Lake Champlain, USA: A Cost-Effective & Sustainable Monitoring Program

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Cyanobacteria In Lake Champlain

Lake Champlain is one of the largest freshwater lakes in the United States, lying primarily between Vermont and New York, with a small portion extending into the province of Quebec in Canada (Figure 1). Although cyanobacteria blooms had been a common occurrence in some areas of the lake, the first toxic blooms were documented in 1999, when two dogs died after consuming cyanobacteria or water containing cyanobacteria.

Cyanobacteria toxins have been recognized since the late 1880s, and the ability of cyanobacteria to produce potent toxins was discussed in most phycology textbooks available in 1999. However, in the Champlain Basin, this aspect of cyanobacteria biology was not widely known. Blooms had been considered an indicator of poor water quality caused by nutrient pollution. With these dog deaths, blooms were no longer perceived as just a nuisance, they were instead seen as a potential human and animal health risk.

After those initial incidents, partners in Vermont recognized the need for monitoring and bloom response on Lake Champlain. Here we share the development of the Champlain cyanobacteria monitoring program and the current design. Its citizen-supported sustainable approach is now applied statewide in Vermont and may be a useful example for others looking to develop a cyanobacteria monitoring program.

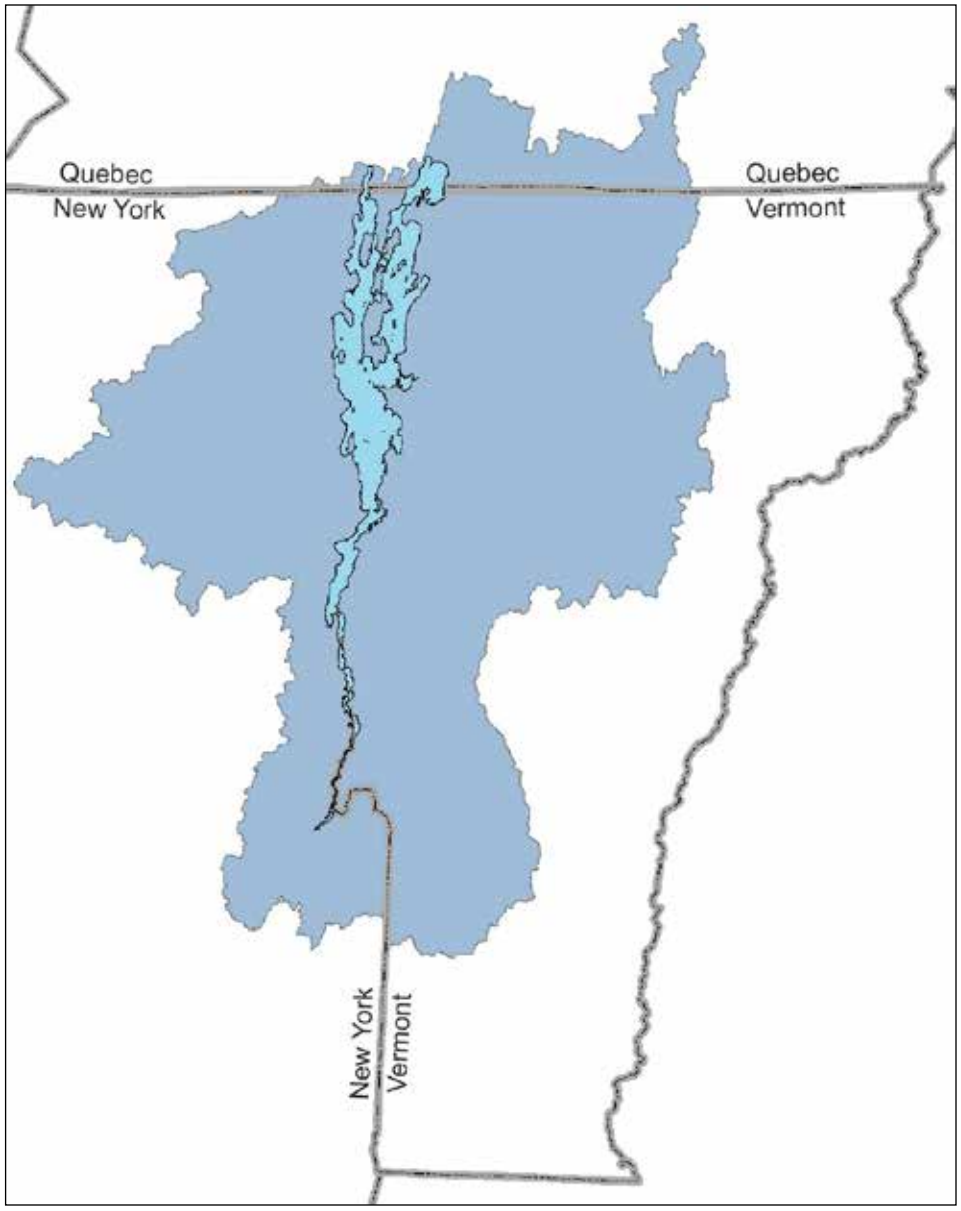


Figure 1. Location of Lake Champlain between Vermont, New York, and Quebec. The lake is shown in light blue and its watershed in the darker blue.

The early days

While a phytoplankton survey had been conducted in the early 1990s and the long-term monitoring program supporting the Champlain Phosphorus Total Maximum Daily Load (TMDL) had routinely measured chlorophyll concentrations since 1991, relatively little was known about the cyanobacteria and other phytoplankton in the lake. There were, however, existing resources in the Basin that quickly mobilized to begin characterizing the lake's cyanobacteria community.

The Lake Champlain Basin Program (LCBP), which facilitates water quality management efforts across the multi-jurisdictional Basin, was able to provide funding to researchers at the University of Vermont (UVM) to begin this research in 2000, the year after the dog deaths were reported. With support from LCBP and federal grants, Dr. Mary Watzin at UVM began developing a cyanobacteria monitoring program in 2001. Initial cyanobacteria monitoring efforts focused on the Burlington area where UVM is located. Burlington is a large population center with good access to the waterfront, popular beaches and drinking water facilities drawing from the lake. However, blooms were not common there and a wider range of conditions were needed to build a robust monitoring system.

