IAGLR

FALL 2026 • ISSUE 31

LAKES Letter



Eutrophication

What we know.
What has changed.

Rethinking old assumptions

Blooms in unexpected places

Adaptive management in a changing world

CONTENTS

FEATURES

12 We thought we solved eutrophication. Then the lakes changed

BY SCOTT HIGGINS

15 From cryptic wetlands to toxic blooms

BY IRENA CREED

18 The HABs era on Lake Superior

BY MATT HUDSON

21 Unmasking the iron shield

BY ALEX NEUMANN, TAO XU, MARIA DITTRICH, YASASI FERNANDO, JOHN GIBSON, RAMIN FARNOOD, DAVID DEPEW, AND GEORGE B. ARHONDITSIS

24 Intercepting the flow

BY ADAM YATES AND ROBERT BRUA

27 Are the wetlands working?

BY KENNETH ANDERSON, MARY ELLEN KLUKOW, AND OLIVIA SCHLOEGEL

30 As Lake Victoria turns green, community knowledge meets the science of HABs

BY DORINE WERE



Cyanobacterial toxin-producing blooms and public health. A toxic algae advisory at a Saskatchewan recreational lake highlights the potential health risks associated with cyanobacterial blooms. Even when warnings are posted, people may overlook, misunderstand, or disregard them, leaving opportunities for exposure. Recent work from Irena Creed's research group shows that cyanobacterial biomass and toxin concentrations do not necessarily follow the same patterns, underscoring the importance of effective monitoring, timely advisories, and clear public communication.



ON THE COVER

Algal bloom in Lake Winnipeg, Manitoba, Canada, on September 25, 2023. Instrument: Landsat 9 — OLI-2. Credit: NASA Earth Observatory.

EDITORIAL

4 Knowledge alone isn't enough to solve problems

BY NOEL URBAN

ASSOCIATION NEWS

5 Call for Abstracts • Awards: Call for nominations • Seeking Indigenous Engagement Coordinator • Brief on Canada's National Water Security Strategy • Sponsor & exhibit at IAGLR 2027 • Support to attend IAGLR 2027

40 2027 Membership Drive

MEMBER NEWS

7 Kudos • New members • Your member checklist

8 Member Spotlight: Haley Dalian

9 Member Spotlight: Emily Shaw





MENTORING Q&A

12 Looking beyond the lake

A CONVERSATION WITH HANS PAERL, INTERVIEWED AND WRITTEN BY ALLYZA TABIRARA

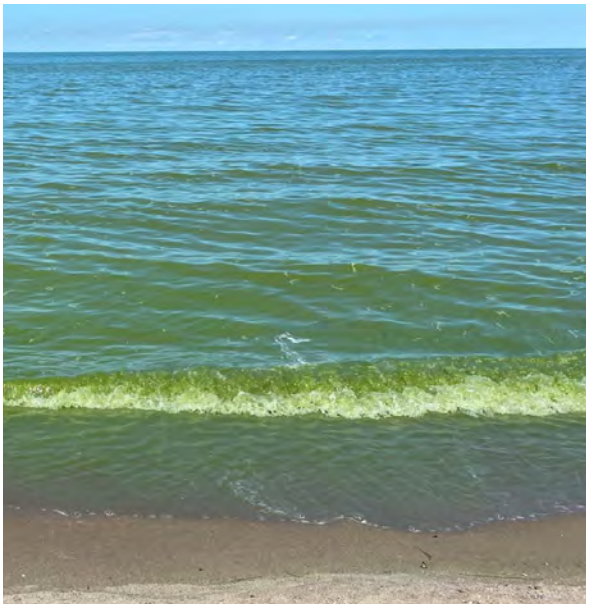
RESEARCH BRIEFS

33 Beyond delisting: Understanding ecosystem recovery in Severn Sound

BY ALANA TYNER, AISHA CHIANDET, OLENA VOLIK, AND ANDREA KIRKWOOD

35 From eutrophication modeling to real time: Forecasting water quality risks

BY MARK ROWE



Microcystis bloom, Crane Creek State Beach (Ohio), Lake Erie, 30 July 2022. Photo: George Bullerjahn.

