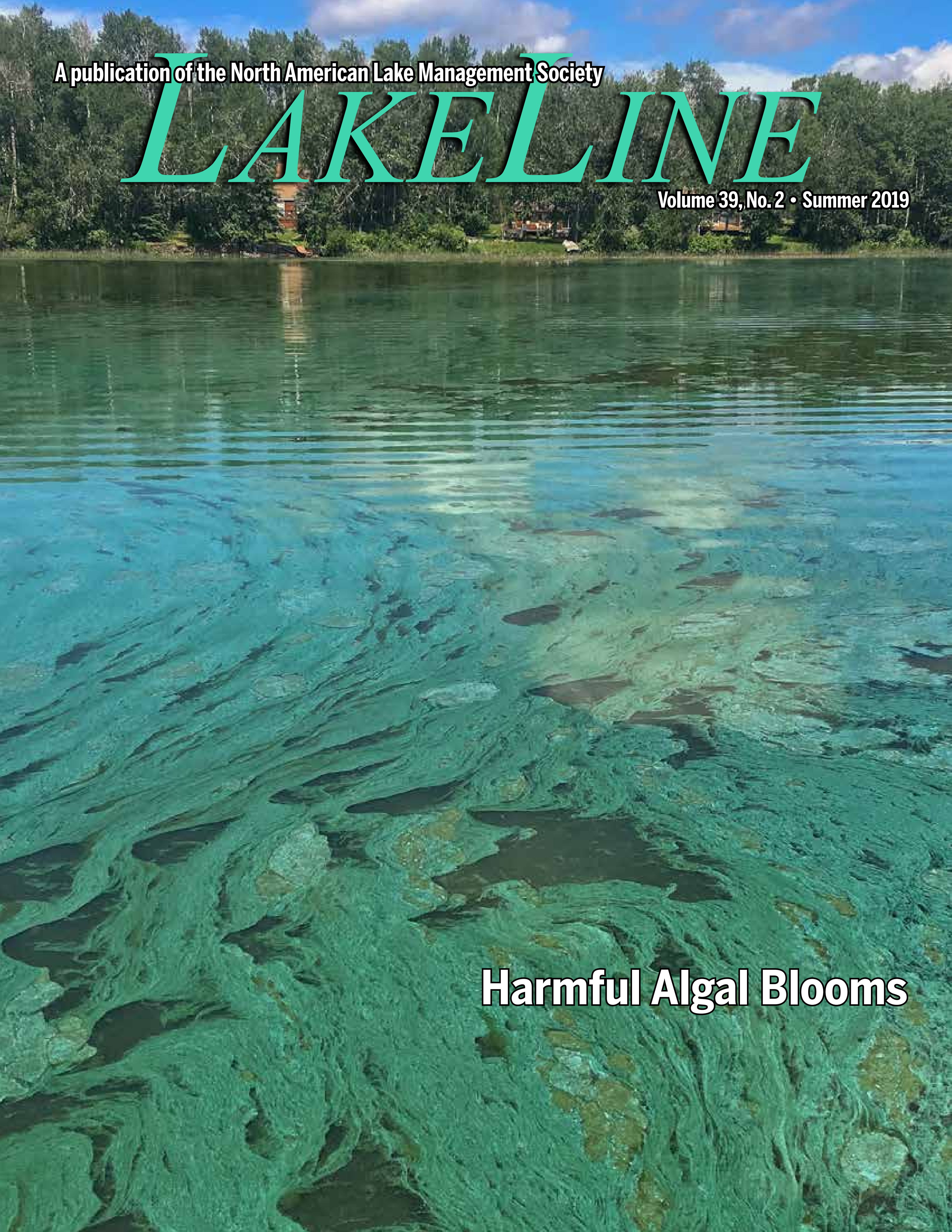
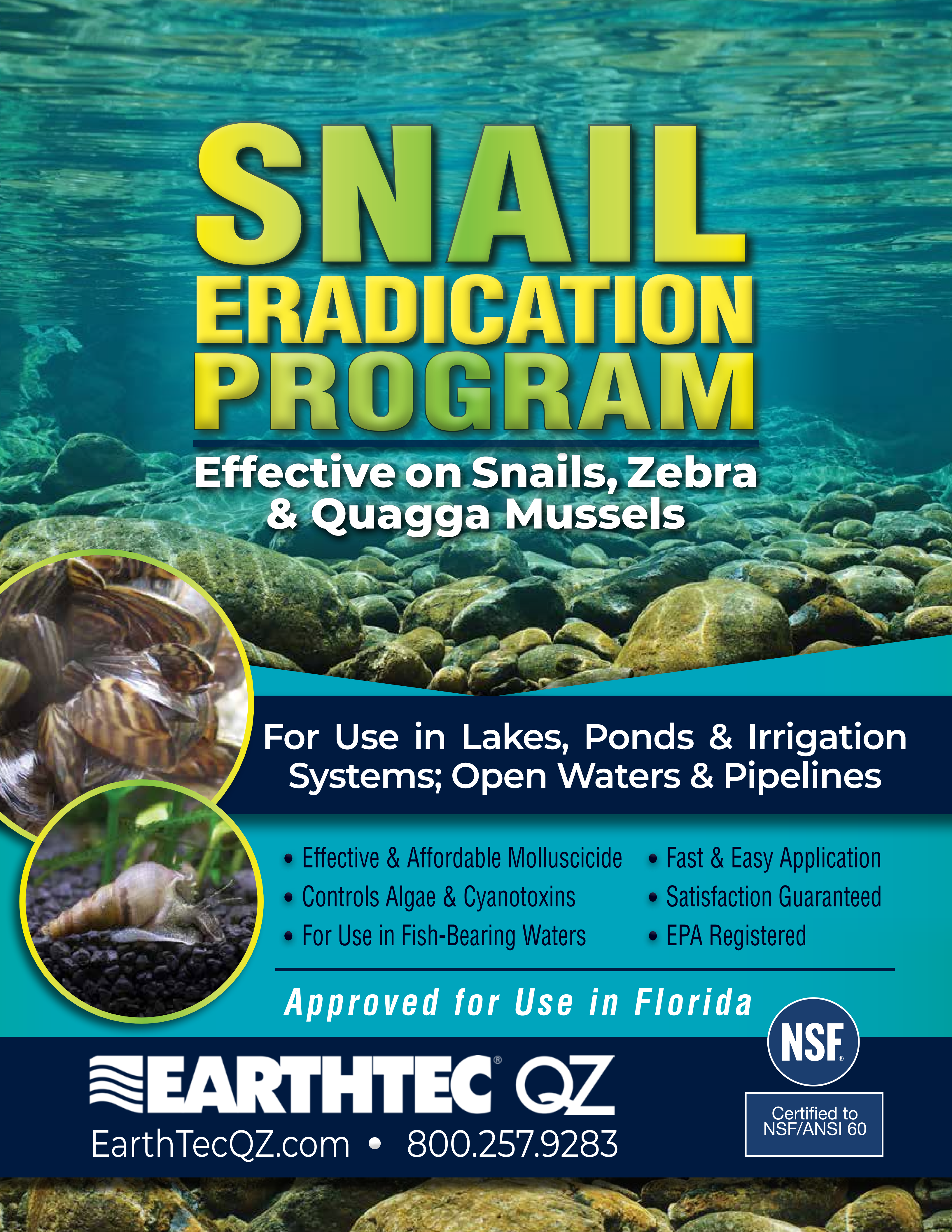
A publication of the North American Lake Management Society

LakeLine

Volume 39, No. 2 • Summer 2019



Harmful Algal Blooms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Let's Solve Water

39th International Symposium of the
North American Lake Management Society

Watershed Moments

Harnessing Data, Science, and Local Knowledge to Protect Lakes

November 11–15, 2019

DoubleTree by Hilton
Burlington, Vermont

Hosted by the New England Chapter of NALMS

Tentative Schedule

Monday, November 11
Lake and Watershed Stewardship Workshops
Technical Workshops
Welcome to Burlington Reception

Tuesday, November 12
Opening Plenary Session
Technical Sessions
Exhibits Open
NALMS Membership Meeting
Exhibitors' Reception and Poster Session

Wednesday, November 13
Clean Lakes Classic
Technical Sessions
Exhibits Open
NALMS Awards

Thursday, November 14
Technical Sessions
Exhibits Open

Friday, November 15
Workshops

Watershed Moments: Harnessing Data, Science, and Local Knowledge to Protect Lakes

Vermont is home to more than 800 stunning lakes and ponds, including Lake Champlain, an aquatic gem we are fortunate to share with New York and Quebec. There is no better place to celebrate the partnership between local knowledge and scientific innovation than this lake that unites three borders. Burlington is a thriving and progressive small city, home to the University of Vermont, endless locally-sourced dining options, and a pedestrian-friendly waterfront. Visitors will enjoy scenic beauty and a wide variety of outdoor recreational opportunities.

NALMS 2019
Burlington | Vermont

#NALMS2019

nalms.org/nalms2019

Photo: Patrick Bald

Technical Program

The NALMS 2019 Program Committee is organizing an excellent array of presentations on diverse aspects of lakes, ponds, reservoirs, their watersheds, and their many users and inhabitants. Below is a sample of session topics, but please check the symposium website regularly for up-to-date program information.

Photo: Todd Tietjen

- Aquatic Invasive Species
- Citizen Science
- Ethics
- Fisheries
- Harmful Algal Blooms
- High Quality Lakes
- Lake Level
- Lake Restoration
- Large-Scale Events
- Modeling
- Monitoring
- Non-Algal Toxins
- Nutrient Loading
- Oxygenation
- Paleolimnology
- Phosphorus Inactivation
- Salt
- Sediment Release
- Septic Systems
- Shoreland and Watershed Solutions
- Social Science and Outreach
- Source Water Management
- Source Water Protection
- Urban Lakes
- Using Social Media to Advance Lake Management
- Voice of Experience
- Water Quality
- Watershed Plan Development

Workshops

We will be offering a variety of full- and half-day workshops on Monday and Friday of the conference. These workshops provide attendees the opportunity for a more in-depth focus on a topic of interest, and many will provide hands-on experience. Monday's schedule will include a number of workshops targeted specifically to citizens scientists and decision makers.


Photo: Todd Tietjen

Monday, November 11

- Advanced Phytoplankton Ecology
- Aquatic Plant Identification
- Aquatic Plant Identification for the Layperson
- Building Effective Watershed Based Plans – A Hands-On Workshop Using MassDEP's Watershed Based Planning Tool
- Intermediate R for Aquatic Research
- Internal Phosphorus Loading and Cyanobacteria
- Introduction to Phytoplankton Ecology and Taxonomy
- Introduction to R for Aquatic Research
- Lake Management Best Practices: Overview of Common Problems and Effective Management Strategies and Technologies
- Lanthanum Modified Bentonite – Dosing, Ecotoxicology and Modelling
- Local to Global Partnerships for Research and Monitoring
- Telling Your Lake Story With Maps: Narrative Story Maps
- Telling Your Lake Story With Maps: Photo-Based Story Maps
- The Role of Aeration/Oxygenation in Lake Management
- Working With Sensors and Analyzing Sensor Data

Friday, November 15

- Alum for Phosphorus Control in Lakes and Ponds
- Collection, Identification, Ecology and Control of Freshwater Algae
- Stormwater Management for Lake Managers

Visit the conference website, www.nalms.org/nalms2019, for more information and pricing.

Contact Information

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Perry Thomas | pthomas@nalms.org

Program Co-Chairs
Amy Smagula | Amy.Smagula@des.nh.gov
Ken Wagner | kjwagner@charter.net

General Conference, Exhibitor & Sponsorship Information
NALMS Office | 608-233-2836 | nalms2019@nalms.org

Important Deadlines

August 30, 2019
Registration for presenters of accepted abstracts due.

September 20, 2019
Early bird registration deadline.

October 19, 2019
Last day conference hotel rate available.

November 1, 2019
Regular registration deadline.

Lake and Watershed Steward Program

The Lake & Watershed Stewards Program is offered on Monday, November 11 and Tuesday, November 12 and is designed for lay lake leaders such as conservation commission members, lake and watershed group leaders and members, lakeside residents, as well as volunteer monitors and program coordinators.

The Lake and Watershed Stewards Program offers presentations and workshops geared for lay lake leaders. Monday's program will include a full slate of half-day workshops held at the University of Vermont's Davis Center. On Tuesday, lake leaders will be able to attend any of the sessions being offered as part of the NALMS Symposium, many of which will be geared toward the needs and interests of lay lake leaders.

The Lake and Watershed Program will give attendees the opportunity to learn from lake managers and other experts from across the country and to discuss real world projects with scientists, policy makers, lake managers, and fellow citizens.

Registration Options

Two-day Registration

- Two half-day workshops on Monday
- Choice of technical sessions on Tuesday, including special Lake and Watershed Steward sessions or any other sessions offered on Tuesday.
- Continental breakfast, lunch, and refreshment breaks on Monday and Tuesday

Monday-only Registration

- Two half-day workshops on Monday
- Continental breakfast, lunch, and refreshment breaks on Monday

Visit the conference website for full details on pricing and available sessions.

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nalms.org/nalms2019

Field Trips and Special Events

In addition to the events listed below, the local committee is working on a number of other events during the conference week. Visit the conference website for updates, additions and more detailed information.

Monday, November 11

Welcome to Burlington Reception

Join us on the shores of Lake Champlain at the ECHO, Leahy Center for Lake Champlain for a meet and greet with your fellow attendees. ECHO is a science and nature museum that's home to more than 70 species of fish, amphibians, invertebrates, and reptiles.

Tuesday, November 12

Exhibitor Reception

NALMS, the local host Committee, and our exhibitors invite you to join us in taking a little time to relax after the first day of sessions, view the poster displays, and visit with the exhibitors and fellow attendees.

