5-2015

Cyanobacteria Monitoring in the Charles River Lower Basin: Water Quality Assessment and Implications for Future Practice 2006-2014

Anjana Tamrakar
Clark University

5-1-2015

Cyanobacteria Monitoring in the Charles River Lower Basin: Water Quality Assessment and Implications for Future Practice 2006-2014

Anjana Tamrakar
Clark University

CYANOBACTERIA MONITORING IN THE CHARLES RIVER LOWER BASIN: WATER QUALITY ASSESSMENT AND IMPLICATIONS FOR FUTURE PRACTICE 2006-2014

ANJANA TAMRAKAR

CO-AUTHOR: ELISABETH CIANCIOLA (SUPERVISOR)

MAY 2015

A PRACTITIONER REPORT

Submitted to the faculty of Clark University, Worcester, Massachusetts, in partial fulfillment of the requirements for the degree of Masters of Science in the department of International Development, Community, and Environment

And accepted in the recommendation of

Prof. Timothy Downs, Chief Instructor

ABSTRACT

CYANOBACTERIA MONITORING IN THE CHARLES RIVER LOWER BASIN: WATER QUALITY ASSESSMENT AND IMPLICATIONS FOR FUTURE PRACTICE 2006-2014

ANJANA TAMRAKAR

The resurgence of cyanobacterial blooms in the Lower Charles River basin is of great concern to public and ecosystem health due to the potential hazard of cyanotoxins produced by these colonial cyanobacteria. In response to public concern about the condition of the river, Charles River Watershed Association (CRWA) is conducting cyanobacteria monitoring program to improve the water quality since 2006 and developing a solutions to watershed problems. This report is a concise overview of the cyanobacterial bloom monitoring results, its relationship to trophic state and temporal dynamics and potential solutions for future monitoring to serve recreational users of the Lower Charles River.

Timothy Downs, D. Env.
Chief Instructor

ACADEMIC HISTORY

Name (in Full): Anjana Tamrakar **Date: March 2015**

Baccalaureate Degree: Environmental Science

Source: Louisiana Tech University, Ruston, LA. **Date: May 18, 2012**

<u>Occupation and Academic Connection</u> since date of baccalaureate degree:

- Watershed Scientist Intern, Charles River Watershed Association
- Watershed and Wastewater Planning Intern, Massachusetts Department of Environmental Protection
- Earth day Intern, Regional Environmental Council

Acknowledgement

I would like to express my sincere appreciation to several people that made this project possible. Firstly, gratitude to Charles River Watershed Association staffs, for providing me with an opportunity to work on this project. A special thank you to Ms. Elisabeth Cianciola, my project supervisor at the Charles River Watershed Association (CRWA), for providing endless guidance and motivation throughout the project period. Gratitude is also extended to my advisor Prof. Timothy Downs, for helping with my coursework and guidance during my graduate years in Clark University. A thanks also goes to my fellow graduate student, Ms. Cathleen Torres Parisian for sharing with me GIS skills and knowledge necessary for the completion of the project. Last but definitely not least, I am thankful to all my family and friends for their unconditional love and endless patience throughout the years.

List of Illustrations

List of Tables

Table of Contents

Introduction

The Charles River is an 80-mile river in eastern Massachusetts that drains a watershed area of 308 square miles. The meandering nature and slow velocity of the Charles River make it suitable for recreational purposes such as boating and fishing. The river flows through 23 communities and has become a popular recreation destination for rowers, sailors, runners, bikers, and even cultural festivals like the annual Hong Kong Boston Dragon Boat Festival. The Upper Watershed includes from Echo Lake to the United States Geological Survey (USGS) Dover Gauge, the Middle Watershed extends from the gauge to the Watertown Dam, and the section between the Watertown Dam and the New Charles River Dam is referred to as the Lower Basin of the Charles River. The Massachusetts Surface Water Quality Standards identify the Lower Charles River as a Class B water that is designated to support aquatic life and recreational uses (MDPH 2007). The Lower Basin of Charles River also drains with small tributary streams that are mostly enclosed and piped storm water drainage systems serving the surrounding communities. Increasing anthropogenic activity and commercial and industrial development poses significant ecological challenges in the Charles River Watershed.

The Charles River Watershed Association (CRWA) was formed to protect the natural environment, develop solutions to watershed problems, and promote sustainable watershed management practices. Wastewater management presents a significant challenge in the Charles River watershed. Although boating is very popular on the Charles, swimming historically has not been allowed due to health risks associated with bacterial contamination from wastewater. For the first time in over half a century, the Charles River was approved for swimming (Braody, 2013). One major concern of CRWA, Massachusetts Department of Public Health

(MA DPH) and potential swimmers and boaters is the presence of cyanobacteria, also known as blue-green algae, in the Charles River. An abundance of cyanobacteria in a water body can produce toxins that are dangerous to the health of humans and animals. The Lower Basin of the Charles River is a calm and warm water body with shallow lagoons that is subject to a hot climate with occasional heavy rain during the summer. These are ideal physical and climatic characteristics for cyanobacteria growth. Cyanobacteria blooms have increasingly become a national concern because of their adverse effects on public health. To help ensure safe use of the Charles River, CRWA has been monitoring cyanobacteria in the river for the last nine years. **The purpose of this study is to determine what these monitoring results show about water quality in the Charles River and how future monitoring can best serve recreational users of the river**.

Background and Problem Definition

Cyanobacteria are naturally-occurring single-celled organisms that can produce their own energy via photosynthesis. Like plants, cyanobacteria require the nutrients nitrogen and phosphorous to grow. Many cyanobacteria are able to fix atmospheric nitrogen for their own use (RDEM, 2011). As a result, the growth of cyanobacteria is often limited by the availability of phosphorus. Unfortunately, phosphorus frequently occurs at excessive levels in the Charles River, as is evident from the Lower Charles River Basin Nutrient TMDL that was established in 2007 (MA DEP, 2007). When both nitrogen and phosphorus are readily available to cyanobacteria, their growth can become exponential, producing a large population of cyanobacteria commonly known as a bloom. Other environmental conditions, such as water temperature, stagnation and stratification can also exacerbate bloom events (Figueiredo, 2006). Weather patterns that include storm events, which deliver nutrients to the river, followed by dry periods during which river flow drops to around 200 cubic feet per second, are typical precursors to cyanobacterial blooms in the Charles River. At the end of a bloom, water pH is often elevated, signifying reduction in acidity whereas the dissolved oxygen level is often depressed due to the decomposition of dead cyanobacteria (Jewel *et al*., 2008).

CRWA first began working with DPH and the Massachusetts Department of Conservation and Recreation (MA DCR) to monitor concentrations of cyanobacteria in the Charles River in 2006, when a bloom of *Microcystis* was detected. A scheduled swim race was cancelled that year due to the bloom. *Microcystis* and other forms of cyanobacteria present a public health risk due to their ability to produce and release cyanotoxins like microcystins, neurotoxins anatoxin-a and saxitoxins. Exposure to cyanotoxins can result in symptoms such as nausea, skin rash, dizziness, headaches, fever, liver damage or nervous system damage depending on whether contact with contaminated water occurred dermally or via ingestion (WHO, 1999).

Quantifying the risk posed by a cyanobacterial bloom presents a significant challenge. Although it is relatively easy to count cyanobacteria cells in a water sample, the number of cyanobacteria cells present in the water only weakly correlates with their toxin production (WHO, 1999). Extreme temperatures (below 10°C or above 30°C) can reduce cyanotoxin production, and different populations of the same species of cyanobacteria vary in their levels of toxin production (Davis *et al*., 2009). CRWA has continued to collect cell count data, however, because none of the local laboratories are equipped to measure cyanotoxins. DPH has tested water samples for microcystin, the best-studied cyanotoxin, using test kits. There are a number of other cyanotoxins that may also occur in the Charles during bloom events, but we do not have the capacity to measure them at this time, and little is known about their toxicity levels. Our lack of knowledge in this area has led us to invoke the precautionary principle, suggesting that recreators exercise caution whenever we observe high concentrations of cyanobacteria in the Charles.

In early August of 2006, during the peak of the bloom, the *Microcystis* cell counts in the Charles ranged from 53,000 to >1,000,000 cells/mL. Based on a study of individuals who frequented a subset of lakes in Australia that often experience cyanobacterial blooms, the World Health Organization (WHO) established 20,000 cells/mL as a standard for low probability of health risk and 100,000 cells/mL for a moderate probability of health risk. Based on average body size and expected recreational exposure levels, DPH has established an intermediate value of 70,000 cells/mL as a standard for issuing public health notifications. DPH also uses the presence of a visible scum or cyanotoxins at concentrations exceeding 14 parts per billion (micrograms per liter) as criteria to define blooms in Massachusetts. Since cyanotoxins can persist in the environment for weeks after the cell count for a bloom event begins to decrease, CRWA and DPH wait until DPH has observed cell counts below the threshold value during two consecutive monitoring events before lifting notifications of public health risk due to the presence of cyanobacteria. This in the form of specific problem, the report will address the monitoring and interpretation of the cyanobacteria detection in the river and will recommend changes and initiatives to implement in future cyanobacteria monitoring program. Furthermore, the report will also analyze the monitoring locations in Lower Charles to establish criteria in order to choose most appropriate locations for cyanobacteria monitoring. The suggested monitoring locations would comprehend the overall water quality of lower basin.

Methodology

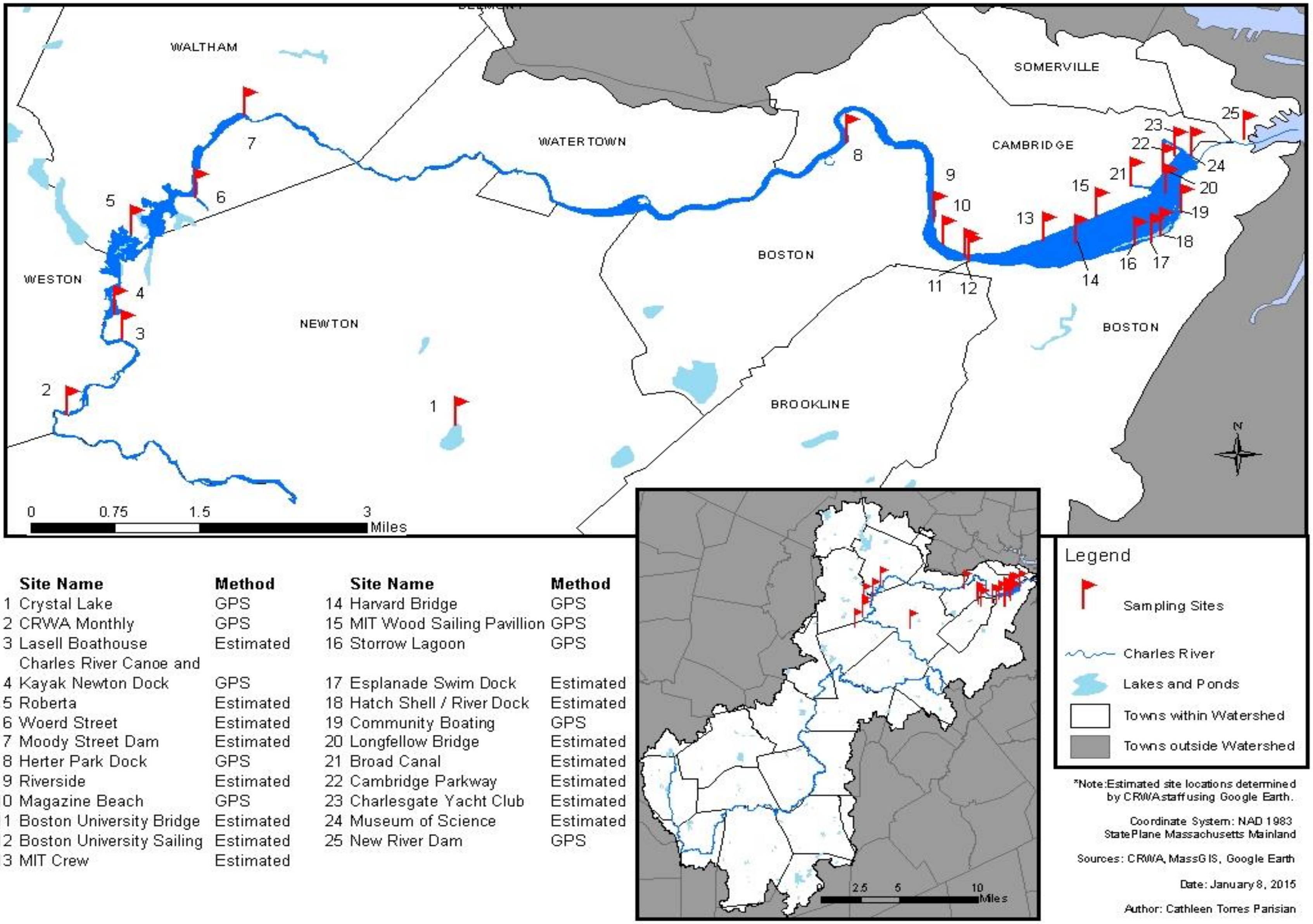
Monitoring Locations

Between 2006 and 2014, CRWA has monitored cyanobacteria levels at a variety of sites in the Charles (Table 1, **Figure 1**). Recently, CRWA have focused on sites in the Lower Basin. The area downstream of the Massachusetts Avenue Bridge encompasses many areas of stagnant waters that are conducive to cyanobacterial blooms, and this stretch of the Charles is also the most heavily recreated. However, in 2012, CRWA monitored a cyanobacterial bloom in the Lakes District of the Charles River.

Table 1 . CRWA cyanobacteria monitoring sites, 2006-2014.

Site Name	Latitude	Longitude
Crystal Lake	42.329045	-71.199989
CRWA Monthly	42.330567	-71.268033
Lasell Boathouse	42.341433	-71.258338
Charles River Canoe and Kayak Newton Dock	42.344930	-71.259502
Roberta	42.356737	-71.256423
Woerd Street	42.361634	-71.245322
Moody Street Dam	42.373206	-71.236680
Herter Park Dock	42.369120	-71.131410
Riverside	42.358076	-71.116243
Magazine Beach	42.354640	-71.114740
Boston University Bridge	42.352746	-71.110820

Site Name	Latitude	Longitude
Boston University Sailing	42.352132	-71.110243
MIT Crew	42.211817	-71.549880
Harvard Bridge	42.354630	-71.091380
MIT Sailing Pavillion	42.358421	-71.087758
Storrow Lagoon	42.354350	-71.081160
Esplanade Swim Dock	42.235670	-71.075840
Hatch Shell /River Dock	42.357616	-71.074186
Community Boating	42.359010	-71.073100
Longfellow Bridge	42.361720	-71.075628
Broad Canal	42.363467	-71.081567
Cambridge Parkway	42.364721	-71.076202
Charlesgate Yacht Club	42.367066	-71.074137
Museum of Science	42.367129	-71.071140
New Charles River Dam	42.369350	-71.061840



Site Name	Method	Site Name	Method
1 Crystal Lake	GPS	14 Harvard Bridge	GPS
2 CRWA Monthly	GPS	15 MIT Wood Sailing Pavillion	GPS
3 Lasell Boathouse	Estimated	16 Storrow Lagoon	GPS
4 Charles River Canoe and Kayak Newton Dock	GPS	17 Esplanade Swim Dock	Estimated
5 Roberta	Estimated	18 Hatch Shell / River Dock	Estimated
6 Woerd Street	Estimated	19 Community Boating	GPS
7 Moody Street Dam	Estimated	20 Longfellow Bridge	Estimated
8 Herter Park Dock	GPS	21 Broad Canal	Estimated
9 Riverside	Estimated	22 Cambridge Parkway	Estimated
10 Magazine Beach	GPS	23 Charlesgate Yacht Club	Estimated
11 Boston University Bridge	Estimated	24 Museum of Science	Estimated
12 Boston University Sailing	Estimated	25 New River Dam	GPS
13 MIT Crew	Estimated		

Figure 1. CRWA's cyanobacteria monitoring sites, 2006-2014.