PERSPECTIVES

37 An inconvenient bloom

BY STEVEN W. WILHELM, R. MICHAEL MCKAY, AND GEORGE S. BULLERJAHN

38 Building a better infrastructure for science communication

BY JOHN C. BESLEY

LAKES *Letter*
Fall 2026 • No. 31

PUBLICATION

Editor
Paula McIntyre

Editorial Associates
Alex Duncan
Jessica Ives

CONTRIBUTORS TO THIS ISSUE

Kenneth Anderson
George B. Arhonditsis
John C. Besley
Robert Brua
George S. Bullerjahn
Aisha Chiandet
Irena Creed
Haley Dalian
David Depew
Maria Dittrich
Ramin Farnood
Yasasi Fernando
John Gibson
Scott Higgins
Matt Hudson
Andrea Kirkwood
Mary Ellen Klukow
R. Michael McKay
Alex Neumann
Mark Rowe
Olivia Schloegel
Emily Shaw
Allyza Tabirara
Alana Tyner
Noel Urban
Olena Volik
Dorine Were
Steven W. Wilhelm
Tao Xu
Adam Yates

THE ASSOCIATION

Executive Director
Jérôme Marty

Board of Directors
Noel Urban, President; Suzanne Gray, Vice President; Donna Kashian, Past President; Mike McKay, Treasurer; Alex Maguffee, Secretary; Navjot Dhaliwal; Sulla Manduwa; Leigh McGaughey; Julia Obuya; Sabina Rakhimbekova; Ronald Semyalo; Cody Sheik; Heather Stirratt; Pengfei Xue; Jérôme Marty (ex officio)

IAGLR

Lakes Letter is published quarterly by the International Association for Great Lakes Research, 4840 South State Road, Ann Arbor, MI 48108 USA; iaglr.org.

Contact: lakesletter@iaglr.org

© 2026 International Association for Great Lakes Research. All rights reserved. No part of this publication may be reproduced without written permission.

EDITORIAL

Knowledge alone isn't enough to solve problems

By Noel Urban, IAGLR President



History provides us with many examples of knotty problems that required tortuous paths toward resolution (e.g., world wars, London's deadly fog, Bubonic plague). In my youth, lake eutrophication seemed to be one of those issues, and that realization influenced my career trajectory. But then scientists at the Experimental Lakes Area (ELA) conducted whole-lake experiments grounded in Liebig's law of the minimum—the principle that growth is controlled by the scarcest necessary resource—and showed conclusively that phosphorus, not carbon or nitrogen, was the nutrient limiting algal growth in freshwater lakes. By "simply" reducing inputs of that limiting nutrient, we could curtail excess biological production and solve that problem. We applied that finding to the Great Lakes in the 1980s and 1990s, and the windrows of algae and dead fish that fouled the shores of Lake Ontario where I lived disappeared.

That seminal finding at ELA occurred half a century ago, and yet we find ourselves in the predicament that the foul-smelling windrows have returned to the shores of lakes Michigan, Erie, and Ontario. Details about this resurgence of eutrophication in the Great Lakes are addressed in other articles in this issue. I want to emphasize here that this is not just a local phenomenon. The planetary boundaries for phosphorus (and nitrogen) releases to the environment have been crossed such that large areas of the globe are experiencing environmental degradation; eutrophication and hypoxia in lakes are manifestations of that degradation. It is not overly surprising that the Great Lakes basin, with a multi-trillion-dollar economy and 10% of the combined populations of Canada and the U.S. living on less than 3% of their combined land area, is experiencing environmental degradation resulting in part from excessive releases of phosphorus to the environment. Should we find solutions to this knotty problem in the Great Lakes, they would likely find application around the world.

We have learned a lot in the 50 years since the ELA experiment. We have learned how to control sewage phosphorus discharges to be within targets, but we have not learned how to recycle phosphorus back to the farms and thereby to reduce global and regional flows of phosphorus. This step may be required for sustainability, which we may not achieve without larger structural changes in our economy and society. We have learned some of the fascinating ways in which the multiple stressors acting on the Great Lakes (excess nutrient inputs, climate change, invasive species, etc.) interact and exacerbate (e.g., harmful algal blooms induced both by excess nutrients and warmer water temperatures) or offset (e.g., oligotrophication of the upper Great Lakes caused by invasive dreissenid mussels) the effects of each other. Some of these stressors cannot be controlled at the watershed scale or at any of the scales of our political institutions.

