).

Objective 4: Develop predictive models based on field and laboratory measurements. **Results:** We designed laboratory bioreactors which reproduce accurately fluid and hydrodynamic conditions for the growth of cyanobacteria under controlled conditions. The cyanobacterial profiler was designed to document spatial and temporal variabilities of cyanobacteria, physical, chemical, and meteorological conditions. **Outcomes:** Scaling relationships were developed among cyanobacterial bio-volume (BV) concentration, thermal stratification stability, and surface water temperature, meteorological conditions, and toxin concentrations. The proposed scaling relationship is relevant to sampling protocols of harmful algal blooms as it informs if the sample depth is representative of the entire water column. Our observations suggest that the temporal/vertical variability of cyanobacteria BV is strongly influenced by lake dynamics, thermal structure, seasonal temperature variation, and light availability. (Wilkinson et al., 2019a; Wilkinson et al., 2019b).

Objectibve 5: Establish state-wide education outreach and training programs. **Results:** We organized "Harmful Algal Blooms" workshops at the St. Anthony Falls Laboratory, the University of Minnesota in March of 2017 and 2018. The workshop included the following modules: HABs research, HABs prediction and modeling, HABs detection and tracking, HABs outreach communication and education. Through this project, we established a "MN HABs" group. Designed webpage and educational materials on HABs "http://hab.umn.edu " We also purchase, retrofitted, and set up a mobile educational trailer to provide hands-on HAB educational activities, including demonstrating the use of drones and spectral camera in detecting and monitoring HABs. We utilized multiple approaches, tools, and delivery systems to provide an effective HAB outreach and educational program. **Outcomes:** We have facilitated public awareness, establish focus groups, and launched a project website (http://hab.umn.edu) on HABs in Minnesota lakes. We had a total of 19 separate outreach and educational activities. We held six (6) different public outreach activities conducting over 365 different individual conversations and conducted five (5) in-person workshops with over 460 participants. We also published six (6) news articles, in various University of Minnesota magazines and newsletter reaching thousands of subscribers.

Funding for our project generated following publications with the acknowledgment of LCCMR support. The publications are attached to this report (please see file Hondzo_Publications_HAB.pdf).

Wilkinson, A., Hondzo, M., and M. Guala (2016). Effect of Small-Scale Turbulence on the Growth and Metabolism of Microcystis aeruginosa, *Advances in Microbiology*, 6, 351-367.

You, J., Mallery K., Hong J., and M. Hondzo (2018). Temperature Effects on Growth and Buoyancy of Microcystis Aeruginosa, *Journal of Plankton Research*, 40(1), 16–28.

Wilkinson, A., Hondzo, and M., Guala (2019a). Investigating Abiotic Drivers for Vertical and Temporal Heterogeneities of Cyanobacteria Concentrations in Lakes Using a Seasonal *In-Situ* Monitoring Station, *Water Resources Research*, 55(2), 954-972.

Wilkinson, A., Hondzo, M., and M. Guala (2019b). Vertical Heterogeneities of Cyanobacteria and Microcystin Concentrations in Lakes Using a Seasonal In situ Monitoring Station, *Freshwater Biology*, under revision.

Overall Project Outcome and Results

Harmful algae, including cyanobacteria, have been populating a growing number of freshwater ecosystems including lakes, rivers, and wetlands in Minnesota. Excessive accumulation of harmful algal biomass and associated toxin generation is referred to the public as a harmful algal bloom (HAB). The algal toxins, called microcystins, are harmful to wildlife and humans. The overall objective of this study was to determine how lake physical processes and meteorological conditions control HABs in three Minnesota lakes. We designed and implemented a unique research station to document HABs and toxin generation. This research station provides full-depth water quality (hourly) and meteorological conditions monitoring (5 min) at the sampling site and the display of data over the Internet. The high cyanobacteria biovolume (BV) in the approximate 4 m of the lake surface water depth was observed in mid-July and persisted until late September. Two types of BV distributions were observed. The first distribution depicted BV uniformly distributed over the surface water depth, and the second BV distribution displayed local underwater BV maxima. A quantitative relationship was developed to determine the anticipation of observing a uniform or underwater peak distribution as a function of the lake physical and meteorological conditions. Toxin microcystins (MC) was observed to accumulate in the lake surface layer and had a vertical distribution similar to BV. The temporal variabilities of BV and MC were different. The maximum toxin concentration occurred on average seven days before or after the maximum HAB concentration was established. The time-lag between the maxima of BV and MC is notable because the maximum toxin concentration could occur before the visual signs of enhanced cyanobacterial accrual are less recognizable to the public and to monitoring. Our findings could have important implications for predicting toxin and cyanobacterial biomass distribution and guiding monitoring strategies for quantifying toxin concentrations in Minnesota lakes.

Project Results Use and Dissemination

Public education and outreach were an integral part of our project. We had a total of 19 separate outreach and educational activities. We held six (6) different public outreach activities conducting over 365 different individual conversations and conducted five (5) in-person workshops with over 460 participants. The project produced three (3) peer-reviewed publications (attached to this report). A new HAB focused webpage (http://hab.umn.edu) was also developed, which remains active. We also purchase, retrofitted, and set-up a mobile educational trailer to provide hands-on HAB educational activities, including demonstrating the use of drones and spectral camera in detecting and monitoring HABs.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Develop and deploy a cyanobacterial profiler

Description:

Harmful algal blooms and related toxic conditions are highly variable in both space and time. Quantifying and understanding them requires novel measurement technologies and monitoring systems not commonly available. Based on our long-term proven experience in the area of lake water quality monitoring, we will develop a unique and robust cyanobacterial and water quality profiler for continuous monitoring of harmful algal blooms in Minnesota lakes.

The profiler will have wireless data transfer and real-time data assessment over the Internet. The sampling sensors will generate data over the lake depth, including cyanobacterial concentration, temperature, pH, dissolved oxygen, depth, and photosynthetically active radiation. Sampling times and depths will be adjustable over the Internet. The data will provide a virtual field laboratory for research and educational outreach.

During the period Feb-Apr, 2016, the instrumentation will be developed, and laboratory tested at SAFL so that the field monitoring program, scheduled to begin in April 2016, can commence without delay. The profiler will generate three years of harmful algal blooms monitoring during the “open water”, or “ice-free” season (Apr-Oct, 2016-18). During these periods, we will measure the water quality and meteorological parameters responsible for triggering harmful algal blooms in Minnesota lakes.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 71,000**
Amount Spent: $ 71,004
Balance: $ -4

Outcome	Completion Date
1. Cyanobacterial and water *quality profiler development, construction and verification at the St. Anthony Falls Laboratory*	April 1, 2016
2. Cyanobacterial profiler deployment in *Madison Lake (Blue Earth County; ID 07-0044). Data acquisition, wireless transfer, and display over the Internet*	June 30, 2016
3. Cyanobacterial profiler deployment in South Center Lake *(Chisago County; ID13-0027)* on May 18, 2017. The profiler will be removed from the lake at the end of October of 2017.	October 31, 2017
4. Cyanobacterial profiler deployment in Ramsey Lake *(Wright County, ID 8601-2000) on May 17, 2018*. The cyanobacterial profiler and meteorological station were removed from the lake on October 18. The outcome of the monitoring effort generated extensive data base cyanobacterial concentrations, water quality, and meteorological parameters over the lake depth every two hours from May 17 to October 18.	October 31, 2018

Activity 1 Status as of July 1, 2016:

The proposed cyanobacterial profiler was designed and constructed at the St. Anthony Falls Laboratory. Before the deployment in Madison Lake, the profiler was tested at the outdoor basins of St. Anthony Falls Laboratory (Figure 1 left). During the testing procedure, communication protocols, sampling software, and the wireless operation of the profiler were tested. The overall proposed and used expenditures have been within the approved budget (please see budget attachment).

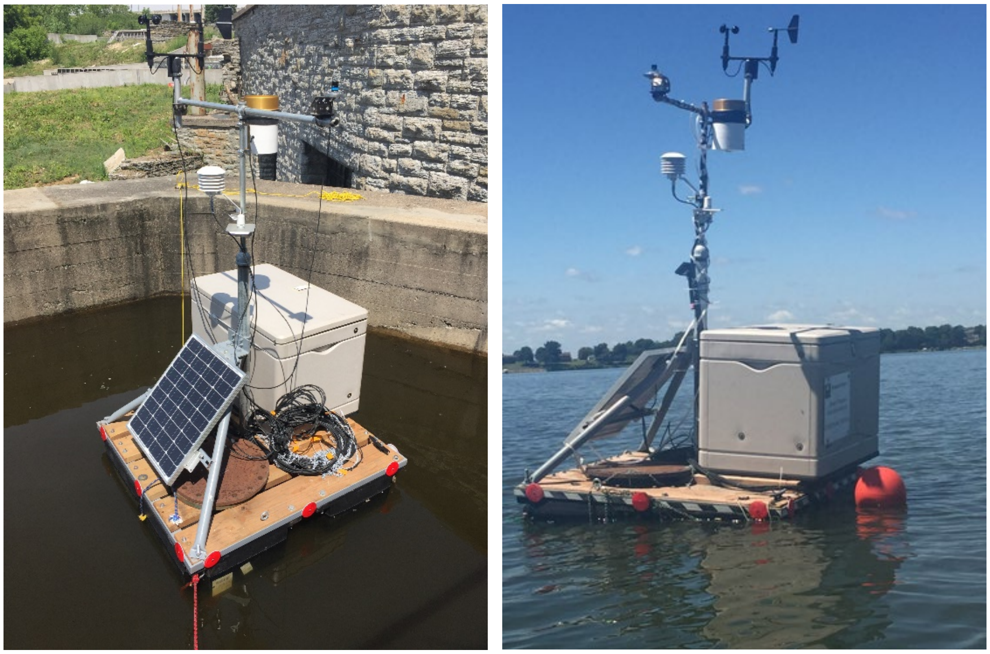


Figure. The proposed cyanobacterial profiler with meteorological sensors, traversing stepper motor, and solar panel. Left: Design and testing procedure at the St. Anthony Falls Laboratory. Right: The profiler deployed in Madison Lake, MN, on June 14, 2016.

Activity 1 Status as of January 1, 2017:
After the satisfactory testing performance at the St. Anthony Falla Laboratory, the profiler was deployed in Madison Lake MN (Figure 1 right). The profiler collected the environmental variables and meteorological conditions above the lake surface until November 25, 2016.

Activity 1 Status as of July 1, 2017:
The profiler successfully collected all the lake data from May 18 to June 30, 2017. The cyanobacterial profiler photo in the South Center Lake and the corresponding thermal stratification and phycocyanin concentrations are provided in figures below.

Figure. The cyanobacterial profiler with meteorological sensors, traversing stepper motor, and solar panel at the South Center lake. The profiler was deployed on May 18th, 2017.

Activity 1 Status as of January 1, 2018

The profiler successfully collected all the lake data from May 18 to October 31, 2017. The cyanobacterial profiler photo in the South Center Lake and the photo of the graduate student during a collection of the samples in the lake are provided below.

Activity Status as of July 1, 2018

The cyanobacterial profiler was successfully deployed in Ramsey Lake (Wright County). The project participants established communication and collaboration with the Lake Association. Since May 17, 2018, we have been monitoring the lake, including a daily data inspection through the wireless network and bi-weekly field visits to the lake.