Monitoring Procedure

During cyanobacteria monitoring events, CRWA interns and staff use a Hydrolab MiniSonde with a Hydrolab Surveyor 4a display unit to collect water quality data. The freshwater phycocyanin probe that CRWA attached to the MiniSonde acts as an optical fluorometer; it emits orange light at a wavelength of 590 nanometers, cyanobacteria absorb this light and emit red light at a wavelength of 520 nanometers, and a sensor on the probe quantifies the strength of the cyanobacteria's fluorescence. The Hydrolab Surveyor 4a reports the fluorescence level as an electrical voltage. CRWA has also calibrated the Surveyor to convert the voltage measured by the MiniSonde into a concentration of cyanobacteria in cells/mL.

In 2014, CRWA began working with U.S. EPA to pilot a standardized cyanobacteria monitoring protocol. The protocol calls for collecting samples with a narrow plastic tube and analyzing them with an optical fluorometer in the field. The optical fluorometer outputs measurements of chlorophyll and phycocyanin in milligrams per liter. Under the protocol, the sampler runs the initial sample through a 45-micron filter to isolate fluorescent dissolved organic matter (FDOM) that can interfere with cyanobacteria fluorescence readings and analyzes the fluorescence of the filtered sample, as well. The New England Cyanobacteria Monitoring Workgroup is still working to finalize the standard operating procedures for this monitoring program.

Monitoring Schedule

CRWA interns and staff typically take the Hydrolab equipment into the field once per week between July and October and collect measurements from multiple sites on each day. When CRWA interns and staff suspect a cyanobacterial bloom based on the fluorescence levels they observe or their visual assessment of a site, they collect a water sample and deliver it to an expert to enumerate the species of cyanobacteria present. Green-colored water and/or visible surface scum are considered to be visual indications of a bloom. DPH has also been monitoring cyanobacteria concentrations on a similar schedule each year since 2006.

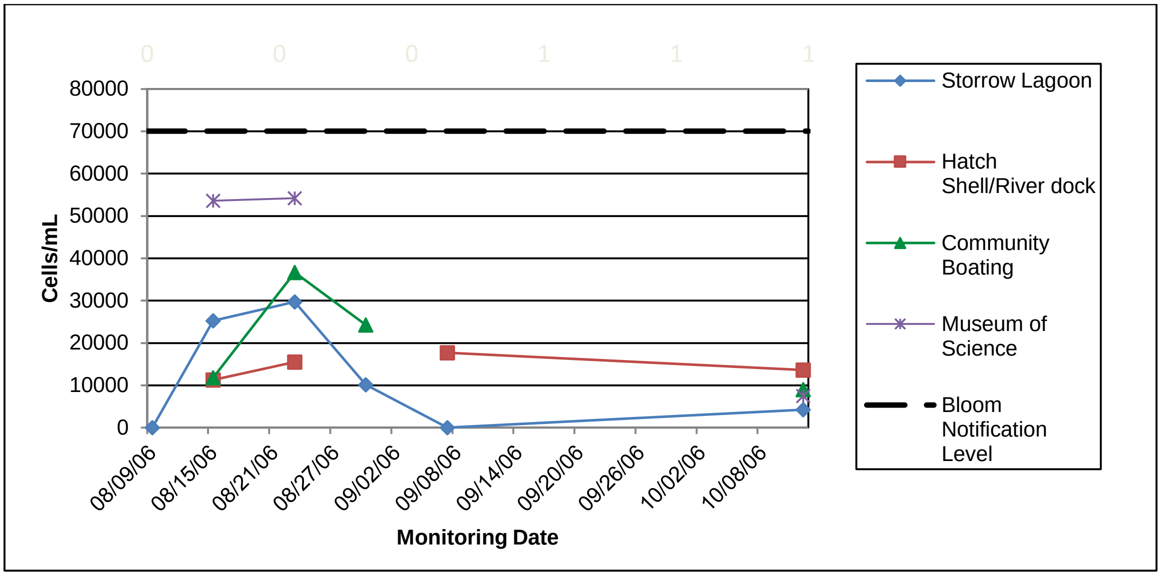
Monitoring Results

CRWA collected 213 cyanobacteria cell count measurements in the Lower Basin between 2006 and 2014 (**Table 2**). However, the number of measurements taken each year varied greatly, with 55 measurements taken from seven different sites in 2007 and 13 measurements taken from one site in 2011. Cyanobacteria cell density varied greatly each year, from no blooms observed to the highest mean and maximum, 173,995 cells/mL and 3,717,036 cells/mL respectively, in 2007. *Aphanizomenon* and *Anabaena* were dominant in most years. Although *Microcystis* was the most common type of cyanobacteria detected in 2008, the cell count remained below the MA DPH bloom threshold. In many years, the maximum cell count occurred near the Community Boating site.

Table 2. Yearly summary statistics for CRWA's cyanobacteria monitoring program.

Year	No. data points	No. sites	Range (cells)	Location of observed max.	Mean (cells)	Cyanobacteria detected most often
2006	16	4	58,111-1,115,281	Museum of Science	21,631	*N/A*
2007	55	7	330-3,717,036	Community Boating	173,995	*Anabaena*
2008	8	2	234-34,124	Community Boating	2,723	*Microcystis*
2009	12	3	16-6,808	Community Boating	3,737	*Anabaena*
2010	48	5	200-717,000	Community Boating	134,442	*Oscillatoria*
2011	13	1	960-66,400	Swim Dock	16,175	*Aphanizomenon*
2012	38	4	8,000-900,000	MIT Sailing	169,247	*Aphanizomenon*
2013	8	1	1,400-89,000	Community Boating	15,837	*N/A*
2014	36	4	658-4,808	Community Boating	1,337	*Aphanizomenon*

In 2006, monitoring did not begin until August, and the highest cell count was measured on August 8, at the Museum of Science site (Figure 2, Appendix A). However, the bloom decreased after August 15 and the cell count remained below bloom level throughout the remainder of the 2006 monitoring period.



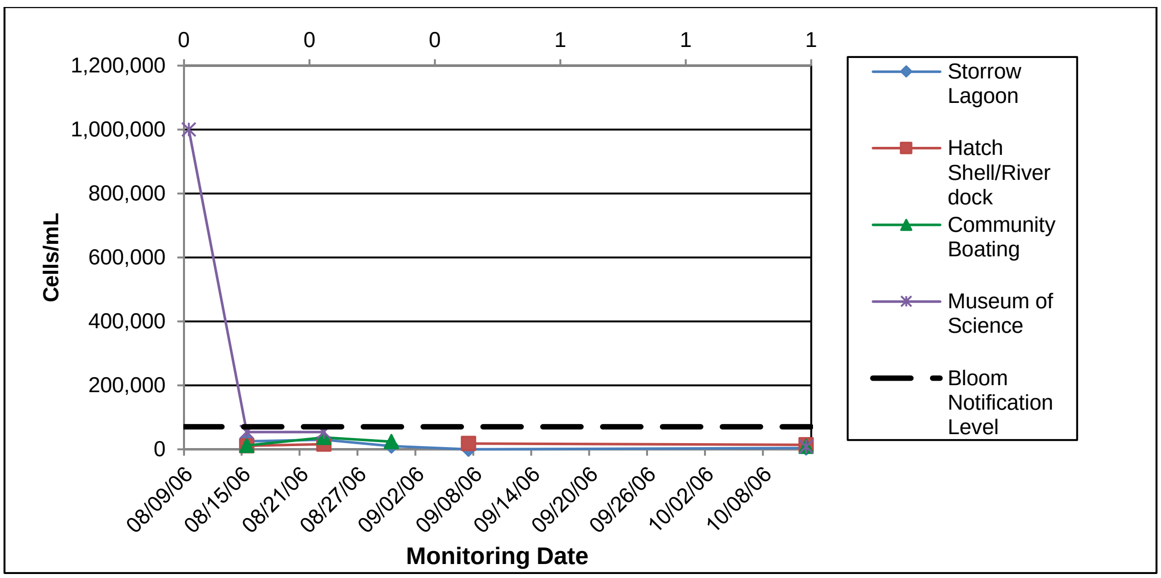


Figure 2. Cyanobacteria total cell counts (cells/ mL) from 2006, Charles River, MA. The top graph displays a more detailed look of the cyanobacteria cell counts through 2006 by excluding the outlier from 8/9/2006, while the bottom graph displays the data from 8/9/2006.

Anabaena circinalis occurred more often than other types of cyanobacteria in 2007 and represented 40.1% of the total cyanobacteria observed (Figure 3, Appendix B) *Phormidium* was also common this year, representing 29.9% of the total cell count. Cyanobacteria that represented <1% of the total cell count, *Aphanizomenon* and *Oscillatoria* in this case, are included in the "Other" category in Figure 3. A cyanobacterial bloom was first observed on July 7, 2007 at the New Charles River Dam site (Figure 4). As of July 24, the other sites began to experience blooms as well. The number of cyanobacteria peaked at all sites on September 11, 2007. The largest bloom was observed at Community Boating, with a cell count of 800,000 cell/mL on a single day. Although the number of cyanobacteria decreased, the Community Boating and New Charles River Dam sites still exceeded the bloom level of 70,000 cell/mL for the remainder of the 2007 monitoring period.

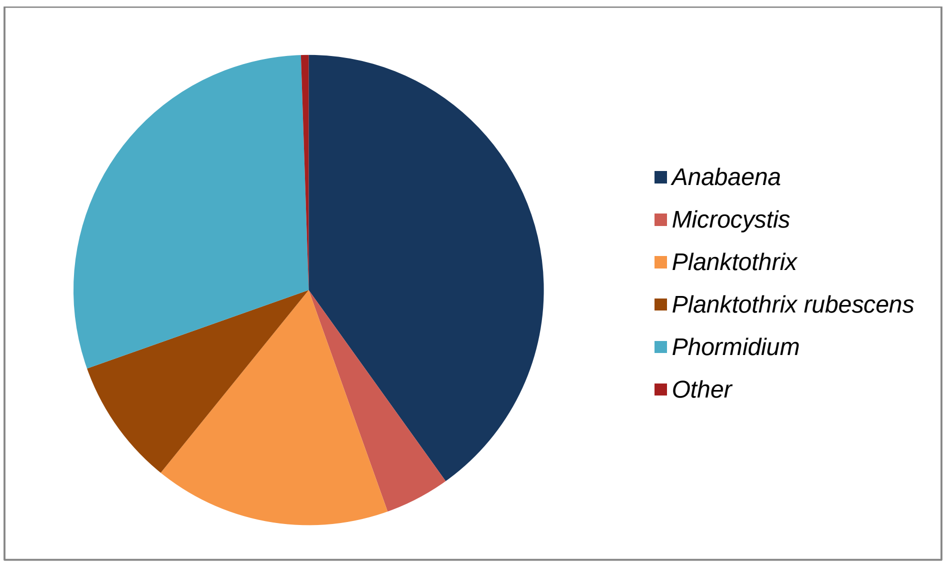


Figure 3. Abundance of cyanobacteria types observed in 2007, Charles River, MA (MA DPH).

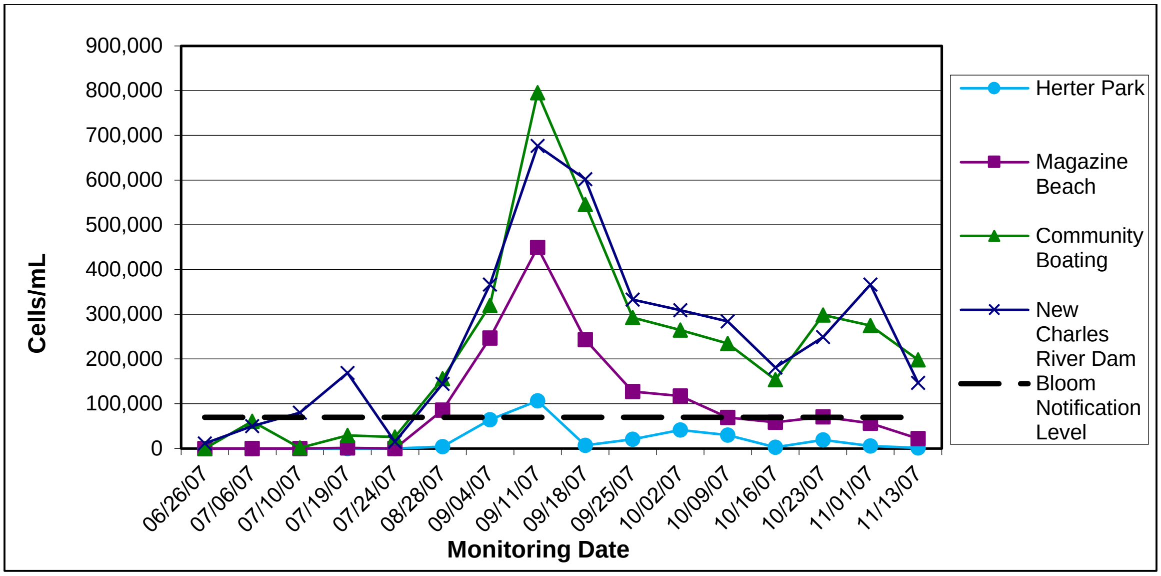


Figure 4. Cyanobacteria total cell counts (cells/mL) from 2007, Charles River, MA.

Microcystis, which can produce the toxin microcystin, occurred more often in comparison to other types of cyanobacteria in 2008 (Figure 5, Appendix C). It represented 39.2% of the total number of cyanobacteria cells identified. *Anabaena, Planktothix, Aphanonthce and Phormidium* were the next most common types of cyanobacteria observed in 2008 and were equally abundant, each representing approximately 15% of the total cell count. No cyanobacterial blooms were observed in 2008, as the cell counts were below the MA DPH bloom level of 70,000 cells/mL (Figure 6). The highest number of cells was observed on July 22, 2008 at both the Community Boating and New Charles River Dam sites and decreased to <6,000 cells/mL at the end of the monitoring period

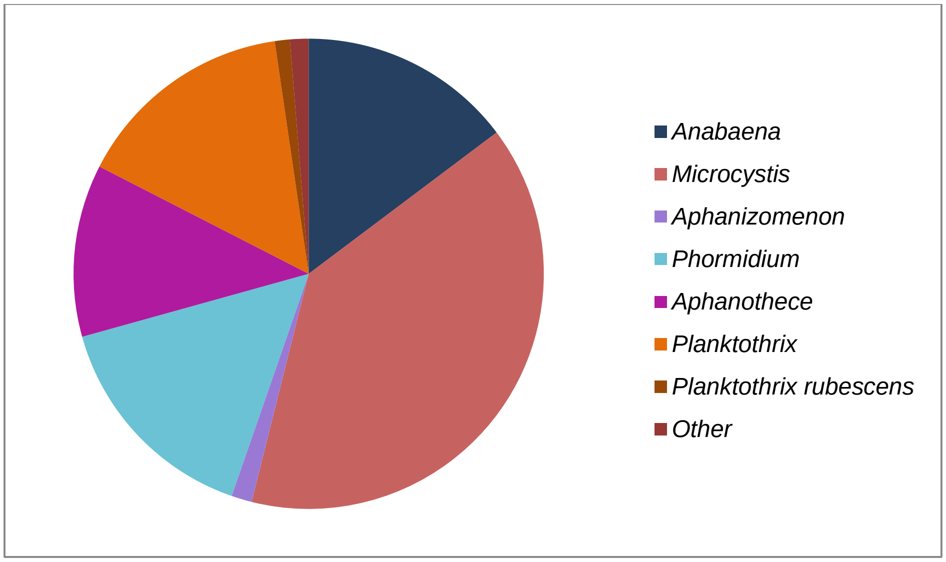


Figure 5. Abundance of cyanobacteria types observed in 2008, Charles River, MA (MA DPH).