EDITORIAL CONTINUED

Our growing knowledge shows that we are good at incremental science, but we may not be quite so good when it comes to implementing that knowledge into policy. What is the role of IAGLR in this arena of bridging science to policy to effective actions? Our mission is to advance understanding of the world's great lake ecosystems. With our conferences and publications, IAGLR fosters and highlights the good science of our members and seeks to identify important areas for future research. By advocating for science and policies based on that science, we attempt to promote stewardship of large lake ecosystems. If our incremental science is embedded in a framework of adaptive management (e.g., the Great Lakes Water Quality Agreement), then perhaps we can solve problems that are confined within the basins of the great lakes. However, many of the issues highlighted above (global carbon emissions, global biotic homogenization, agricultural policies, etc.) are not confined to lake basins. To solve those larger problems, we must advocate to decision makers within governments at all levels, domestic and global, for support of science and for policies promoting stewardship of the global ecosystem in which even great lakes are but small components. For this reason, it is important that the members, the board, and the staff of IAGLR not only continue to work together across borders but also continue to speak up for our shared values of good science, effective science-based policies, and goodwill for all neighbors.



IAGLR AWARDS
Recognize Excellence. Nominate a Colleague

Nominees of all identities, perspectives, and experiences are encouraged.

Journal Awards

Nominate a notable paper from the Journal of Great Lakes Research, volume 52 (2026) for one of three awards recognizing lead authors at different career stages.

Due January 15

Professional Awards

IAGLR members may nominate for three awards: the Lifetime Achievement Award, the Large Lake Champion Award, and the John R. (Jack) Vallentyne Award.

Due February 1

iaglr.org/awards-scholarships

IAGLR, GLFC seek Indigenous Engagement Coordinator

IAGLR and the Great Lakes Fishery Commission are hiring a part-time Indigenous Engagement Coordinator, employed by IAGLR. The contractor will help strengthen relationships among Indigenous Nations, researchers, and fisheries and environmental organizations. Their work will include coordinating Indigenous-led sessions and networking at the IAGLR conference, elevating Indigenous knowledge systems, and fostering culturally respectful spaces for participation in scientific and professional settings. One-year contract renewable for up to three years. View the job description and please share with your networks.

Applications are due December 20, 2026.

IAGLR submits brief on Canada's National Water Security Strategy

IAGLR has submitted a brief to the Canada Water Agency with recommended priorities for the forthcoming National Water Security Strategy. Our recommendations call for a clear, operational definition of water security with ecosystem health as foundational and First Nations water security embedded throughout, alongside dedicated attention to shared and transboundary waters—including the Great Lakes–St. Lawrence system—given risks from emerging U.S. policies and climate-driven hydrological change.

Sponsors & exhibitors, plan now for IAGLR 2027

Gain visibility with the largest gathering of Great Lakes researchers and practitioners. Explore sponsorship packages and exhibitor opportunities at IAGLR's 70th Annual Conference on Great Lakes Research, scheduled for May 24–28, 2027, in Duluth, Minnesota.



Download the 2027 Prospectus

Support to attend IAGLR 2027

Did you know IAGLR offers support to attend the annual conference? Learn more about the opportunities below. We hope to see you next May in Duluth!

- **Student Travel Awards** provide funds to IAGLR student members to help with travel costs. Conference registration will open in early March, and applicants are accepted through early bird registration. First come, first served as funds allow. Make sure to sign up for your 2027 membership to qualify!
- **Honoraria and abstract fee waiver for Indigenous participants.** IAGLR may provide honoraria to Indigenous individuals who contribute their time, knowledge, experience, or guidance to a conference session in a voluntary capacity and who are not otherwise compensated or financially supported for that contribution.
- **Our registration-waiver program** supports Indigenous and Black scholars and others who historically may not have participated in the conference.
- **IAGLR members enjoy discounted registration rates.** To take advantage of best rates, join IAGLR or renew your membership before you register.
- **Register early for the best rates!** Everyone can take advantage of discounted early rates when registration opens next year.

Member kudos

Every quarter brings new reasons to celebrate the people who make up IAGLR. Join us in congratulating these members on their achievements.

Christine Atuhaire successfully defending her Ph.D. thesis titled "From Field Spectroscopy to Top of Atmosphere Reflectance: Advancing Remote Sensing of Plastics in Freshwater Environments" at Makerere University in Uganda. Her work was partly supported by the IDEA+ Research Scholarship in 2023.