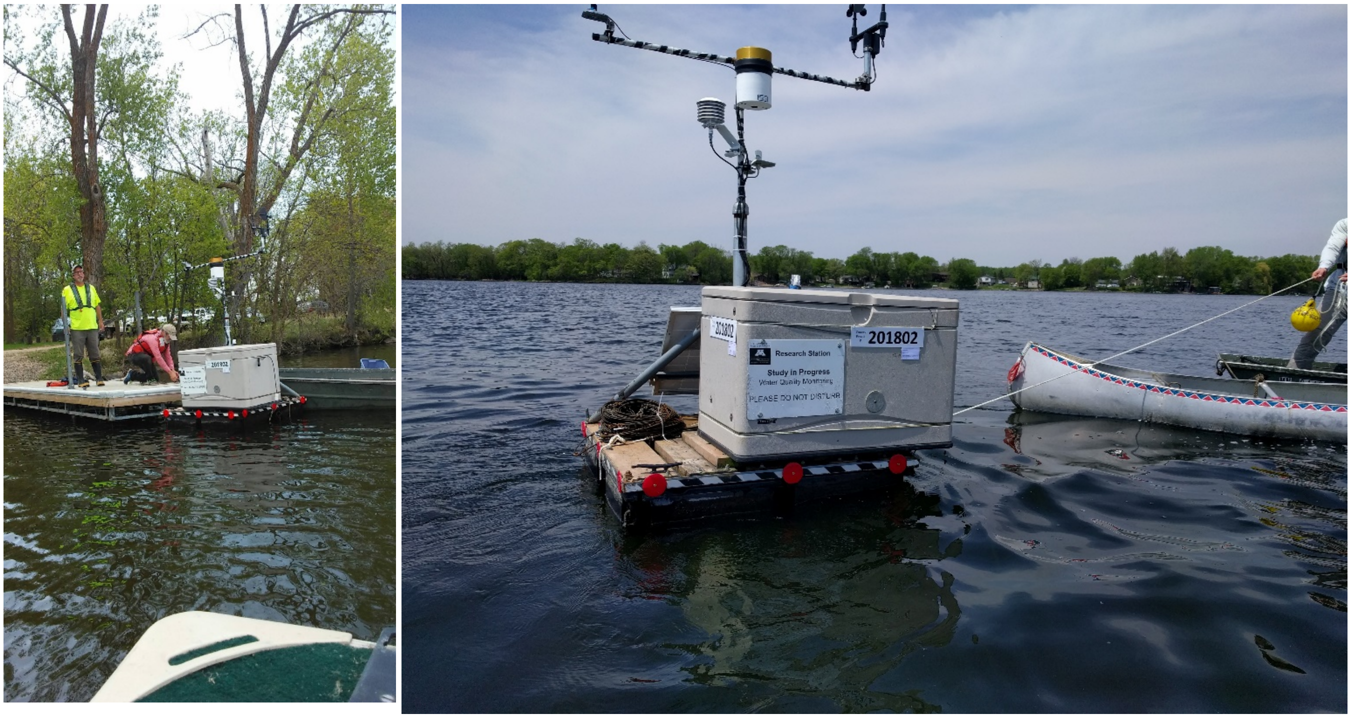


Figure. The cyanobacterial profiler with meteorological sensors, traversing stepper motor, and solar panel at the Ramsey Lake. The profiler was deployed on May 17th, 2018.

Activity Status as of January 1, 2019

The cyanobacterial profiler and meteorological station were successfully removed from Ramsey Lake on October 18, 2018. Since October 18, 2018, we have been working on the analysis of data and documenting possible improvements in the monitoring efforts.

Activity Status as of July 1, 2019

The cyanobacterial profiler dissembled and stored at the St. Anthony Falls Laboratory for future research on HAB in Minnesota Lakes.

Final Report Summary:

Our objective was to develop and deploy a cyanobacterial profiler for detecting meteorological, physical, chemical, and cyanobacterial concentration conditions in Minnesota lakes. The cyanobacterial profiler was successfully designed and deployed in three Minnesota lakes. The profiler consists of a floating platform with three synchronized measuring systems. For local weather conditions, a 1.5-m-high meteorological station enables simultaneous measurements of wind speed, wind direction, ambient photosynthetically active radiation (PAR), air temperature, and relative humidity. These measurements were sampled at 1 Hz, 60 samples per minute, were connected to a data logger (Campbell Scientific, UT, USA). The data logger outputs 5-min average for all meteorological station data. The second measuring component is a water quality profiler measuring every 0.5 m, in a range of 1- to 8.5-m depths, profiling every 2 hr. The specific multiprobe was a Hydrolab DS5 Water Quality Multiprobe (Hach Environmental, CO, USA) which was equipped with pH, dissolved oxygen, temperature, PAR, specific conductivity, and phycocyanin fluorometry (Turner Designs, CA, USA,) sensors. The probe was suspended in the water at 1 m until it was triggered to profile on every even hour. For every profile (12/day), the probe was lowered by a motorized reel (Hannay Reels, NY, USA) at 0.5 m increments and acquired measurements from each sensor at that depth for 2 min. The third measuring system was an anchored thermistor chain with 12 stainless steel temperature probes (Campbell Scientific, UT, USA) placed every 0.5 m (in the range 0–2.5 m) and every meter (in the range of 3.5–8.5 m). The data logger outputs 5-min average temperature data at all depths. All the Hydrolab, meteorological station and thermistor chain data were transferred to the main data logger (Campbell Scientific, UT, USA), which had wireless data transfer to a server, allowing real-time data assessment. The outcome of the monitoring effort is a unique dataset of cyanobacterial concentrations, water quality and meteorological and variables in three Minnesota lakes over the lake depth every two hours from May to October.

ACTIVITY 2: Investigate lake processes and meteorological conditions triggering harmful algal blooms and toxin production

Description:

The proposed activity will determine how lake physical processes and meteorological conditions control *Microcystis* bloom and toxin production in Minnesota lakes. In collaboration with the Science Museum of Minnesota and the Minnesota Pollution Control Agency (MPCA), the following lakes are selected for field measurements: Madison Lake (Blue Earth County; ID 07-0044), Peltier Lake (Anoka County; ID 02-0004), and South Center Lake (Chisago County; ID 13-0027) (please see SECTION IX: Visual Component). The selected lakes are part of the MPCA long-term monitoring program. The lakes are eutrophic with documented HABs in the past. The morphometry data of selected lakes (maximum depth and lake surface area) indicate that the selected lakes are dimictic (Madison Lake and South Center Lake) and polymictic (Peltier Lake). The proposed cyanobacterial profiler (Activity 1) will be deployed during the "open water" season in Madison Lake (Apr-Oct, 2016), Peltier Lake (Apr-Oct, 2017), and South Center Lake (Apr-Oct, 2018). During these periods, we will measure the water quality and meteorological parameters responsible for triggering harmful algal bloom and toxin production in Minnesota lakes.

Controlled laboratory measurements will be conducted at the St. Anthony Falls Laboratory, University of Minnesota, where we have developed experimental bioreactors and flumes to study *Microcystis* physiology under controlled temperature, light, nutrient, and turbulence conditions. The laboratory experiments will be guided by field measurements in the selected lakes. In the laboratory bioreactors, we will replicate the field conditions and systematically change fluid flow variables (4-5 turbulence levels) and nutrient concentrations (high and low phosphate and nitrate), while monitoring *Microcystis* growth and toxin production. The proposed toxin measurements will be quantified at the Center for Drug Design, University of Minnesota. The combination of proposed field and laboratory observations will be used to develop methods and tools for detecting and predicting harmful algal blooms and toxin production in Minnesota lakes.

Summary Budget Information for Activity 2:	**ENRTF Budget:**	**$ 193,923**
	Amount Spent:	**$ 177,927**
	Balance:	**$ 15,996**

Outcome	**Completion Date**
1. Quantified meteorological conditions (temperature, wind), lake physical variables (temperature, velocities, light) and nutrient concentrations (nitrate and phosphate) that trigger Microcystis bloom and toxin production in Madison Lake (2016), South Center Lake (2017), and Ramsey Lake (2018)	December 31, 2016 (Madison Lake) December 31, 2017 (South Center Lake) Jul 1, 2019 (Ramsey Lake)
2. Quantified physical variables and nutrient concentrations that trigger high Microcystis biomass and Microcystin concentration generation in bioreactors at the St. Anthony Falls Laboratory. The laboratory bioreactors will be populated by the field species of Microcystis (Madison Lake, 2016; South Center Lake, 2017; Ramsey Lake, 2018)	June 30, 2017 June 30, 2018 December 31, 2018 Jul 1, 2019

3. Quantified combinations of meteorological-physical-chemical conditions that maximize intra-cellular and extra-cellular toxin production	December 31, 2018 Jul 1, 2019

Activity Status as of January 1, 2017:
In Madison Lake, we collected water temperatures at ten water depths every 5 minutes and stored the data into a data logger (Figure 2).

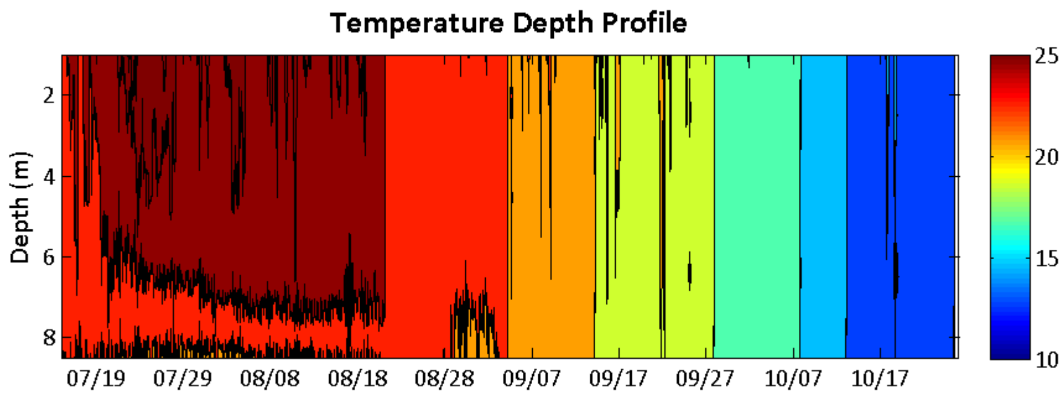


Figure 2. Temperature measurements in Madison Lake, MN, 2016. The color legend indicates water temperature in degrees Celsius. The y-axis is water depth starting at the lake surface and the x-axis is time.

At the lake surface, meteorological data (wind speed, wind direction, air temperature, and solar radiation) were collected every 5 minutes. Simultaneously, the data were transferred over the Internet and displayed in the EcoLab for real-time inspection. The proposed profiler collected water quality and phycocyanin data with 0.5 m depth increment over the 10 m lake depth at the buoy location in the Madison Lake (Figure 3). The data were transferred over the Internet and displayed at the EcoLab.

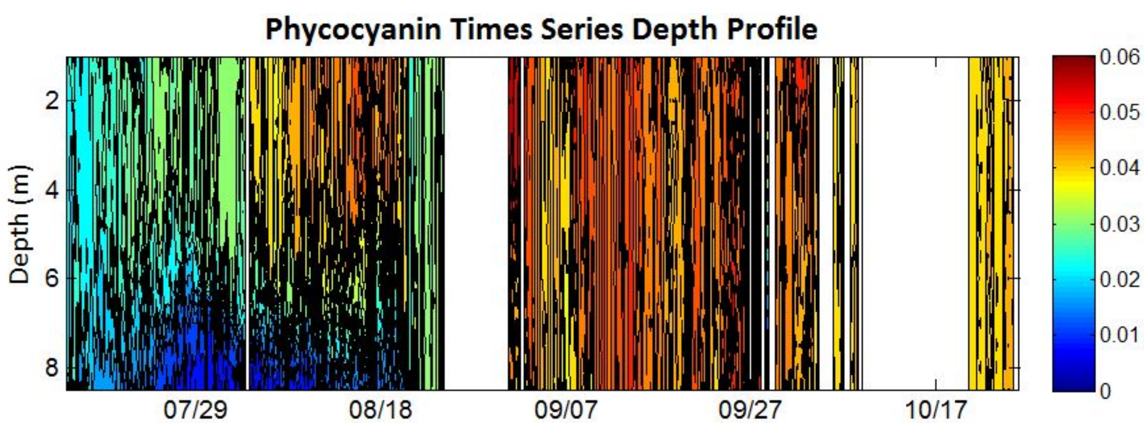
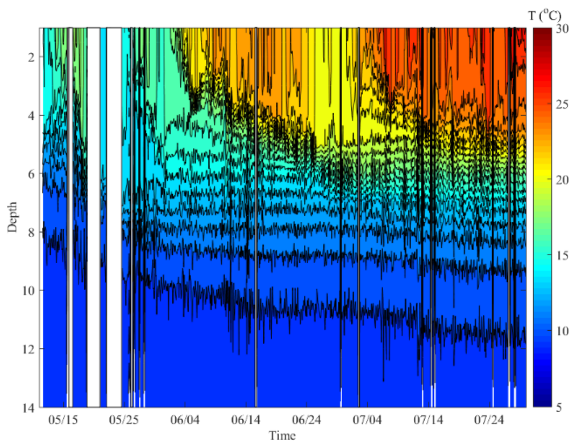


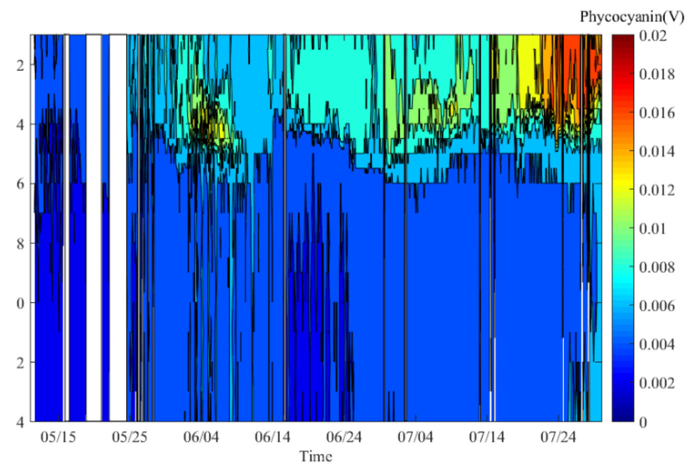
Figure 3. Phycocyanin measurements in Madison Lake, MN. The color legend indicates equivalent phycocyanin concentration in the lake. The y-axis is water depth starting at the lake surface, and the x-axis is time. The white rectangles (beginning of September and November) indicate periods when the profiler was not functioning to the excessive wind conditions above the lake surface.