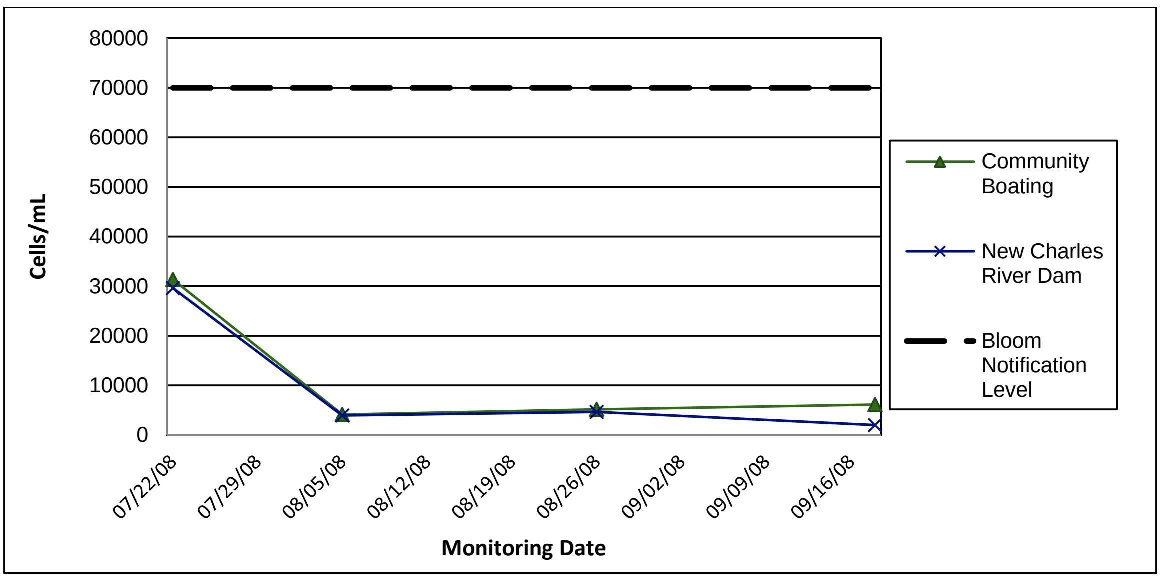


Figure 6. Cyanobacteria total cell counts (cells/mL) from 2008, Charles River, MA.

In 2009, *Anabaena* and *Aphanizomenon* were equally dominant, comprising 37.8% and 37.8% respectively of the total cyanobacteria cells (Figure 7, Appendix D). Cyanobacteria that represented <1% of the total cell count, *Lyngbya* and *Chroococcus* in this case, are included in the "Other" category in Figure 7. No cyanobacterial blooms were observed in 2009. The highest number of cells was observed on September 1, 2009 at Community Boating and was <21,000 cells/mL (Figure 8).

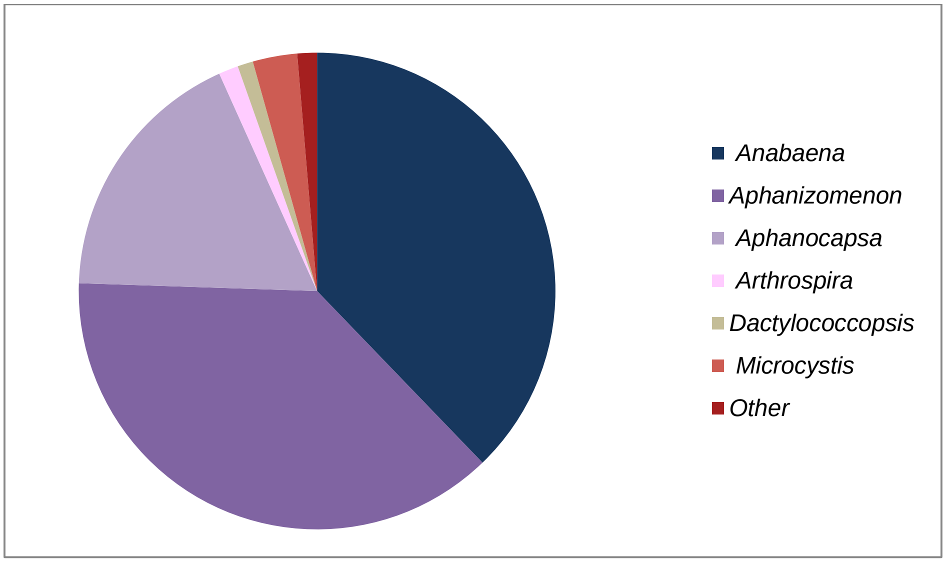


Figure 7. Abundance of cyanobacteria types observed in 2009, Charles River, MA (MA DPH).

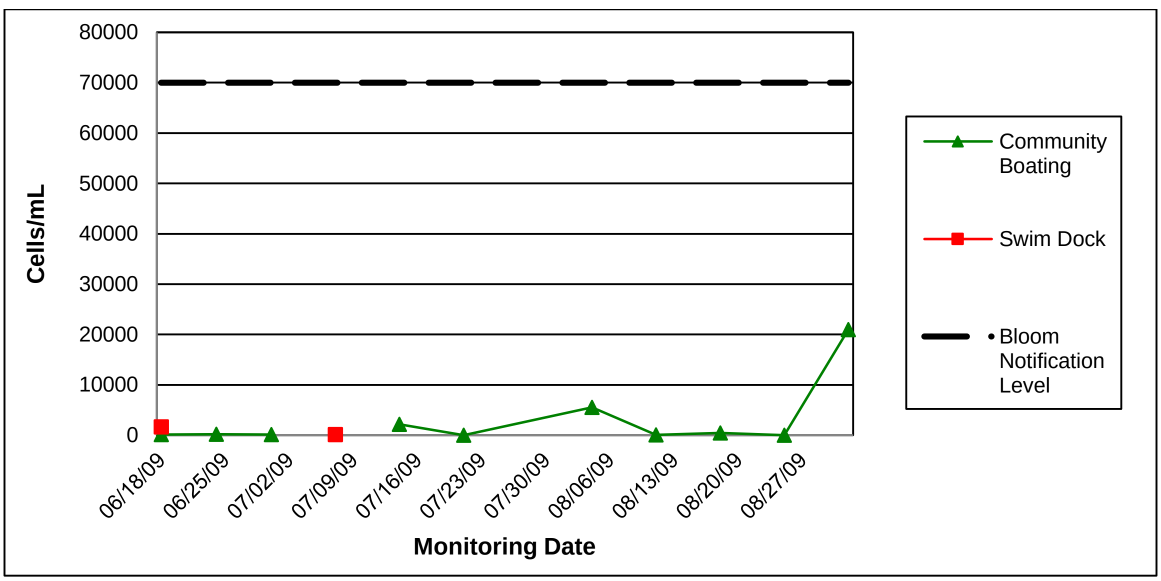


Figure 8. Cyanobacteria total cell counts (cells/mL) from 2009, Charles River, MA.

In 2010, *Oscillatoria* was the dominant cyanobacterium, comprising 71.1% of the total cell count (Figure 9, Appendix E). Cyanobacteria that represented <1% of the total cell count, *Aphanocapsa, Merismopedia, Dactylococcopsis,* and *Spirulina* in this case, and cells that were not identified, constituting approximately 16% of the total, are included in the "Other" category in Figure 9. The first cyanobacterial bloom was observed on July 12, 2010 at the Community Boating site (Figure 10). Other sites also began to experience blooms after July 22. On September 13, the number of cyanobacteria peaked with a cell count of 717,000 cell/mL at the Community Boating site and then decreased at all the sites for the remainder of the monitoring period.

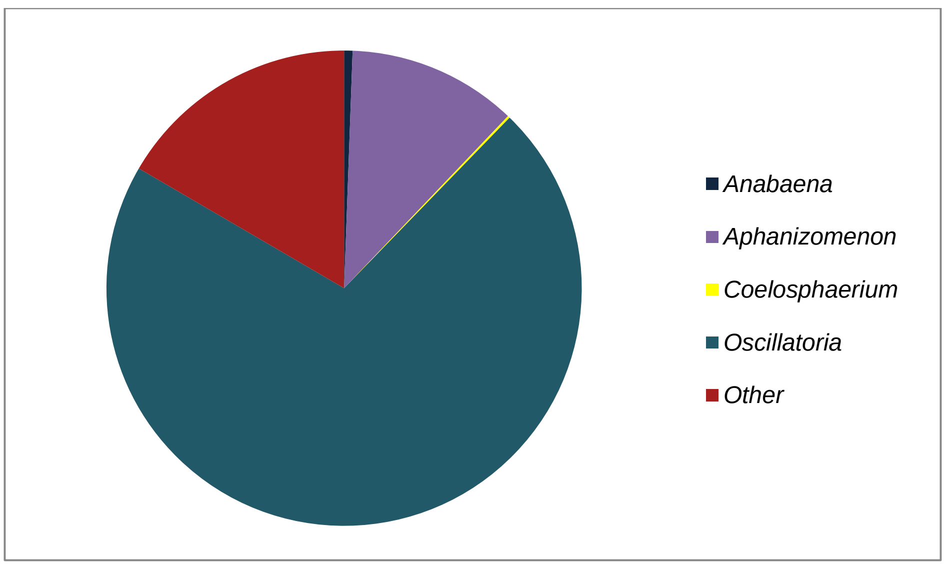


Figure 9. Abundance of cyanobacteria types observed in 2010, Charles River, MA (MA DPH).

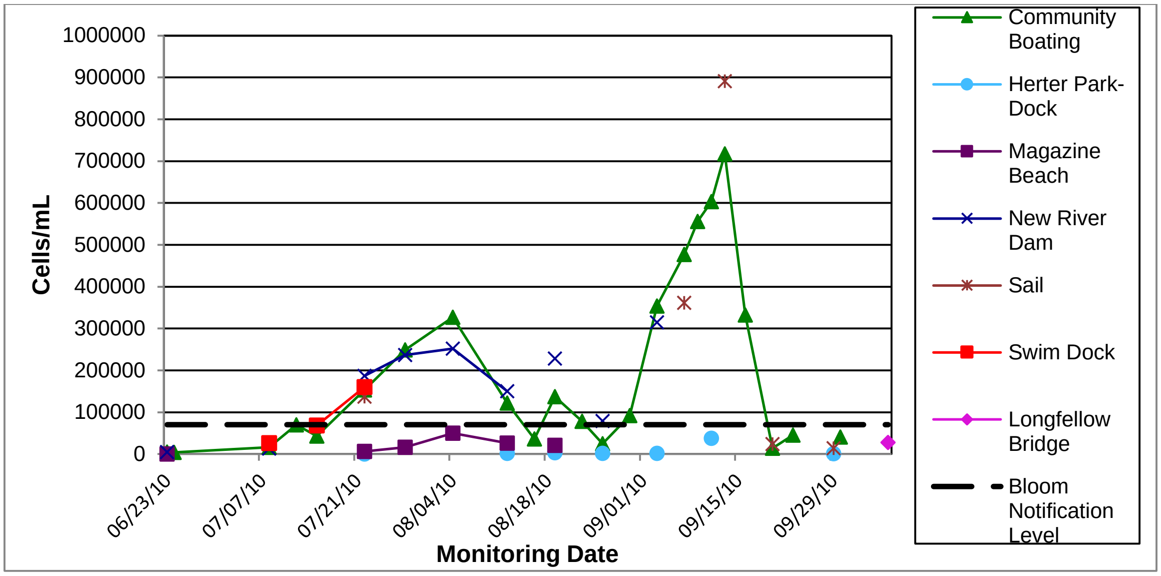


Figure 10. Cyanobacteria total cell counts (cells/mL) from 2010, Charles River, MA.

In 2011, *Aphanizomenon* was observed most often; but only represented 32.2% of the total number of cyanobacteria cells (Figure 11, Appendix F). The cyanobacteria population was more diverse compared to other years, and *Cuspidothrix* was detected for the first time in the 2006-2014 monitoring period. Although *Microcystis* was the second-most dominant cyanobacteria in 2011, no cyanobacterial bloom was detected this year. The highest cell count was 66,400 cells on July 5, 2011 (Figure 12).

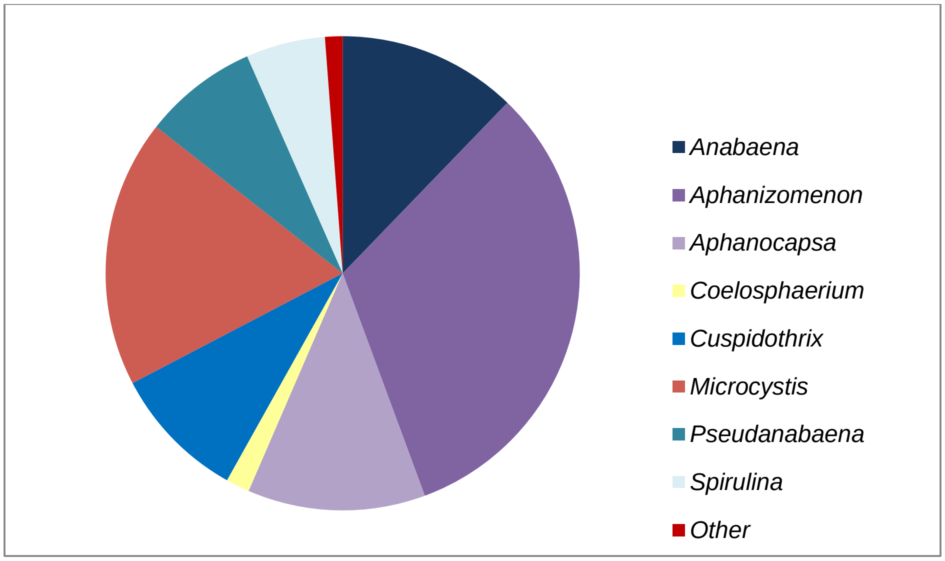


Figure 11. Abundance of cyanobacteria type observed in 2011, Charles River, MA (MA DPH).

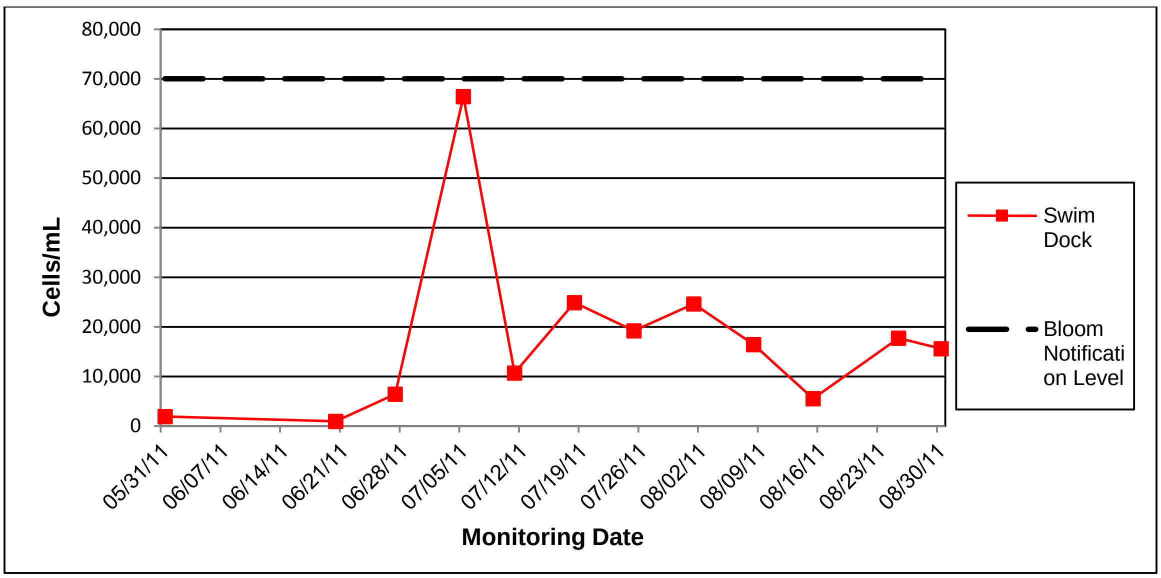


Figure 12. Cyanobacteria total cell counts (cells/mL) from 2011, Charles River, MA.