Catherine Febria, associate professor and Tier 2 Canada Research Chair in Freshwater Restoration Ecology at the University of Windsor, has been elected to the Royal Society of Canada's College of New Scholars, Artists and Scientists. This is in recognition of her high level of achievement in freshwater biodiversity, ecosystem restoration, and the relationships between healthy watersheds and healthy communities.

Alice Auma Hamisi earned the Project Management Professional certification from the Project Management Institute in October. She is a fisheries and aquaculture professional with diverse experience in aquatic resource management and sustainable development, research, community engagement, and program and project coordination. This milestone strengthens her capacity to lead collaborative projects supporting sustainable aquatic food systems and African Great Lakes conservation.

Dani Jones and **Lindsay Fitzpatrick**, University of Michigan, who were part of a team that received the 2026 NOAA Oceanic and Atmospheric Research Team Members of the Year Award. The team was recognized for its leadership and technical contributions to developing the next-generation Great Lakes water supply forecast, known as the Net Basin Supply (NBS)-Predictor.

Nick Mandrak was named an American Fisheries Society Fellow. Mandrak is a professor in biological sciences at the University of Toronto Scarborough.

Don Felix Ouma graduated in October with a master's degree in natural resource ecology, management and conservation from Mbarara University of Science and Technology, Uganda

Augustus Pendleton defended his doctoral dissertation at Cornell University, presenting his work on the microbial communities of Lake Ontario, Lake Erie, and the St. Louis River Estuary. He will be starting a new role as a data scientist at Ferring Pharmaceuticals in Minneapolis, Minnesota.

Submit a kudo

IAGLR members, do you have a recent achievement, award, or milestone you'd like to celebrate? Let us know! Submit a kudo to lakesletter@iaglr.org, and we'll share your accomplishment with the IAGLR community. Your success inspires us all.

Welcome to IAGLR

Please join us in welcoming the following members who joined IAGLR between August and October 2025.

Rachel Bratton
Saad Jasim
Steven Quijas
Riley Renfro
Cera Shelafoe
Yuhao Wu

We're glad to have you as part of the IAGLR community!

Your member checklist

- ✓ **Renew your membership** for 2027 so you don't miss a thing.
- ✓ **Update your contact info** (address, email, and affiliation) in the member portal.
- ✓ **Cast your vote** in the board election by December 4. Check your email for the ballot.
- ✓ **Submit an abstract for IAGLR 2027**—review the Call for Abstracts by December 18.
- ✓ **Recognize excellence** by nominating a standout paper in the Journal of Great Lakes Research (due Jan. 15) or a colleague (due Feb. 1) for an IAGLR award.
- ✓ **Read the Editor's Choice article** in the October journal. Avneet Kaur and Gail Krantzberg examine climate migration through a rarely studied lens: the communities that may receive newcomers.
- ✓ Pour a cup of coffee and **enjoy this issue of Lakes Letter!**

MEMBER SPOTLIGHT

Haley Dalian

Great Lakes Regional Coordinator
National Oceanic and Atmospheric Administration
Marine Debris Program (Federal contractor)



What first drew you to Great Lakes work?

I'm a lifelong Michigander. Living in the state that borders four of the five Great Lakes, my appreciation for their wonder and vital services has only grown over time. I also grew up on a small inland lake where I was fortunate to regularly interact with painted turtles, mudpuppies, and great blue herons, which are among my favorite native species. In 2018, I took up scuba diving with my dad, Terry, and have since explored historic shipwrecks in lakes Michigan, Superior, and Huron, as well as Georgian Bay. Through these experiences, I've come to love burbot and despise round gobies. My personal connection to freshwater has always felt intrinsic and necessary to align with my professional career.

What have you learned from working across research, government, communities, and the public?

There are many issues plaguing the Great Lakes and many actors with the tools to address them. I've learned the best outcomes emerge from a systems-level approach to problem solving. This underscores how vital it is to work across sectors and use strategic levers for systemwide change. Pairing NGO resources and community enthusiasm with government coordination and scientific findings is a powerful combination.

Was there a point when you realized that making the impact you wanted would require skills beyond scientific training?