Approximately, weekly field trips were conducted at Madison Lake. During the field campaign, we collected water samples over the depth of the lake for the analysis of cyanobacteria, nutrient, and phycocyanin concentrations. The data were analyzed at the EcoLab in the St. Anthony Falls Laboratory. During November and December, we have been quantifying and correlating the meteorological and lake physical data with Microcystis biomass concentrations. In the outdoor bioreactors, we have populated the water by cyanobacteria which are collected in Madison Lake. The objective is to investigate the effect of turbulence on the growth of Microcystis under the variable environmental conditions of wind, temperature, and solar radiation.

Activity Status as of July 1, 2017:

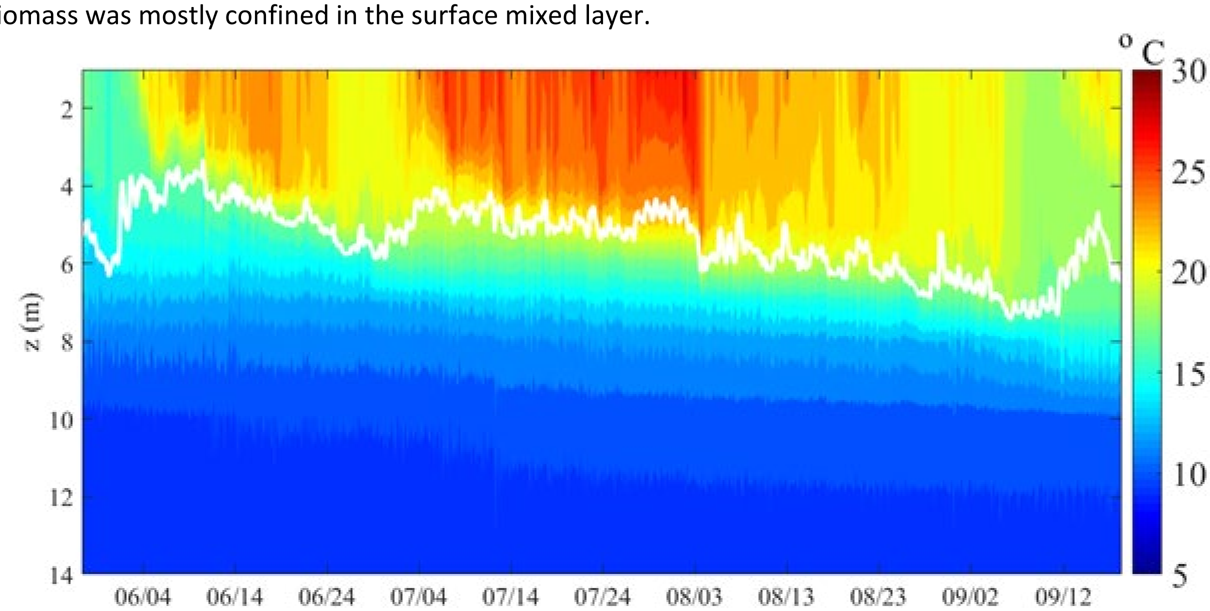
In the South Center Lake, we collected water temperature, dissolved oxygen, pH, light, phycocyanin, nutrient, and algal biomass data. The lake is seasonally stratified and promotes high cyanobacterial concentrations in the surface (epilimnion) layer. An example of temperature contours (figure below left) and the corresponding phycocyanin data (figure below right) is provided below.



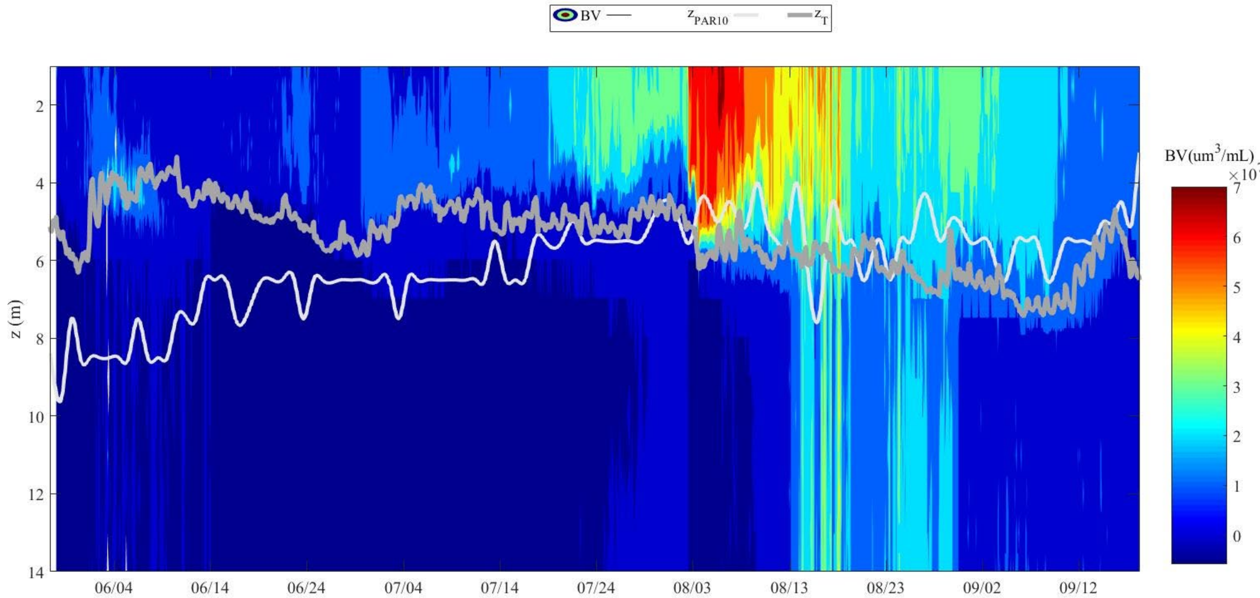


Activity Status as of January 1, 2018:

Water temperature and cyanobacterial biomass conditions were quantified in the South Center Lake. The corresponding thermal structure in the lake is provided below. The lake experienced a typical dimictic thermal regime whereas water temperature stratification was stable from May to October of 2017. Cyanobacterial biomass was mostly confined in the surface mixed layer.



The corresponding algal biovolume (BV), thermocline depth (maximum temperature gradient), and underwater photosynthetically active radiation (PAR) at PAR=10 (μE $m^{-2}s^{-1}$) are depicted below. It is apparent that algal BV follows the trend of thermocline depth, which indicates the importance of lake hydrodynamics on the distribution of algal biomass.



Activity Status as of July 1, 2018:
We quantified a wide range of local meteorological conditions, water temperature, and water chemistry, including phycocyanin, in Madison Lake and South Center Lake. The monitoring effort was coupled with discrete weekly sampling measuring nutrients, cyanobacteria composition, and microcystin concentrations. Our objective was to describe the distributions of cyanobacteria biovolume (BV) and microcystin concentrations (MC) using physical lake parameters.

Two types of BV distributions were observed above the thermocline. The first distribution depicted BV uniformly distributed over the diurnal surface mixed layer (SL). The second BV distribution displayed local BV maxima near and under the water surface. MC and BV accumulated above the thermocline and were highly correlated. Understanding vertical distribution of BV and MC is important for directing sampling efforts, because it narrows the range of BV and MC heterogeneity above the thermocline, and suggests a more (or less) detailed vertical sampling protocol to detect potential maxima and compute representative depth-average concentrations.

We explored the temporal variability of the MC to BV ratio, spatially averaged in the epilimnion (MCep / BVep). The maximum MCep / BVep occurred before the maximum BVep and specifically, during the onset of significant biomass growth. This observation is notable because the maximum MCep/BVep occurs before substantial BV accumulation when the physical signs of HABs are less recognizable to the public and surface monitoring efforts. Our findings could have important implications for predicting MC distribution and guiding monitoring strategies for quantifying MC concentrations in stratified lakes.

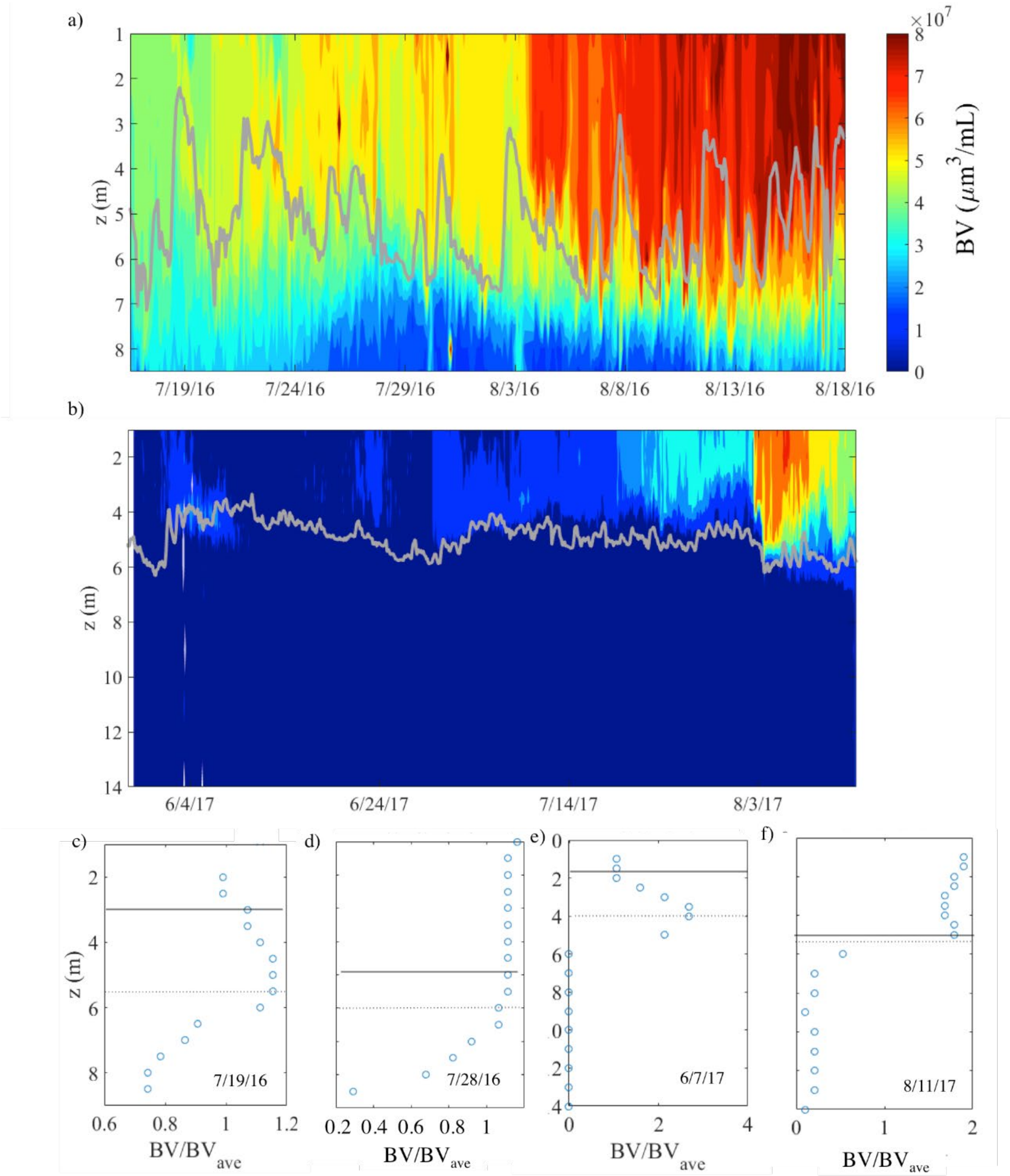


Figure. The temporal contour of BV water column profiles, where the gray line is the thermocline depth for a) Madison Lake and b) South Center Lake. c-f) Selected BV profiles from c,d) Madison Lake and e,f) South Center Lake. The dotted line is the thermocline depth, and the solid line is the depth of the diurnal surface layer.