Again in 2012, *Aphanizomenon* was the dominant cyanobacteria, comprising 62.0% of the total cyanobacteria cells identified (Figure 13, Appendix G). The first cyanobacterial bloom was observed on June 20 this year (Figure 14). A bloom that paralleled the bloom at MIT Sailing, but with lower cell counts, occurred at the Community Boating site early this summer. Although the number of cyanobacteria decreased after July, it persistently exceeded the bloom threshold after August 24, 2012 until October 5, 2012. The bloom peaked on September 12, 2012 at the MIT sailing, Community Boating, and New Charles River Dam sites.

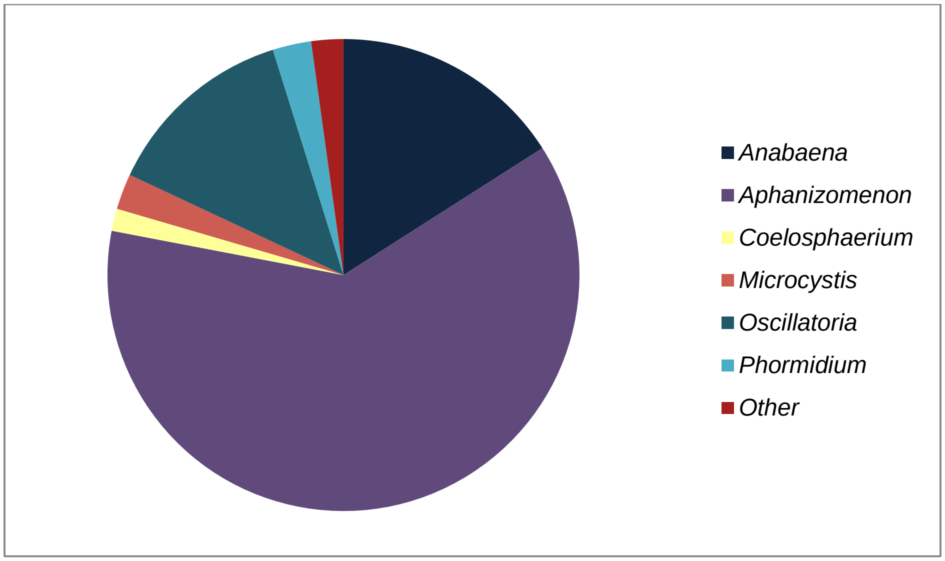


Figure 13. Abundance of cyanobacteria types observed in 2012, Charles River, MA (MA DPH).

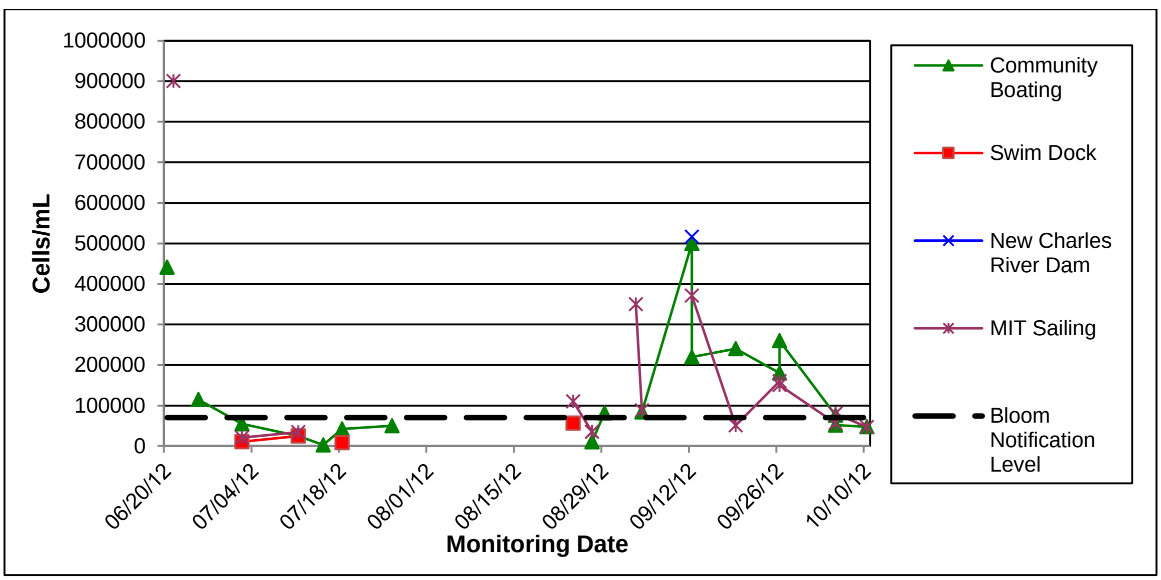


Figure 14. Cyanobacteria total cell counts (cells/mL) from 2012, Charles River, MA.

In 2013, cyanobacteria concentrations remained below bloom level throughout the monitoring period. The highest cell count for the monitoring period was 19,200 cells/mL, observed on August 9, 2013 at the Roberta site (Figure 15, Appendix J).

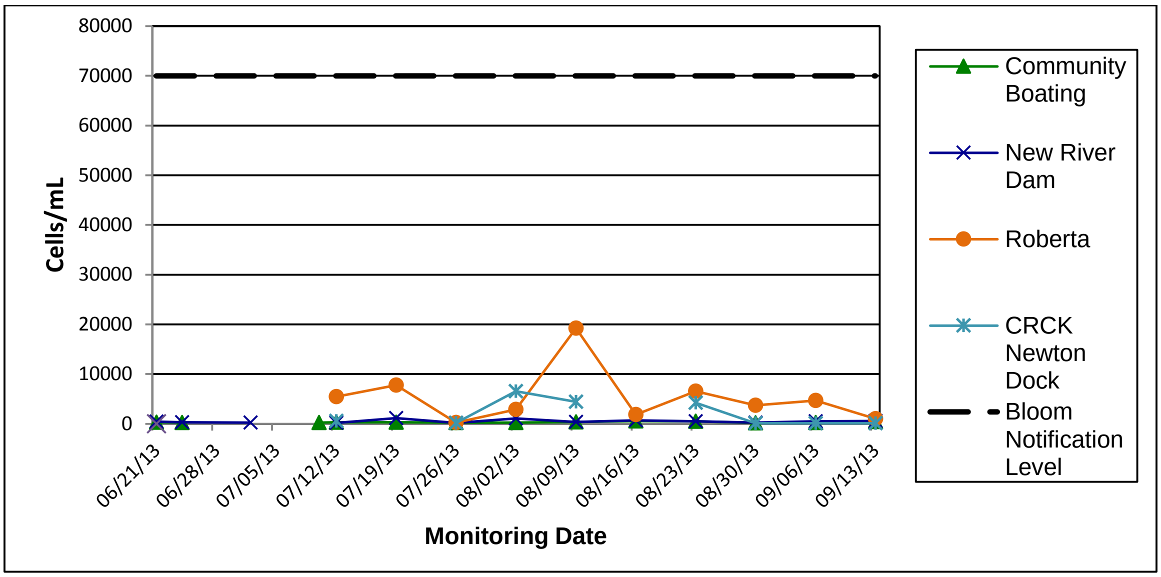


Figure 15. Cyanobacteria total cell counts (cells/mL) from 2013, Charles River, MA.

Aphanizomenon was the dominant cyanobacteria again in 2014, comprising 67.8% of the total cyanobacteria cells identified (Figure 16, Appendix I). CRWA's data did not show a cyanobacterial bloom this year based on MA DPH's cell count standard (Figure 17, Appendix K). The highest number of cyanobacteria cells was observed on September 11 at the Community Boating site with 4,800 cells/mL.

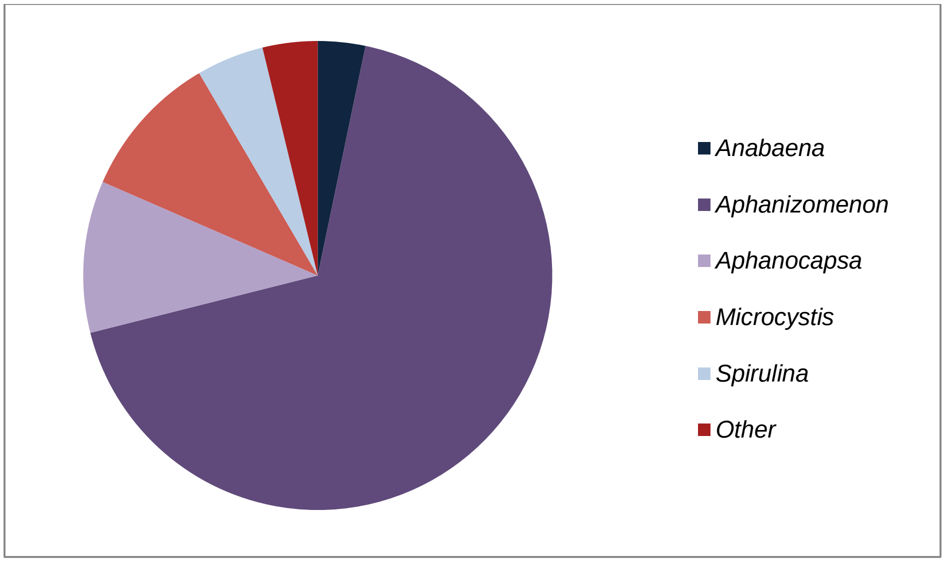


Figure 16. Abundance of cyanobacteria types observed in 2014, Charles River, MA (MA DPH).

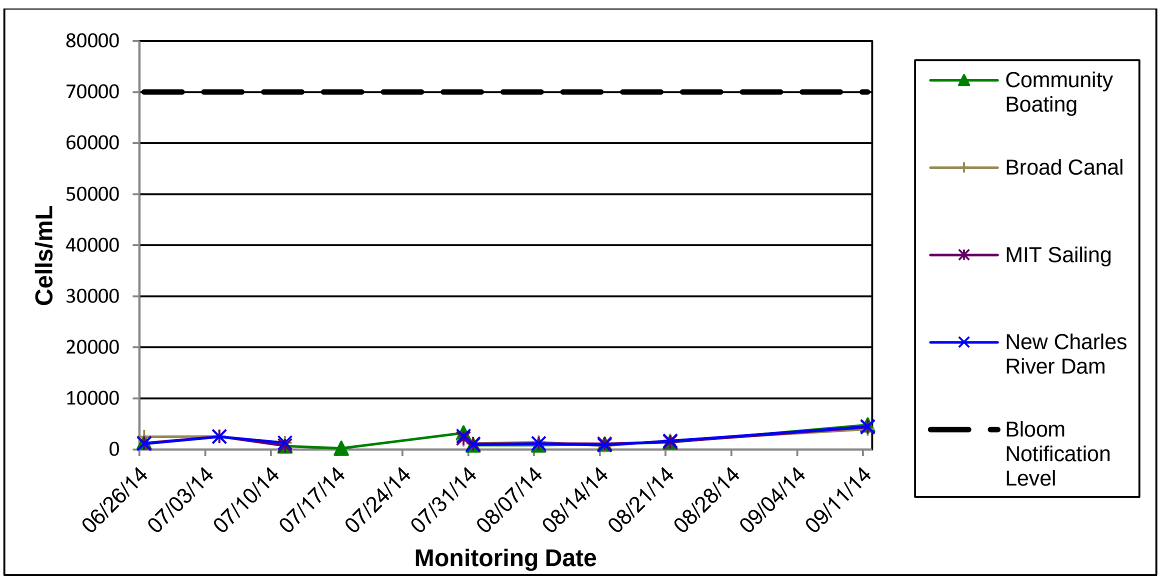


Figure 17. Cyanobacteria total cell counts (cells/mL) from 2014, Charles River, MA.

Water Quality Notification Program Analysis

As part of its efforts to empower river users to make informed decisions regarding recreational opportunities, CRWA coordinates with boathouses along the Lower Basin of the Charles River to run a water quality notification program during summer months. Under the program, CRWA uses a water quality model to predict whether or not *E. coli* levels in the Lower Basin will exceed the state standard for safe boating. CRWA personnel collect water samples from four monitoring locations on a weekly basis in order to verify the accuracy of the model predictions. Boathouses display blue flags when *E. coli* levels fall below the state standard and red flags when *E. coli* levels exceed the state standard. The concentration of *E. coli* Charles River increases after a period of rainfall which suggests that the various drivers including upstream and downstream flow, wind, combined sewer overflow (CSO) and non-CSO flow from small tributaries specifically two major tributaries, the Muddy River and the Stony Brook, are the sources of *E. coli* in Charles River (NU,2008). CRWA asks boathouses to display yellow flags when the public health risk posed by the current water quality is uncertain. Since we have begun to monitor cyanobacteria levels, we have begun asking boathouses to also display yellow flags when cyanobacteria concentrations exceed the state definition of a cyanobacterial bloom, 70,000 cells per milliliter, since cyanobacteria also present an uncertain public health risk. Per state protocol, a cyanobacterial bloom does not end until cell counts below the state definition are measured in two consecutive weeks.

In the nine years that CRWA has monitored cyanobacteria levels, we have observed blooms at sites that we monitor under the water quality notification program in four years (Table 3). Except for the year 2007, blooms have only occurred at the Longfellow Bridge site. A typical cyanobacterial bloom on the Charles lasts 8-10 weeks, approaching half of the summer days that would be suitable for river recreation. However, the severity of the 2014 bloom appears to be much less than has been documented in past years. To date, not more than one bloom event was observed at the same site in the same year.

Table 3 . Summary of cyanobacterial blooms as they have impacted recreational use of the Charles River, 2007-2014. Note that the number of yellow flags may be less than the number of days in which a bloom occurred at a site because of the red flags flown during the bloom due to heavy rainfall.

Year	Site	No. Yellow Flags	No. Flagging Days	Percentage Yellow Flags	Bloom Dates	Bloom Duration
2007	Larz Anderson Bridge	48	116	41	8/30-10/20	8 weeks
2007	Boston University Bridge	46	116	40	8/30-10/20	8 weeks
2007	Longfellow Bridge	52	116	45	8/30-10/20	8 weeks
2010	Longfellow Bridge	61	101	62	7/23-9/29	10 weeks
2012	Longfellow Bridge	66	112	60	8/23-10/18	8 weeks
2014	Longfellow Bridge	20	111	18	6/30-7/23	3 weeks

Quality Control/Quality Assurance

Because the Hydrolab sonde relies on a linear relationship to estimate cell counts from measured phycocyanin levels, CRWA staff must calibrate the sonde to translate phycocyanin readings into cell counts. Examining the relationship between the phycocyanin readings and cell counts from the Hydrolab for different types of cyanobacteria shows that in 2008, for example, the calibrated relationship on the sonde was most accurate in estimating the number of *Anabaena* cells and the total number of cyanobacteria cells (Table 4). However, the fact that other types of cyanobacteria are observed less frequently may be affecting our assessment and performance of the calibration in estimating the magnitude of their presence.

Table 4. Linear relationships between phycocyanin voltage v/s cell count by genus based on 2008 data.