On a daily basis, I interact with many different stakeholders. Some days, it's leading a research session with the premier experts on microplastics in freshwater. Other times, I'm presenting about the Great Pacific Garbage Patch to a fourth-grade class in Minnesota. Regardless of the audience's age or prior knowledge, all of these interactions highlight the importance of communication and knowing your audience. If someone cannot make meaning of your message and find relevance in their everyday life, you have fallen short of the potential impact of your communication and missed a key opportunity to establish long-term trust. I strongly believe technical translation, facilitation, and relationship-building skills are as valuable as scientific training. One should not exist without the others.

What do you wish more scientists understood about working to protect the Great Lakes?

Our region is truly one of a kind. Though we may work in different states and provinces on seemingly disparate issues—harmful algal blooms, plastic pollution, chemical contamination, shoreline erosion, invasive species—we are working toward the same collective goal: ensuring the health and prosperity of the Great Lakes region and its people. Therefore, it's important to collaborate across disciplines and networks to find efficiencies in accomplishing our work. The interconnectedness of emerging and legacy contaminants (e.g., PFAS, lead) and microplastics is a prime example of why. People perceive these threats in similar ways: mostly invisible to the human eye, pervasive in our drinking water, and challenging to address. There's immense value in embracing more communities of practice for shared learnings and effective action across issue areas.

Emily Shaw

Great Lakes Resources Specialist
Keweenaw Bay Indian Community



What connects the different parts of your career?

Relationships to both people and place are the common thread woven through my career. Childhood summers on Lake Michigan grew into a decade-long career on three different Great Lakes. Onboard a schooner, I welcomed students of all ages to learn Great Lakes ecology through hands-on experiences. Working alongside passionate volunteers, I came to understand the roles people and the environment play in how we experience and remember a place. My graduate research with the Keweenaw Bay Indian Community (KBIC) and then my Knauss fellowship on Capitol Hill reiterated the centrality of relationships. In both roles, I arrived someplace new, literally and figuratively, and needed to acclimate and cultivate relationships with the people and place. But my primary responsibility was to work with others to address their priorities and concerns, which meant learning their relationships to the same places. With KBIC, that meant extensive reading and reflection to understand their culture, historical context, and desirable futures.

What do you wish more researchers understood about building relationships with communities?

I envision a future where building and maintaining community partnerships in research is approached with the same integrity and discipline as other methodological elements of our work—model validation, lab-based QA/QC, and data interpretation. To get there, researchers must understand that reading lists filled with technical and non-technical Indigenous and community perspectives are necessary for context, but we cannot literature review our way to partnership. We must spend time learning from those communities: attend events and become a familiar face, listen to people's stories, and build authentic relationships. Be transparent about your desire to collaborate, and remain open to ideas and priorities that influence the direction of your work. All of this needs to happen before finalizing an idea and submitting a grant. Meaningful collaboration generates research that meets both academic and community priorities. Influenced by the work of Kyle Whyte, Maggie Walter, and many others, I believe that any "research" conducted without community consent—or "research" that centers 5D data (deficit, difference, disparity, disadvantage, and disfunction)—isn't enough. Rather, researchers should be grounded in community needs, values, and priorities and support people in shaping futures they envision for themselves and all their relatives.

How has working in research, federal policy, and tribal natural resources management shaped your view of the role of science in decision making?

My views are shaded with some pessimism, but I also am hopeful we can overcome the undermining of expertise and return to a shared understanding of science as a process rather than a set of beliefs. We all—scientists, decision makers, community members—have responsibilities for reestablishing those shared understandings. Scientists must practice communicating the bigger picture of their work and why it is important. Community members must practice critical thinking and learn to assess the reliability of information. Decision makers must create systems that give people the tools they need to fulfill their responsibilities and that turn shared knowledge into action. Perhaps most importantly, the power of money in politics must be eliminated. So long as private interests can buy out the public interest, community concerns and priorities can easily be ignored. As we work toward a society that values expertise and holds high expectations of our representatives, I hope we can expand our definitions of science, apply equal weight to Indigenous and dominant science, and bring those place-based knowledges into resource management decisions, too.

Looking beyond the lake

A conversation with Hans Paerl, interviewed and written by Allyza Tabirara

Mentoring Q&A pairs a student or early career researcher with an established scientist for a conversation about career, science, and lessons learned along the way.