Wednesday, November 13

Clean Lakes Classic 5k Run/Walk

Take part in this annual event. You need not be a runner to participate! All pre-registered participants receive a t-shirt as part of the sign-up fee.

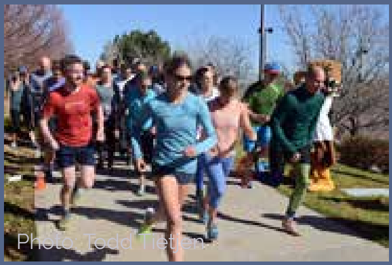

Photo: Todd Tietjen

NALMS Awards

Join us for a special evening of food, fellowship and recognition. The NALMS Awards is the culmination of the Society's year. Awards are presented for Leadership and Service, Advancements in Lake Management Technologies, and Lake Management Success Stories, along with our special recognition awards: Friends of NALMS, the Jim LaBounty Best Paper Award, Jim Flynn Award (outstanding corporation) and the Secchi Disk Award. Our most prestigious award, the Secchi Disk Award, honors the NALMS member who has made the most significant contributions to the goals and objectives of the Society.

Hotel Information

DoubleTree by Hilton Burlington Vermont
870 Williston Road
South Burlington, Vermont

- Room rates are $125/night for single or double occupancy (plus taxes)
- Government rate rooms are available at the federal per diem rate for single or double occupancy rooms.
- The sales tax rate is 7% and the hotel occupancy tax rate is 10%. The hotel also charges a $1 Destination Marketing Fee.
- Conference rates are available for November 9–15, 2019.
- Complimentary airport shuttle service from 4:30 am – 12:00 am.
- Complimentary basic guest room and public space internet.
- Complimentary indoor heated pool and 24-hour fitness center.
- Complimentary self-parking.
- Hotel check in is 4:00 pm and check out is 11:00 am.
- Cancellation Policy: 7 days prior to arrival
- Deposit Policy: A non-refundable deposit equal to one night's room and tax will be charged 7 days prior to arrival. This amount will be credited towards your final balance.
- An early checkout fee of one night's room and tax charges will apply unless guests inform the DoubleTree of any change in planned stay prior to or during check-in.
- **The conference rate is available until October 19, 2019.**

Visit the conference website to reserve your room at the discounted conference rate.

Transportation

The Burlington International Airport is located just 1.5 miles from the DoubleTree by Hilton Burlington Vermont and is served by major airlines including American Airlines, Delta, Frontier Airlines, jetBlue, Porter (seasonal), and United.

Airline	Markets Served Non-Stop
American Airlines	Chicago (ORD), Charlotte (CLT), Denver (DEV), Philadelphia (PHL), Washington, DC (National, DCA)
Delta	Atlanta(ATL), Detroit (DTW), New York City (LGA)
Frontier Airlines	Denver (DEN), Orlando (MCO)
jetBlue	New York City (JFK)
Porter (seasonal)	Toronto City, Ontario, Canada (YTZ)
United	Chicago (ORD), Denver (DEN), Washington, DC (Dulles, IAD), and Newark (EWR)

The DoubleTree by Hilton Burlington Vermont offers complimentary airport shuttle service daily from 4:30 am – 12:00 am.

Visit nalms.org/nalms2019 to register!

Photo: Gautam Krishnan

LakeLine

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Harmful Algal Blooms

On the cover:
"Boreal Lake in Bloom"– visually stunning *Aphanizomenon* bloom on Baptiste Lake in the boreal region of Alberta, Canada. Photographed by Ron Zurawell.

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From the Editor

Amy Smagula

LakeLine encourages letters to the editor. Do you have a lake-related question? Or, have you read something in *LakeLine* that stimulates your interest? We'd love to hear from you via e-mail, telephone, or postal letter.

Happy summer! It's prime lake time right now, with many people out and enjoying what our lakes, ponds, and reservoirs have to offer. Among the activities to enjoy, remember that July is Lakes Appreciation Month, and the annual Secchi Dip-In event is kicking into gear. We hope you take time to organize or participate in an event, and take a few minutes to measure and report the Secchi depth measurement in your favorite waterbody.

While you are out and about on the water, please take caution and note any possible murkiness, scums, or other manifestations of algal blooms that might be occurring. It is also prime time for potentially Harmful Algal Blooms (HABs) to pop up, so much so, that every other year *LakeLine* focuses the summer issue on the topic of HABs, and what is currently going on in terms of research, technologies and advisories. Summer 2019 is one of those years where we check in on HABs.

It seems like HABs are occurring at an ever-increasing frequency, with Lake Erie's large and long-lived bloom well-publicized in the media in recent years, and fears lingering of another such epic bloom. More locally and recently I am sure many of you have had your fair share of HABs that threaten drinking water supplies, reduce recreational values and opportunities in waterbodies, and that pose human health risks.

NALMS is fortunate to have members who are active in research related to HABs, many of whom participate in the NALMS HABs Program, co-chaired by Angela Shambaugh (VT DEC) and Shane Bradt (UNH Cooperative Extension). The membership of this group is large and diverse both in backgrounds and geographic distribution of the participants, both key in contributing to the knowledge base of this group.

Co-chair Angela Shambaugh took a co-editor role with me for this issue of *LakeLine*, and identified authors who could provide some interesting updates on their work and the science of HABs. Angela provides an introduction to the issue on page 10, where she outlines the topics and authors of each article in this issue.

In addition to contributing to the *LakeLine* HABs issues every other summer, the NALMS HABs Program is focusing on developing a webpage and Story Map related to inland HAB issues in the US and parts of Canada. This will help to connect NALMS members with information and up-to-date HABs as they occur. Watch for that to be unveiled in the coming months from NALMS.

Further, co-chair Angela Shambaugh was selected to lead an Interstate Technology and Regulatory Council (ITRC) team on cyanobacteria prevention and management. The primary outcome of this effort is a web portal resource for state and private lake managers to assist in bloom response. As an organization, NALMS plans to contribute significantly to this effort.

The group also developed a position statement and associated white paper on HABs as part of their work for NALMS. Both documents can be found on the NALMS website at https://www.nalms.org/nalms-position-papers/toxic-cyanobacterial-blooms/.

Thank you to the NALMS HABs Program, and the contributions of each of the authors in this issue. These updates and the emerging information and technologies shared here will aid us in recognizing and reporting blooms in the months and years ahead.

We hope you enjoy this issue of *LakeLine*.

Amy Smagula is a limnologist with the New Hampshire Department of Environmental Services, where she coordinates the Exotic Species Program and special studies of the state's lakes and ponds.

From Sara Peel the President

As we move from spring into summer, we celebrate the success of the 2019 Monitoring Conference (which NALMS assists in planning and hosting) and highlight the NALMS mid-term board meeting. NALMS continues to benefit from the efforts of competent staff and a motivated board; membership numbers continue to increase providing stability to NALMS in this economy. And thanks to the efforts of the NALMS board and staff, conference coordinator, the Cincinnati host committee and the monitoring council, NALMS is rebuilding our budget reserve. This seems like a good time to reflect on what has been accomplished since the 2018 NALMS symposium in Cincinnati.

The NALMS board's midterm meeting occurred in chilly but lovely Denver, Colorado, the weekend of March 23-24 – just prior to the beginning of the 11th National Water Quality Monitoring Conference. The board reviewed ethics committee work and identified steps for completing our ethics statement; provided input and approved steps to complete NALMS' inaugural development plan, and reviewed committee and program work products in light of the NALMS strategic plan.

The board completed several housekeeping tasks including approving updates to the NALMS Operations Manual, approving NALMS contributions to the Association of Fundraising Professionals (AFP) Donor List, adopting the AFP donor bill of rights, formulating revised staff position descriptions and evaluation procedures, and implementing 100 percent board member donor participation guidance.

Additionally, the inaugural NALMS diversity statement was approved as follows:

> *Diversity for NALMS means creating a community of inclusion. We respect and value the unique contributions and perspectives of all members, employees, event participants, students, volunteers, and our local and international communities. Diversity includes age, culture, disability, ethnicity, gender, national origin, color, race, religion, sexual orientation, diversity of thought, ideas, and more. Diversity maximizes our true potential for creativity, innovation, and collaborative problem solving. NALMS strives to cultivate a Society built on mentorship, encouragement, tolerance, and mutual respect, thereby engendering a welcoming environment for all. NALMS promotes diversity in all areas of activity, including fostering diversity in membership, leadership, committees, staff, outreach, public engagement, recruitment, and all other areas of Societal activity.*

We are looking forward to the 39th International NALMS Symposium, which will be in Burlington, Vermont, this fall. We were last in New England in 2009 when we visited Hartford, Connecticut. The Vermont Host Committee and New England NALMS Affiliate volunteers are finalizing field trip options – those along with a draft conference agenda, draft program, plenary speaker details, Clean Lakes Classic 5K registration information, and hotel room reservation and conference registration information will be posted soon. Concurrently, the 2020 Minnesota host committee is gearing up to provide details for the 40th Annual NALMS symposium – if you have ideas about how NALMS should celebrate our 40th Anniversary, please share those details with NALMS staff or board members.

This issue of *LakeLine* deals with the important topic of Harmful Algal Blooms. As we track algal blooms in the Western Lake Erie Basin via the National Weather Services' bloom forecast (https://www.weather.gov/cle/LakeErieHAB) and follow bloom documentation within our local waterbodies, NALMS aims to help identify resources available in other states and provinces. With this in mind, our HAB Program launches NALMS' Harmful Algal Bloom story map with this edition. Read on, and see what HAB-based monitoring, early detection, and treatment mechanism you can incorporate from efforts to address Harmful Algal Blooms.

Here's to a safe and productive summer ,and we hope you can join us in Burlington, Vermont, this fall!

Sara Peel, CLM, is the NALMS president, previously serving as the director at large, two terms as secretary, and one term as the Region 5 director. Sara received her B.S. in biology and Chemistry from Alma College and her M.S. in environmental science from Indiana University School of Public and Environmental Affairs. Sara is the lead scientist and co-owner of Arion Consultants – a regional environmental consulting firm with a focus on lake and watershed management. She is an experienced leader in water quality and watershed management.

Summer 2019 **Cyanobacteria** *LakeLine* Introduction

Angela Shambaugh, NALMS HABs Program Co-Chair

The organisms known as cyanobacteria are millions of years old. They can be found in every environment – from the poles to the equator, from deserts to rainforests, on dry land or in lakes and wetlands. Scientists recognize the critical ecological role these organisms have in the natural world and hope to utilize cyanobacteria as future sources of biofuels, pharmaceuticals, and other products. Yet, there is a downside to their success. Increasing nutrient levels in surfaces waters and the warming climate are supporting ideal conditions for intense cyanobacteria growth. For reasons not yet clearly understood, cyanobacteria may also produce potent toxins harmful to people, pets and wildlife. Each year, the presence of blooms impacts drinking water, recreation and health in waters around the world. In this issue, you will learn how satellites and citizen monitors support cyanobacteria response, how you can harness the power of satellites to learn about cyanobacteria conditions on your lake, and also be introduced to bottom-dwelling cyanobacteria.

Bridget O'Brien, Lori Fisher, Heather Campbel, and I discuss the long-term cyanobacteria monitoring effort on Lake Champlain, entering its 18th year this summer. This project utilizes citizen volunteers and a visual protocol to provide data supporting cyanobacteria risk assessment across a large highly diverse lake that is both a state and international boundary.

Margaret Spoo-Chupka, Jade Young, and Rich Fadness will take you below the surface to learn about bottom-dwelling, or benthic, cyanobacteria. Outreach and communication about cyanobacteria is currently focused almost exclusively on surface blooms. As the authors explain, benthic cyanobacteria are very common and lake managers should be aware that they also may produce harmful toxins.

Blake A. Schaeffer, Robyn N. Conmy, Mike Galvin, John M. Johnston, Darryl J. Keith, and Erin Urquhart have developed an Android-based app that will bring that same cyanobacteria sensing technology to your phone. The app goes live in early summer 2019. In their article, the authors will tell you how to customize it for your location so you can get information about cyanobacteria before you reach the lake.

Randy Turner and Pete Kauhanen have created the California Satellite Analysis Tool that allows residents to quickly learn about cyanobacteria abundance on larger lakes, how abundance changes over time, and water quality parameters that may influence that change. In their article, they'll introduce you to this online tool and the remote sensing technology that supports it.

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

Angela Shambaugh, Bridget O'Brien, Lori Fisher, and Heather Campbell

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.