	Best Fit Line	R^2 Value	# Observations
Total	y = 2E-07x + 0.0131	0.84	72
Mycrosystis	y = 5E-08x + 0.0228	0.014	10
Phormidium (like)	y = 2E-07x + 0.0368	0.59	20
Anabaena	y = 3E-07x + 0.0175	0.86	35
Planktothrix	y = 9E-07x + 0.0284	0.3413	20

Monitoring Location Analysis

Analysis Objective

The objective of this analysis was to facilitate effective science and research for cyanobacterial bloom mitigation efforts initiated by CRWA. The analysis was conducted using a Geographic Information System (GIS) to address our research question of how to establish criteria that will determine the most suitable sites for CRWA to monitor cyanobacteria in the Charles River Lower Basin (historically the location of most cyanobacterial blooms). In order to provide a successful monitoring program that addresses cyanobacterial blooms, the selection of sampling sites should be carefully determined and fully cognizant of the program's objectives to understand water quality in the Lower Basin and protect the safety of recreational river users.

Data Compilation

The majority of the data used in this analysis are available on the MassGIS website and from CRWA as shapefiles (**Error! Reference source not found.**). The data from MassGIS were c lipped to the study area of the Charles River Lower Basin. GIS is necessary for this analysis because in selecting monitoring locations, we are choosing a way to represent spatial variability.

Table 5. Data used in cyanobacteria monitoring site analysis for Charles River Lower Basin.

Data Set	Year	Source Organization	Website
Land use	2005	MassGIS	www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
Major roads	2010	MassGIS	www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
Boathouses	2014	Geocoded adresses from CRWA	
Census 2010 by Block	2010	MassGIS	www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
Census SF1 Table	2010	MassGIS	www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
Massachusetts state	2001	MassGIS	www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
Slope	2005	MassGIS	www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
Watershed boundary	2000	CRWA	www.crwa.org
Watershed towns	2005	MassGIS	www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
Charles River	2013	MassGIS	www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/

Data Processing

The data acquired from CRWA and MassGIS were preprocessed to apply the Multi Criteria Analysis (MCE) tool. The criteria have to be assigned with appropriate percentage weights for the MCE process. In order to allocate weights, the factors boathouses, roads, slope, land use and population were ranked in terms of for the strength of their relationship to the occurrence of cyanobacterial blooms. The least important criterion was ranked 1 and the most important criterion was ranked 4. Runoff from roads and densely populated areas drive the level of nutrients in the Charles, favoring cyanobacteria growth; thus, these two criteria were ranked 4. Similarly, land use can be used to identify urban and industrial areas that are more likely to export nutrient and thermal pollution to the Charles, so this factor was ranked 3. We assigned site suitability based on land use using the following categories ranked from most to least suitable: Industrial, Commercial, High density residential, Urban Public/Institutional, Multi-family residential, Water-based recreation ,Participation recreation (facilities used by the public for active recreation like ball fields, tennis courts, basketball courts, playgrounds, bike paths and associated parking lots) and Bushland/Successional. A shallow slope in the landscape could allow more opportunity for stormwater to remain in contact with riparian wetlands and potentially be filtered, hence this factor is ranked 2. Although there is little reason to expect these locations to be susceptible to blooms, proximity to the nearest boathouse was included as a factor, ranked 1, because these locations represent places where people would be likely to be exposed to cyanobacteria and associated cyanotoxins, so it is important that we are aware of water quality conditions here. The weight for each criterion was assigned from the formula $\frac{\text{Rank}}{\text{Sum of all rankings}}$ X 100, where the sum of all rankings is 14, resulting in weights as follows:

Roads = 29%

Population = 29%

Land use =21%

Slope = 14%

Boathouses = 7%

The weights of these factors were then used in a GIS Weighted Overlay query to identify suitable sites for monitoring cyanobacteria. The process is shown in detail below (Figure 18**Error! Reference source not found.**).

Figure 18. Data processing steps for cyanobacteria monitoring site analysis.

Results

The analysis identified 14 sites in the Lower Basin that have a suitability of 80–100% for cyanobacteria monitoring (Table 6). The inclusion of a buffer zone around boathouses and Euclidean distance between the nearest road and the river produced more areas of 70–100% suitability and fewer areas of 10–60% suitability. The buffer zone around boathouses emphasized the area near boathouses where more people would come in direct contact with water, and the Euclidean distance query placed more weight on nearby roads that have a higher probability of exporting phosphorous into the Charles River. The most suitable monitoring sites identified in this analysis are located along the riverbank in the Boston area. The cityscape produces high volumes of runoff that introduce nutrients into the river, and the MA DCR parklands also offer easy access for CRWA staff and volunteers to monitor water quality. Figure 19 shows that many of CRWA's past cyanobacteria monitoring locations are very close to locations that showed high suitability for monitoring in this analysis.

Table 6. Potentially suitable cyanobacteria monitoring sites identified in site analysis.

Proposed Location	Status	Latitude	Longitude
Watertown Yacht Club	New	42.361806	-71.168922
Charles River Canoe & Kayak Herter Park	Historic	42.369120	-71.131410
Cambridge Boat Club	New	42.374490	-71.137909
Larz Anderson Bridge	New	42.369000	-71.123400
Boston University	Historic	42.217530	-71.636330

DeWolfe Boathouse			
Pierce Boathouse	New	42.355097	-71.097274
MIT Sailing Pavilion	Shift from existing	42.358421	-71.087758
Charles River Canoe & Kayak Kendall Square	Existing	42.363467	-71.081567
Community Boating	Existing	42.359010	-71.073100
New River Dam	Shift from existing	42.369350	-71.061840

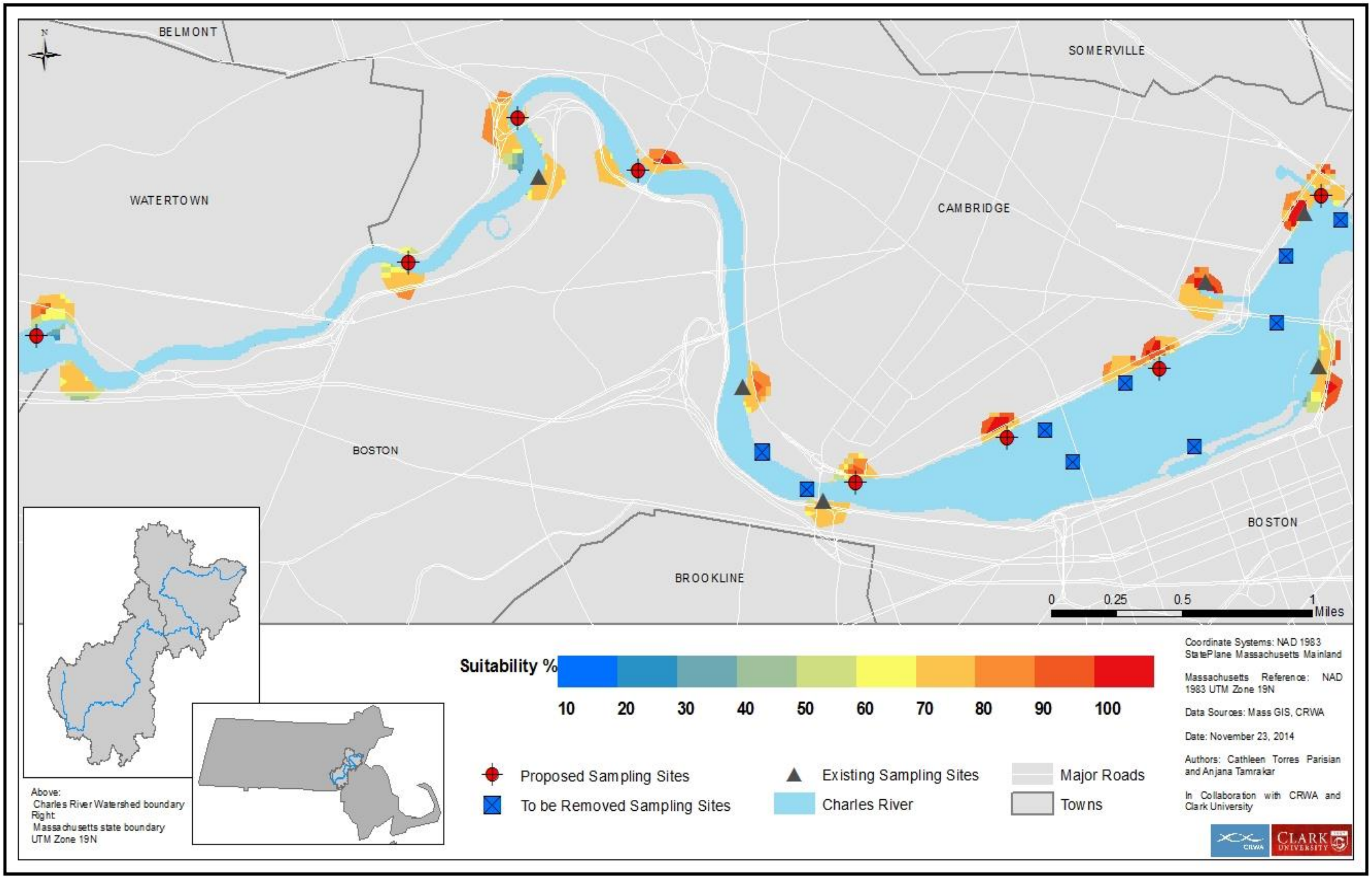


Figure 19. Existing and proposed cyanobacteria monitoring sites, Charles River Lower Basin, MA.

Discussion

Characterization of Water Quality in the Lower Basin

CRWA's monitoring program successfully detected and documented the intensity and duration of cyanobacterial blooms in the Charles River Lower Basin from 2006 to 2014. The waters of the Lower Basin are characterized by a diverse group of cyanobacteria frequently dominated by *Aphanizomenon* and *Anabaena*. Cyanobacteria density exceeded the MA DPH threshold of 70,000 cells/mL in 2006, 2007, 2010 and 2012 and remained below bloom level in 2008, 2009, and 2011. In 2014, MA DPH observed a cell count that exceeded the bloom threshold, but CRWA's monitoring data did not confirm this observation. The swings between persistent cyanobacteria blooms and no bloom at all from year to year suggest that the water quality of the Charles River is highly sensitive to year-to-year variations in weather conditions such as rainfall and temperature.

The high frequency of blooms in August and September agrees with the finding of Jewel *et al.* (2008) who observed 98.5% of total annual cyanobacteria occurred in August and September in ponds in Rajshahi, Bangladesh. The higher temperatures in August and September often encourage cyanobacterial blooms because cyanobacteria achieve optimum growth at higher temperatures than other phytoplankton (Rolland *et al.,* 2013). Many of the highest cell counts we observed in the Charles River coincided with water temperatures of 20-25^{o}C (Appendix 12), which is regarded as the optimal range for cyanobacteria growth (Tilman *et al*. 1986). However, in 2013, a bloom was detected in early summer when the temperature was approximately 18^{o}C. Because cyanobacteria are most toxic during periods of warm weather (WHO 1998), it may be especially useful to test blooms that occur early in summer for the presence of cyanotoxins so that we can accurately represent the public health risk associated with these blooms. According to the CDC, the number of waterborne disease outbreaks like visual disturbances, nausea, vomiting and skin irritations associated with recreational water in 2009–2010 was frequent during the months of June, July and August, with few outbreaks in March, May, and October. Almost half of the outbreaks related to untreated recreational water venues in 2009-2010 were confirmed or suspected to correlate with cyanotoxins (CDC 2014).

Characterization of Public Health Risk

The highest density of cyanobacteria in the Charles River occurred in 2007, exceeding three million cells per milliliter at the Community Boating site. The Center for Disease Control and Prevention (CDC) has recognized 2007 as the year with the highest number of disease outbreaks related to recreational water use nationally. Although no cases of illness have been definitively linked to exposure to cyanotoxins in the Charles River, we have reason to believe that the public has been at risk for exposure to cyanotoxins in the Charles River between 2006 and 2014. Although a cyanobacteria advisory was only in effect for 18% of CRWA's water quality notification program in 2014, cyanobacterial blooms have impacted 40% (2007) to 62% (2010) of the summer recreation period in years past. We have observed a pattern in which a single cyanobacterial bloom that persists for 8-10 weeks occurs every few years. Because high cyanobacteria levels have impacted more than half of the summer recreation season in bloom years, further research that quantifies the risks associated with cyanotoxin exposure in the Charles is warranted.

Anabaena, Aphanizomenon, Microcystis and *Oscillatoria* are among the genera that have the potential to produce the cyanotoxin microcystin. *Microcystis* was the dominant cyanobacterium in the Lower Basin in 2008; however, its abundance varied considerably over the monitoring period. Although 70,000 cells/mL has been generally accepted as the threshold for microcystin production, lower densities of cyanobacteria can produce microcystin (Dyble *et al*., 2008). High concentrations of ammonia can also cause *Microcystis* to produce toxins (Davis *et al.,* 2009). Consequently, it is appropriate for CRWA to continue to encourage river users to exercise caution when we observe cyanobacteria at levels below the MA DPH bloom threshold, especially if the presence of potentially toxin-producing cyanobacteria has been confirmed.

Watershed Management

The predominance of *Anabaena* and *Aphanizomenon* suggests that high phosphorous concentrations are likely favoring the growth of these nitrogen-fixing genera (Figueiredo, 2006). This trend is further supported by the predominance of the non-nitrogen-fixing genus *Microcystis* in 2008, a year in which cell counts never exceeded the MA DPH bloom threshold. State and local officials should commit to implementing the nutrient total maximum daily loads (TMDLs) for the Upper/Middle and Lower Charles River to the fullest degree with as much expedience as possible to minimize the public health risks presented by cyanobacterial blooms in the future.

As long as the Charles River remains a eutrophic system i.e high concentration of nutrients, warm water temperature, low DO level, we would expect heavy rainfall to dilute or flush nutrients dissolved in the water, thus reducing cyanobacterial bloom intensity. However, volunteer scientist Roger Frymire's observations with City of Cambridge personnel have shown that the outfall at the upstream end of the Broad Canal actually draws canal water into the outfall pipe unless a short, intense storm event occurs. Because the dominant cyanobacterium in the Lower Basin in 2014 was one that has a habit of forming floating clumps, we suspect that the clumps of cells accumulated in the upper water column in the outfall pipe. After short, intense storm events, these clumps of cells likely were flushed into the Broad Canal and Longfellow Bridge area, producing temporarily high cell counts. This may explain the discrepancy between CRWA's and MA DPH's cell count data in year 2014, as CRWA did not detect cyanobacterial bloom during 2014 monitoring period while MA DPH record shows cyanobacterial bloom. The close proximity of the outfall pipe suspected to be the source of this water quality problem to Charles River Canoe and Kayak's Kendall Square rental facility and the possible implications of discrepancies between observations makes it important to resolve this issue quickly and effectively.

Conclusion

Cyanobacteria bloom along the lower basin of Charles River is one of the major concerns for CRWA, Massachusetts Department of Public Health (MA DPH) and recreation users. The World Health Organization has recognized it as a human health hazard and DPH has established a standard value of the bloom level for recreational purpose. The cyanobacteria monitoring program of CRWA in Lower Charles has been contributing to improve water quality and developing solutions for watershed problems. CRWA's effort on monitor different sites of Lower Charles River for cyanobacteria bloom contributes to minimize health risk from using river. It continues to promote activities and awareness that reduce nutrient loading to the river and shifting algal communities to a more desirable or at least more tolerable state. While significant progress has been made in Charles River watersheds, treatment to address the external nutrient load is important part of the picture. The water quality improvement approaches can meet the expectations for better outcomes, particularly if a holistic approach to nutrient management is taken.