Hans Paerl's career began in a broccoli field at University of California, Davis, and eventually took him across the world, from New Zealand and China to Canada and the United States. Now a longtime and recently retired Kenan Professor at the University of North Carolina at Chapel Hill's Institute of Marine Sciences, he has spent decades studying eutrophication, harmful algal blooms, and the effects of nutrient loading across freshwater and marine systems, including the Great Lakes. His work has helped shape how researchers understand the relationship between nitrogen and phosphorus loading and cycling, and why managing one nutrient alone is not always enough to control algal blooms. Along the way, he has also carried that science beyond the lab, testifying before policy committees and serving on advisory boards.

For this installment, he sat down with Allyza Tabirara, a graduate student at the University of Winnipeg whose undergraduate research focused on internal loading and sediment phosphorus in the FortWhyte Alive lakes, and whose graduate research examines whether drainage ditch cleanouts can help reduce phosphorus loading into Lake Winnipeg. They talked about how thinking around nitrogen and phosphorus has changed, what managers should consider when planning for a changing climate, and what early career researchers should keep in mind. And one theme kept surfacing: phosphorus still matters, but it's not the whole story.

ALLYZA: What first drew you to this work, and what keeps you curious about it today?

HANS: As an undergrad, I needed a work-study job at UC Davis and ended up cutting broccoli in pesticide-infested fields. I disliked it, and a friend told me Professor Charles Goldman's students were studying California lakes. Charles took me under his wing and transferred my job to his laboratory. At "not so clear" Clear Lake, I conducted microscopic observations and noticed bacteria gathering around the heterocysts of the bloom-forming cyanobacterium *Aphanizomenon*, where nitrogen fixation occurs. That was the first question I really asked myself—why is this happening and does it enhance the growth of this bloom-former? Since then, I've been looking at microbially mediated nutrient cycling impacts across what I call the freshwater-marine continuum, which has taken me to a lot of places.

ALLYZA: Have your own data ever forced you to rethink a long-held assumption?

HANS: Yes, that controlling phosphorus alone is enough. Phosphorus reductions have been successful—including detergent bans and improved wastewater phosphorus treatment—and the notion became deeply ingrained in research and teaching. But over time, we've continued loading up lakes with phosphorus, which has no gaseous forms to escape. As a result, it ain't going anywhere. Because nitrogen can escape as gaseous forms, it has become the nutrient playing an increasingly important role in limiting primary production and often also controlling species composition.

Phosphorus has long been recognized as a major driver of freshwater eutrophication, but its role cannot always be considered in isolation. Where phosphorus inputs have accumulated over decades, sediments can continue releasing it into the water, even after external loading have been reduced. At the same time, nitrogen availability can influence how much additional algal growth occurs and which species dominate. A system may be phosphorus-limited in spring but become limited by both nutrients or shift toward nitrogen limitation during the summer and fall, like what is seen in numerous lakes, including those experiencing advanced eutrophication. The balance also depends on nutrient inputs, internal loading, and the composition of the algal community. This makes it difficult to assume that reducing one nutrient will consistently produce the same response across an entire watershed and downstream

lakes. The bottom line is we've got to deal with both nutrients.

ALLYZA: How do you navigate debates with colleagues who favor phosphorus-only control?

HANS: There have been some long-standing arguments over whether phosphorus control alone is sufficient. The assumption was that nitrogen-fixing cyanobacteria would supply the nitrogen needed to support growth of the lake algal community, but, in fact, they can't convert enough atmospheric nitrogen into a usable form to satisfy demand. In Lake Erie, phosphorus limits growth in spring, followed by co-limitation and nitrogen limitation in summer. I'm not downgrading phosphorus. I'm just saying that you've got to look beyond phosphorus.

ALLYZA: Looking across the different systems you've studied, what surprises have most challenged established ideas?

HANS: In North Carolina, phosphorus reductions reduced blooms in the upper freshwater reaches, but blooms increased downstream in nitrogen-limited estuaries. We had moved the problem rather than solved it. Lake Taihu, China, and Lake Erie also show how legacy phosphorus loading continues to affect water quality.

These examples highlight the importance of considering nutrient management across connected aquatic systems. Reducing phosphorus in one location does not necessarily eliminate the effects of nutrient loading downstream, particularly where nitrogen becomes more important in controlling algal growth. Management strategies need to account for how nutrients move through watersheds and how their effects change along the way.



Hans Paerl, at left, with students, technicians and collaborators conducting a mesocosm nutrient enrichment study at The Ohio State University's Stone Laboratory at Lake Erie in 2025.