Partnering for success

Many of the locations most likely to experience blooms were far from the university. Sampling for cyanobacteria is also notoriously difficult because conditions can change very quickly in response to weather conditions (e.g., shift in wind direction, change in wind intensity). To increase the ability to reach blooms when they occurred, especially in areas of high public contact, UVM built a collaborative network of local partners between 2002 and 2003.

The Lake Champlain Committee (LCC), a bi-state NGO focused on lake health and accessibility, offered to recruit volunteers from among their members to be part of the sampling network for shoreland locations. Development of the near-shore monitoring program initially began in Missisquoi Bay where the blooms were most intense, then expanded to St. Albans Bay, another shallow water bay often compromised by blooms, and ultimately expanded into the Burlington area. LCC members were provided with sampling kits and trained to collect weekly samples for phytoplankton and microcystin.

The partnership also included the Lake Champlain Long-term Water Quality and Biological Monitoring Program housed within the VT Department of Environmental Conservation (VDEC), which monitors 15 open water stations in the lake during the open water season. Their field staff also provided phytoplankton and toxin samples to UVM. Samples were initially collected from early July through early September, eventually expanding into June. Phytoplankton samples were collected as a 3m tow using 63-µm mesh nets or as whole water surface grabs. Champlain is frequently choppy and open water sampling from a larger volume and depth via the net provided a better indication of the cyanobacteria population that had the potential to accumulate at the surface under calm conditions.

The initial monitoring program developed by Watzin et al. utilized cell density of potentially toxic cyanobacteria and microcystin concentrations to characterize recreational risk into one of five categories (see Table 1). Weekly results from the Lake Champlain cyanobacteria monitoring program were provided by UVM in both tabular form and color-coded map to the VT Department of Health (VDH), local water suppliers, and beach managers.

The Lake Champlain Committee also relayed results to monitors and interested citizens and posted them publicly through their website and social media channels. This system was used until 2011 with great success, supported primarily with funding from the LCBP to UVM and LCC volunteers, and the partnership with VDEC, which is also supported with funding from the LCBP.