Recommendation

Future Cyanobacteria Monitoring in the Lower Basin

The analysis of monitoring sites identified eight new potential monitoring locations. Unless conditions change, CRWA will not revisit the nine sites that we have monitored in the past that ranked low in the monitoring site analysis. Resources permitting, CRWA will explore options for monitoring cyanobacteria at the new proposed locations and shifting the two existing monitoring locations for the next monitoring season. A number of constraints that were not taken into consideration in the site analysis, such as the bank hardening on the northern bank of the river and private ownership of some docks and boating facilities, will limit which of the proposed sites CRWA is able to monitor in the future. Likewise, the deployment of environmental sensors at these sites could be consider in future to better predict bloom development and intensity and to collect high temporal frequency nutrient data in Lower Charles. Similarly, cyanobacteria bloom is also largely influenced by surface hydrology as it varies with surface water movement, the distribution of surface water and flow within a year and between years. Since variability in water quantity is largely associated by climate, the future anticipation for CRWA would also includes collecting hydrologic data as part of the hydrologic regime that creates and maintains a healthy river system. CRWA intends to continue working closely with the New England Cyanobacteria Monitoring Workgroup following the 2014 pilot season to implement standardized data collection procedures to produce comparable data throughout the region. Furthermore, MA DCR is scheduled to apply SONAR to Purgatory Cove in the Lakes District of the Charles River in year 2015 so additional monitoring will be needed in this area this year. Herbicide application may create opportunities for cyanobacterial growth to increase, further complicating the task of balancing a variety of watershed management objectives.

References

Braody, S. (2013, July 13). *Public Swim Follows 50 Years Of Dirty Water*. Retrieved November 14, 2014, from 90.9 Wbur: http://www.wbur.org/2013/07/13/public-swim-charles

Center for Disease Control and Precention. (2014). *Recreational Water–Associated Disease Outbreaks — United States, 2009–2010.* (Vol. 63). MMWR.

Davis T. W., B. D. (2009). *The effects of temperature and nutrients on the growth and dynamics of toxic and non-toxic strains of Microcystis during cyanobacteria blooms* (Vol. 8).

Dyble, J. F. (2008). *Microcystin Concentrations and Genetic Diversity of Microcystis in the Lower Great Lakes.* (W. Interscience, Ed.) uman Health, NOAA Great Lakes Environmental Research Laboratory.

Environmental Protection Agency (EPA). (2012). . *Establishing a TMDL for Phosphorus in the Charles River.* EPA.

Environmental Protection Agency (EPA). (2012). *Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems.* Environmental Protection Agency, Office of Water.

Figueiredo, D. A. (2006). *The effect of environmental parameters and cyanobacterial blooms on phytoplankton dynamics of a Portuguese temperate lake.* (Vol. 568).

Jewel, A. S. (2008). *Cyanobacterial blooms and water quality in two urban fish ponds* (Vol. 27). Department of Fisheries, University of Rajshahi.

Massachusetts Department of Environmental Protection. (2007). *Lower Charles River Basin Nutrient (Phosphorus) TMDL.*

Massachusetts Department of Public Health. (2014). *MDPH Guidelines for Cyanobacteria in Freshwater Recreational Water Bodies in Massachusetts.* Boston, Massachusetts: Boston: Bureau of Environmental Health. .

University., N. (2008, May 2). *E. Coli In Charles River Found To Be High After Long Periods Without Rain: New Model Developed.* Science Daily.

Rhode Island Department of Environmental Management. (2011.). *Blue Green Algae (Cyanobacteria) Fact Sheet.* Office of Water Resources.

Rolland, D. B. (2013). *Extreme variability of cyanobacterial blooms in an urban drinking water supply* (Vol. 0). Journal of Plankton Research .

The World Health Organization (WHO). (1998). *Cyanobacterial toxins: Microcystin-LR in Drinking-water* (Health criteria and other supporting information. ed., Vol. 2). Geneva.

The World Health Organization (WHO). (1999). *Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring, and management.* London: F & FN Spon.

Tilman, D. K. (1986). *Green, blue-green and diatom algae: differences in competitive ability for phosphorous, silicon and nitrogen.* (Vol. 106).

Appendices

Appendix A. MA DPH cyanobacteria cell counts by genus, 2006.

Date	Site	Total (Cells/mL)	*Microcystis*	*Anabaena spiroides*	*Aphanizomenon flos-aquae*	*Oscillatoria*
8/9	Storrow Lagoon	25275				
8/9	Hatch Shell/River dock	11297				
8/9	Community Boating	11810				
8/9	Museum of Science	53582				
8/23	Storrow lagoon	29685	21333	1612	1934	4805
8/23	Hatch Shell/River dock	15473	9846		1289	4337
8/23	Community Boating	36703	29538	2711		4454
8/23	Museum of Science	54212	45128	2051		7033
8/30	Storrow lagoon	10110				
8/30	Community Boating	24264				
9/7	Hatch Shell/River dock	17700				
10/12	Storrow Lagoon	4205				
10/12	Hatch Shell/River dock	13641				
10/12	Community Boating	9026				
10/12	Museum of Science	7487				

Appendix B. MA DPH cyanobacteria cell counts by genus, 2007.

Date	Site	Total (cells/mL)	*Oscillatoria*	*Microcystis*	*Anabaena*	*Planktothrix* spp.	*Planktothrix rubescens*	*Aphanizomenon* (like)	*Phormidium* -like
6/26	Community Boating	0	0	0	0	0	0	0	0
7/6	Community Boating	61,000	0	0	61,000	0	0	0	0
7/10	Community Boating	1,000	0	1,000	0	0	0	0	0
7/19	Community Boating	29,500	0	29,500	0	0	0	0	0
7/24	Community Boating	25,903	0	24,498	937	468	0	0	0
8/28	Community Boating	155,603	0	0	114,988	40,615	0	0	0
9/4	Community Boating	320,044	0	0	192,000	26,857	0	4,308	96,879
9/11	Community Boating	795,516	0	0	247,208	51,428	0	0	496,879
9/18	Community Boating	545,231	0	0	209,934	0	43,077	2,462	289,758
9/25	Community Boating	292,835	0	0	162,462	28,571	0	0	101,802
10/2	Community Boating	264,967	0	0	189,187	25,846	12,308	0	37,626
10/9	Community Boating	234549	0	0	202197	0	0	0	20044
10/16	Community Boating	153,582	0	0	83,692	39,385	8,000	0	22,505
10/23	Community Boating	298725	0	0	11077	235077	0	0	52571
11/1	Community Boating	274813	0	0	7209	237538	4308	0	25758
11/13	Community Boating	197890	0	0	2989	34462	51692	0	108747
6/26	Herter Park Dock	0	0	0	0	0	0	0	0
7/10	Herter Park Dock	0	0	0	0	0	0	0	0
7/19	Herter Park Dock	0	0	0	0	0	0	0	0
7/24	Herter Park Dock	0	0	0	0	0	0	0	0
8/28	Herter Park Dock	4,043	0	0	2,813	1,230	0	0	0

Date	Site	Total (cells/mL)	*Oscillatoria*	*Microcystis*	*Anabaena*	*Planktothrix* spp.	*Planktothrix rubescens*	*Aphanizomenon* (like)	*Phormidium* -like
9/4	Herter Park Dock	64,352	0	0	18,637	22,857	0	0	22,857
9/11	Herter Park Dock	106,374	0	0	6,329	45,142	21,142	0	33,758
9/18	Herter Park Dock	7,275	0	0	2,792	0	0	0	4,484
9/25	Herter Park Dock	20,901	0	0	9,319	3,143	0	0	8,440
10/2	Herter Park Dock	41,143	0	0	527	7,385	0	0	33,231
10/9	Herter Park Dock	29,846	0	0	2,462	6,462	17,846	0	3,077
10/16	Herter Park Dock	2,432	0	0	586	1,846	0	0	
10/23	Herter Park Dock	19018	0	0	234	17436	0	0	1348
11/1	Herter Park Dock	5773	0	0	0	3897	1641	0	234
11/13	Herter Park Dock	1260	0	0	0	0	1026	0	234
6/26	Magazine Beach	0	0	0	0	0	0	0	0
7/10	Magazine Beach	0	0	0	0	0	0	0	0
7/19	Magazine Beach	1,500	0	1,500	0	0	0	0	0
7/24	Magazine Beach	0	0	0	0	0	0	0	0
8/28	Magazine Beach	85,581	0	0	41,560	44,021	0	0	0
9/4	Magazine Beach	247,209	0	0	129,055	57,143	0	3,868	57,143
9/11	Magazine Beach	449,714	0	0	208,175	68,000	0	0	173,538
9/18	Magazine Beach	243,253	0	0	89,670	0	17,846	2,110	133,626
9/25	Magazine Beach	127,340	0	0	75,604	12,000	0	0	39,736
10/2	Magazine Beach	117,275	0	0	1,758	16,000	7,385	0	92,132
10/9	Magazine Beach	69,011	0	0	32,527	27,077	4,308	0	5,099
10/16	Magazine Beach	58,505	0	0	20,044	26,462	8,308	0	3,692
10/23	Magazine Beach	70505	0	0	9319	46154	0	0	15033
11/1	Magazine Beach	56733	0	0	1407	39795	3692	0	11839
11/13	Magazine Beach	22418	0	0	0	0	11385	3385	7648
6/26	New River Dam	11,077	762	10,315	0	0	0	0	0
7/6	New River Dam	50,000	0	0	50,000	0	0	0	0
7/10	New River Dam	80,000	0	80,000	0	0	0	0	0
7/19	New River Dam	169,000	0	169,000	0	0	0	0	0
7/24	New River Dam	14,828	0	14,828	0	0	0	0	0
8/28	New River Dam	144,700	0	0	106,723	27,780	0	10,197	0
9/4	New River Dam	366,505	0	9,495	213,451	42,286	0	7,736	93,538
9/11	New River Dam	676,176	0	0	243,691	74,857	0	0	357,626
9/18	New River Dam	602,022	0	0	195,165	0	83,692	13,714	309,451

Date	Site	Total (cells/mL)	*Oscillatoria*	*Microcystis*	*Anabaena*	*Planktothrix* spp.	*Planktothrix rubescens*	*Aphanizomenon* (like)	*Phormidium* -like
9/25	New River Dam	333,055	0	0	228,220	5,143	0	0	99,692
10/2	New River Dam	309,451	0	0	233,143	40,000	4,308	0	32,000
10/9	New River Dam	284,220	0	0	206,769	49,231	8,000	0	20,220
10/16	New River Dam	181,187	0	0	81,582	60,308	9,231	0	30,066
10/23	New River Dam	249143	0	0	13011	190769	0	0	45363
11/1	New River Dam	366330	0	0	7560	272308	13231	0	73231
11/13	New River Dam	146637	0	0	352	9846	36923	0	99516
7/19	Swim Dock	5,800	0	5,800	0	0	0	0	0

Appendix C. MA DPH cyanobacteria cell counts by genus, 2008.

Date	Site	Total (cells/mL)	*Microcystis*	*Anabaena*	*Phormdium*	*Aphanothece*	*Planktothrix*	*Planktothrix rubescens*	*Aphanizomenon*
7/22	Community Boating	31386	23912	5209	440	440	1385		
7/22	New River Dam	29626	9846	3473	3077	9890	2615	725	
8/5	Community Boating-	4132		322	2403		1231		176
8/5	New River Dam	3985	366	630	1055		1758	176	
8/26	Community Boating-	5187			1524		3663		
8/26	New River Dam	4660			2286		1319		1055
9/18	Community Boating-	6125		2110	1905		1231		
9/18	New River Dam	2036		1333	703				

Appendix D. MA DPH cyanobacteria cell counts by genus, 2009.

Date	Site	Total (cells/mL)	*Anabae na*	*Microcyst is*	*Aphanizo menon*	*Lyngbya*	*Arthro spira*	*Chrooc occus*	*Rivul aria*	*Merismo pedia*	*Ocillat oria*	*Aphano capsa*	*Spiruli na*	*Anaba enopsis*	*Dactyloc occopsis*
6/18	Swim Dock	128	32	16				80							
6/18	Community Boating	104	8	16				48	24	8					
6/24	Community Boating	164	100	40	24										
6/30	Community Boating	144	48			64					24			8	
7/7	Swim Dock	1,648	1,600			48									
7/14	Community Boating	2,180	1,300	400	480										
7/21	Community Boating	<8													
8/4	Community Boating	5,536	320		4,800							400	16		
8/11	Community Boating	40													
8/18	Community Boating	430					240								190
8/25	Community Boating	<8													
9/1	Community Boating	21,000	3,400		1,500							2800			

Appendix E. MA DPH cyanobacteria cell counts by genus, 2010.

Date	Site	Total (cells/mL)	*Oscillatoria*	*Microcystis*	*Anabaena*	*Aphanizomenon (like)*	*Merismopedia*	*ui coccoid colonial*	*Coelosphaerium*	*Aphanocapsa*	*Spirulina*	*Dactylococcopsis*
6/15	Community Boating	930	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6/21	Community Boating	6500	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6/24	Community Boating	3660	260	0	220	3180	0	0	0	0	0	0
6/24	WEDGE	12720	0	0	3040	0	0	0	9680	0	0	0
7/8	Community Boating	16222	1244	0	400	14578	0	0	0	0	0	0
7/8	MIT Sailing	13378	622	0	711	11378	666	0	0	0	0	0
7/8	Swim Dock	25822	1244	0	889	22578	0	1111	0	0	0	0
7/8	Community Boating	52000	0	3100	1200	46000	0	0	0	1000	140	700
7/8	Swim Dock	53960	0	3400	1400	47000	0	0	0	1400	190	570
7/12	Community Boating	70112	0	3600	1100	64000	0	0	0	1200	140	72
7/15	Community Boating	43000	18000	0	1000	24000	0	0	0	0	0	0
7/15	Swim Dock	68000	22000	0	2000	44000	0	0	0	0	0	0
7/22	Community Boating	153000	130000	<3000	0	remainder	0	0	0	0	0	0
7/22	Herter Park Dock	<1000	<1000	0	0	0	0	0	0	0	0	0
7/22	Magazine Beach	6000	5000	0	0	1000	0	0	0	0	0	0
7/22	New River Dam	187000	163000	4000	2000	18000	0	0	0	0	0	0
7/22	MIT Sailing	137000	128000	<3000	0	remainder	0	0	0	0	0	0
7/22	Swim Dock	160000	147000	<3000	0	remainder	0	0	0	0	0	0
7/28	New River Dam	237000	120000	0	0	117000	0	0	0	0	0	0
7/28	Community Boating	249000	98000	0	0	151000	0	0	0	0	0	0

Date	Site	Total (cells/mL)	*Oscillatoria*	*Microcystis*	*Anabaena*	*Aphanizomenon (like)*	*Merismopedia*	*ui coccoid colonial*	*Coelospharium*	*Aphanocapsa*	*Spirulina*	*Dactylococcopsis*
7/28	Magazine Beach	16000	11000	0	0	5000	0	0	0	0	0	0
7/26	Community Boating	68000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/4	Community Boating	327000	199000	0	0	128000	0	0	0	0	0	0
8/4	Magazine Beach	50000	11000	0	0	36000	0	0	0	0	0	0
8/4	New River Dam	252000	157000	0	0	95000	0	0	0	0	0	0
8/4	Swim Dock	133000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/4	MIT Sailing	100000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/9	Swim Dock	32000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/9	MIT Sailing	41000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/12	New River Dam	150000	130000	0	1000	29000	0	0	0	0	0	0
8/12	Community Boating	122000	88000	0	0	34000	0	0	0	0	0	0
8/12	Community Boating	114000	94000	0	0	20000	0	0	0	0	0	0
8/12	Magazine Beach	26000	10000	0	0	16000	0	0	0	0	0	0
8/12	Herter Park Dock	2000	0	0	2000	0	0	0	0	0	0	0
8/16	New River Dam	228000	208000	12000	1000	4000	0	0	0	0	0	0
8/16	Community Boating	110000	109000	0	0	1000	0	0	0	0	0	0
8/16	Community Boating	100000	98000	0	0	6000	0	0	0	0	0	0
8/16	Community Boating	137000	129000	0	2000	6000	0	0	0	0	0	0
8/16	Magazine Beach	21000	20000	0	0	1000	0	0	0	0	0	0
8/16	Herter Park Dock	3000	3000	0	0	0	0	0	0	0	0	0