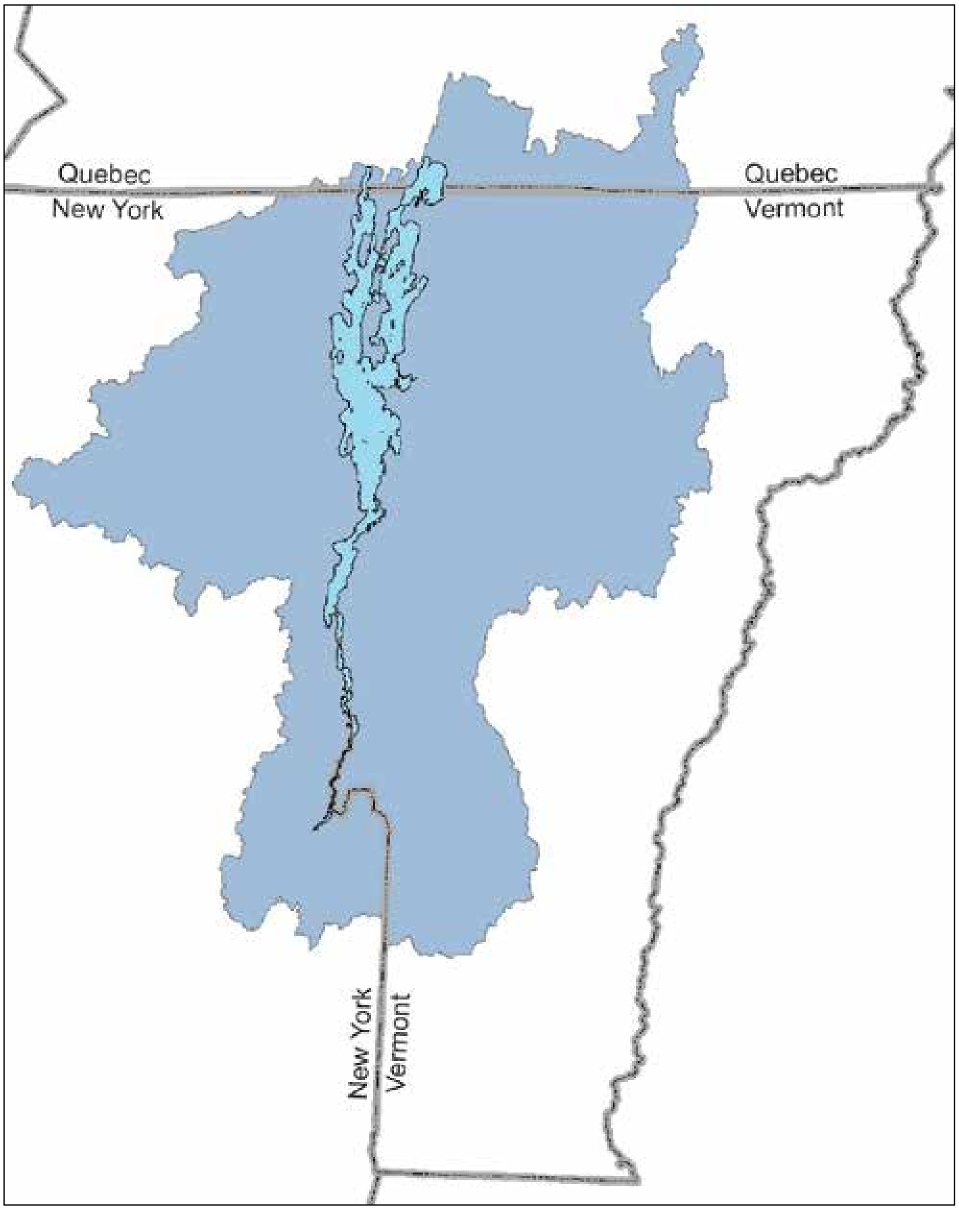


Figure 1. Location of Lake Champlain between Vermont, New York, and Quebec. The lake is shown in light blue and its watershed in the darker blue.

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)

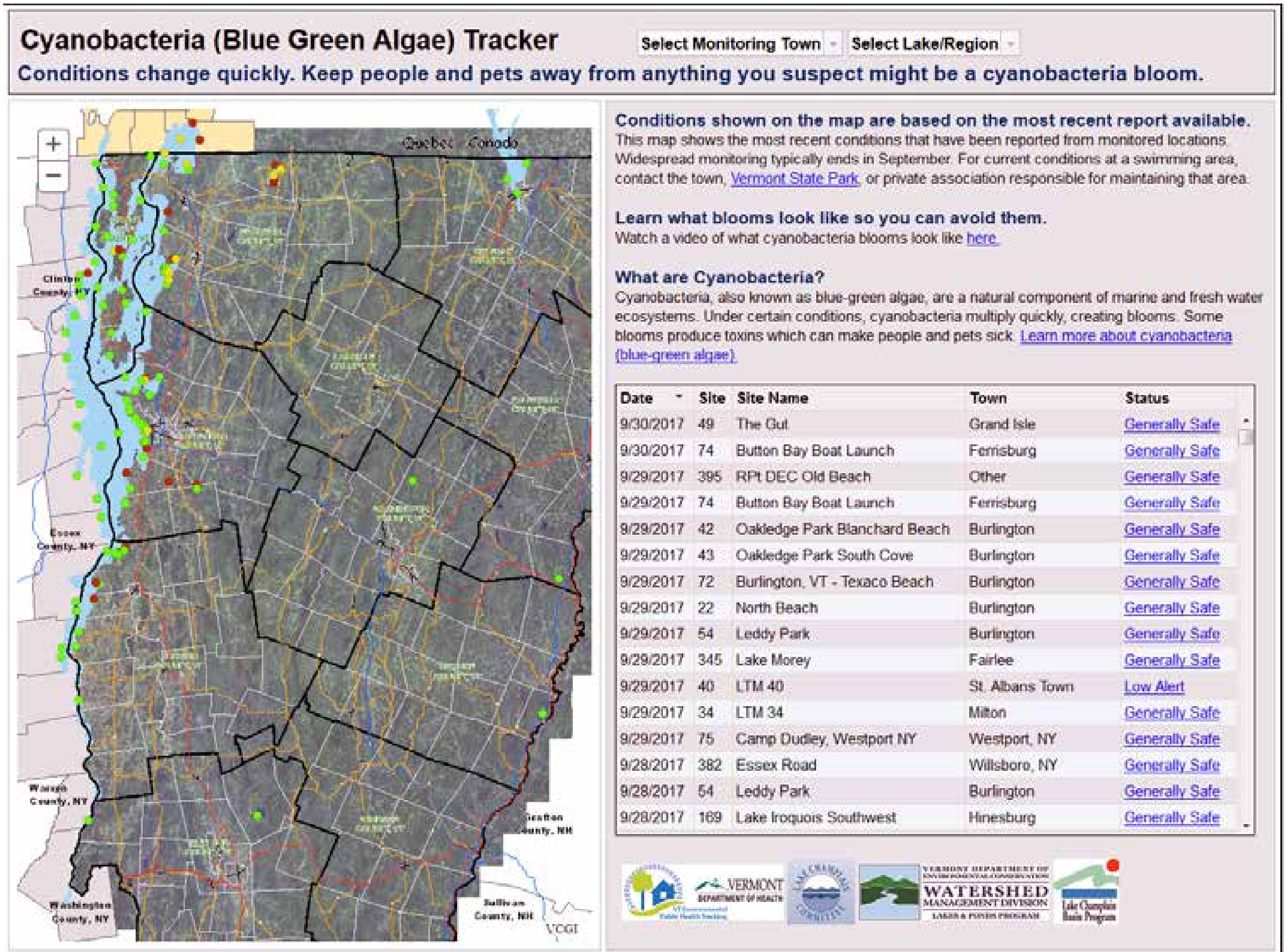
Collect: As for Alert Level 1

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.

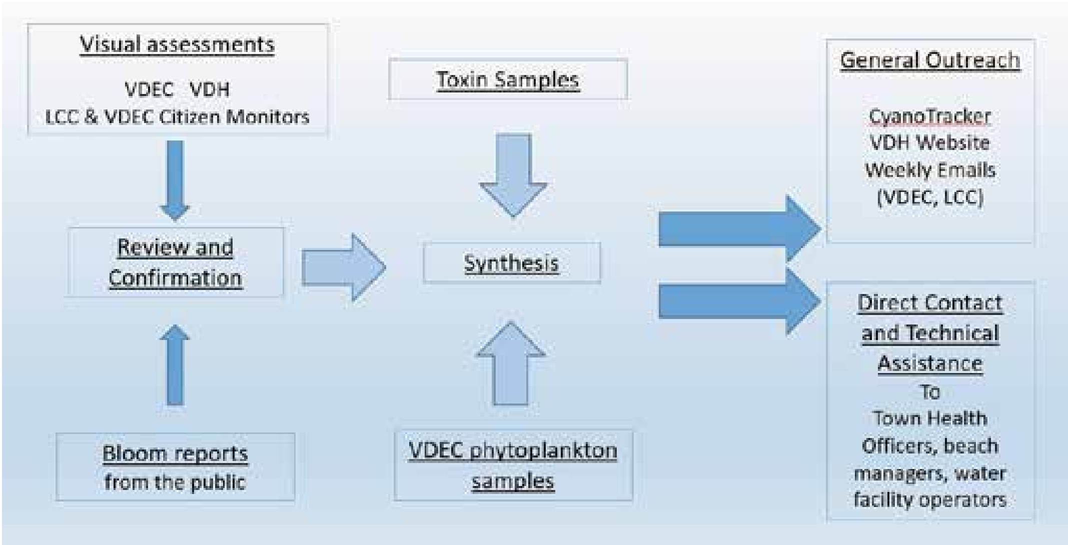


Figure 4. Cyanobacteria severity assessment process utilized for Lake Champlain and Vermont's inland lakes.

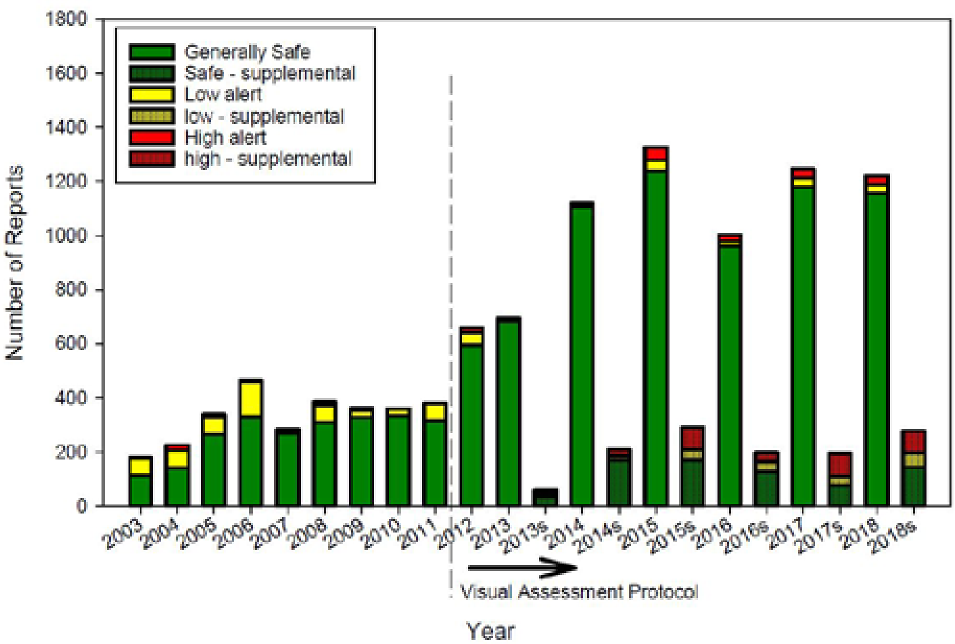


Figure 5. A historical summary of cyanobacteria severity on Lake Champlain since 2003. Supplemental reports are those provided in addition to weekly routine monitoring reports, from locations that are not routinely monitored, or those submitted by the general public.

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.

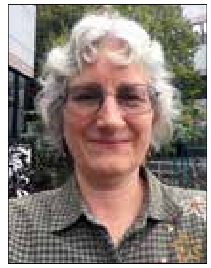
Establishing and operating a long-term monitoring program is never easy. We have been able to maintain annual monitoring for many years by leveraging existing resources and partnerships. Federal funding from the U.S. Environmental Protection Agency and the Centers for Disease Control to the state agencies 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

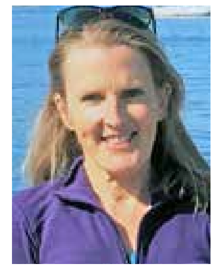
and Groundwater Protection Division – drinking water operator resources, cyanotoxin test results: https://dec.vermont.gov/water/drinking-water/water-quality-monitoring/blue-green-algae.

- 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/

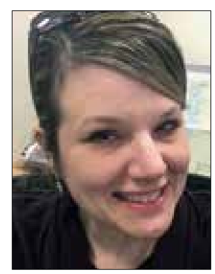


Angela Shambaugh is an aquatic biologist with the Lakes and Ponds Program (VDEC). She has over 30 years of experience in the fields of water quality and plankton ecology. Currently, she coordinates the Lake Champlain Cyanobacteria Monitoring Project on Champlain and co-leads the Interstate Technology 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.

A Deeper Look at HABs

Margaret Spoo-Chupka, Jade Young, and Rich Fadness

Cyanobacteria that have the potential to cause HABs can be found in a diverse array of aquatic systems, from the highly visible planktonic blooms to less conspicuous benthic mats. The potential risks and detrimental effects of planktonic blooms have been well studied in recent years. Most alert-level framework monitoring programs and guidelines are based on planktonic cyanobacteria and their associated toxins (EPA).

To date, benthic cyanobacteria that grow on substrates in aquatic ecosystems have been overlooked in risk assessments. Toxin production in benthic cyanobacteria mats has been documented worldwide and linked to dog and livestock deaths in various countries. Despite the potential detrimental effects they present, benthic populations have been largely overlooked because they are less visible and therefore, more difficult to detect. This article aims to bring awareness to those who manage aquatic systems to look deeper, beyond the water's surface, when evaluating and responding to HABs in their systems.

Benthic communities in lakes and rivers

The term "periphyton" refers to the complex communities of phototrophs attached to submerged surfaces in aquatic ecosystems, which can include benthic cyanobacteria. Environmental controls that can influence the periphytic communities and the benthic cyanobacteria within include physical disturbances, light, temperature, nutrients, and grazing. The influence each environmental factor has on the communities can vary and depends on the habitat.

Benthic cyanobacteria have been found to inhabit all ecological niches within the riverine system, from slow-moving backwater locations to swift water riffle and cascade habitats. In some instances, a river reach can contain several different habitats containing dozens of cyanobacteria species with the potential to release several cyanotoxins at the same time. Periods of stable flow, temperature, and light availability provide an environment conducive to the proliferation of periphytic communities that may lead to benthic HABs.