Expanded monitoring

In 2012, oversight of the program transferred from UVM to VDEC and VDH, allowing opportunity to modify our approach. There were several reasons we felt changes were needed. It is not possible to tell by looking whether blooms are toxic and it was difficult for the public to interpret monitoring descriptions (e.g., they didn't know what 4,000 cells/mL looked like in the water). There was also a delay of at least 24 hours before data became available to the public as tests were completed. By that time, blooms often had disappeared due to changing environmental conditions. LCC and partners had an interest in expanding the program to include more sites and involve more interested citizens, but analytical costs limited the number of stations which could logistically be monitored on a large lake that experienced highly variable conditions. Finally, microcystin was only one of many potential toxins that cyanobacteria may produce. The transition provided opportunity to introduce a new protocol that allowed us to make a rapid determination of public health risk not limited to one of many potential cyanotoxins. At the same time, we could geographically expand our volunteer network to monitor under-served areas of Lake Champlain and inland Vermont waters.

Utilizing VDH recreational guidance that recommended public beaches be closed when a visible (presumed) cyanobacteria bloom was present and/or cyanotoxins exceeded guidelines, VDEC, VDH, and LCC developed a visual assessment protocol to be used by volunteers during their weekly visits that characterized cyanobacteria conditions as *generally safe, low alert,* and *high alert* (see Figure 2). This new protocol allowed us to easily train beach managers and others to assess recreational risk using images and descriptive prompts. Reports with appropriate documentation provided by other untrained individuals could also be interpreted through this system and utilized to inform bloom response. VDH staff added a GIS-based tracking map to accommodate the larger number of data points and easily share the information with the general public (Figure 3). All reports are reviewed internally by VDH, VDEC, or LCC staff before being posted to the interactive map.

This semi-qualitative visual approach is supported with quantitative data. Volunteers, trained annually by LCC or VDEC, provide a series of photographs to document bloom conditions and may be asked to collect samples. The LCC provides support to monitors throughout the season and reaches out to volunteers for report clarification and further details as necessary. At selected shoreline locations, phytoplankton and toxin samples are routinely collected by volunteers, LCC and VDH staff. Long-term Monitoring Program staff collect phytoplankton during each site visit and also collect toxin samples during bloom events. This robust system allows us to respond quickly to new bloom reports by building on data already in house (Figure 4). Additionally, the quantitative data have shown that the visual assessment protocol effectively characterizes cyanobacteria risk on Lake Champlain and Vermont inland lakes. (See the annual reports

Table 1. Original Structure of the Lake Champlain Cyanobacteria Monitoring Program

Qualitative Sampling

Frequency: 2/month

Collect: Vertical plankton tows (63-µm net, upper 3m), screened within 48 hours

Action: If potential toxin-producing taxa observed, proceed to ***Quantitative sampling***

Quantitative Sampling

Frequency: 2/month

Collect: Vertical plankton tow (63-µm net, upper 3m), full enumeration within 48 hours

Action: If cyanobacteria densities > 2000 cells/mL, proceed to ***Vigilance level***

Vigilance Level

Frequency: 1/wk at midday

Collect: Vertical plankton tow (63-µm net, upper 3m), full enumeration within 48 hours

Action: Return to ***Quantitative sampling*** if cyanobacteria densities < 2,000 cells/mL.

If cyanobacteria > 4,000 cells/mL, proceed to ***Alert Level 1*** and notify public health officials that cyanobacteria are abundant and blooms could form

Alert Level 1

Frequency: 1/wk at midday (or more frequently as needed)

Collect: Whole water phytoplankton, whole water chlorophyll-a, whole water toxin samples

Action: Return to ***Vigilance sampling*** if cyanobacteria densities < 4,000 cells/mL

If microcystin concentration exceeds 6 µg/L (VDH recreational standard), proceed to ***Alert Level 2*** and notify public health officials of potential risks to humans and animals

Alert Level 2

Frequency: 1/wk at mid-day (or more frequently as weather conditions dictate)