Activity Status as of January 1, 2019:

We quantified cyanobacterial biovolume (BV) vertical distribution and the corresponding microcystin vertical distribution to explore possible correlations between the maxima of BV and MC in two monitoring lakes (Figure below). For all dates, a uniform BV distribution was observed in the surface layer, decaying with a steep gradient in the proximity of the thermocline zT. For both lakes, similar patterns in the distribution of BV and MC were observed. However, Madison Lake exhibits low MC concentrations that are close to the detection limit and are therefore more noisy profiles. The vertical MC distributions qualitatively agree with the BV profiles for all the monitored days. MC was fairly homogeneous in the surface mixed layer and negligible below the thermocline.

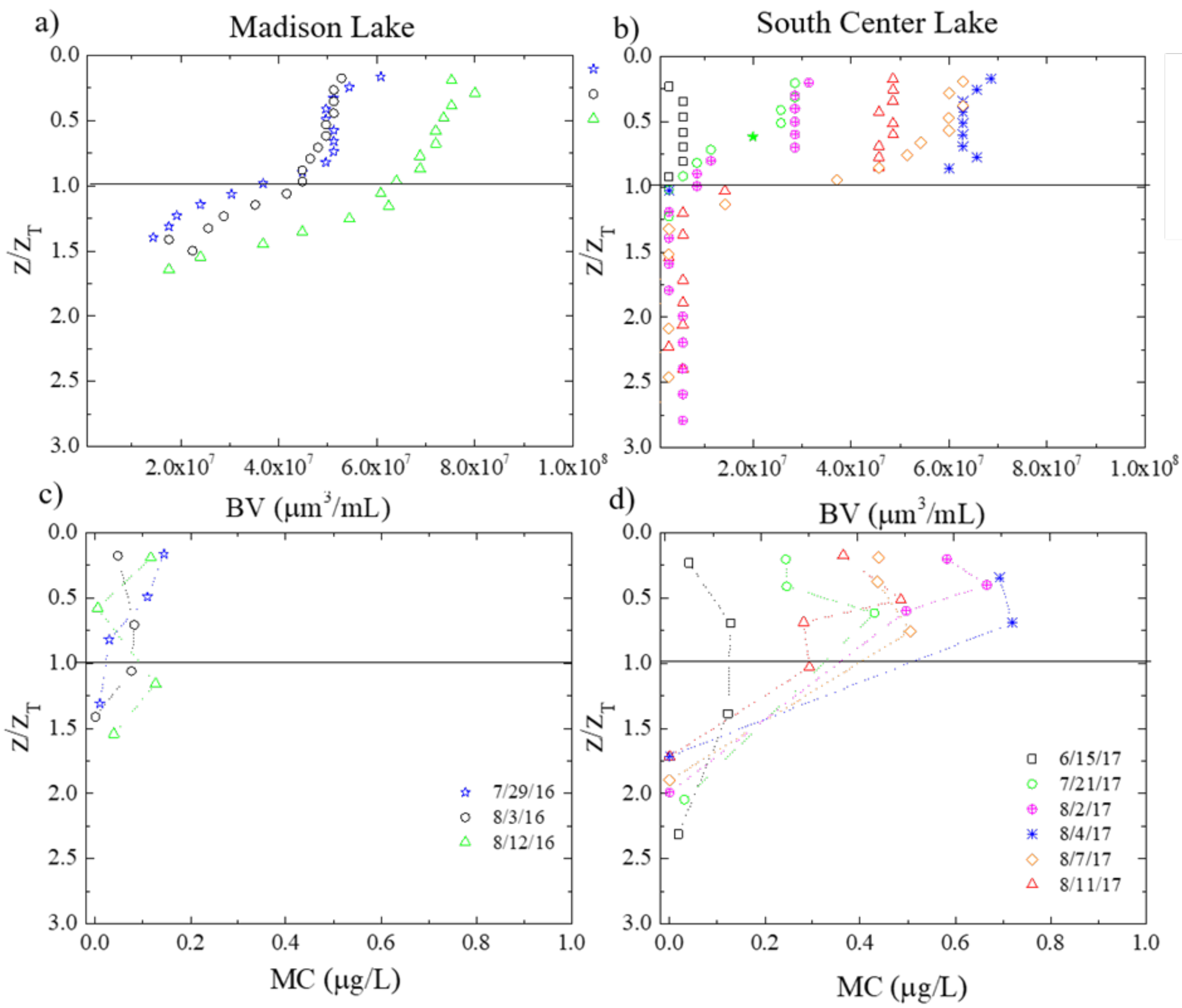
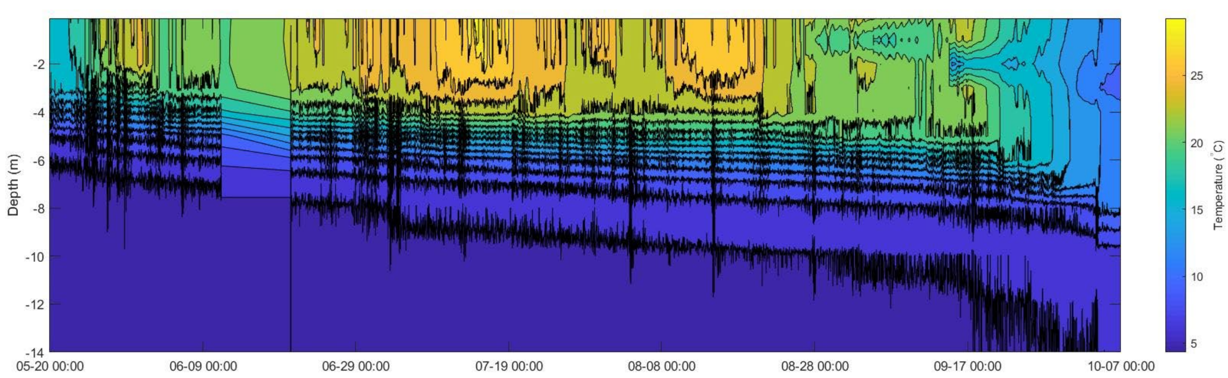
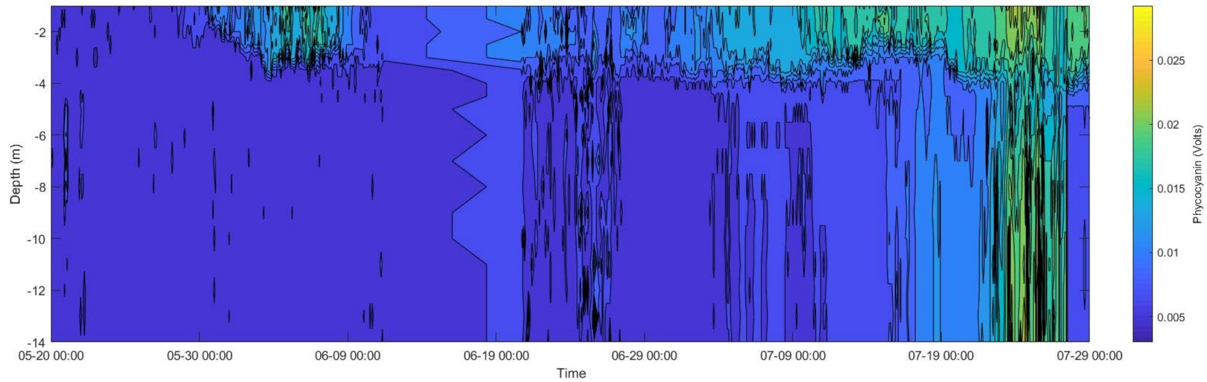


Figure. Vertical cyanobacterial biovolume (BV) and microcystin concentration (MC) profiles normalized by the thermocline depth z_T from samples throughout the season in Madison Lake (a,c) and South Center Lake (b, d). Each MC data point is an average of duplicate samples. The horizontal line represents the thermocline depth.

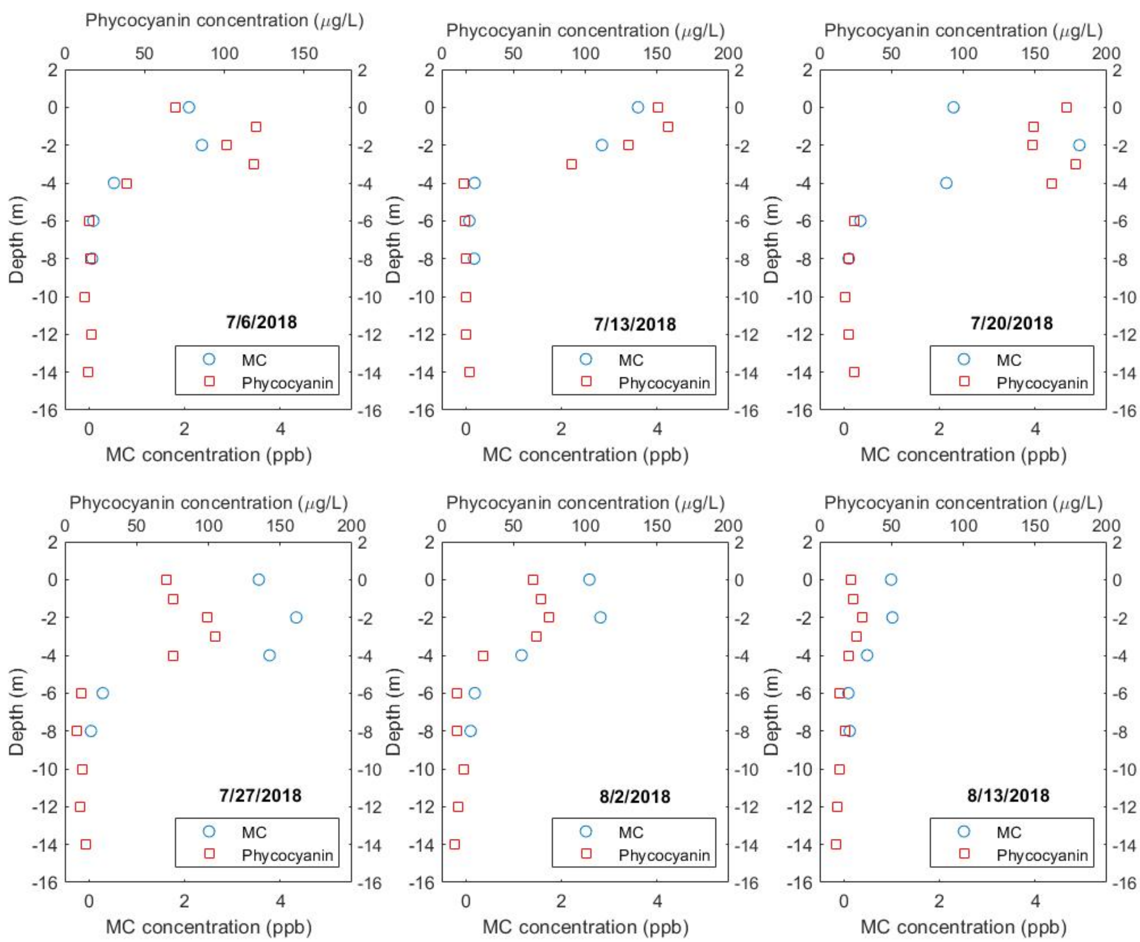
Activity Status as of July 1, 2019:

In the Ramsey Lake, we collected water temperature, dissolved oxygen, pH, light, phycocyanin, nutrient, and algal biomass data. The lake is seasonally stratified and promotes high cyanobacterial concentrations in the surface (epilimnion) layer. An example of temperature contours (figure below top), and the corresponding phycocyanin data (figure below bottom) are provided below.