ALLYZA: What role should researchers play in shaping policy, and what determines whether research actually influences it?

HANS: Scientists have a huge role to play, particularly now with fake news and money-driven interests. Scientists should remain scientists and stick to what they know and what the facts show them. In North Carolina, a group of researchers combined modeling, bioassays, and nutrient budgets to recommend a 40% reduction in nitrogen, which became a state target. This happened through scientists testifying, publishing, getting interviewed by the press. The net reduction has fallen short of 40% because rising organic nitrogen inputs have partly offset the decrease in inorganic nitrogen, but water quality has improved.

ALLYZA: What would you tell a manager writing a 20-year plan for a lake today?

HANS: Plan for more extreme rainfall and drought events and start treating the runoff on land, not exclusively in the receiving water body, for example, by using wetlands to remove nutrients. Many wetlands will have to be created, which requires funding for developing and maintaining them. We can't control the weather, so we have to control nutrient loading from watersheds, and those efforts will need to become more intensive over time.

ALLYZA: What should early career researchers keep in mind, and what would you focus on if you were starting over today?

HANS: Think of things in a more interdisciplinary and interconnected way. And connect research to a changing climate and growing populations. In northern lakes, earlier ice-out and later freeze-up give blooms more time to develop. Human health also needs to be considered, including cyanotoxins and drinking water. Groundwater contamination might be another interesting area. You have to look way beyond the lake itself.



Cladophora growing on rocks three meters below the surface in Lake Ontario. Photo: Megan Lewan, USGS.

We thought we solved eutrophication. Then the lakes changed

By Scott Higgins

On summer days along the lower Great Lakes, the shoreline itself turns green. Mats of *Cladophora*, a filamentous alga anchored to the lake bottom, dislodge in storms and pile onto beaches in staggering quantities. As the mats decay, they become habitat for bacteria including *E. coli*, *Shigella*, and *Campylobacter*. They foul drinking-water intakes and the cooling systems of power plants, clog fishing nets, depress property values, and keep swimmers out of the water.

In the 1960s and 1970s, eutrophication, or the over-enrichment of lakes by nutrients that fuel runaway algal growth, was considered the world's leading water quality problem. Fifty years later, it still is. Yet the fuller history is more encouraging than the green shorelines suggest. Scientists and policymakers really did learn what causes algal blooms, proved it rigorously enough to change policy worldwide, and watched lakes recover when that knowledge was applied. What has changed since is not our understanding of the fundamentals. It's the lakes themselves and the watersheds around them.

Uncertainty stalls action

In the 1950s and 1960s, phytoplankton and *Cladophora* blooms choked the lower Laurentian Great Lakes. The Cuyahoga River caught on fire from industrial pollution. Rachel Carson's *Silent Spring* had helped spark an environmental awakening, and the public demanded action. But the science was equivocal on the central question for limiting eutrophication: which nutrient to control.

Many leading limnologists argued that phosphorus was the culprit. Others made a credible case for carbon or nitrogen, and the detergent industry, a major phosphorus source at the time, seized on that ambiguity: the science was equivocal, it argued, and the costs of action too high. Policy stalled. Algal blooms continued.

Researchers think big

The central problem facing both researchers and policymakers was whether costly phosphorus abatement programs would reduce algal blooms under real-world conditions. Small and short-term experiments conducted in the laboratory or within mesocosms provided contradictory results. Further, scaling these results to natural ecosystems with all their inherent complexities and feedbacks required numerous assumptions. Would these assumptions hold?

The log jam broke because of an innovative idea and strong collaborative ties between American and Canadian researchers. The idea came from Art Hasler, an American researcher at the University of Wisconsin's Center for Limnology, who was amongst the first to undertake

controlled whole-lake experiments to address applied ecological problems. Wally Johnson, a Canadian, had been a graduate student of Hasler, and was taken with his novel approach—controlled studies undertaken at scales of space, time, and ecosystem complexity where environmental problems actually live. Johnson, now back in Canada, convinced policymakers that researchers would need to think big. Johnson conceived of Canada's Experimental Lakes Area (ELA), and with Jack Vallentyne implementing the vision, the project began recruiting an international team of scientists.