Collect: As for Alert Level 1

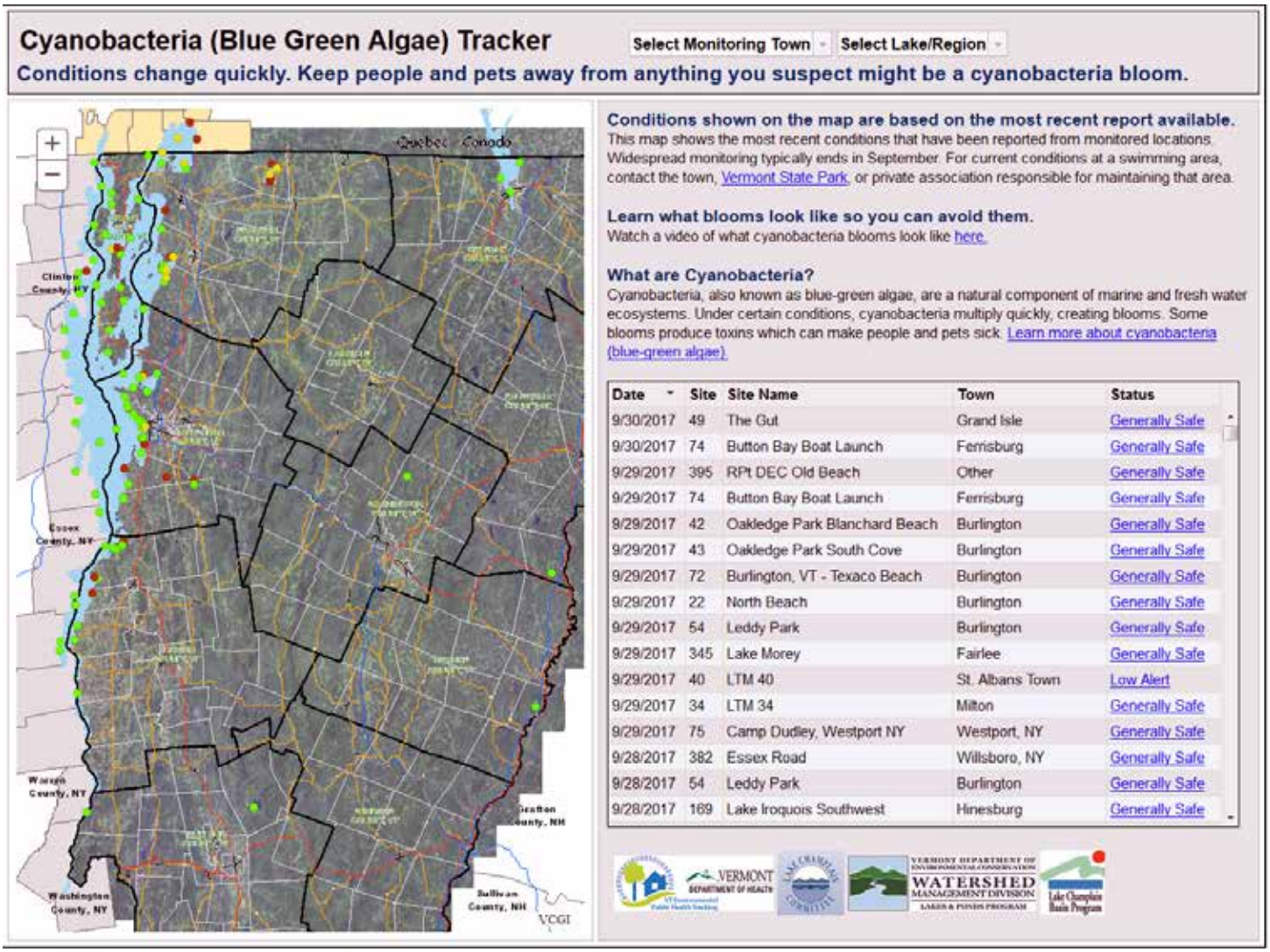
Action: Return to ***Alert Level 1*** if microcystin concentration drops below 6 µg/L

Otherwise, notify public health officials that significant risk to humans and animals exists. Public Health Advisories should be issued by appropriate agencies.