Benthic cyanobacteria in lakes are commonly found in the periphyton of shallow near-shore waters or littoral zone where light penetrates to sediments. They frequently form mat communities that exhibit complex ecological interactions among the diverse assemblage of organisms. The spatial distribution of cyanobacteria mats in lakes is largely dependent on light availability, which in turn is affected by lake size, morphometry, and water clarity. The taxonomic composition of these mats is also influenced by light availability; for example some potentially harmful genera of cyanobacteria, like *Phormidium* spp., can be found under low-light conditions due to the presence of phycobilins, photosynthetic pigments that can capture longer wavelengths of light.

Planktonic blooms, common in eutrophic lakes, can reduce water clarity and limit light penetration to the benthos. Water clarity in oligotrophic lakes is high compared to eutrophic lakes and favors deeper growth of potentially toxigenic cyanobacteria mats. Lake managers should not assume that oligotrophic lakes with seemingly high water quality cannot be a source of HABs.

Toxins within

Benthic cyanobacteria are capable of producing several cyanotoxins such as hepatotoxins, neurotoxins, and dermatoxins. These toxins are known to contribute to human and animal illness and, in the worst case scenario, death. Reports of benthic HABs contributing to animal poisonings have increased in recent years. In Northern California's rivers, several dog deaths have been attributed to benthic cyanotoxin poisonings since 2000. Due to the inconspicuous nature of benthic cyanobacteria, there has been a lack of research into the health risks associated with benthic cyanobacteria. The ability to quantify the health risks requires new research and the development of new tools for risk assessment.

Despite these challenges, there are countries (e.g., Scotland, New Zealand, Cuba) that are responding to these needs. Periphytic communities are complex, composed of numerous organisms and substrates. They are also less accessible than the planktonic community and, therefore, more difficult to observe and sample.

Only two countries, Cuba and New Zealand, have introduced guidelines for monitoring benthic cyanobacteria. In both cases, the action triggers are based upon percent coverage of the benthos by potentially toxigenic cyanobacteria species. This type of guidance requires the determination of the toxigenic potential of cyanobacteria assemblages, which can be difficult, requiring time-consuming microscopy or DNA analysis and potentially cost-prohibitive toxin analysis.

Benthic cyanobacteria have been shown to produce toxins that are harmful to humans, animals, and aquatic life. It is important that water managers work together with regulators to develop protocols and establish water quality criteria that protects the public, animals and aquatic life. There are several documented cyanotoxins released by benthic cyanobacteria, but draft water quality criteria developed by the EPA for recreational water and health advisories for drinking water focus on just microcystin and cylindrospermopsin (EPA Document Number: 822-P-16-002). These criteria were developed in response to research conducted on planktonic species. The lack of research into the various other toxins produced by benthic species and potential associated health risks leaves individual States to determine criteria on their own or to ignore the risks associated with exposure to these toxins either singly or synergistically.

Recent research (Anderson et al. 2018) suggests that cyanotoxins may have a deleterious effect on macroinvertebrates. Anderson found that anatoxin (a neurotoxin) can be lethal to invertebrates in the laboratory setting at environmentally relevant concentrations. This can have far-reaching management implications by interrupting the base of the aquatic food web or altering the way we evaluate water quality conditions or impairments when macroinvertebrate population data may be the criteria of determination.

Sampling benthic mats

Many of the tools utilized in planktonic toxin detection and analysis can be employed for benthic cyanobacteria with some modification. These include the development and calibration of visual cues for determining benthic species present and bloom size, and toxin testing of both ambient water and benthic mats to evaluate the overall risk. In addition, passive samplers, like solid phase adsorption toxin tracking (SPATT) samplers, may be useful in determining the presence of low-level cyanotoxin concentrations and in documenting seasonal trends.

Unless mats are detaching from the substrate and floating to the surface, benthic cyanobacteria can be difficult to detect. Sediment samplers such as the PONAR grab sampler allows for the recovery of soft sediment benthic material, but this sampling method is like taking a shot in the dark when trying to find benthic mats. SCUBA divers can be an effective means of surveying and monitoring benthic cyanobacterial mats (Figure 1). The divers can collect grab samples and make observations on percent coverage of potentially toxigenic mats.

The location and spatial extent of rivers can pose a hindrance to the detection and evaluation of benthic cyanobacteria mats. Whereas a lake is a contained body of water with a finite location and often complete accessibility, rivers and streams often flow through private lands or other areas that may be otherwise inaccessible. In a single watershed, this may account for hundreds of miles of habitat in which toxic benthic HABs can proliferate unnoticed, affecting water quality conditions for many miles downstream of a benthic bloom. Limitations such as this may require the development of a susceptibility framework to determine environmental factors and conditions that may be conducive to bloom development.

Guidelines generally lacking

In general, HABs are increasing in spatial extent, frequency, and severity as well as temporally as blooms persist throughout the year. It is critical that water managers have good guidance to aid them in protecting the public from HABs, whether planktonic or benthic. While guidance regarding planktonic HABs exists, it is lacking for benthic HABs. Additionally, benthic cyanobacteria have been linked to numerous animal deaths worldwide, increasing pressure and need for the development of such guidance. Unfortunately, at the time of this publication, no federal or state guidelines, water quality criteria or regulations exist to provide recommendations to water managers (e.g., government agencies, local authorities, drinking water suppliers) regarding the appropriate response to or management of benthic HABs.

A few countries (e.g., New Zealand and Cuba) have developed guidelines for mitigating human risks associated with benthic cyanobacteria. Guidelines in New Zealand have been developed for both recreation and drinking water supplies. These guidelines include recommendations on agency roles and responsibilities, a monitoring and action plan and sampling advice. The guidelines are intended to help agencies develop monitoring protocols and encourage a consistent national approach to managing

Figure 1. Metropolitan Water District of Southern California SCUBA diver Kelly Lorenz collecting benthic samples.

risk in recreational water. The most advanced action level (red mode) is triggered when there is greater than fifty percent coverage by potentially toxigenic cyanobacteria or when potentially toxigenic cyanobacteria are detaching from the substrate. Actions taken during the red mode include notifying the public health unit, testing for cyanotoxins, and notifying the public to the health risks.

Establishing water quality regulatory guidelines for benthic cyanobacterial toxins is challenging for several reasons. These reasons include the variability of toxin production by a given taxon, limited understanding of the environmental triggers of toxin production, and the diversity of toxigenic cyanobacterial taxa. Compounding these challenges is the fact that cyanotoxins produced by benthic cyanobacteria can travel far downstream of their source. Additionally, benthic algal mats can become buoyant when dislodged, increasing the risk of accidental ingestion as the liberated mats float in the water column or collect along the shoreline (Figure 2).

The importance of integrating research on benthic HABs into models that will aid predictions related to the occurrence of HABs cannot be understated given the potential risks they pose. The development of guidance and effective management approaches is needed in North America. Collaborative workgroups like the international benthic HABs discussion group, coordinated by Christine Joab, Jade L. Young, Margaret Spoo-Chupka, and Lesley D'Anglada, https://www.epa.gov/nutrient-policy-data/benthic-habs-discussion-group, aim to facilitate the sharing of data, experiences and lessons learned from both an academic and water-management point of view. These collaborative workgroups and partnerships will become more important as global warming and anthropogenic activities are likely to increase in the occurrence of HABs in the future.

Figure 2. Benthic mat of anatoxin-producing cyanobacteria (Phormidium sp.) *in the Eel River.*

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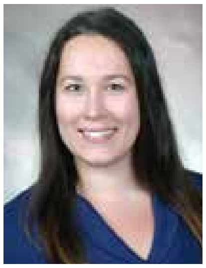
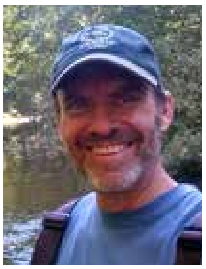
Margaret K. Spoo-Chupka is a biologist at the Metropolitan Water District of Southern California in the Reservoir Management team at the Water Quality Laboratory. Her work focuses on the ecology/taxonomy of algae in drinking water systems and management of HABs in those systems.

Jade L. Young is a limnologist with the U.S .Army Corps of Engineers, Louisville District. Ms. Young oversees the District's Water Quality Program, which includes the assessment of reservoirs, streams and rivers. Her areas of expertise include freshwater algal and macroinvertebrate ecology as well as the assessment of chemical and physical properties within aquatic environments.



Rich Fadness is an engineering geologist with the State of California's North Coast Regional Water Quality Control Board. As the regional coordinator for California's Surface Water Ambient Monitoring Program (SWAMP), he is involved in the investigation and assessment of water quality conditions in the reservoirs, streams, and rivers throughout Northern California.



Satellite-Detected Cyanobacteria in Large U.S. Lakes **on Your Android Phone**

Blake A. Schaeffer, Robyn N. Conmy, Mike Galvin, John M. Johnston, Darryl J. Keith, and Erin Urquhartn

Problem – Harmful cyanobacterial blooms and protecting public health

Safe and clean water is necessary for human and ecosystem health and economic growth. Over the last 40 years, water quality in the United States has improved, but threats to water quality remain. One issue that continues is the occurrence of cyanobacterial harmful algal blooms, or cyanoHABs. Health advisories and closure of recreational areas are often due to cyanoHAB events in our lakes and reservoirs. CyanoHABs can produce toxins but they also cause nuisance odors, and hypoxia. They are also visually noticeable by their unappealing surface scums. CyanoHABs negatively impact drinking water and can increase drinking water treatment costs for communities. They also impact the local economy, via revenue loss from recreation and businesses that rely on safe and clean water. Most cyanoHAB events are dealt with reactively, after the bloom has occurred in a response to the visual, odor, or toxin confirmation. What if we could proactively monitor and detect early development of cyanobacteria harmful algal blooms?

Solution – The power of satellite information in the hands of people

Typically, a single organization is responsible for monitoring water quality across numerous lakes covering a vast geographic area. Additionally, monitoring efforts are often constrained by limited resources including the availability of personnel. Water quality managers need access to current, inexpensive and quality data to protect water resources. To assist in the proactive management of cyanoHAB events, EPA researchers, along with researchers from NASA, NOAA, and USGS, have developed a time-efficient way to use satellite data in monitoring for cyanoHAB events to help protect recreational and drinking water sources.

The EPA developed and beta-tested the Cyanobacteria Assessment Network (CyAN) app for Android operating systems. This app uses information from the European Space Agency's Sentinel-3 satellite Ocean and Land Colour Imager to create a free, current, and immediately intuitive satellite data delivery system accessible through Android version 4.1 and above smartphones. A prototype of this mobile application was originally described in the Summer 2015 issue of *LakeLine* (35[2]:28-31). Since that time, EPA researchers have updated the app and beta tested with multiple non-government organizations, as well as state and federal agencies for managing cyanoHAB events. It is now ready for public release to support a much broader audience.

Though satellite data have been available for many years, use in decision making has been hindered by difficulties with compatibility of complicated data formats and the time burden to process and access the data. The CyAN app gives water quality managers the ability to distill and assess satellite derived cyanoHAB biomass concentrations occurring over large areas across the country. This app reduces the need for scientific expertise in satellite data processing, analysis and interpretation, and eliminates barriers to computer hardware requirements associated with the use of satellite data files. The CyAN app provides an easy to use, customizable interface to scan water bodies for changes in cyanoHAB occurrence without requiring computer programming expertise. Thus, managers can rapidly distill critical water quality information over large temporal and spatial areas. (See Figure 1.)

App functionality and satellite data have already been successfully demonstrated against 25 state health advisories, across seven states, issued in 2017. The app reported cyanoHAB increases in concentration in the same location and during the same time as an independent state issued health advisory. Over 2,000 of the largest lakes and reservoirs can be monitored across the continental U.S., with a complete list by state available in the supplemental material of Schaeffer et al. (2018).

The georeferenced data in the app allow water quality managers the ability to passively monitor a specific water body without having to filter through numerous satellite images of water bodies that aren't associated with their area of interest. Simply, users open the app once a week to receive the updated imagery. The mobile app provides monitoring data of cyanoHAB values for locations of interest for the current season, as well as on daily and weekly intervals to provide a temporal context. The app provides approximately 70 percent of the monitoring information, whereas the remaining information (such as identifying site locations of interest, setting warning thresholds) is input by the water quality manager during the setup process.