Also, weekly grab samples were collected and analyzed for the microscopic verification of cyanobacteria and toxin concentrations. An example of the analysis of grab samples is provided below.



Final Report Summary:

During the strongly stratified period, cyanobacterial bio-volume (BV) accumulated above the thermocline and in the photic zone, with distinct peaks occasionally forming both near the water surface and at locations with photosynthetically active radiation approximately equal to 10 µE/m2s. Our observations suggest that the temporal/vertical variability of cyanobacteria BV is strongly influenced by lake dynamics, thermal structure, seasonal temperature variation, and light availability. The data in three Minnesota lakes demonstrate that cyanobacteria tend to move and accumulate in specific warm water layers, confined by the thermocline and determined by well-defined light conditions. Microcystin concentrations (MC) were observed to accumulate above the thermocline and have a vertical distribution similar to BV, thus depending on the surface Reynolds number (Re_{SL}). This is important for directing sampling efforts, because it narrows the range of BV and MC heterogeneity above the thermocline, and suggests a vertical sampling protocol to detect potential maxima and compute representative depth-average concentrations. The temporal variability of the MC to BV ratio spatially averaged in the epilimnion (MC_{ep} / BV_{ep}) suggests that the maximum MC_{ep} / BV_{ep} occurred before the maximum BVep and specifically, during the onset of significant biomass growth in both lakes. This observation is notable because the maximum MCep occurs before the visual signs of enhanced cyanobacterial accrual are less recognizable to the public and to monitoring efforts. Our findings could have important implications for predicting MC distribution and guiding monitoring strategies for quantifying MC concentrations in small stratified lakes.

ACTIVITY 3: Develop models for alerting and reporting harmful algal blooms
Description:
Monitoring harmful algal blooms is difficult because of their patchy and transient distribution in lakes. Also, toxin detection and harmful algal bloom identification usually take several days after the collection of samples. For the development of predictive models, we thus plan to use identified and verified proxies emerging from the proposed laboratory and field measurements (outcomes of Activity 1 and Activity 2). We will identify statistically significant variables that explain the presence of high *Microcystis* biomass and toxin concentrations. The variables will be grouped and implanted in the prediction models of *Microcystis* biomass and toxin production. A guiding principle will be to investigate available real-time data, including air and water temperatures, wind speed, as well as lake specific variables such as lake morphometry, stability, and stratification. An overall objective is to develop simple prediction models, which use the readily available proxies, for alerting and predicting harmful algal blooms and toxin production in Minnesota lakes.

Summary Budget Information for Activity 3:	**ENRTF Budget:**	**$ 35,557**
	Amount Spent:	**$ 35,557**
	Balance:	**$ 0,0**

Outcome	Completion Date
1. Developed scaling relationships for assessing HABs in MN lakes	January 1, 2018
2. Developed scaling relationships for assessing toxin production in MN lakes	July 1, 2018
3. Developed models for predicting HABs and toxin production in MN lakes	Jul 1, 2019

Activity Status as of July 1, 2017:
We have analyzed data of temperature stratification, meteorological conditions, and cyanobacterial (harmful algal bloom-HAB) biomass. The occurrences of toxic HAB are highly spatially and temporarily variable in Madison and South Center Lake, MN. The analysis of vertical heterogeneity of cyanobacteria revealed high positive correlations among BV stratification, surface water temperature, stratification intensity, quantified by the Schmidt stability, and the dynamic lake stability, quantified by the Lake Number. The depth at maximum BV accumulation was observed to be driven diurnally by the thermocline depth and light penetration, with peaks both near the surface and at locations with active photosynthetic radiation approximately equal to 10 µE/m2 s. The outcome of this analysis is the first step towards the quantification and prediction of temporal dynamics and vertical stratification of cyanobacteria biomass as a function of abiotic drivers including local meteorological and physical conditions in a stratified lake.

Activity Status as of January 1, 2018:
Scaling relationships between the biovolume (BV) of HAB and driving physical variables have been explored using the data in Madison Lake. A time-series of BV_{max}/ BV_{ave} (maximum biovolume/depth-averaged biovolume) is depicted in the panel **a)** of the figure below. The BV ratio was high during periods of stable stratification, seasonal average BV ratio of each profile is 1.26, and then declines as the water column mixes due to weak stratification (from mid-August to the end of September). After several iterations, we identified two independent lake dimensionless groups that significantly describe the s BV_{max}/ BV_{ave}. The first dimensionless group is ($St\ A_s /C_pT_s$)

that can be used to scale HAB biomass vertical heterogeneities (St is the lake stability, As is the lake surface area, C_p is the specific heat of water, and T_s is the lake surface temperature). The scaling relationship is provided in the panel **b)** of the figure below. The proposed scaling relationship described the 70% (R^2=0.70) of BV_{max}/ BV_{ave} ratio.

$$\frac{BV_{max}}{BV_{ave}} = 0.0045\left(\frac{St\ A_S}{C_p T_s}\right)^{0.57} + 1$$

The second dimensionless group is the Lake Number (LN). A scaling relationship between BV_{max}/ BV_{ave} and LN is provided in the panel **c)** of the figure below. The proposed scaling relationship described the 45% (R^2=0.45) of BV_{max}/ BV_{ave} ratio.

$$\frac{BV_{max}}{BV_{ave}} = 0.17(LN)^{0.25} + 1$$

The lower R^2-value may be due to the periodic diurnal nature of the wind, which introduces variability in LN without necessarily inducing an equivalent variability in the thermocline depth and the BV ratio. This is expected because correlations, as well as scatter plot do not allow for any time, lags between the increase in wind and the vertical adjustments of the lake temperature and BV vertical distributions

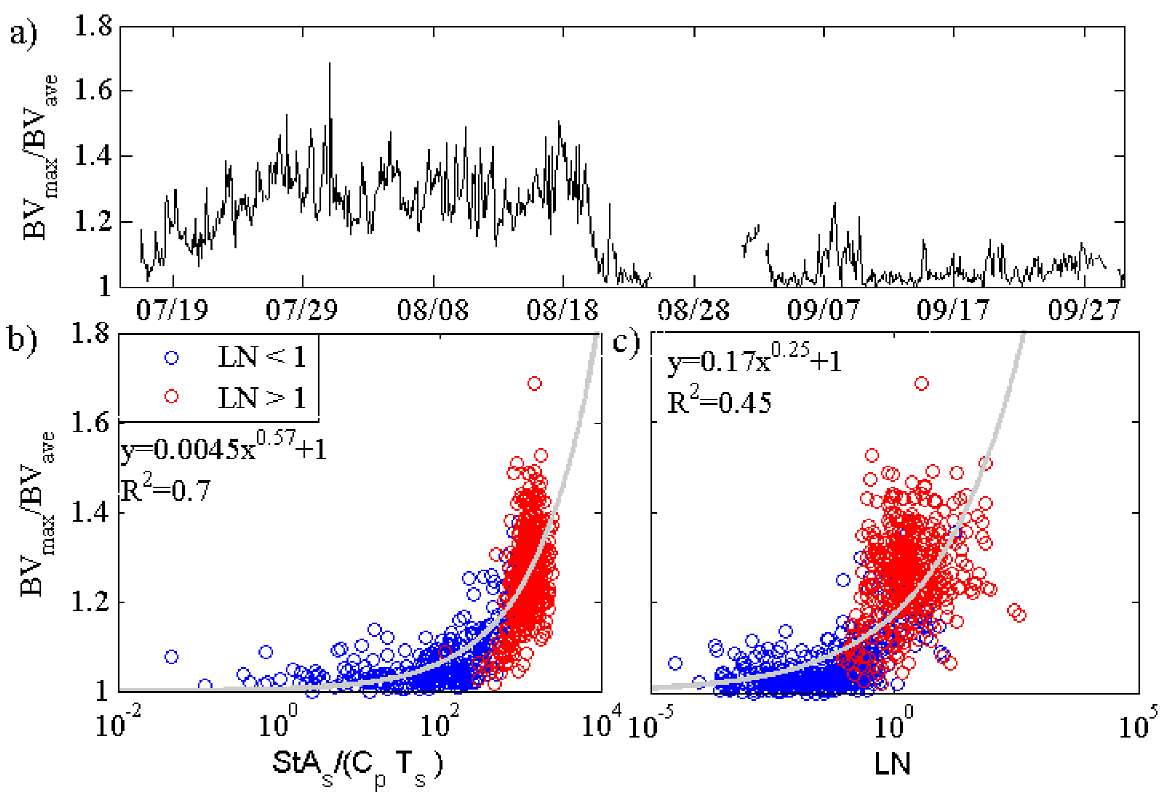


Figure**. a)** Time series of BV ratio throughout the summer **b) and c)** BV ratio versus dimensionless groups driving cyanobacteria biomass. The red circles represent the data points observed in the $\overline{LN}$ > 1 and the blue circles represent data during the $\overline{LN}$ < 1. The gray line represents the fitted line described by the above equations.

Activity Status as of July 1, 2018:

A quantitative relationship was developed to determine the probability of observing a uniform cyanobacterial biovolume distribution as a function of the surface layer Reynolds number (Re_{SL}), the dimensionless ratio of inertial to viscous forces. The uniform distribution was observed systematically for Re_{SL}>50,000.

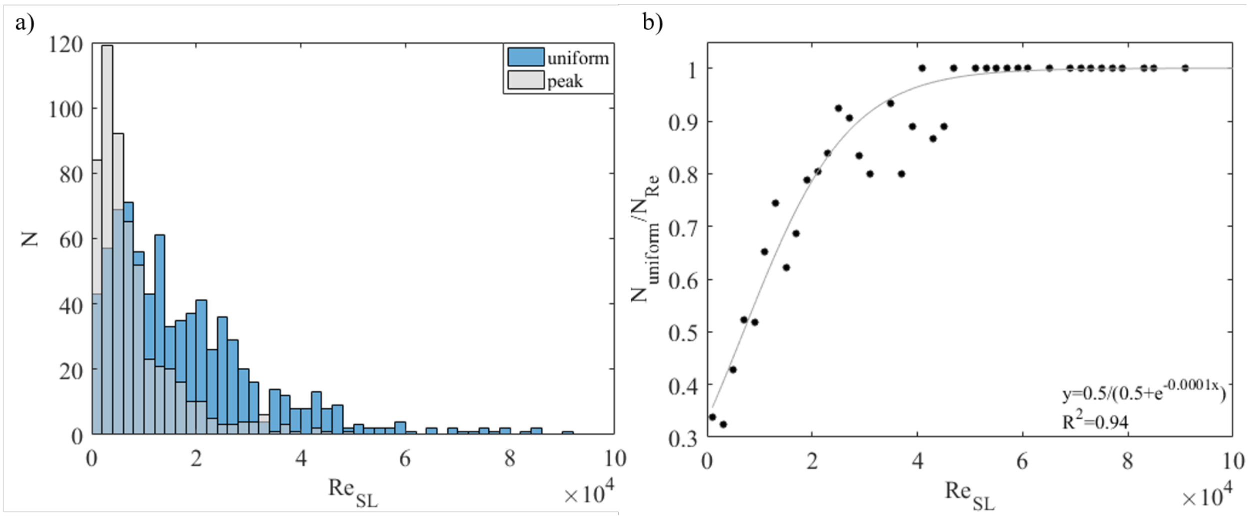


Figure. a) Frequency of peak (grey) and uniform (blue) BV distributions as a function of Re_{SL}, with a bin size of 2000. b) The ratio of uniform distributions to a total number of profiles as a function of Re_{SL}. These data represent all profiles for Madison and South Center Lakes.

Activity Status as of January 1, 2019:

We explored the overall relationship between MC and BV measured from the discrete samples (Figure below). Regression analysis between MC and BV depicted linear relationships from both South Center Lake and Madison Lake data. The data encompassed a wide range of depths, atmospheric conditions, BV and MC concentrations, and composition of cyanobacteria. The linear regression, quantified over the entire measuring season, indicated that 84% of data variability was explained by the regression line in South Center Lake (R^2=0.84), and 33% of data variability was explained by the regression line Madison Lake.