Date	**Site**	**Total (cells/mL)**	***Oscillatoria***	***Microcystis***	***Anabaena***	***Aphanizomenon (like)***	***Merismopedia***	***ui coccoid colonial***	***Coelosphaerium***	***Aphanocapsa***	***Spirulina***	***Dactylococcopsis***
8/19	MIT Sailing	46000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/19	Community Boating	36000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/19	New River Dam	228000										
8/19	Community Boating	137000										
8/19	Magazine Beach	21000										
8/23	MIT Sailing \	69400	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/23	Community Boating	78500	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/26	New River Dam	79000	75000	0	3000	1000	0	0	0	0	0	0
8/26	Community Boating	31000	30000	0	1000	0	0	0	0	0	0	0
8/26	Community Boating	25000	25000	0	0	0	0	0	0	0	0	0
8/26	Magazine Beach	2000	1000	0	1000	0	0	0	0	0	0	0
8/30	MIT Sailing	75000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/30	Community Boating	92000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9/3	Community Boating	354000	335000	0	8000	11000	0	0	0	0	0	0
9/3	New River Dam	315000	300000	0	6000	9000	0	0	0	0	0	0
9/3	Magazine Beach	2000	2000	0	0	0	0	0	0	0	0	0
9/7	MIT Sailing	180000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9/7	Community Boating	240000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9/7	MIT Sailing	361000	357000	0	4000	0	0	0	0	0	0	0
9/7	Community Boating	477000	474000	0	3000	0	0	0	0	0	0	0

Date	Site	Total (cells/mL)	*Oscillatoria*	*Microcystis*	*Anabaena*	*Aphanizomenon (like)*	*Merismopedia*	*ui coccoid colonial*	*Coelosphaerium*	*Aphanocapsa*	*Spirulina*	*Dactylococcopsis*
9/9	Community Boating	556000	552000		3000		0	0	0	0	0	0
9/11	Community Boating	603,000	598,000	0	2000	3000	0	0	0	0	0	0
9/11	Magazine Beach	38,000	37000	0	0	1000	0	0	0	0	0	0
9/13	MIT Sailing	891,000	889000	0	1000	1000	0	0	0	0	0	0
9/13	Community Boating	717,000	715000	0	2000	0	0	0	0	0	0	0
9/13	MIT Sailing	200,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9/13	Community Boating	180,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9/16	Community Boating	332,000	332000	0	0	0	0	0	0	0	0	0
9/20	Community Boating	14000	14000	0	0	0	0	0	0	0	0	0
9/20	MIT Sailing	24000	18000	0	0	1000	0	0	5000	0	0	0
9/20	MIT Sailing	37,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9/20	Community Boating	33,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9/23	Community Boating	45000	40000	0	0	5000	0	0	0	0	0	0
9/29	MIT Sailing	14000	9000	0	0	5000	0	0	0	0	0	0
9/29	Magazine Beach	1000	1000	0	0	0	0	0	0	0	0	0
9/30	Community Boating	41000	36000	4000	0	1000	0	0	0	0	0	0
10/7	Long Fellow Bridge	28000	28000	0	0	0	0	0	0	0	0	0
10/7	Boston University	0	0	0	0	0	0	0	0	0	0	0

Appendix F. MA DPH cyanobacteria cell counts by genus, 2011.

Date	Site	Total (cells/mL)	*Spirulina*	*Coelosphaerium*	*Anabaena*	*Microcystis*	*Nostoc*	*Chroococcus*	*Aphanizomenon*	*Cuspidothrix*	*Pseudanabaena*	*Aphanocapsa*
5/31	Swim Dock	1,900	1900									
6/20	Swim Dock	960	960									
6/27	Swim Dock	6,400		3400	3000							
7/5	Swim Dock	66,400			3200	10000	2200		51000			
7/11	Swim Dock	10,720	400		10000			320				
7/18	Swim Dock	24,900			1000	11000			4000		400	8500
7/25	Swim Dock	19,200	1900						6600	5300	2800	2600
8/1	Swim Dock	24,600	1900		2400					3500	5800	11000
8/8	Swim Dock	16,400			4600					6000	3800	2000
8/15	Swim Dock	5,500			500					4600	400	
8/25	Swim Dock	17,700	4300		1000	6400			6000			
8/30	Swim Dock	15,600				11000					3200	1400

Appendix G. MA DPH cyanobacteria cell counts by genus, 2012.

Date	Site	Total (cells/mL)	*Anabaena*	*Aphanizomenon*	*Spirulina*	*Oscillatoria*	*Chroococcus*	*Aphanocapsa*	*Microcystis*	*Radiocystis*	*Arthrospira*	*Merismopedia*	*Gienocapsa*	*Phormidium*	*Cylindrospharium*
6/20	Community Boating	441000		441000											
6/21	MIT Sailing	900000													
6/25	Community Boating	115000		114000											
7/2	Community Boating	55000		29000		4000	3800	6800	11000						
7/2	Swim Dock	11000	7000	4900											
7/2	MIT Sailing	21000		21000											
7/15	Community Boating	2500							1500	1000					
7/18	Community Boating	42000	1000	6800			3200	6000	25000						
7/18	Swim Dock	8000	3600	4400											
7/26	Community Boating	50000		4000	5600	2400		16000			14000	7700			
8/24	MIT Sailing	110000	35000	26000		50000									
8/27	MIT Sailing	35000	3400	22000		7000							2900		
8/27	Community Boating	11000	2400	9000											
8/27	MIT Sailing	35000	3400	22000		7000		2900							
8/29	Community Boating	82000	9000	38000		35000									
9/3	MIT Sailing	350000													
9/4	Community Boating	84000	3500	66000		14000									
9/4	MIT Sailing	88000		75000		13000									
9/12	Community Boating	500000		409000		91000									
9/12	New River Dam	516000													
9/12	MIT Sailing	371000													
9/13	Community	220000	4000	200000		14000									

Date	**Site**	**Total (cells/mL)**	***Anabaena***	***Aphanizomenon***	***Spirulina***	***Oscillatoria***	***Chroococcus***	***Aphanocapsa***	***Microcystis***	***Radiocystis***	***Arthrospira***	***Merismopedia***	***Gienocapsa***	***Phormidium***	***Cylindrospharium***
	Boating														
9/13	MIT Sailing	51000		48000		3000									
9/19	Community Boating	240000	45000			21000								170000	
9/26	Community Boating	180000	24000	120000		26000									8600
9/26	MIT Sailing	150000													
10/5	Community Boating	76000	9600	61000		5300									
10/5	MIT Sailing	56000	4800	40000		11000									
10/5	Community Boating	52000		44000		8000									
10/10	Community Boating	48000		44000	3600										

Appendix H. MA DPH cyanobacteria cell counts by genus, 2013.

Date	Site	Total (Cells/mL)	*Anabaena*	*Microcystis*	*Gomphosphaeria*	*Aphanizomenon*	*Chroococcus*
6/10	Community Boating	89,000	39000	25000	12000	11000	1900
6/17	Community Boating	<1					
7/1	Community Boating	6,200					
7/15	Community Boating	16,000					
7/22	Community Boating	12,000					
7/29	Community Boating	<1					
8/5	Community Boating	1,400					
8/19	Community Boating	2100					

Appendix I. MA DPH cyanobacteria cell counts by genus, 2014.

Date	**Site**	**Total (cells/ml)**	***Pseudanabaena***	***Anabaena***	***Spirulina***	***Aphanizomen on***	***Aphanocaps a***	***Microcystis***	***Merismo pedia***	***Coelosphaerium***
6/3	Community Boating	16,000	11,000							
6/11	Swim Dock	14,000		5,000	9,000					
6/24	Swim Dock	28,000		11,000		14,000	3,000			
6/30	Swim Dock	50,000				32,000	18,000			
6/30	MIT Sailing	72,000		2,600		31,000	19,000	19,000		
6/30	Broad Canal	76,000				37,000	9,500	29,000		
7/8	Broad Canal	150,000			4,000	130,000		23,000		
7/8	MIT Sailing	89,000		1,000	2,000	77,000	8,500			
7/8	Broad Canal	160,000			5,000	140,000	12,000			
7/15	Swim Dock	17,000			2,100	15,000				
7/15	MIT Sailing	37,000		3,000	4,000	8,800	6,000	9,000	6,400	
7/15	Broad Canal	25,000	1,600			11,000	7,500			5,000
7/22	Swim Dock	26,000	6,200			20,000				
7/22	MIT Sailing	22,000		3,500	4,000	14,000				
7/22	Broad Canal	13,000			2,000	11,000				

Appendix J. CRWA Hydrolab data, 2013.

Date	Site ID	Time	Barometric Pressure	Temp.	pH	Specific Conductivity	Salinity	DO	DO	Phycocyanin	Phycocyanin	Depth
		HHMMSS	mmHg	°C		µS/cm	ppth	% sat.	mg/L	cells/mL	volts	meters
06/21	Community Boating	10:04:44	734.9	22.09	6.95	340.5	0.17	80.7	7.11	327	0.0045	0.01
06/21	Community Boating	10:05:56	749.7	21.23	6.94	338.2	0.17	76.8	6.87	378	0.0046	0.99
06/21	New River Dam	10:55:14	735.2	21.92	6.97	583.9	0.3	79.3	6.99	450	0.0048	0.04
06/21	New River Dam	10:56:41	735.2	21.86	6.93	585.9	0.3	79.1	6.99	488	0.0048	0.98
06/24	New River Dam	10:34:00	741.4	24.04	7.05	1024	0.54	79.9	6.68	269	0.0043	0.11
06/24	New River Dam	10:35:17	727.8	23.9	7.04	1018	0.53	78.9	6.62	287	0.0044	1.08
06/24	Community Boating	11:12:05	737.4	26.4	7.18	392.2	0.2	N/A	N/A	364	0.0046	0
06/24	Community Boating	11:13:03	727.2	24.21	7.07	391.6	0.19	N/A	N/A	245	0.0043	1.01
07/02	New River Dam	14:22:03	765	25.57	7.04	905.9	0.47	143.2	12.24	200	0.0042	-0.02
07/02	New River Dam	14:23:05	764.9	25.57	7.03	922.2	0.48	172.5	14.74	177	0.0041	0.96
07/10	Community Boating	16:04:42	757.3	27.75	7.2	585.3	0.3	N/A	N/A	218	0.0042	-0.02
07/10	Community Boating	16:05:19	757.4	27.74	7.16	585.4	0.3	N/A	N/A	248	0.0043	1.01
07/12	Roberta	12:14:27	764.1	23.61	6.33	447.2	0.22	8.5	0.75	3279	0.0113	0.77
07/12	Roberta	12:15:09	764	23.62	6.31	447.9	0.22	7.1	0.63	2127	0.0088	0.77
07/12	Roberta	12:16:01	764	23.84	6.36	445.7	0.22	4	0.35	5468	0.0176	0.68
07/12	CRCK Newton Dock	12:40:33	763.5	26.13	7.11	421.4	0.21	87	7.37	148	0.0041	-0.01
07/12	CRCK Newton Dock	12:41:23	763.6	26.04	7.09	421.8	0.21	94.2	7.99	541	0.0049	0.55
07/12	New River Dam	14:10:55	764.1	26.51	7.14	979.4	0.51	91.5	7.69	178	0.0041	0.06
07/12	New River Dam	14:11:48	764.4	26.46	7.11	1009	0.53	74.5	6.26	148	0.0041	1.04
07/12	New River Dam	14:12:21	764.3	26.46	7.11	1004	0.53	71.3	5.99	161	0.0041	1.04
07/12	Community Boating	14:34:19	764.9	26.34	7.24	595.7	0.3	90	7.6	279	0.0044	0.08
07/12	Community Boating	14:35:07	764.6	26.29	7.17	599.7	0.31	90.5	7.64	288	0.0044	0.99

Date	Site ID	Time	Barometric Pressure	Temp.	pH	Specific Conductivity	Salinity	DO	DO	Phycocyanin	Phycocyanin	Depth
		HHMMSS	mmHg	°C		µS/cm	ppth	% sat.	mg/L	cells/mL	volts	meters
07/19	Roberta	11:37:43	757.5	28.54	6.34	480.7	0.24	17	1.37	261	0.0043	0.01
07/19	Roberta	11:38:16	757.3	23.73	6.16	543.3	0.28	10.6	0.93	7745	0.0241	0.88
07/19	Roberta	11:38:39	757.3	24.75	6.13	531.1	0.27	4.4	0.38	5810	0.0205	0.85
07/19	New River Dam	13:11:25	757.8	29.96	8.2	813.1	0.42	123.4	9.66	1139	0.0064	0.12
07/19	New River Dam	13:11:59	757.5	29.32	7.85	809.5	0.42	116.8	9.24	836	0.0057	1.09
07/19	Community Boating	13:35:04	757.8	30.67	8.57	653.3	0.34	126.4	9.78	696	0.0053	0
07/19	Community Boating	13:35:39	757.5	30.16	8.41	655	0.34	124.4	9.71	736	0.0055	1.03
07/26	CRCK Newton Dock	10:28:41	759.2	21.71	7	375.2	0.19	93	8.5	140	0.004	0.48
07/26	CRCK Newton Dock	10:28:57	758.7	21.71	6.98	374.2	0.19	88.5	8.09	143	0.004	0.53
07/26	CRCK Newton Dock	10:29:14	758.7	21.71	6.97	374	0.19	86.5	7.91	127	0.004	1.07
07/26	CRCK Newton Dock	11:39:59	772.3	24.55	7.14	872.9	0.45	70.3	6.08	211	0.0042	0.03
07/26	Community Boating	11:40:14	758.9	24.56	7.14	873	0.45	68.8	5.95	222	0.0042	0.02
07/26	Community Boating	11:40:56	758.5	24.59	7.12	872.4	0.45	67.5	5.83	185	0.0041	1.05
07/26	New River Dam	12:40:21	769	24.9	7.17	2301	1.23	78.1	6.67	135	0.004	0.16
07/26	New River Dam	12:41:18	758.7	24.92	7.02	2296	1.23	66.2	5.65	143	0.004	0.91
07/26	Roberta	14:05:19	757.5	21.25	6.99	528.2	0.27	N/A	N/A	254	0.0043	0.19
07/26	Roberta	14:05:38	757.2	21.4	6.69	526.3	0.27	N/A	N/A	160	0.0041	0.19
07/26	Roberta	14:05:55	757.5	21.26	6.56	528.8	0.27	N/A	N/A	165	0.0041	0.22
08/02	CRCK Newton Dock	10:39:33	771.4	24.58	7.03	406.8	0.2	69.8	6.02	929	0.0059	-0.06
08/02	CRCK Newton Dock	10:39:56	756.4	24.58	6.74	434.3	0.22	60.7	5.24	6584	0.0148	0.32
08/02	Roberta	10:55:12	756.5	22	6.36	432.2	0.22	5.6	0.51	418	0.0047	-0.01
08/02	Roberta	10:57:21	756.5	21.79	6.31	448.1	0.23	1.6	0.14	2857	0.0105	0.12
08/02	New River Dam	12:19:54	756.7	25.26	7.49	1225	0.65	99.6	8.47	1072	0.0063	0.11