Examples of feedback provided from CyAN mobile app beta testers:

Aaron Borisenko, State of Oregon Department of Environmental Quality: *"Moving ahead we want to spread the word about the application and get more eyes on the situation. It is important to identify where blooms are typically occurring using CyAN app as an early warning system."*

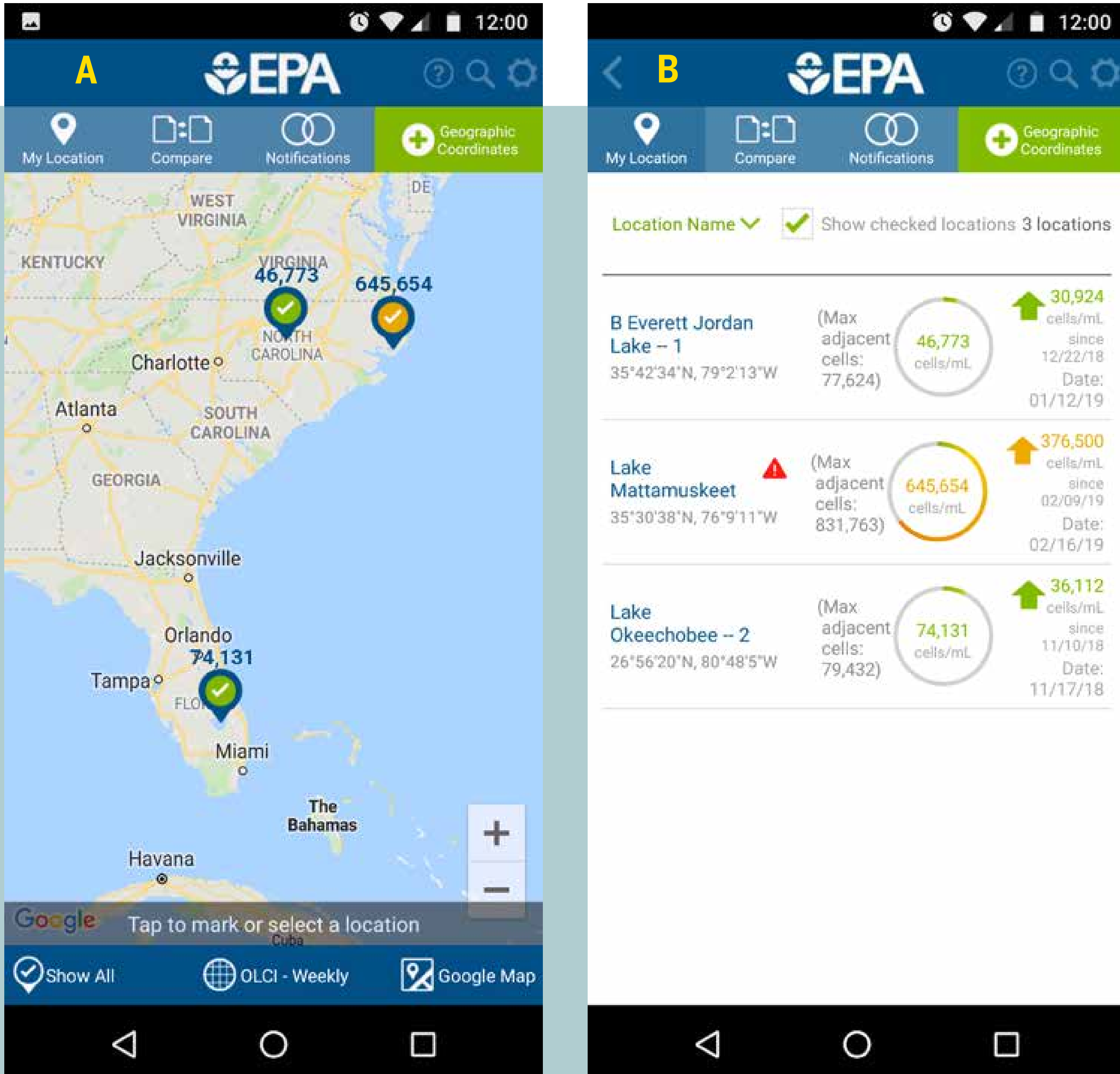
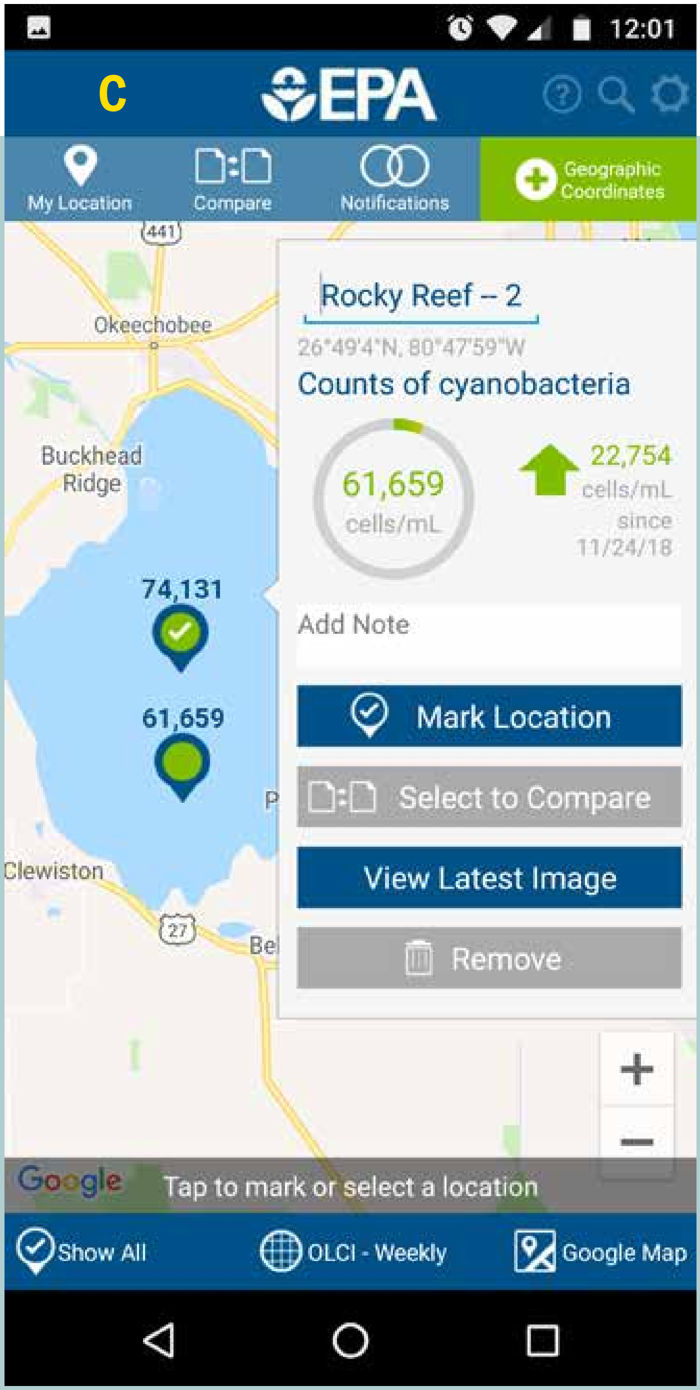
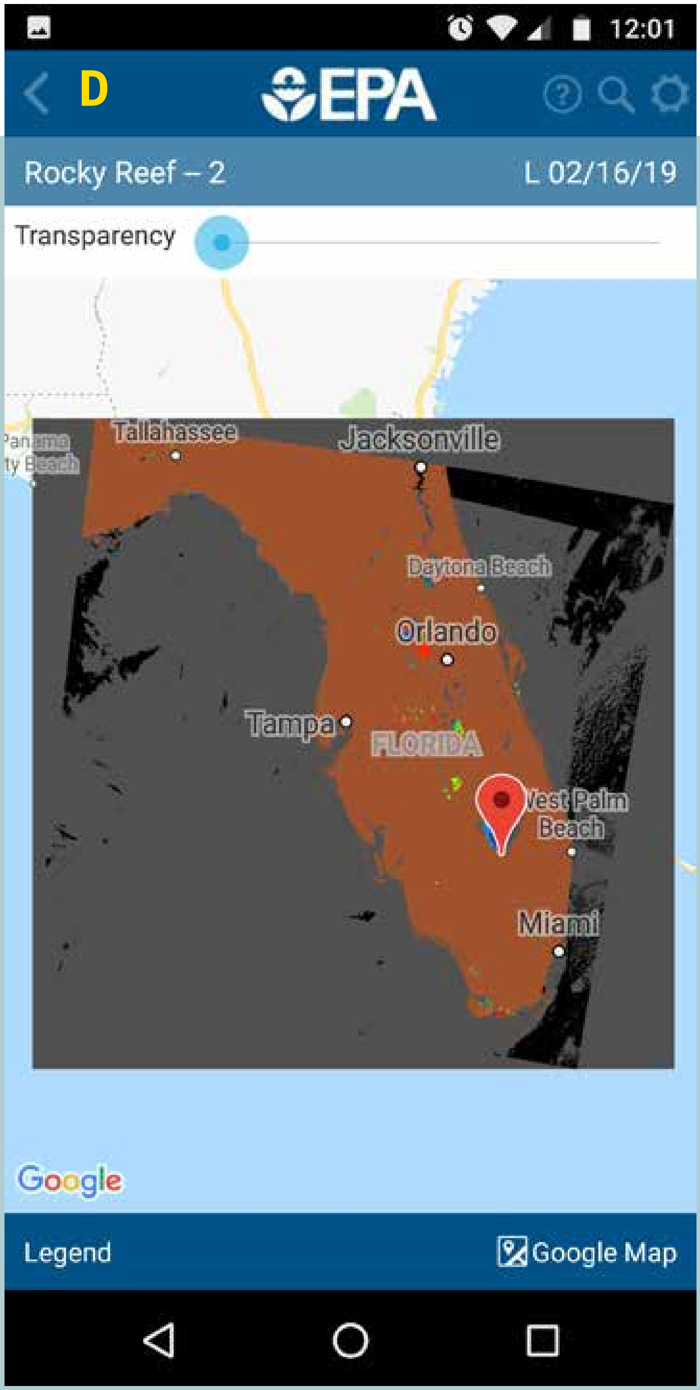


Figure 1. Main page (A) of the CyAN app allows for pin placement in locations of interest, where the user can see an alphabetical list of locations (B) with coordinates, biomass concentrations and changes from previous detections. Viewing a specific pin location (C) and selecting "View Latest Image" allows the user to (D) view the satellite area to identify if another location may be of interest.

Benjamin Holcomb, Utah Department of Water Quality: *"The images we've been receiving through the CyAN project have been tremendously helpful to the Utah Division of Water Quality (UDWQ), providing the foundation for a wide range of useful outputs. It allows UDWQ to better target field sampling and more efficiently use our limited resources to protect public health. Finally, images are easily shared with response agencies as a useful visual communication aid."*

Daniela Gurlin, Wisconsin Department of Natural Resources: *"The CyAN app provides our water resources specialists a tool to access near real-time satellite data products for detecting and quantifying algal blooms in hundreds of lakes across Wisconsin. Simple map navigation and minimal steps required to mark locations and view the latest images make this app a useful tool for responding to questions related to the potential presence of harmful algal blooms in specific lakes. Time series images and blooming charts provide*





additional insights into the temporal dynamics and intensities of algal blooms at a particular location."

Angela Shambaugh, Vermont Department of Environmental Conservation: *"Large lakes like Lake Champlain have an extremely patchy distribution of cyanobacteria due to varying environmental conditions and lake shape. The CyAN app helps viewers visualize that patchiness and provides additional context for our [cyanobacteria] Tracker Map which shares data gathered by our cyanobacteria monitoring program."*

Bart Johnsen-Harris, Environment America: *"From Florida to the Great Lakes to California, we are seeing widespread outbreaks of toxic algae in our waterways. As I work on these issues and advocate for clean water policy, CyAN has proved to be a uniquely helpful tool. I expect that scientists, lawmakers, and concerned citizens alike will benefit from these maps."*

Lenard Long, Lake Cascade Citizen Scientist Monitoring Group: *"Our goal is to enhance the community's ability to rapidly respond to and manage the growing threat posed by toxic algae by reducing human controlled nutrient pollution; the CyAN app helps us do that . . . the CyAN app has been extremely useful. . . ."*

Into the details – Translating satellite data for decisions

Within the Geographic Coordinates tab on the app, the user can add specific location information such as latitude and longitude for monitoring stations, recreational locations, and public drinking water surface intakes. Adding and removing locations is also a simple process. Locations are stored in list-form for a quick and easy way to visualize the current data and recent changes in thresholds. It is important to know that a pin location only provides data that is a cyanoHAB detect in that specific pixel location. If that specific pixel location does not have any detectable measures of cyanoHAB, or is covered with clouds during the season, no data are returned to the end user to conserve data transfer