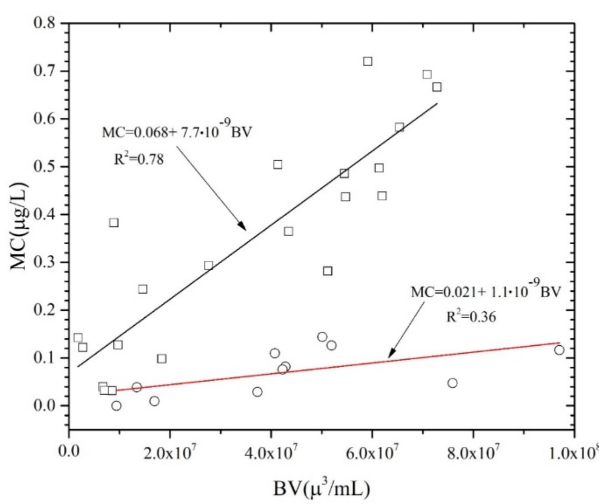
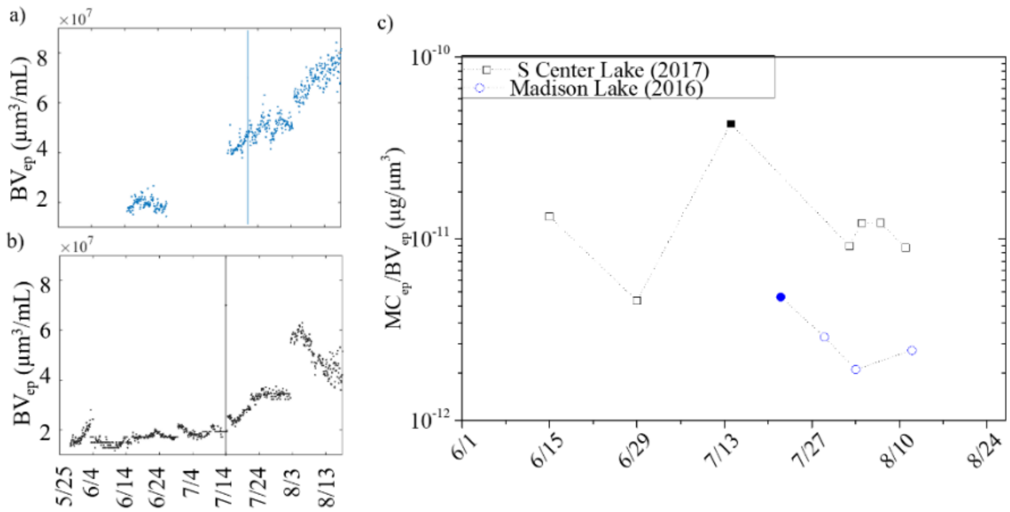


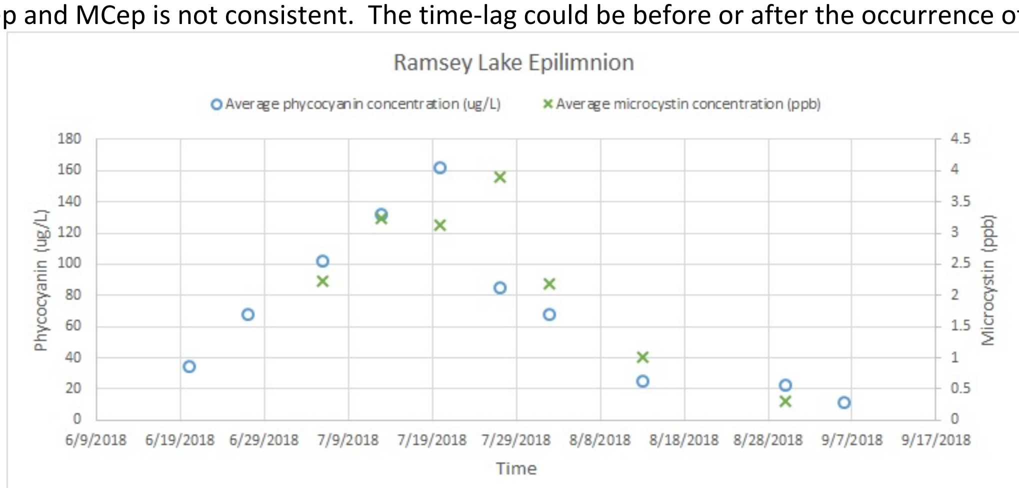
Figure. The concentration of MC versus BV in South Center Lake (square symbol) and Madison Lake (circle symbol). The data points represent the average of a replicate of MC.

Activity Status as of July 1, 2019:

The temporal variabilities of the average cyanobacterial bio-volume in the epilimnion (BV_{ep}) are depicted for Madison and South Center Lakes in Figure a) and Figure b) below. Both lakes show similar patterns of BV accrual from May to August during the two different measuring seasons. Temporal variability in the ratio of average MC in the epilimnion, to average BV in the epilimnion (MC_{ep} /BV_{ep}), were observed consistently in the two seasons. In both lakes, the maximum MC_{ep} /BV_{ep} preceded the maximum BV in the epilimnion. This trend was observed over a similar period (from July 14th to August 11th) in the two lakes, despite the different years and different environmental conditions. In South Center Lake, the maximum ratio occurs at the beginning of the BV_{ep} growth . The maxima MC_{ep}/BV_{ep} are the filled symbols in c) and correspond to the dates marked by the vertical lines in panels a) and b).



The temporal variabilities and time-lag between MCep and BVep were analyzed in Ramsy Lake (figure below). In contrast to the findings of Madison Lake and South Center Lake, the maximum of MC_{ep} occurred approximately seven days after the maximum of BV_{ep}. The results demonstrate that each of the three lakes a time lag between BVep and MCep is not consistent. The time-lag could be before or after the occurrence of BVep.



Final Report Summary:

Batch cultures of *Microcystis aeruginosa* (*M. aeruginosa*) were cultivated at seven different temperatures to measure the specific growth rate at each temperature. A relationship between temperature and specific growth rate was established. We propose a cardinal temperature model for *M. aeruginosa* with the inflection point (optimal temperature) located at 27.5°C. The model describes 98% of the variability of experimental data from 5°C to 35°C. The results demonstrated a five-times difference in buoyant velocities of colonies at

17.5°C and 28°C. A model was derived from calculating the density of a colony using the buoyant velocity and colony size. The derived models will be useful in predicting seasonal HABs growth and buoyant velocities in lakes.

Scaling relationships were developed among cyanobacterial bio-volume (BV) heterogeneity, thermal stratification stability, and surface water temperature. The proposed scaling relationships are relevant to Sampling protocols of HAB as it informs if the sample depth is representative of the entire water column. During the strongly stratified period, BV accumulated above the thermocline and in the photic zone, with distinct peaks occasionally forming both near the water surface and at locations with photosynthetically active radiation approximately equal to 10 µE/m2s. Our observations suggest that the temporal/vertical variability of cyanobacteria BV is strongly influenced by lake dynamics, thermal structure, seasonal temperature variation, and light availability. Microcystin (MC) was observed to accumulate above the thermocline and have a vertical distribution similar to BV. This is important for directing sampling efforts, because it narrows the range of BV and MC heterogeneity above the thermocline, and suggests a vertical sampling protocol to detect potential maxima and compute representative depth-average concentrations. We explored the temporal variability of the MC to BV ratio, spatially averaged in the epilimnion (MC_{ep} / BV_{ep}). The maximum MC_{ep} / BV_{ep} occurred before or after the maximum BVep. This observation is notable because the maximum MCep could occur before the visual signs of enhanced cyanobacterial accrual are less recognizable to the public and to monitoring efforts. Our findings could have important implications for predicting MC distribution and guiding monitoring strategies for quantifying MC concentrations in small stratified lakes.

ACTIVITY 4: Education and public outreach: Detection, prediction, impact mitigation
Description:
Education and Public Outreach (EPO) activity will promote and enhance education and communication on harmful algal blooms in Minnesota lakes. The audience will be water quality managers, lake management associations, public and government agencies, and drinking water utilities. We will identify and form 3 to 5 focus groups (state agencies, watershed managers, public, high school students, graduate students) and asses public awareness and interest in harmful algal blooms. A designated website (http://hab.umn.edu) will be established and used to conduct the proposed EPO. The educational modules will be developed based on the assessment of public awareness, peer-reviewed publications, and our laboratory and field measurement in Minnesota lakes. The educational modules will include 1) field detection (biomass quantification, and toxin evaluation); 2) online reporting; 3) prediction (biomass and toxin concentrations); and 4) mitigation strategies. Selected data and procedures will be available on the website to further promote scientific collaboration with other universities and research groups. A regional workshop is planned to present and provide an overview of (1) algae, their identification, and harmful algal blooms, (2) toxin generation and detection, (3) risk to public health and wildlife survival, and (4) prediction and impact mitigation of harmful algal blooms. The workshop will be conducted in December 2018, at the St. Anthony Falls Laboratory, University of Minnesota. The training portions of the workshop will be recorded for future reference.

Summary Budget Information for Activity 4: **ENRTF Budget: $ 40,520**
Amount Spent: $ 38,210
Balance: $ 2,308

Outcome	**Completion Date**
1. Assess public awareness, establish focus groups, establish project website (http://hab.umn.edu)	July 1, 2019
2. *Compile a list of available freshwater HAB educational materials (work other researchers & agencies), including web-accessible outreach materials*	May 31, 2018
3. *Establishment of educational modules on harmful algal blooms, video development, and online placement* (http://hab.umn.edu)	Jun 31, 2018

4. *Demonstration and training on detection, prediction, and impact mitigation techniques*	December 31, 2018
5. Regional workshop at the University of MN: Harmful algal blooms detection, prediction, and mitigation	December 31, 2018

<u>What is done:</u>

Activity Status as of January 1, 2018:

We designed a posted a website (https://extension.umn.edu/shoreland-property-owners/blue-green-algae-minnesota-lakes)through the University of Minnesota Extension. The project website is operational and contains materials which promote the awareness of harmful algal blooms in Minnesota lakes. We founded "Harmful Algal Bloom" group, and developed planning for the state-wide workshop. The workshop will be conducted on March 29, 2018.

The partners of Harmful Algal Group are St. Anthony Falls Laboratory, the Natural Resources Research Institute, University of Minnesota Duluth, the St. Croix Watershed Research Station, the Minnesota Pollution Control Agency, and the West Central Research and Outreach Center, University of Minnesota.

Activity Status as of July 1, 2018:

Organized HARMFUL ALGAL BLOOMS (HABs) IN MINNESOTA workshop on March 29, 2018, at the St. Anthony Falls Laboratory, University of Minnesota. The workshop included the following modules: HABs research, HABs prediction and modeling, HABs detection and tracking, and Outreach, communication and education.

Activity Status as of January 1, 2019:

We have accomplished much of outcomes #1, #5, & #6 already through our annual HAB Workshops. We have developed various outreach materials, presentations, and have participated in multiple events and activities (#1 & #5). Early on, we developed and hosted our Webpage (z.umn.edu/algae) (#2 & #3) but is in Google site format.

What needs to be done (deliverables- amendment request November 2018 and approved by the LCCMR on Jan 28, 2019):

Because of our research findings and the rapid changes in HAB tracking and identification technology, we have had to change and update the original outreach plan/budget and requested approval by LCCMR on November 7, 2018. The rationale of the requested amendment and remaining deliverables are provided below.

A. Update Webpage

B. Developing "accessible educational materials" (#2) and establishing a uniform logo. The idea is to develop a set of digital and accessible HAB fliers that are formatted in a way that all partners can use them for their publications, yet allowing for branding each partner and Extension and the University.

C. A series of 3-5 workshops around the State as outreach for research findings

D. Purchasing a set of Cyanosensors for demonstration

E. Purchase and set up a Mobile HAB Educational trailer (SAFL will do all retrofit and maintenance; winter storage at Dakota County Fairgrounds, summer storage at UoM Farmington parking lot &/or SAFL)

F. Purchase a spectral camera for the areal (lake surface) quantification of lake temperatures and cyanobacterial concentration. The camera will be tested at SAFL (January 2019) and deployed to the proposed series of 3-5 workshops around the State.