Figure 2. Overview of the visual assessment categories used on Lake Champlain and Vermont's inland lakes.

found on the VDEC website shared in the resources section of this article.)

Since 2015, VDH and VDEC have provided 12 weeks of summer toxin testing for the 22 Vermont public water systems drawing from Lake Champlain. Operators receive annual training on cyanobacteria and participate in the summer testing program at no cost. The VDEC Drinking Water and Groundwater Protection Program has developed a practice for facility operators which



Date	Site	Site Name	Town	Status
9/30/2017	49	The Gut	Grand Isle	Generally Safe
9/30/2017	74	Button Bay Boat Launch	Ferrisburg	Generally Safe
9/29/2017	395	RPt DEC Old Beach	Other	Generally Safe
9/29/2017	74	Button Bay Boat Launch	Ferrisburg	Generally Safe
9/29/2017	42	Oakledge Park Blanchard Beach	Burlington	Generally Safe
9/29/2017	43	Oakledge Park South Cove	Burlington	Generally Safe
9/29/2017	72	Burlington, VT - Texaco Beach	Burlington	Generally Safe
9/29/2017	22	North Beach	Burlington	Generally Safe
9/29/2017	54	Leddy Park	Burlington	Generally Safe
9/29/2017	345	Lake Morey	Fairlee	Generally Safe
9/29/2017	40	LTM 40	St. Albans Town	Low Alert
9/29/2017	34	LTM 34	Milton	Generally Safe
9/29/2017	75	Camp Dudley, Westport NY	Westport, NY	Generally Safe
9/28/2017	382	Essex Road	Willsboro, NY	Generally Safe
9/28/2017	54	Leddy Park	Burlington	Generally Safe
9/28/2017	169	Lake Iroquois Southwest	Hinesburg	Generally Safe

Figure 3. The Vermont Department of Health's CyanoTracker used to share information about cyanobacteria blooms in Vermont and around Lake Champlain.

specifies protocols to be used when responding to a cyanobacteria bloom or cyanotoxin detection above the VT health advisory levels in raw or finished water. Additionally, if a bloom is suspected, operators can submit samples for phytoplankton or toxin analyses and work closely with state staff to respond to any events.

What we've learned

In 2019, we'll begin our 18th year of monitoring on Lake Champlain. During this period, we've created an effective and economical approach that provides a great deal of information about cyanobacteria blooms on Lake Champlain. Key information provided by the project includes the following:

- Much of Champlain experiences generally safe conditions most of the summer. More than 80 percent of the reports received each year fall into this category (Figure 5).
- Certain areas of the lake are more likely to experience blooms, e.g., Missisquoi and St. Albans Bays, but many areas have had at least one bloom over the years.
- Areas of the lake with high phosphorus levels are most likely to experience blooms, however areas with low nutrient levels also experience them.
- Microcystin is detected almost every year. In recent years, it rarely exceeded the VT recreational guideline of 6 µg/L, but higher concentrations have been found in blooms on Missisquoi Bay in the past.
- Cyanobacteria are present in all areas of the lake much of the summer every year, but densities vary significantly.
- To date, there have been no confirmed microcystin detections above health advisory levels for public drinking water systems operating in Vermont. However, facilities operating in Quebec, on the northern shores of Missisquoi Bay, have modified operating procedures and infrastructure in direct response to severe cyanobacteria blooms.
- The cyanobacteria bloom season on Champlain appears to be longer now than it was in 2001. Routine monitoring has expanded to include early June and occasionally continues into early November as we document more events during these shoulder months.