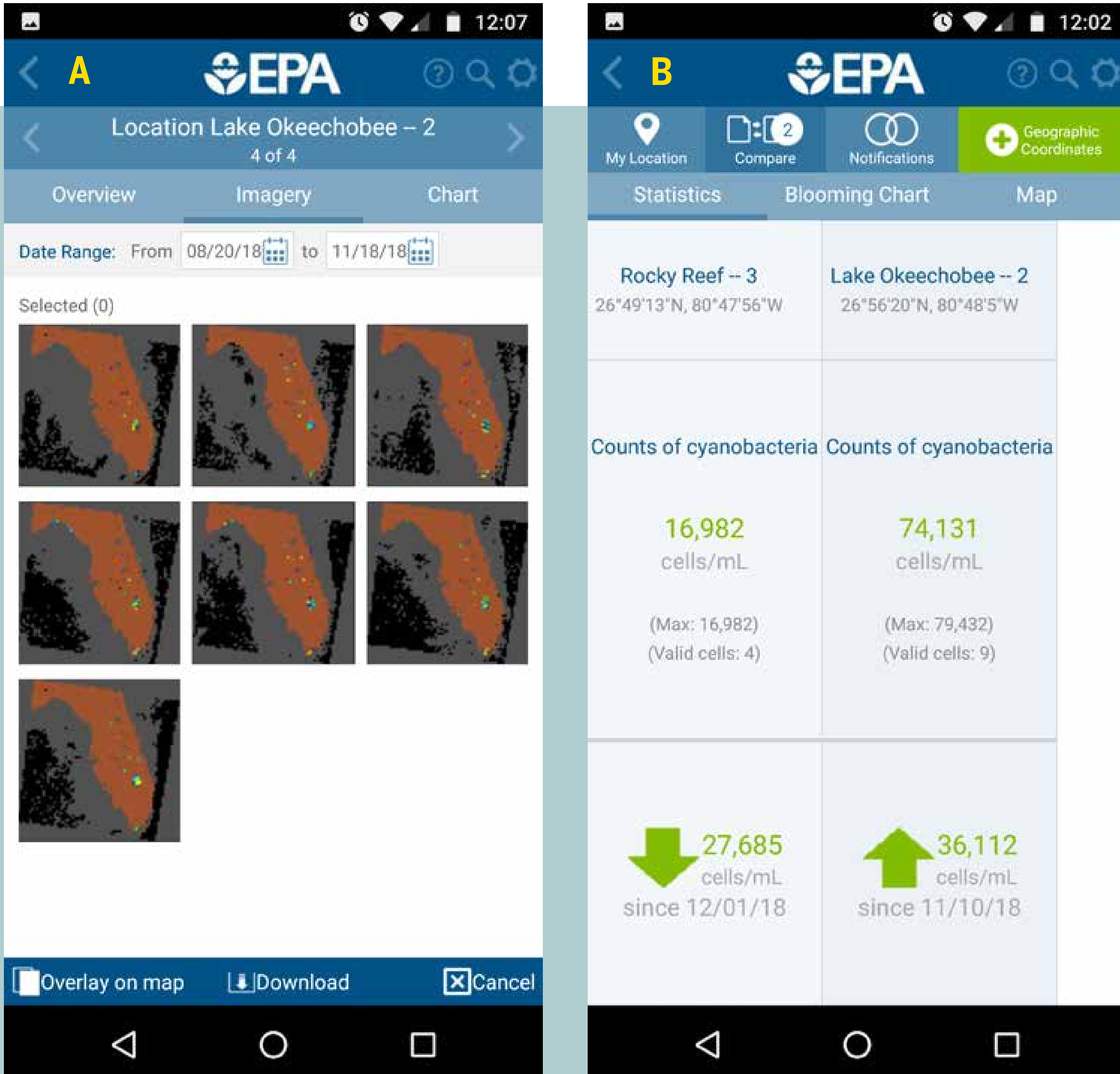
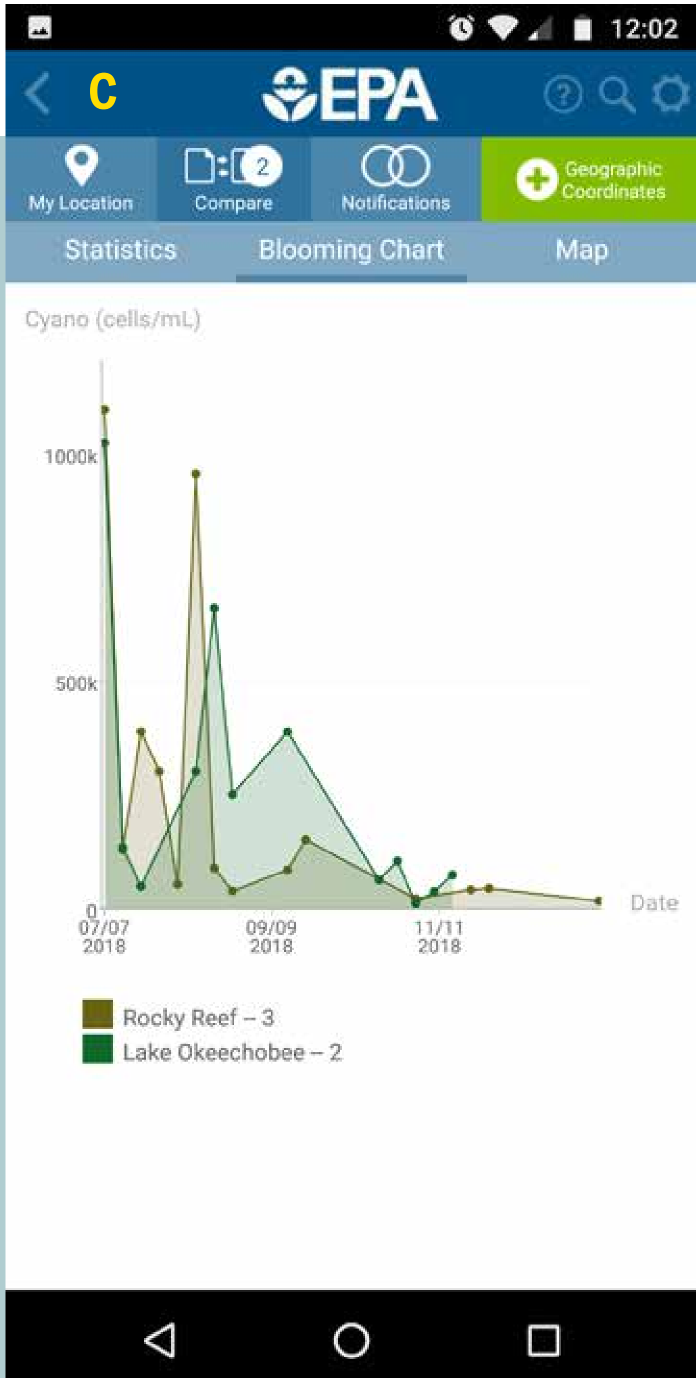


Figure 2. Users can (A) browse through a time series of images for their areas of interest, compare (B) concentrations and changes at specific locations, (C) visualize time series, and (D) switch between locations to see available satellite images.

rates. Based on user feedback, there is now an option for tapping a pin on the main page and viewing the entire satellite area that contains their locations of interest, so the entire geographic location can be quickly viewed and determine if a different location should be selected. The satellite images may also be downloaded to the mobile device as a PNG file for record-keeping or exported for quick use in a presentation. Data used in the app are considered provisional and will contain errors, such as potential false positive detections near shore and during snow and ice events. Data were validated to stage 2 of 4 on NASA's data maturity level ranking. This is defined as "data product accuracy is estimated using a significant set (although not full US) of independent measurements obtained from selected locations and time periods and field program efforts. There have been some peer-reviewed publications on the accuracy, but for limited spatial areas."

Summary

The CyAN app provides easy access to satellite data and some basic analyses, delivering a proactive ability to monitor spatial and temporal information on



cyanoHAB events across more than 2,000 of the largest U.S. lakes and reservoirs. This intuitive tool reduces the barriers to accessing satellite water quality data for monitoring and improves the use of limited resources in responding to events. More detailed technical information on the CyAN mobile application is found in Schaeffer et al. (2018). The mobile application is available to the public this year and will soon be on the Google Play store and at https://www.epa.gov/water-research/cyanobacteria-assessment-network-mobile-application-cyan-app.

Reference

Schaeffer et al. 2018. Mobile device application for monitoring cyanobacteria harmful algal blooms using Sentinel-3 Ocean and Land Colour Instruments. *Environmental Modelling and Software* 109: 93-103.

Acknowledgements

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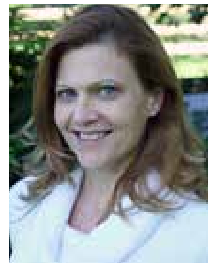
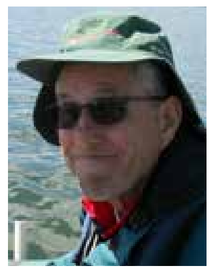


Robyn N. Conmy is a research ecologist at the Environmental Protection Agency in Cincinnati, OH. Her research is dedicated to characterizing optical properties of organic matter in water bodies and discerning their impact to water quality conditions. Her research interests include carbon biogeochemical cycling, optical tracking tools (in-situ and satellite remote sensing), landscape-watershed interactions, crude oil fate and transport, light attenuation in water and surface-groundwater interactions. You can contact Robyn at conmy.robyn@epa.gov.



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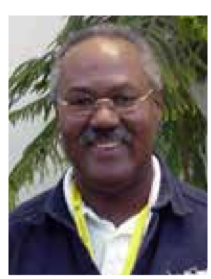

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UPCOMING IN *LAKELINE* –

LakeLine Fall 2019:

The fall issue of *LakeLine* will cover topics related to Source Water Protection. Articles will cover a range of management, protection, and planning maasures utilized in keeping our drinking water supplies safe and available.

Visualizing Cyanobacteria **from Space**

Randy Turner and Pete Kauhanen

A web tool highlighting long-term trends and where to sample tomorrow

While naturally part of freshwater ecosystems across the planet, cyanobacteria, or blue-green algae, have expanded in recent decades resulting in blooms that dominate many lakes, rivers, and other water bodies. With many cyanobacteria species naturally producing toxins, this creates potential risks and new management challenges for public health agencies, drinking water facilities, and lake managers. With an increasing need to understand cyanobacteria bloom trends and have up to date information, a valuable screening tool was developed for use in California that provides a new and unique understanding of cyanobacteria blooms by utilizing daily updated satellite data and over a decade of historical images taken from space.

Remote sensing data

Satellite imagery provides a lot more than just pretty true-color imagery like you see in Google Earth. Specialized satellites can estimate not just how much algal biomass exists in large lakes and other waterbodies, but how much cyanobacterial biomass exists, based on the intensity of specific wavelengths of light that reflects back to the satellite. This ability to literally see what human eyes can't, and allows for the detection of cyanobacteria at levels lower that what is observable to the human eye, which allows them to be especially effective as an early warning tool for developing blooms. Using imagery collected roughly every other day by two European Space Agency (ESA) satellites, the National Aeronautical and Atmospheric Administration (NOAA) processes and shares these data to reveal an incredible dataset that can document in near real-time when and where cyanobacteria blooms are occurring and how severe they are.

Following the pioneering use of processed satellite imagery for assessing cyanobacteria blooms in Lake Erie and Florida by NOAA and others (Wynne et al. 2008; Stumpf et al. 2012), California has funded the San Francisco Estuary Institute (SFEI) to develop an interactive Satellite Analysis Tool (cchab.sfei.org) to characterize the seasonality, spatial distribution, and development of harmful algal blooms (HABs) in 250 of the state's largest waterbodies. This tool provides a spatial display of cyanobacteria blooms, easy to understand charts that let you see long-term and short-term trends based on lake-wide statistics, queries relevant field data entered into a public environmental database (CEDEN.org) to allow comparisons to the satellite data, and generates an automatic email notification when satellites detect cyanobacteria concentrations rising above background levels. These features allow for a much better understanding of the status and trends of cyanobacteria blooms and provide a useful screening tool for blooms across California.

Interactive satellite analysis tool

The entry page to the tool provides a map that spans California, allowing users to pan throughout the state's large waterbodies to get an overview of the latest conditions (Figure 1). Satellite data is displayed spatially as estimates of cyanobacteria abundance for each of the individual 300 meter x 300 meter pixels the satellite data is able to repeatedly capture. The pixels are displayed in an easy to understand and color-blind-friendly heat map where warmer colors represent high concentrations and cool colors, lower concentrations of cyanobacteria, allowing the user to intuitively see bloom intensity.

Users can click on a lake, or type in the name of their lake of interest, to quickly navigate to view to the heart of the tool, where spatial and temporal data are separately displayed for the lake of interest (Figure 2).

For each lake, this main page has three features that are displayed: (1) a map on the left showing estimates of the cyanobacteria abundance within each pixel, (2) a long time-series chart in the upper right that plots the lake-wide mean and 90th percentile data for multiple years, and (3) short time-series charts for a detailed view of statistics. These three displays are all linked to a movable "window" within the upper timeline graph that allows the user to quickly select different time periods to dynamically change the data displayed within the map and charts. Scrolling across the long time-series plot reveals data collected by the ESA's MERIS instrument from 2002-2012, and for their OLCI instrument from 2017 to present. This long time-series view is a great way to compare how bloom events change from year to year and quickly get the big picture of cyanobacteria trends across most of the 21st century.

Most users will quickly appreciate the ability to navigate through bloom seasons by changing dates for the window, allowing them to visualize cyanobacteria blooms like they never have before, revealing when and where cyanobacteria blooms develop, how the

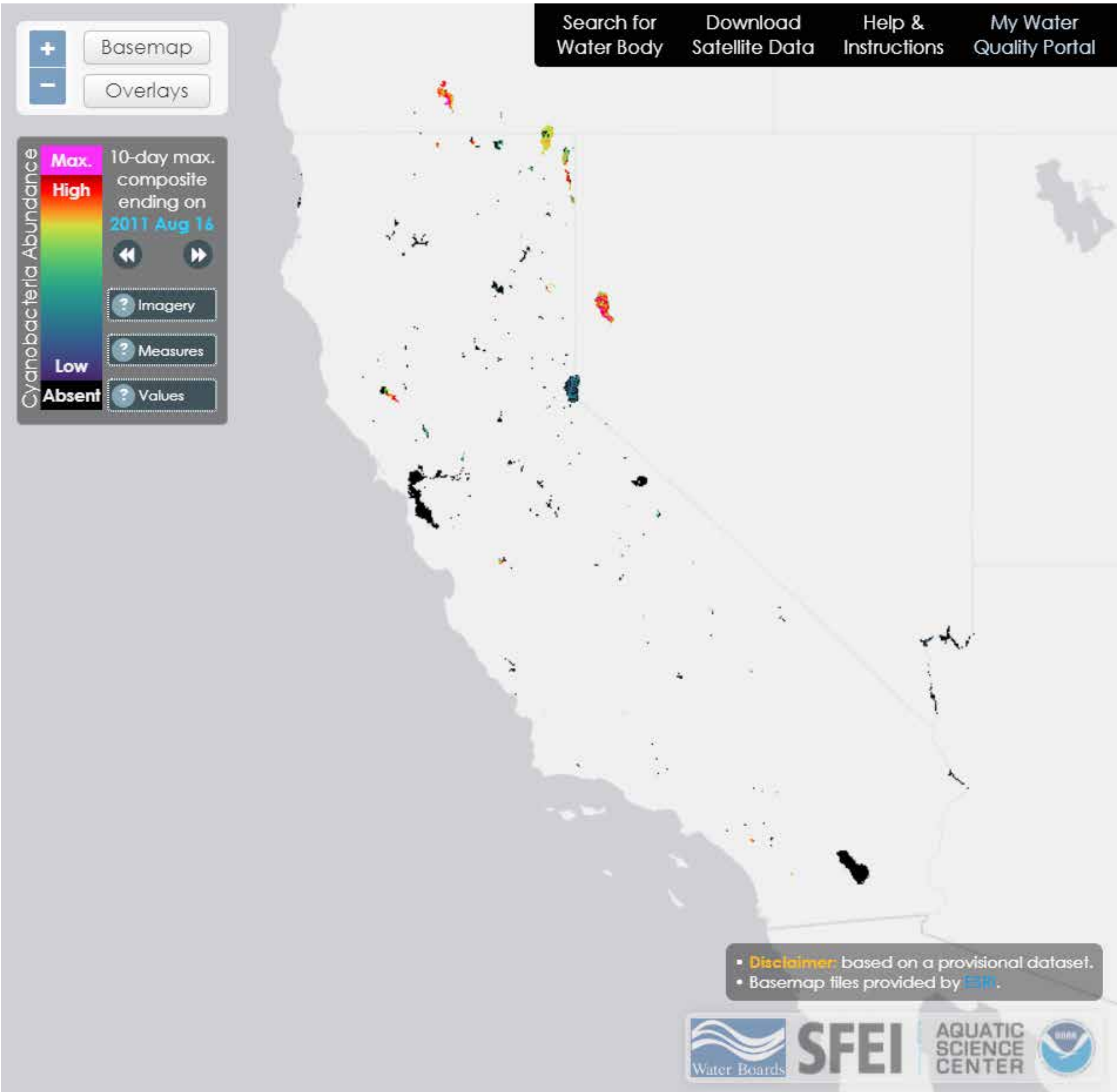

Figure 1. Satellite Analysis Tool entry page displaying status of lakes across California.

bloom grows over time, shift based on wind and currents, and inevitably decline. By navigating to the time just prior to a bloom, you can also select the "play" button on the map legend to watch a daily advancing animation of the map and charts, revealing the fascinating birth, life, and death of a cyanobacteria bloom.