The revised budget for Activity 4

Task ("#"s refer to the outcomes listed in the Activity 4 of the proposal)	**Timeline**	**Budget**
Update Webpage; updating the current webpage (**z.umn.edu/algae**) from a Google site into a uniform UoM webpage (#2 & #3) Developing "accessible educational materials" (#2) and establishing a uniform public education message. The idea is to develop a set of digital and accessible HAB fliers that are formatted in a way that all partners can use them for their publications, yet allowing for individual use by each partner and the University. Itemized: Personnel: ~$2,000; To contract with the UoM Extension IT department to complete this task.	December 31, 2018	$ 2,000
A series of 3 workshops around the State as outreach for research findings (#1 & #5) -will need the support (teaching & presentations) from SAFL researchers and other MN HAB Group collaborators Itemized: -Workshops: We anticipate up to 50-60 participants attending each workshop and will be held from March to end of May 2019. There will be no net revenue generated from the workshops. We plan to have no fees for attending the workshops. If it becomes necessary, fees will be used only to cover any additional costs and not to generate any over the expense revenue. -Refreshment and Food; $400/Workshop for food = $1,200. The refreshment and food for each workshop will consist of very basic light refreshment (bagels, fruit, & pastry) and beverages (coffee, tea, water) at the beginning of the workshop and during the one break period. Offering refreshment is inline and a customary practice with most local community meetings. The cost of the food will be reasonable and proportionate to the type of planned workshops. -Mileage; $300/Workshop for mileage x 3 = $900 The mileage will cover the cost of travel for staff traveling to each workshop and meeting with the host community.	May 2019	$ 1,200
Purchase and set up a Mobile HAB Educational trailer (#4 & #5) -will need support from SAFL to retrofit the trailer -winter storage will be at Dakota County Fairground, and summer storage at UoM Farmington office. Itemized: -Non-capital equipment: Purchase of a trailer $3,700 -Supplies: shelves, lights, wires, hardware, paneling, wood/lumber $ 600	January 2019	$ 4,300
Purchase spectral camera for the areal quantification of cyanobacteria and water temperatures. We propose the spectral camera Altum by https://www.micasense.com/altum (#4 & #5) Spectral camera ($10,000), DJI Matrix ($ 3,000), Integration kit ($700) Itemized: Total equipment: $13,700	February 2019	$13,700

Total ==>	$21,200

Activity Status as of July 1, 2019:

A. Updated Webpage: The **http://hab.umn.edu** was updated by the MN Extension IT team along with converting all of the pdf files on the web site to the text which dramatically increased site accessibility.

B. HAB educational materials are shared among all MN HAB partners.

C. Public outreach: Originally, we had planned to offer a few workshops around the State to promote the research findings of the Minnesota HAB related researches. Instead, the MN HAB Group was able to secure a three hour Special HAB Session at the 2019 MN Water Resources Conference planned with ten speakers and expected to reach over 500 participants. The planned Special HAB Session will offer a greater number of MN HAB researchers to share their findings with many more of MN water resources professional. The session announcement has already been well received.

D. The MN HAB Education Trailer. We purchase, retrofitted, and set up a mobile educational trailer. The purpose of the trailer is to offer hands-on HAB educational activities to educators, water resource professionals, and the general public at various educational events throughout the State of Minnesota. The trailer can be loaned out to other MN HAB researchers for their educational activities as well (see photos below).

1. **E. Spectral Camera and Drone.** Spectral camera and drone were purchased for the areal (lake surface) quantification of lake temperatures and cyanobacterial concentrations. The camera was assembled and tested under field conditions (please see figures below). The camera-drone setup was presented to the public at the educational workshops (Gathering Partners of Natural Resources conference,(Willmar, MN, May 19, 2019) and at the Twin Cities Water Monitoring and Data Assessment Group (TC-WaMoDaG) workshop on June 26, 2019.


Additional educational activities:

Newsletters and articles: Two major MN HAB articles and news stories were published:

--Extension Magazine (https://extension.umn.edu/source-magazine/harmful-algal-bloom), and

--MN Daily (https://www.mndaily.com/article/2019/04/n-the-bloom-boom-increasing-frequency-of-algal-blooms-may-be-due-to-climate-change)

Workshops:
March 18, 2019. Delivered a presentation at the 2019 Ramsey County Public Forum called: Harmful Algae Blooms on March 18, 2019.https://www.ramseycounty.us/content/public-forum-harmful-algae-blooms. There were more than fifty (50) participants, along with City staff and State agencies at the workshop.

May 19, 2019, Gathering Partners of Natural Resources' conference (Willmar, MN). Attended, presented on the topic of HAB and showcased the new MN HAB Education Trailer with the drone and spectral camera.

June 26, 2019. Attended and presented a 30 minutes outdoor session four times at the Twin Cities Water Monitoring and Data Assessment Group (TC-WaMoDaG) workshop. There were about 80 participants at the workshop (https://sites.google.com/view/tc-wamodag/events?authuser=0).

Our HAB educational efforts will continue well into the future. Following are a few examples of the ***confirmed*** future MN HAB educational outreach efforts:

August 15, 2019, The MN HAB Education Trailer at **Aqua Chautauqua** in Detroit Lakes, MN (https://ne-np.facebook.com/events/2192986590992493/**).**
October 15-6, 2019: Special HAB Session at the 2019 MN Water Resources Conference (https://ccaps.umn.edu/minnesota-water-resources-conference), St. MN.
June 9-10, 2020: Special HAB Track at Universities Council on Water Resources Conference, Minneapolis, MN.
November 2020: Special HAB Track at the 2020 North American Lake Management Society https://ccaps.umn.edu/minnesota-water-resources-conference, st. Paul, MN.

Final Report Summary:
Public education and outreach were an integral part of our project. We had a total of 19 separate outreach and educational activities. We held six (6) different public outreach activities conducting over 365 different individual conversations and conducted five (5) in-person workshops with over 460 participants. Almost 100% of workshop participants indicated that they had learned something significantly new, wanted to continue learning more about HABs. We also published six (6) news articles, in various University of Minnesota magazines and newsletter reaching thousands of subscribers. In addition to the public education and outreach activities, we also formed the MN HAB Group - a collaborative group of HAB researchers and educators that work to increase understanding and predication of HABs in Minnesota lakes. A new HAB focused webpage (http://hab.umn.edu) was also developed, which remains active. We also purchase, retrofitted, and set up a mobile educational trailer to provide hands-on HAB educational activities, including demonstrating the use of drones and spectral camera in detecting and monitoring HABs. We utilized multiple approaches, tools, and delivery systems to provide an effective HAB outreach and educational program. A summary table of our education and public outreach activities is provided below.

Approximate attendance	Name	Date	Newsletter articles	Outreach events	Workshops
40	University-wide HAB Workshop	2/10/2016			X
	UoM Alumni newsletter;	7/1/2016	X		
	Collage Newsletter	7/1/2016	X		
50	University-wide HAB Workshop	3/28/2017			X
50	Aqua Chautuqua	8/12/2017		X	
	HABs Explained	1/1/2018	X		
70	University-wide HAB Workshop	3/29/2018			
	North Central Region Water Network Regional HAB Management	4/1/2018			
70	State of Water Conference	4/12/2018			X

20	Science-Policy Confluence Conference-Great Lakes Harmful Algal Blooms	5/1/2018		x	
100	Gathering Partners	5/18/2018		x	
70	Aqua Chautuqua Fergus Falls	6/23/2018		x	
75	Aqua Chautuqua Detroit Lakes	8/9/2018		x	
100	Minnesota Water Resources Conference - MN HAB History & Future	10/15/2018			
50	Ramsy County	3/18/2019			X
	Extension magazine	Apr-19	X		
	MN Dialy	4/22/2019	x		
50	Gathering Partners – Wilmar	5/29/2019		x	
80	TC-WAMODaG Workshop	7/26/2019			X
Total					
825	**19**		**5**	**7**	**7**

V. DISSEMINATION:

Description:

During the duration of the project, major research findings will be submitted to peer-reviewed publications, regional and national conferences with emphasis on harmful algal blooms. The proposed EPO activity will be administrated through the designated website http://hab.umn.edu. A short 3-minute video will be developed to introduce and promote the project, disseminate awareness on the potential impact of harmful algal blooms, and advocate early detection and mitigation strategies. The video will be posted on the project website (http://hab.umn.edu, social media) and will be publicly available. The video will be intended for the general public with interest in the project. It can also be used as an introduction of the project at City Council, County Commissioners lake associations, or any other agencies or organizational meetings.

Final Report Summary:

During the project, three peer-reviewed publications were produced. The support of LCCMR is acknowledged in each publication (Acknowledgement section). The fourth publication is under review. The publications are as follows:

Wilkinson, A., Hondzo, M., and M. Guala (2016). Effect of Small-Scale Turbulence on the Growth and Metabolism of Microcystis aeruginosa, *Advances in Microbiology*, 6, 351-367.

You, J., Mallery K., Hong J., and M. Hondzo (2018). Temperature Effects on Growth and Buoyancy of Microcystis Aeruginosa, *Journal of Plankton Research*, 40(1), 16–28.

Wilkinson, A., Hondzo, and M., Guala (2019a). Investigating Abiotic Drivers for Vertical and Temporal Heterogeneities of Cyanobacteria Concentrations in Lakes Using a Seasonal *In-Situ* Monitoring Station, *Water Resources Research*, 55(2), 954-972.

Wilkinson, A., Hondzo, M., and M. Guala (2019b). Vertical Heterogeneities of Cyanobacteria and Microcystin Concentrations in Lakes Using a Seasonal In situ Monitoring Station, *Freshwater Biology*, under revision.

Several workshops were organized, and research findings were sheared with the public and research communities (please see Section 4: Educational outreach). One of the dissemination examples could be viewed through the YouTube posted video https://www.youtube.com/watch?v=2c2bdpKP1kw, or through the University of Minnesota link: https://cse.umn.edu/college/feature-stories/researchers-work-understand-harmful-algal-blooms-minnesota-lakes

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:
Our project had two ENRF appropriations including Emergency Issues on "**Increasing Harmful Algal Blooms in Minnesota Lakes: $71,000)"** and **"Assessing the Increasing Harmful Algal Blooms in Minnesota Lakes."** We ended the project with the total unspent amount of $18,200. The largest amount of unspent appropriation ($10,507) is in the supplies category. The reason for the surplus is the following a) existing supplies were used and were not restocked, and b) sensors associated with the capital equipment were not replaced at the end of projects. The second-largest amount of unspent appropriation ($4,991). Originally, we had planned to offer a few workshops around the State in 2019 to promote the research findings of the Minnesota HAB related researches. Instead, the MN HAB Group was able to secure a three hour Special HAB Session at the 2019 MN Water Resources Conference planned with ten speakers and expected to reach over 500 participants.

		Emerging Issues Account $	Work Plan $
Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$71,000**	**$270,000**
	Amount Spent:	**$71,004**	**$251,696**
	Balance	**-$4**	**$18,304**

Please, see the attached spreadsheet.

Explanation of Use of Classified Staff:

Explanation of Capital Expenditures Greater Than $5,000:
A laboratory fluorometer will be used for the proposed analysis of chlorophyll, nitrate, and phosphate concentrations in the laboratory and field samples. The cost of the equipment with an educational discount is $8,792 (Turner Designs). A Cyanobacterial autonomous profiler will be used in the field. The profiler can provide cyanobacterial concentration profiles over the lake depth, and it will have adjustable sampling times and depths over the Internet. The profiler will have a wireless data transfer with the display over the Internet. The cost of profiler with an educational discount is $10,922 (OTT Hydromet).

If the intended use of the requested capital equipment (Laboratory fluorometer Turner Design, $8,792; Cyanobacterial water quality profiler OTT Hydromet, $10,922; and the drone with spectral camera MicaSense Altum, $13,700) changes, the research team is committed to pay back to the Environment and Natural Resources Trust Fund an amount equal to either the cash value received or a residual value approved by the director of the LCCMR if it is not sold.

Activity status as of January 1, 2017:
The proposed laboratory fluorometer and cyanobacterial profiler were acquired and successfully used in the field and the St. Anthony Falls Laboratory, University of Minnesota.

The proposed drone and spectral camera were acquired, assembled, verified, and successfully used through the educational outreach.

Activity status as of July 1, 2019:
The proposed laboratory fluorometer and cyanobacterial profiler were acquired and successfully used in the field and the St. Anthony Falls Laboratory, University of Minnesota.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 1.5

The number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: Na

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
	$	$	
State			
	$	$	
TOTAL OTHER FUNDS:	**$**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners:

The project team consists of the Principal Investigator (PI) Prof. Miki Hondzo (University of Minnesota) and Co-PIs Prof. Michele Guala, Prof. Christine Salomon, and Dr. Shahram Missaghi. Project Partner not receiving funds: Steven Heiskary (Minnesota Pollution Control Agency). This proposed project will be conducted in collaboration with the St. Croix Watershed Station of the Science Museum of Minnesota.