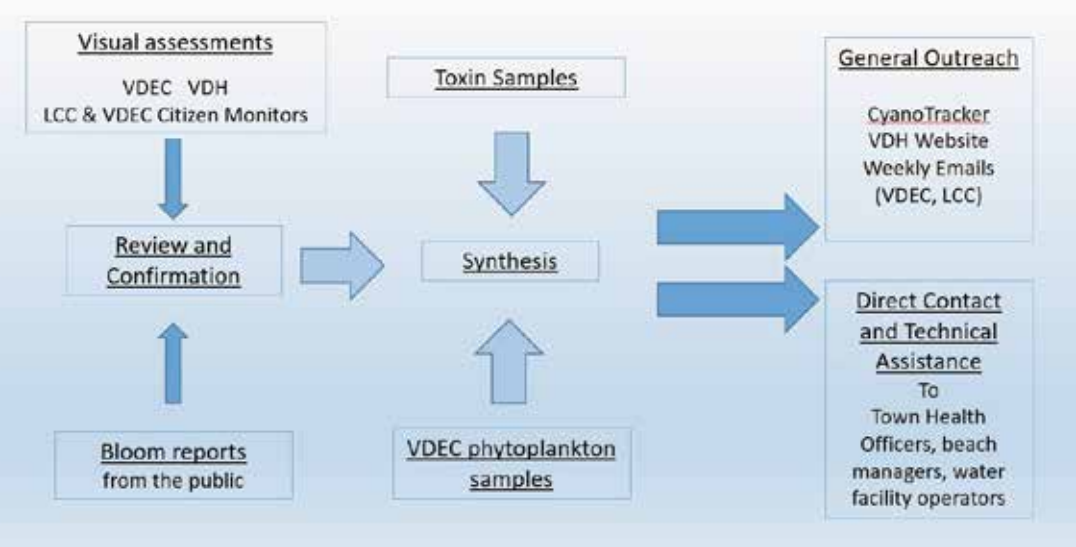


Figure 4. Cyanobacteria severity assessment process utilized for Lake Champlain and Vermont's inland lakes.

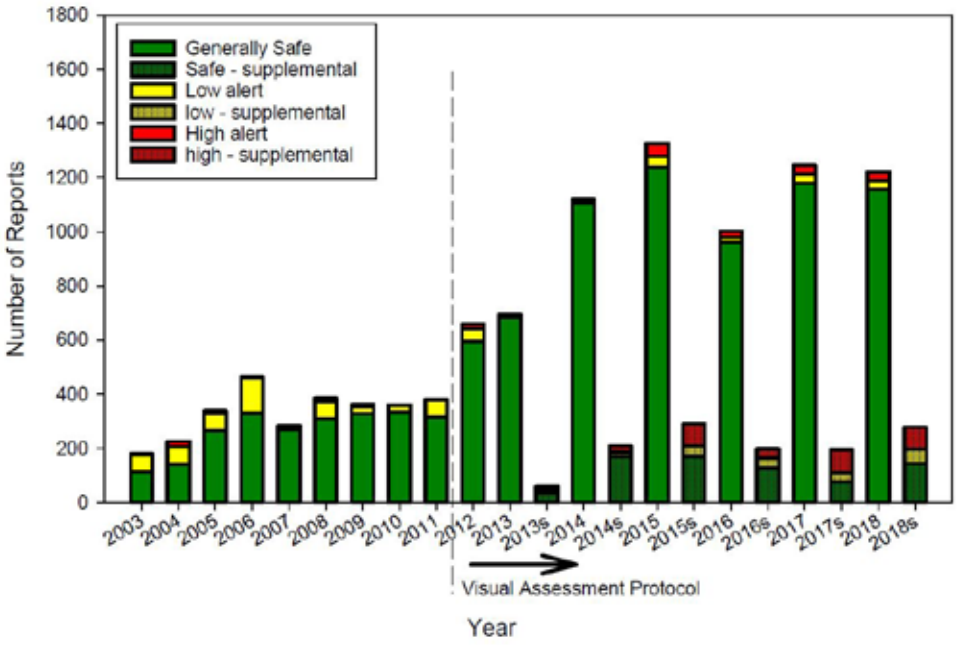


Figure 5. A historical summary of cyanobacteria severity on Lake Champlain since 2003. Supplemental reports are those provided in addition to weekly routine monitoring reports, from locations that are not routinely monitored, or those submitted by the general public.