In addition to the satellite-derived statistics and products, selecting the "CEDEN Analytes" tab allows users to query relevant water quality and cyanotoxin data from California's public environmental database CEDEN to display alongside the continuous satellite trend data seen in the short time-series chart, as well as display of each sampling location on the lake map (Figure 3). This comparison of field data, both in time and space, allow users to better see trends in commonly collected data like chlorophyll-a, and how these values track with the trends in the satellite data and spatially depending on where the sample was collected. While there is only a limited amount of relevant data in CEDEN, this querying capacity can be expanded to other public databases in the future.

Where data, charts, or maps are needed outside of the Satellite Analysis Tool, there are a variety of ways to put the information on the tool into reports, emails, or for use in GIS programs. The "Tables" tab can display either satellite or field data in tabular form for viewing or downloading. Charts can also be downloaded, as can the map views as clipped raster images, or within the statewide view, monthly mosaic images for all lakes can be generated for use in ArcGIS and other programs.

Complement to traditional monitoring

The Satellite Analysis Tool is not meant to be used to directly post public health warnings or closures for waterbodies for a few reasons. Most public health thresholds are based on cyanotoxin concentrations, and the satellite measures cyanobacteria abundance and not toxins. Additionally, not all cyanobacteria produce toxins. Rather, managers may see the most value on a day to day basis by using this as a screening tool to complement any regular monitoring programs or help guide event-based monitoring.

With automated processing the morning after each satellite flyover, the tool can provide near-real-time updates on the development, growth, and movement of cyanobacteria blooms. This information can prove critical to understanding whether cyanobacteria blooms are developing, worsening, or shifting towards areas of beneficial uses and can be used to help direct any monitoring resources towards areas of importance. Knowing that there are limited dollars for nearly every monitoring program out there, being able to target monitoring to times and locations when cyanobacteria is detected can lead to much more efficient and effective monitoring programs, ultimately providing better protection for the public and likely fewer expensive non-detections.

Satellite data

With the satellite flying over roughly every other day, occasional clouds and wind events that disperse blooms into deeper water or along shorelines result in highly variable bloom patterns within individual images. This might show a bloom on Monday, no bloom on Wednesday due to clouds, and a bloom again on Friday. To produce more reliable imagery that can account for clouds or other issues, we incorporate all imagery within a ten-day period to produce a running ten-day max composite. Within each ten-day running max composite we capture the maximum value for each pixel from any imagery collected within the previous ten days, then repeat this method every day. This results in timelier data than a static ten-day composites that is only available every ten days and produces a smoother time-series which reveals bloom growth and movement in striking detail.

To ensure that the lake-wide statistics don't get skewed too greatly from a few errant pixels, we require 18 pixels with valid data within each composite to generate any values. For conveying information to public health officials, we often use the 90th percentile value for the lake, which will provide information on what is close to, but not the highest, concentrations within the lake. The mean or median values for the lake while important, may underestimate the risk in any one part of the lake.

One of the complications of using satellite data is that the metric used is one that isn't used by most scientists, the unit-less metric Cyanobacteria Index (CI). While some researchers have been able to establish relationships between CI data and two other more common environmental datasets, Chl-a (ug/L) and the common cyanobacteria *Microcystis sp.* (cells/mL), these conversions can introduce some error and are not used here. Additionally, with the range of CI values being very small numbers (0.00006 - 0.06), getting the data into values that are easier to digest resulted in us creating a Modified CI, where we multiply these CI values by 15,805.18 to produce a much easier to understand range of 1-1000 for our Modified CI. While not used elsewhere, we believe this approach will help translate these important data into a value that is quickly understood by scientists and citizens alike.

Limitations and next steps

While we see great promise from the satellite data, there are a few limitations that can limit its value. The satellites can't see through clouds or fog, limiting its value in some locations and seasons, but we have seen better than expected coverage through wildfire smoke. Also, lakes smaller than 250 acres do not have enough open water pixels to meet our statistical threshold, and narrow lakes often have too many pixels with land/water interface, resulting in invalid data. As technology develops, we hope that additional satellites with better spatial resolution and a similar ability to distinguish cyanobacteria will be able to see blooms in smaller lakes, ponds, and rivers and greatly increase the breadth of use for this type of satellite data.

At this time, the satellite data within the tool are considered provisional since there has yet to be an extensive comparison of the satellite data to field-collected data in California. While the accuracy of the satellite data has been confirmed in other parts of the U.S., the use of this imagery in California brings environmental conditions that haven't yet undergone these comparisons such as high elevation, high salinity, seasonal alkali lakes, and especially clear water. These conditions have challenged the satellite data but through much interaction with NOAA scientists, we believe most of these concerns have been addressed.

With the Satellite Analysis Tool now developed and functioning, we anticipate improvements to this tool in the coming years will make it even more useful. The addition of other environmental databases to query for comparisons to field data, linking to relevant reports and documents for specific lakes, improved access to export raw satellite data, and expanding the tool beyond California are all areas that are being considered. Additionally, the ability to merge this dataset with other satellite data could be helpful in determining relationships to other water quality parameters that might help identify drivers of blooms and how water quality is impacted.

Conclusions

For now, the Satellite Analysis Tool offers a variety of unique features that will complement any existing HAB program. This includes helping managers easily visualize over a decade of imagery, revealing precise details in spatial and temporal trends of cyanobacteria blooms, providing near real-time updates that automatically screen for early detections of blooms to help direct any monitoring activity toward the places and times where blooms are observed, and allowing for easy comparisons to field data entered in a public database. Any way you look at it, the Satellite Analysis Tool can transform your understanding of and ability to respond to cyanobacteria blooms so much that you'll never look at cyanobacteria blooms in the same way again.

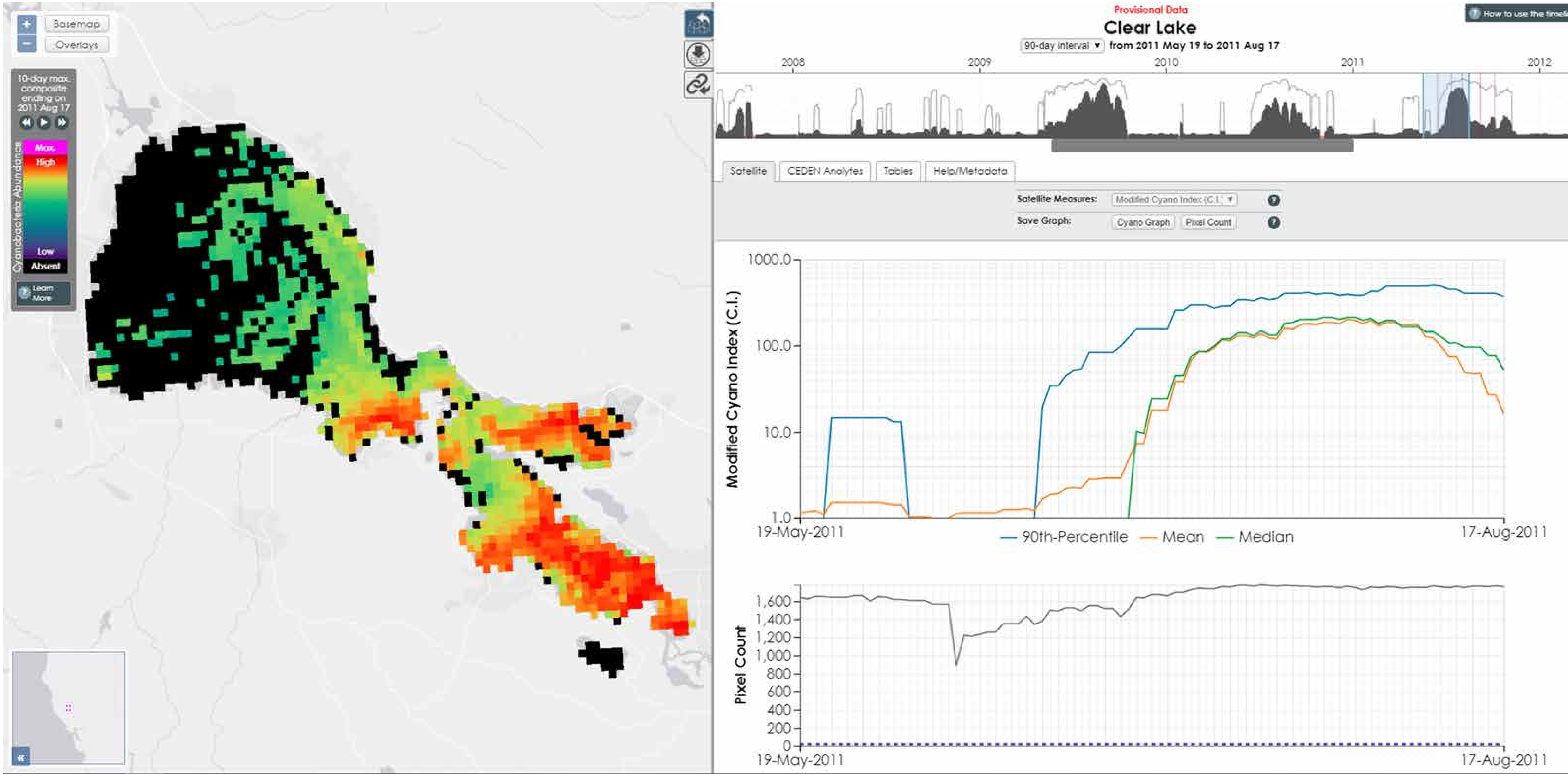

Figure 2. Satellite Analysis Tool display for Clear Lake, CA.

Acknowledgements

We graciously thank NOAA researchers Rick Stumpf, Andrew Meredith, and Shelly Tomlinson for all their amazing work on the satellite data that makes this tool possible. Additionally, we thank Ali Dunn, Marisa Van Dyke, Bev Anderson-Abs and all the staff at California State Water Resources Control Board that supported our project, as well as Lawrence Sim and Tony Hale from the San Francisco Estuary Institute for their tireless effort in developing the tool.

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Randy Turner (pictured at right) is an associate environmental scientist at the San Francisco Estuary Institute. Besides his work on CyanoHABs for SFEI, he works extensively in the Klamath River basin, helping coordinate efforts for a diverse stakeholder driven water quality monitoring and research program.

Pete Kauhanen (at right) is the GIS manager at the San Francisco Estuary Institute. He uses remote sensing and GIS to address issues ranging from the mapping of wetlands throughout California, detecting trash via drones, to planning for the most cost-effective placement of green infrastructure for municipalities.