Date	Site ID	Time	Barometric Pressure	Temp.	pH	Specific Conductivity	Salinity	DO	DO	Phycocyanin	Phycocyanin	Depth
		HHMMSS	mmHg	°C		µS/cm	ppth	% sat.	mg/L	cells/mL	volts	meters
08/02	New River Dam	12:20:30	756.8	25.11	7.44	1219	0.64	97	8.26	1033	0.0061	1.26
08/02	Community Boating	12:41:49	757.1	25.63	7.5	623.8	0.32	103.8	8.78	843	0.0057	0
08/02	Community Boating	12:42:21	773.7	25.25	7.38	623.8	0.32	95.9	8.17	448	0.0048	1.05
08/09	CRCK Newton Dock	10:59:08	758.2	23.47	7.03	475.5	0.24	74.4	6.57	127	0.004	-0.01
08/09	CRCK Newton Dock	10:59:32	757.9	23.41	6.97	478.3	0.24	70.8	6.26	4404	0.014	0.54
08/09	Roberta	11:14:33	758.1	23.01	6.66	459.6	0.23	N/A	N/A	605	0.005	0.03
08/09	Roberta	11:15:09	757.7	21.91	6.35	483.7	0.24	N/A	N/A	19196	0.0523	0.57
08/09	Roberta	11:16:15	758	22.69	6.57	457.4	0.23	33.5	3	815	0.0055	0.04
08/09	Roberta	11:17:11	758	21.91	6.5	472.7	0.24	8.6	0.78	1152	0.0064	0.49
08/09	Community Boating	12:55:18	757	23.88	7.27	771	0.4	84.1	7.37	325	0.0045	0.06
08/09	Community Boating	12:55:48	756.8	23.89	7.26	774.1	0.4	83.5	7.31	292	0.0044	0.99
08/09	New River Dam	13:23:10	756.4	23.9	7.29	1571	0.83	97.6	8.52	359	0.0046	0.06
08/09	New River Dam	13:23:41	756.1	23.91	7.27	1568	0.83	94	8.2	374	0.0046	0.99
08/16	Roberta	11:49:54	764.8	20.43	6.3	472.6	0.24	9.7	0.91	1413	0.007	0.46
08/16	Roberta	11:50:07	775.4	20.47	6.27	472.1	0.24	7.9	0.74	1836	0.0097	0.42
08/16	New River Dam	14:15:07	765.1	24.04	6.98	1304	0.69	103.7	9.09	651	0.0053	0.42
08/16	New River Dam	14:15:42	765	23.7	7.08	1304	0.69	100.2	8.85	649	0.0053	0.94
08/16	Community Boating	14:33:09	765.4	24.04	7.43	876.9	0.46	98.7	8.67	562	0.005	0.02
08/16	Community Boating	14:34:04	765.2	23.87	7.2	881	0.46	96.3	8.49	475	0.0048	0.99
08/23	New River Dam	11:45:13	759.9	26.88	7.39	1254	0.66	99.3	8.23	408	0.0046	0.05
08/23	New River Dam	11:45:55	760	26.66	7.31	1256	0.66	93.5	7.78	462	0.0048	0.99
08/23	Community Boating	12:01:16	767.9	26.89	7.48	1057	0.55	119.9	9.94	367	0.0046	0
08/23	Community Boating	12:02:09	760.1	26.55	7.36	1058	0.55	116.3	9.7	451	0.0047	1.03

Date	Site ID	Time	Barometric Pressure	Temp.	pH	Specific Conductivity	Salinity	DO	DO	Phycocyanin	Phycocyanin	Depth
		HHMMSS	mmHg	°C		µS/cm	ppth	% sat.	mg/L	cells/mL	volts	meters
08/23	Community Boating	12:13:57	772.6	25.94	7.43	968.9	0.51	119.3	10.06	384	0.0046	0
08/23	Community Boating	12:14:32	759.9	25.8	7.44	968.1	0.51	118.3	10.01	493	0.0049	1.05
08/23	CRCK Newton Dock	12:42:19	758.9	25.67	7.55	513.6	0.26	129.8	11.02	99	0.0039	0.03
08/23	CRCK Newton Dock	12:42:36	758.7	25.19	7.35	515.1	0.26	123.8	10.61	4249	0.0091	0.47
08/23	Roberta	12:55:44	759	24.75	6.71	475.3	0.24	24.8	2.14	1017	0.0062	0
08/23	Roberta	12:57:03	759.2	21.08	6.19	590.9	0.3	4.1	0.38	6546	0.0198	0.88
08/30	New River Dam	10:35:42	759.4	24.54	7.19	1652	0.88	87.9	7.57	233	0.0042	0.04
08/30	New River Dam	10:36:11	759.2	24.46	7.2	1652	0.88	84.8	7.32	188	0.0042	1.05
08/30	Community Boating	10:54:14	759.3	24.3	7.34	1413	0.75	82.2	7.11	182	0.0041	0.05
08/30	Community Boating	10:54:47	759.5	24.33	7.26	1411	0.75	80.1	6.93	176	0.0041	1.04
08/30	CRCK Newton Dock	12:32:38	757.7	23.17	7.1	602.8	0.31	89.9	7.98	115	0.004	-0.05
08/30	Roberta	12:48:33	771	21.22	6.44	594.1	0.3	7.8	0.72	261	0.0043	0.02
08/30	Roberta	12:49:28	767.7	20.59	6.45	598.8	0.31	4	0.38	3711	0.0122	0.43
09/06	Roberta	11:22:48	765.7	20.65	6.57	450.8	0.23	20.3	1.91	258	0.0043	0.01
09/06	Roberta	11:23:58	765.3	18.53	6.33	463.6	0.23	6.6	0.64	4648	0.0146	0.57
09/06	CRCK Newton Dock	11:44:00	765.7	21.78	7.11	419.5	0.21	72.1	6.64	76	0.0039	0.01
09/06	CRCK Newton Dock	11:44:22	765.7	21.74	6.95	419.7	0.21	72	6.63	99	0.0039	0.35
09/06	Community Boating	12:32:55	766.9	23.86	7.14	1359	0.72	79.7	7.03	234	0.0043	0.03
09/06	Community Boating	12:33:46	767.1	23.5	7.09	1358	0.72	78.8	7	227	0.0042	1.04
09/06	New River Dam	13:25:03	765.3	24.07	6.98	1578	0.84	81.7	7.17	283	0.0044	0
09/06	New River Dam	13:25:37	765.3	23.51	7.11	1567	0.83	78.7	6.98	455	0.0048	1.02
09/13	Community Boating	12:07:43	750.8	24.86	7.54	1531	0.81	101.9	8.62	396	0.0046	0

Date	Site ID	Time	Barometric Pressure	Temp.	pH	Specific Conductivity	Salinity	DO	DO	Phycocyanin	Phycocyanin	Depth
		HHMMSS	mmHg	°C		µS/cm	ppth	% sat.	mg/L	cells/mL	volts	meters
09/13	Community Boating	12:08:05	750.6	24.14	7.47	1501	0.8	97.1	8.33	425	0.0048	1
09/13	New River Dam	12:37:55	761.8	25.07	7.86	1830	0.98	121.1	10.21	537	0.005	0.07
09/13	New River Dam	12:38:27	762.9	24.58	7.6	1873	1	114.3	9.72	495	0.005	1.05
09/13	CRCK Newton Dock	13:30:44	748.4	24.8	7.56	467.3	0.24	104	8.85	77	0.0039	0.02
09/13	Roberta	13:41:58	749.2	25.73	7.4	478.8	0.24	82.7	6.92	996	0.0061	0.05
09/13	Roberta	13:44:12	749.5	23.06	6.45	498.8	0.25	7.8	0.68	20384	0.0522	0.63
09/20	Roberta	10:58:28	762	19.24	6.86	535.2	0.27	44.2	4.25	509	0.0049	0.02
10/11	Roberta	10:13:13	764.2	15.97	7.03	632.1	0.32	57.7	5.88	510	0.0049	0.36
10/11	Roberta	10:13:25	753.5	15.97	7.04	632.9	0.32	58.3	5.94	482	0.0048	0.36
10/17	Roberta	10:41:44	745.5	15.28	6.82	602.1	0.31	67.8	6.77	499	0.0049	0.02
10/17	Roberta	11:10:41	745.7	15.31	6.93	605	0.31	60.8	6.06	463	0.0048	-0.01
10/25	Roberta	10:31:55	749.1	10.53	7.01	668.7	0.34	84.3	9.4	228	0.0042	0.04
11/01	Roberta	12:02:40	737.2	12.71	7.45	665.5	0.34	97.9	10.23	436	0.0047	0
11/01	Roberta	12:02:58	737	12.58	7.39	665.6	0.34	99	10.38	17765	0.0392	0.5
11/08	Roberta	11:09:34	746.5	8.62	7.35	618.2	0.32	91	10.59	135	0.004	0.01

Appendix K. CRWA Hydrolab data, 2014.

Date	Site ID	Time	Barometric Pressure	Temp.	pH	Specific Conductivity	Salinity	DO	DO	Phycocyanin	Phycocyanin	Depth
		HHMMSS	mmHg	°C		µS/cm	ppth	% sat.	mg/L	cells/mL	volts	meters
6/27	Community Boating	14:36:39	748.4	26.8	7.61	1010	0.53	N/A	N/A	1392	0.0069	0.02
6/27	MIT Sailing	14:51:23	748.2	25.17	7.52	964.9	0.5	N/A	N/A	1221	0.0066	0.06
6/27	Broad Canal	15:06:20	748.2	26.14	7.53	1001	0.52	N/A	N/A	2499	0.0078	0.1
6/27	New Charles River Dam	15:46:28	747.8	26.32	7.45	1193	0.63	N/A	N/A	1079	0.0063	0.11
7/3	MIT Sailing	10:21:51	751	26.99	8.32	1216	0.64	N/A	N/A	2556	0.0096	0.06
7/3	Broad Canal	10:47:49	751.3	28.07	8.09	1252	0.66	N/A	N/A	2551	0.0099	0.05
7/3	New River Dam	11:20:24	751.6	28.21	8.14	1285	0.68	N/A	N/A	2449	0.0096	0.01
7/10	Community Boating	14:22:53	755	28.33	7.77	1121	0.59	N/A	N/A	658	0.0053	0.11
7/10	MIT Sailing	14:37:04	754.7	25.92	7.95	974.8	0.51	N/A	N/A	701	0.0054	0.39
7/10	Broad Canal	15:09:47	754.5	27.32	7.91	1097	0.58	93.7	7.65	1280	0.0067	0.23
7/10	New River Dam	15:52:07	753.5	27.65	7.72	1303	0.69	90.5	7.34	1291	0.0067	0.15
7/17	Broad Canal	11:09:56	751.3	27.15	7.25	1459	0.77	98.1	7.97	0	0.0022	0.03
7/17	New River Dam	11:44:10	751.1	28.21		1888	1.01	N/A	N/A	0	0.0045	0.01
7/17	Community Boating	12:12:13	751	28.29	7.55	1297	0.68	N/A	N/A	194	0.0042	0.05
7/17	Community Boating	12:13:01	767.4	28.28	7.54	1297	0.68	N/A	N/A	243	0.004	0.08
7/17	Community Boating	12:39:17	749.5	26.45	7.72	1264	0.67	100.3	8.26	0	0.0046	-0.02
7/17	Broad Canal	11:09:56	751.3	27.15	7.25	1459	0.77	98.1	7.97	0	0.0022	0.03
7/17	New River Dam	11:44:10	751.1	28.21	N/A	1888	1.01	N/A	N/A	0	0.0045	0.01
7/17	Community Boating	12:12:13	751	28.29	7.55	1297	0.68	N/A	N/A	194	0.0042	0.05
7/17	MIT Sailing	12:39:17	749.5	26.45	7.72	1264	0.67	100.3	8.26	0	0.0046	-0.02
7/30	MIT Sailing	13:57:33	751	28.06	7.43	610.5	0.31	67.8	5.45	2161	0.0089	0.41

Date	Site ID	Time	Barometric Pressure	Temp.	pH	Specific Conductivity	Salinity	DO	DO	Phycocyanin	Phycocyanin	Depth
		HHMMSS	mmHg	°C		µS/cm	ppth	% sat.	mg/L	cells/mL	volts	meters
7/30	Community Boating	14:04:36	751.1	28.39	7.58	557.9	0.28	74.8	5.98	3217	0.0113	0.35
7/30	Broad Canal	14:09:17	750.8	28.62	7.82	543.9	0.28	65.5	5.21	1863	0.0082	0.31
7/30	New Charles River Dam	14:13:30	750.9	28.67	7.75	843.7	0.44	67.8	5.38	2576	0.0099	0.34
7/31	Broad Canal	10:47:34	754.1	26.67	7.54	1160	0.61	N/A	N/A	1136	0.0064	0.19
7/31	Community Boating	11:10:52	754.4	27.28	7.88	1184	0.62	N/A	N/A	818	0.0057	0.12
7/31	MIT Sailing	11:52:53	754.5	25.53	7.96	1039	0.54	110.7	9.33	1127	0.0064	0.11
7/31	New River Dam	12:12:41	754.1	27.12	8.15	1335	0.71	113.8	9.3	913	0.0059	0.17
8/7	Broad Canal	13:42:42	748.3	26.94	8.46	1123	0.59	124.6	10.16	1411	0.0071	0.14
8/7	New River Dam	14:15:45	748	27.28	8.12	1283	0.68	147.3	11.94	1162	0.0065	0.1
8/7	Community Boating	14:42:06	748.2	27.87	8.34	1157	0.61	147.6	11.84	868	0.0058	0.05
8/7	MIT Sailing	15:20:36	748.3	26.56	8.37	1072	0.56	147.1	12.08	1132	0.0064	0.06
8/14	Broad Canal	10:51:55	759.9	25.09	7.17	1303	0.69	73.3	6.16	732	0.0055	0.14
8/14	New River Dam	11:21:24	746.4	25.67	7.61	1928	1.03	88.2	7.33	818	0.0057	0.04
8/14	Community Boating	11:43:18	761.5	25.62	7.86	1371	0.72	95.1	7.92	1053	0.0062	0.01
8/14	MIT Sailing	12:12:38	746.9	24.52	7.68	1283	0.68	96.7	8.22	1091	0.0061	0.07
8/21	MIT Sailing	13:54:23	753.9	25.37	7.69	1400	0.74	117.5	9.82	1447	0.0071	0.09
8/21	MIT Sailing	13:54:47	767.8	25.35	8.48	1400	0.74	120.6	10.09	1470	0.0072	0.09
8/21	Broad Canal	14:32:17	754.2	25.18	8.97	1417	0.75	117	9.82	1727	0.0078	-0.08
8/21	New River Dam	14:54:22	754.1	25.05	8.53	1771	0.94	118.3	9.94	1679	0.0077	0.31
8/21	Community Boating	15:22:39	754	26.25	9.11	1457	0.77	127	10.45	1419	0.0071	0.04
9/11	MIT Sailing	13:06:06	747.9	24.22	7.57	2084	1.12	102.3	8.72	4364	0.0142	0.1
9/11	Broad Canal	13:25:59	747.5	24.85	7.97	2253	1.21	76.4	6.43	3972	0.0132	0.06
9/11	New River Dam	14:03:46	746.5	25.06	8.59	2370	1.27	94.9	7.96	4488	0.0144	0.18

Date	Site ID	Time	Barometric Pressure	Temp.	pH	Specific Conductivity	Salinity	DO	DO	Phycocyanin	Phycocyanin	Depth
		HHMMSS	mmHg	°C		µS/cm	ppth	% sat.	mg/L	cells/mL	volts	meters
9/11	Community Boating	14:40:28	746.8	25.39	8.85	2250	1.21	N/A	N/A	4808	0.0153	0.11

Appendix L. Annual water temperature statistics from CRWA's cyanobacteria monitoring program.

Year	Temperature range (°C)	Temperature on day of highest cell count (°C)
2007	6.62 - 27.4	21.67
2008	19.06 - 29	29
2009	16.67 - 27.23	23.79
2010	19.52 - 28.56	24.5
2011	24.21 - 28.57	27.4
2012	N/A	N/A
2013	8.62 - 30.67	21.91
2014	24.22 - 28.67	24.88