As noted above, Lake Champlain lies within several jurisdictions – Vermont, New York, and Quebec. Each has its own approach to cyanobacteria bloom response. An important goal of the monitoring program has been to provide routine consistent data that can be utilized by each jurisdiction to facilitate response. It also provides a consistent approach to communicate about the severity of blooms to anyone who is active on the lake or lakeshore, regardless of their location and knowledge level. The LCBP continues to facilitate communication among the three jurisdictions to improve consistency in communication and response around the entire lake.

Vermont's inland lakes have benefitted from the Champlain cyanobacteria monitoring program and its strong partnerships. The Champlain protocol is employed at several inland lakes that experience annual cyanobacteria blooms. Consistent data interpretation, reporting, and communication protocols are in place across the state as a result.

Establishing and operating a long-term monitoring program is never easy. We have been able to maintain annual monitoring for many years by leveraging existing resources and partnerships. Federal funding from the U.S. Environmental Protection Agency and the Centers for Disease Control to the state agencies and LCBP supports monitoring staff, however funding for toxin analyses in recreational waters is not covered. As a result, our toxin monitoring program changes somewhat each year, dependent upon the source and amount of funding. Resources are especially tight during late season blooms, when seasonal state and local employees are no longer available to assist. By leveraging existing partnerships and using a visual assessment, we've been able to provide useful information quickly, economically, and in a format that is useful to those unfamiliar with cyanobacteria.

For more information on cyanobacteria efforts in Lake Champlain and Vermont, please visit our websites:

- Vermont Department of Health (VDH) – factsheets, videos, historical project data: http://www.healthvermont.gov/health-environment/recreational-water/cyanobacteria-blue-green-algae
- Cyanobacteria (Blue-Green Algae) Tracker Map: http://www.healthvermont.gov/tracking/cyanobacteria-tracker
- Lake Champlain Committee (LCC) – volunteer protocols and guidance: https://www.lakechamplaincommittee.org/lcc-at-work/algae-in-lake/#c824.
- Vermont Department of Environmental Conservation (VDEC) Watershed Management Division – project quality assurance plan and historical reports: https://dec.vermont.gov/watershed/lakes-ponds/learn-more/cyanobacteria.
- Vermont Department of Environmental Conservation (VDEC) – Drinking Water

and Groundwater Protection Division – drinking water operator resources, cyanotoxin test results: https://dec.vermont.gov/water/drinking-water/water-quality-monitoring/blue-green-algae.

- Procedure for managing cyanotoxin detections in drinking water: https://dec.vermont.gov/sites/dec/files/dwgwp/bluegreen/pdf/FINAL_CYANOPRACTICE2015.pdf
- LCBP – http://www.lcbp.org/water-environment/human-health/cyanobacteria/

Angela Shambaugh is an aquatic biologist with the Lakes and Ponds Program (VDEC). She has over 30 years of experience in the fields of water quality and plankton ecology. Currently, she coordinates the Lake Champlain Cyanobacteria Monitoring Project on Champlain and co-leads the Interstate Technology and Regulatory Council's national team project, "Strategies for Preventing and Managing Harmful Cyanobacteria Blooms." Angela has served as co-chair of the NALMS Inland HAB Program since 2016.

Bridget O'Brien works in the Environmental Health Division at the Vermont Department of Health, where she coordinates programs aimed at protecting public health from contaminants in the environment and serves as the department's cyanobacteria lead. Her background is on the toxicology side of public health, and she completed an ORISE fellowship at EPA before moving to Vermont.

Lori Fisher is executive director of the Lake Champlain Committee, a bi-state nonprofit that uses science-based advocacy, education and collaborative action to promote a clean, accessible lake. A two-time recipient of the Environmental Protection Agency's Environmental Merit Award, she has more than 30 years of experience working on water issues and implementing water protection programs and has authored numerous publications on lake issues and recreation. She is chair of the Lake Champlain Citizens' Advisory Committee, a member of Lake Champlain Sea Grant Public Advisory Committee, and a Steering Committee member and policy advisor for the national America's Great Waters Coalition.

Heather Campbell works in the Drinking Water and Groundwater Protection Division at the Vermont Department of Environmental Conservation. She assists drinking water facilities whenever there is a concern regarding cyanobacteria and coordinates the annual drinking water cyanotoxin testing program on Lake Champlain.