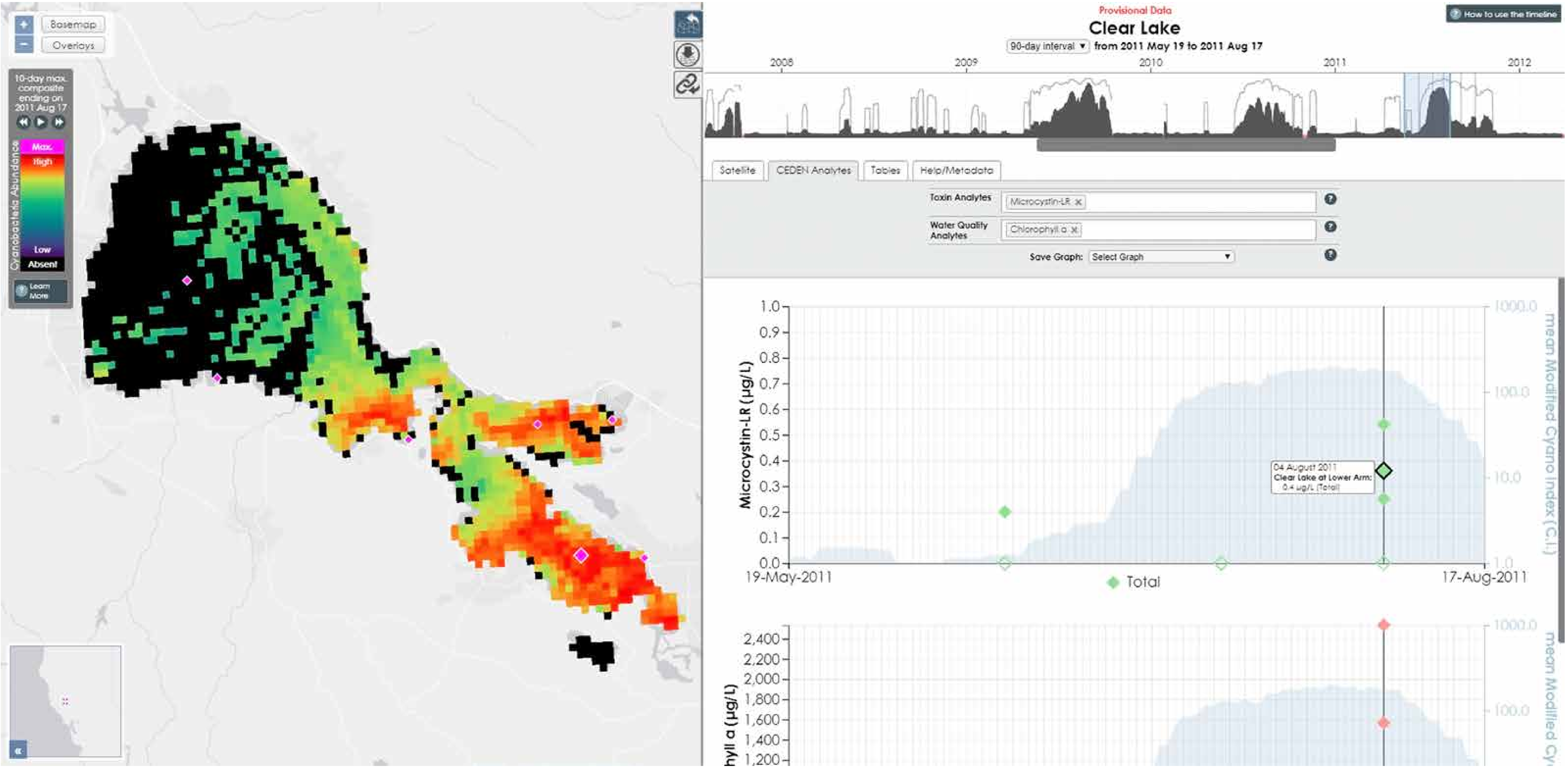

Figure 3. Comparing satellite and field collected data for Chlorophyll-a

FOCUS! YOU could be the winner of the 2019 NALMS Annual Photo Contest.

Two winning images will be selected, a Member's Choice winner selected by Symposium attendees and an Editors' Choice winner selected by the editor and production editor for the entry that will make the best LakeLine cover. We have secured sponsorship for the Photo Contest so a $250 gift card will be awarded to each winner.

Your favorite lake or reservoir photo could grace a cover of LakeLine!
Entries will be judged during the 2019 NALMS Symposium . . .
in Burlington, Vermont!

Only electronic submissions will be accepted.
You must be a NALMS member to submit an entry.

Photos should be of sufficient resolution to print from (approximately 300 dpi at 8.5" x 11").
Maximum of one submission per person.

Entries must be received by October 15, 2019.

Send your entry to:
Amy Smagula, Editor, LakeLine
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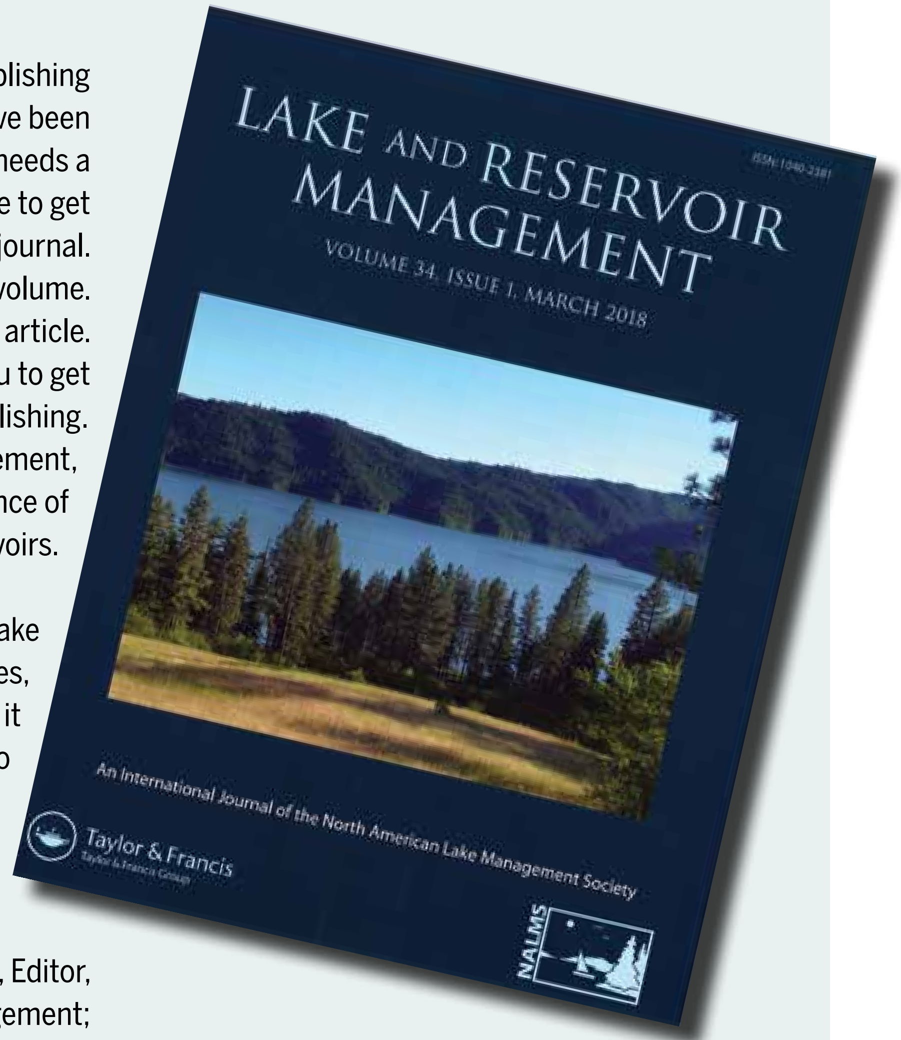
LAKE and RESERVOIR MANAGEMENT

A scientific publication of NALMS published up to four times per year solicits articles of a scientific nature, including case studies.



If you have been thinking about publishing the results of a recent study, or you have been hanging on to an old manuscript that just needs a little more polishing, now is the time to get those articles into your journal.
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Send those articles or, if you have any questions at all, contact: Ken Wagner, Editor, Lake and Reservoir Management; kjwagner@charter.net.

If there is anyone who would like to read articles for scientific content, please contact Ken Wagner. The journal can use your help in helping the editorial staff in editing articles.

North American Lake Management Society 2019 Call for Nominations

The North American Lake Management Society (NALMS) is seeking nominations for individuals interested in serving on the board, and for individuals, papers and projects that should be recognized at our Annual Symposium in November 2019.

CALL FOR NOMINATIONS FOR BOARD POSITIONS

This year NALMS will be looking to fill vacancies in the following positions:

- President-elect
- Treasurer
- A Regional Director for:
  - Region 1: Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, Vermont
  - Region 3: District of Columbia, Delaware, Maryland, Pennsylvania, Virginia, West Virginia
  - Region 5: Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin
  - Region 9: Arizona, California, Hawaii, Nevada
- Student Director
- At-large Director

The North American Lake Management Society (NALMS) is seeking nominations for individuals interested in serving on the board, and for individuals, papers and projects that should be recognized at our Annual Symposium in November 2019.

CALL FOR NOMINATIONS FOR AWARDS

Each year NALMS recognizes individuals, organizations, and programs, corporations and projects that have contributed to the Society and to the science of lake and watershed management. Below awards were established to encourage advancement of NALMS' goals and recognize outstanding efforts of our colleagues. Awards be presented this year at the Society's 39th Annual Meeting in Burlington, Vermont.

Please see the NALMS website for detailed information regarding each award along with the location to submit award nominations. Please note nominations are to not exceed 500 words in length.

Nominations can be submitted online at https://www.nalms.org/nalms-achievement-awards/nomination-process/

Deadline for nominations is August 15, 2019 by 11:59 PM EST. Contact the NALMS Award Liaison, Dana Stephens with any questions at stephed@nwfsc.edu or 850-729-6469.

Summary of award categories are as follows:

- **Secchi Disk Award** – for the individual member considered to have contributed the most to the achievement of NALMS' goals. Recipient must be a NALMS member.
- **Jim Flynn Award** – for the organizational member considered to have contributed the most to NALMS's goal. Recipient must be a NALMS Corporate member.
- **Friends of NALMS Award** – awarded to individuals or corporations making major contributions to NALMS. Recipients do not have to be NALMS members, and "contributions" extend beyond monetary donations.
- **Lake Management Success Stories** – Individuals or organizations who have accomplished successful lake or watershed management efforts. Nominees must show demonstrable improvements in lake condition as a result of their efforts. Up to three projects may receive awards each year.
- **Advancements in Lake Management Technologies** – Individuals or organizations, who have refined, developed or discovered new, innovative or improved methods, technologies or processes for achieving lake or watershed management outcomes in manners that are safer, cheaper or more effective. Objective documentation should accompany the nomination. Up to three projects may receive awards each year.

Establishing Flow-Ecology Relationships

by Harmonizing Heterogeneous Data

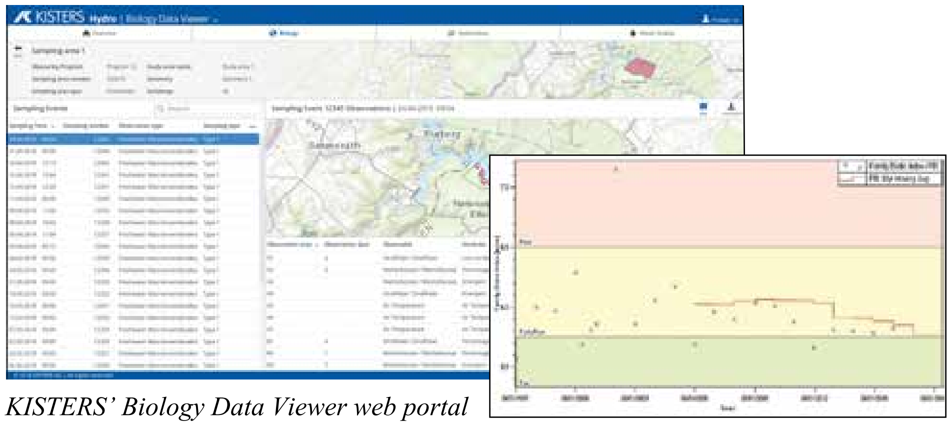
Elena L. Blair

Ecological surveys are an important tool for assessing the condition of aquatic and terrestrial resources. However, many and varied challenges exist when it comes to storing, managing and reporting on this type of data. The inherent complexity and heterogeneity of the information has made it difficult for a single database to effectively consolidate datasets.

Ideally, a flow-ecology data system should be sufficiently flexible to allow for data structuring that caters to different sampling methodologies. Employing many methodologies helps obtain unbiased and representative data to achieve realistic estimates at a given location. Sampling methods may include transects / quadrats, nested plots, stratified random samples, catchment/reaches, and stations/subplots/ seedling plots / tiers. The same system must also have the ability to spatially represent these features as either points, lines, or polygons.

Biological survey data, or data related to identified organisms, can be as diverse as the taxa themselves. For example, the observed properties of a group of fish surveyed in a river reach could relate to length, weight, age, or scale packets. You may store these properties related to an individual fish or the overall group. In contrast, the observed properties of benthic macroinvertebrates (BMI) are remarkably different. A simple count of each identified species requires a distinct number of dead from living and a notation of an actual count or an estimate. Counts may be further translated into abundance codes specific to a county, region or even catchment.

Recognizing ecological interactions that exist between organisms and the physical environment is critical. Macroinvertebrates play a central role in stream ecosystems as they feed on periphyton, macrophytes, detritus or each other before they become a food source for fish and birds. Biological surveys often gather data about weather, habitat (e.g. dominant or substrate) or related environmental features and conditions such as sedimentation/erosion, adjacent land use, or damage caused by wildlife), which may be helpful knowledge to others within the same organization.



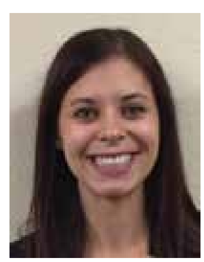
KISTERS' Biology Data Viewer web portal equips KiECO users with tools to analyze, visualize, report and share information from ecological surveys. Graph results from discrete biological sampling events as time series; select options to customize colors, symbols and more to quickly reveal conditions.

Building on many existing features in KISTERS' hydrologic information system, a specialized application was developed to resolve fundamental ecological data storage issues described above. Using the flexibility and functionality of meta data and GIS tools KISTERS' ecological software (KiECO) provides an efficient and solid framework to readily store an array of bioassessment data.

Location data are recorded using the open standard Well Known Text (WKT) format and a four-tier sampling hierarchy accommodates different types of surveys. Users are able to customize meta data fields to document survey techniques such as electric fishing, and specify the equipment used. Additional notes about the sample analysis applied can also be easily captured. The processing method or agency can be recorded, and later audited if necessary.

Customized data entry forms for mobile devices can emulate familiar paper forms. Not only does this reduce the risk of transposing errors, but it can save staff time for other tasks.

Taxa related biological data can be stored via intricate links in the system, so any combination of data that is specific to a given type of data can be documented. For example, the absence or presence of invasive species like *Dreissena polymorpha* (zebra mussel) near Vivans Cove after surveying Existing Surfaces during warmer months and depending on environmental conditions of the Modesto Reservoir.



Elena L. Blair is a water quality and ecology specialist with KISTERS North America. She has worked on a variety of aquatic & habitat surveys related to endangered and special status species as well as water chemistry for the City of San Francisco (Calif.). She earned a Master's in Ecology & Sustainability from Stanislaus State University and a Bachelor's in Environmental Studies from Sonoma State University.