B. Project Impact and Long-term Strategy:

Harmful algal blooms, including the toxin-producing cyanobacterium *Microcystis,* are a global environmental concern worldwide. A key question in the proposed study is: What combination of environmental non-biological conditions enhances the blooms of *Microcystis* and toxin production in Minnesota lakes? Predictive models of *Microcystis* growth and toxin production in lakes, integrated with the readily available variables including air and water temperatures, wind speed, lake morphometry, lake stability, and stratification meteorological conditions, will be the core of research strategy. The long-term goal will be to build a computational framework over the Internet for alerting and predicting harmful algal blooms and toxin production in Minnesota lakes (*algae tracker*). A similar approach has been used to alert and forecast pollen concentration (*allergy tracker*) by the Internet-based weather prediction models. The proposed website will be developed to interface with existing resources (LakeFinder from DNR, or MPCA lake website) to assist water quality managers, public, government agencies, and drinking water utilities in the prediction and management of the detrimental impacts of harmful algal blooms in Minnesota lakes.

C. Funding History:

Anne Wilkinson, the National Science Foundation Fellow, has been funded for three years (Sep 2013 to August 2016) to conduct laboratory and field measurements with focus on *Microcystis* bloom in Minnesota lakes. That funding provided a basis for the proposed research. The proposed project provided 50% research assistantship for Ms. Wilkinson for year 1 and year 2 of the project. Anne's Ph.D. thesis was focused on cyanobacterial blooms and microcystin production in Minnesota lakes.

Funding Source and Use of Funds	Funding Timeframe	$ Amount
Funding History: salary and tuition of NSF-funded student Anne Wilkinson that is currently investigating algal blooms for her Ph.D. thesis. The total, for the period before the project start date September 2013 to February 2016, is based on the 51,500 yearly NSF contribution	Sep 2013-August 2016	$154,500

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS:

A. Parcel List: NA

B. Acquisition/Restoration Information: NA

IX. VISUAL COMPONENT or MAP(S):

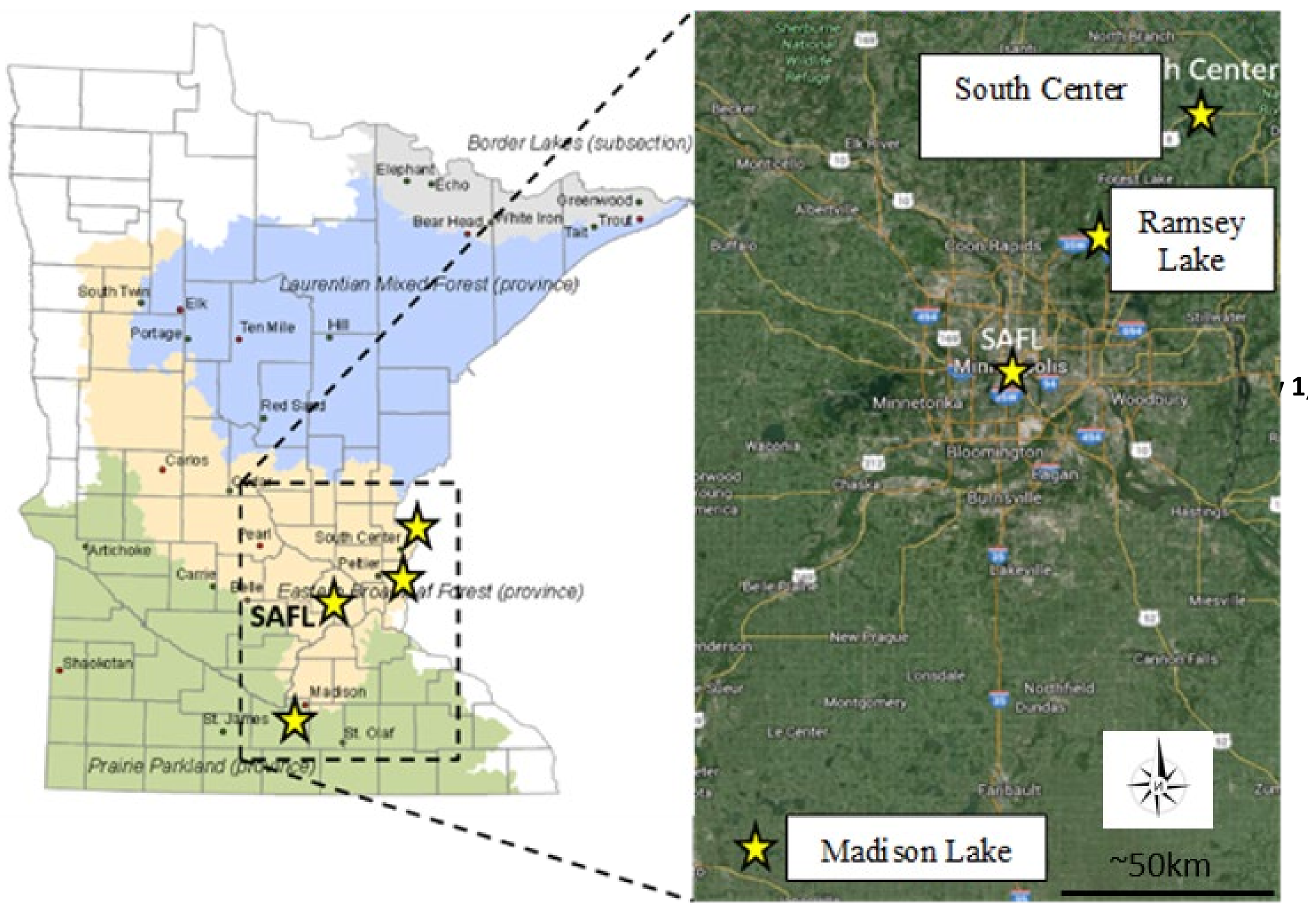


Figure. Geographic locations of selected lakes for field measurements (star symbols) and laboratory measurements (SAFL) at the University of Minnesota.

Environment and Natural Resources Trust Fund
Final M.L. 2016 Project Budget
Project Title: : Assessing the Increasing Harmful Algal Blooms in Minnesota Lakes
Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 04b; M.L. 2015, Chp. 76, Sec. 2, Subd. 10
Project Manager: Miki Hondzo
Organization: St. Anthony Falls Laboratory, University of Minnesota
M.L. 2016 ENRTF Appropriation: *$ 270,000*
Project Length and Completion Date: 3.5 years, *June 30, 2019*
Date of Report: 8/12/19

Final M.L. 2015 Project Budget
Emerging Issues: Increasing Harmful Algal Blooms In Minnesota Lakes
Legal Citation M.L. 2015, Chep 76, Sec. 2, Subd. 10
Project Manager: Miki Hondzo
Organization: St. Anthony Falls Laboratory, University of Minnesota
M.L. 2016 ENRTF Appropriation: *$ 71,000*
Project Length and Completion Date: 3.5 years, *June 30, 2019*
Date of Report: 8/12/19

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget (Emerging issues)	Amount Spent 6/30/19	Activity 1 Balance	Activity 2 Budget	Amount Spent 6/30/19	Activity 2 Balance	Activity 3 Budget	Amount Spent 6/30/19	Activity 3 Balance	Activity 4 Budget	Amount Spent 6/30/19	Activity 4 Balance	TOTAL BUDGET	Total spent	TOTAL BALANCE
BUDGET ITEM	***Develop and deploy cyanobacterial profiler***			***Assess algal bloom and toxin production in Minnesota Lakes***			***Develop models for algae blooms and toxin production***			***Education and public outreach***					
Personnel (Wages and Benefits)	$37,518	$37,517	$1	$161,690	$161,690	$0	$35,557	$35,557	$0	$21,320	$20,857	$463	$256,085	$255,621	$464
Miki Hondzo, Project Manager: $21,524 (75% salary, 25% benefits); 10% FTE year 1, 5% FTE year 2, and 5% FTE year 3			$0			$0			$0			$0	$0	$0	$0
Michele Guala, Co-PI: $20,225 (75% salary, 25%benefits); 5% FTE each year for 3 years			$0			$0			$0			$0	$0	$0	$0
Christine Salomon, Co-PI: $13,296 (75% salary, 25% benefits); 3% FTE each year for 3 years			$0			$0			$0			$0	$0	$0	$0
Shahram Missaghi, Co-PI: $16,442 (75% salary, 25% benefits); 10% FTE year 2, and 10% FTE year 3			$0			$0			$0			$0	$0	$0	$0
IT Technician: $2,453 (78% salary, 22% fringe): 2% FTE year 2, and 2% FTE year 3			$0			$0			$0			$0	$0	$0	$0
Lab Technician: $35,792 (78% salary, 22% fringe): 20% FTE each year for 3 years			$0			$0			$0			$0	$0	$0	$0
Graduate student: $98,249 (59% salary, 41% fringe): 50% FTE year 1 and year 2, and 12.5 % FTE year 3			$0			$0			$0			$0	$0	$0	$0
Undergraduate student (100% salary): $10,161: 25% FTE year 1, 17% FTE year 2, and 17% FTE year 3			$0			$0			$0			$0	$0	$0	$0
UM Extension IT - update webpage ($2,000) into a uniform UoM webpage (#2 & #3)			$0			$0			$0			$0	$0	$0	$0
Professional/Technical/Service Contracts			$0			$0			$0			$0	$0	$0	$0
NA															
Equipment/Tools/Supplies			$0			$0			$0			$0	$0	$0	$0
General supplies for laboratory and field analyses are quantified based on previous experience. The supplies for Year 1 are $26,000, Year 2 are $6,625; and Year 3 are $2,600. The supplies include materials for the field floating raft with instrumentation and laboratory supplies including 1) optical components for PIV/PTV experiments (one fixed focal macro lens, laser mirrors and mounting posts), 2) display components for the visualization of field and laboratory data, 3) chemical components for Microcystis laboratory experiments (BG-11 medium, Microcystis culture, nitrogen gas, carbon dioxide gas, acetone, reagents for nutrient analysis, microcystin detection), and 4) parts and labor for laboratory bioreactor modifications and field deployments. In Year 2 and Year 3, supplies and tools will be utilized for the proposed education and public outreach. The supplies will include assessment, chlorophyll detection kits, assessment survey materials, supplies for the proposed workshop.; Additionally a trailer ($3700) will be purchased to facilitate the outreach events.	$12,468	$13,845	-$1,377	$26,533	$14,653	$11,880			$0	$4,300	$4,295	$5	$43,301	$32,793	$10,508
Capital Expenditures Over $5,000															
Laboratory fluorometer (Turner Design, chlorophyll, nitrate, and phosphate detection, $8,792). Cyanobacterial water quality profiler for measuring algal concentration, temperature, oxygen, pH, and underwater light intensity at specified times and water depth increments which are adjustable over the Internet (OTT Hydromet, $10,922). Capital Equipment: Spectral camera for the areal quantification of cyanobacteria and water temperatures. Spectral camera ($10,000), DJI matrix ($3,000), Integration Kit ($700)	$19,714	$19,642	$72			$0			$0	$13,700	$13,060	$640	$33,414	$32,702	$712
			$0			$0			$0			$0	$0	$0	$0

Fee Title Acquisition			$0			$0			$0			$0	$0	$0	$0
NA			$0			$0			$0			$0	$0	$0	$0
Easement Acquisition			$0			$0			$0			$0	$0	$0	$0
NA			$0			$0			$0			$0	$0	$0	$0
Professional Services for Acquisition			$0			$0			$0			$0	$0	$0	$0
Printing			$0			$0			$0			$0	$0	$0	$0
Travel expenses in Minnesota															
The proposed education and public outreach include:	$1,300	$0	$1,300	$3,900	$1,409	$2,491			$0	$0	$0	$0	$5,200	$1,409	$3,791
A series of 3 workshops around the state as outreach for			$0			$0			$0	$1,200		$1,200	$1,200	$0	$1,200
Other															
Wireless data download from the proposed field sites to designated project website (hab.safl.umn.edu) at the University of Minnesota.				$1,800	$175	$1,625			$0			$0	$1,800	$175	$1,625
COLUMN TOTAL	**$71,000**	**$71,004**	**-$4**	**$193,923**	**$177,927**	**$15,996**	**$35,557**	**$35,557**	**$0**	**$40,520**	**$38,212**	**$2,308**	**$341,000**	**$322,700**	**$18,300**