The first whole-ecosystem experiment at the new ELA began in 1968 in Lake 227, and it was designed to test the carbon hypothesis. We may scoff at this now, but the argument was not foolish at the time. Phytoplankton need roughly 40 times more carbon than phosphorus to grow, and the movement of carbon from the atmosphere into lake water can be slow. If carbon trickled in too slowly to keep pace, perhaps carbon, not phosphorus, was the limiting nutrient.

To test this, the researchers chose a low-alkalinity lake, meaning one with a naturally small reserve of dissolved carbon. This was the worst-case scenario: if carbon were to limit algal blooms anywhere, it should be there. Then they added nitrogen and phosphorus in excess of growth demands, but not carbon. If the carbon-supply hypothesis was right, the bloom should stall.

Decision makers didn't need a fancy graph to see the answer. A massive bloom formed. Even in a low-alkalinity lake, carbon limitation had not prevented it. So the question was settled: carbon was not the limiting nutrient.

The decisive test came in Lake 226, an hourglass-shaped lake split down the middle by a plastic curtain to hydrologically separate the two basins. Carbon, nitrogen, and phosphorus went into one basin; carbon and nitrogen only into the other. The side with phosphorus bloomed. The other stayed clear. The photograph that resulted has anchored limnology textbooks ever since because it ended the debate; algal blooms would not occur without excess phosphorus.



The dividing line says it all: Lake 226, divided by a plastic curtain, with carbon and nitrogen added to both basins and phosphorus to only one. Photo: IISD Experimental Lakes Area.

Lakes prove they can heal

After Lake 226, policy moved on two fronts. Regulators required phosphorus removal at wastewater treatment plants across the Great Lakes basin, an approach since adopted in many, though not all, parts of the world. And they banned phosphates from laundry detergents, which at the time supplied roughly half the phosphorus reaching those plants. Loads fell, and treatment costs fell with them.

The lakes responded. Phosphorus concentrations in Erie and Ontario dropped by about half, and many lakes throughout the world have benefited, not only by reducing or eliminating existing blooms but preventing them in the first place. This achievement should not be understated: identifying the cause, acting on it, and watching lakes rebound is one of environmental science's clearest success stories, and the Great Lakes science and policy communities led the way for policies enacted globally.

The lakes changed on us

So why do blooms persist? Part of the answer is that the lakes have changed.

In the lower Great Lakes, *Cladophora* has come roaring back, even while offshore phosphorus concentrations remain well below historical levels. This resurgence has been mechanistically linked to zebra and quagga mussels. Through their enormous filtration capacity, these mussels intercept nutrients before they reach the offshore, concentrating bioavailable phosphorus in the nearshore zone—a dynamic Hecky and colleagues called the "nearshore phosphorus shunt." Their seminal 2004 paper described the dramatic effects of dreissenid mussels and the nearshore–offshore disparity that whole-lake models had, until then, ignored. Where that phosphorus collects, coastal blooms thrive. Why are these widespread blooms, with their associated problems for human health and local economies, nearly absent from our discussions of harmful algal blooms? Are offshore phosphorus and chlorophyll indicators sufficient to assess the status of the Great Lakes?

Another part of the answer is that we failed to address non-point sources, which have become increasingly important with climate change. Lake Winnipeg offers a stark case. Schindler, Hecky, and McCullough documented how a major increase in precipitation in the 1990s doubled discharge from the Red River—which supplies nearly 70% of the lake's phosphorus—without diluting concentrations. Phosphorus concentrations doubled anyway. Loads quadrupled, and phytoplankton biomass quadrupled with them. The linkages between climate, nutrient loads, and blooms are not unique to Lake Winnipeg, and they are not going away; IPCC projections suggest wetter futures for much of the northern hemisphere. This strengthened hydrologic connection between land and water makes lakes and rivers more sensitive to land use.

Open limnological questions remain. Among them, under what conditions is co-management of nitrogen and phosphorus (rather than phosphorus alone) appropriate for controlling eutrophication? What factors govern the capacity for nitrogen fixation to offset potential nitrogen load reductions? And what are the most effective approaches to manage algal toxins? Despite these remaining scientific uncertainties and disagreements, for the Laurentian Great Lakes and many lakes around the world, I contend that the future success of eutrophication management will be won or lost in the watershed.

What has changed since is not our understanding of the fundamentals. It's the lakes themselves and the watersheds around them.

The next experiment is already running

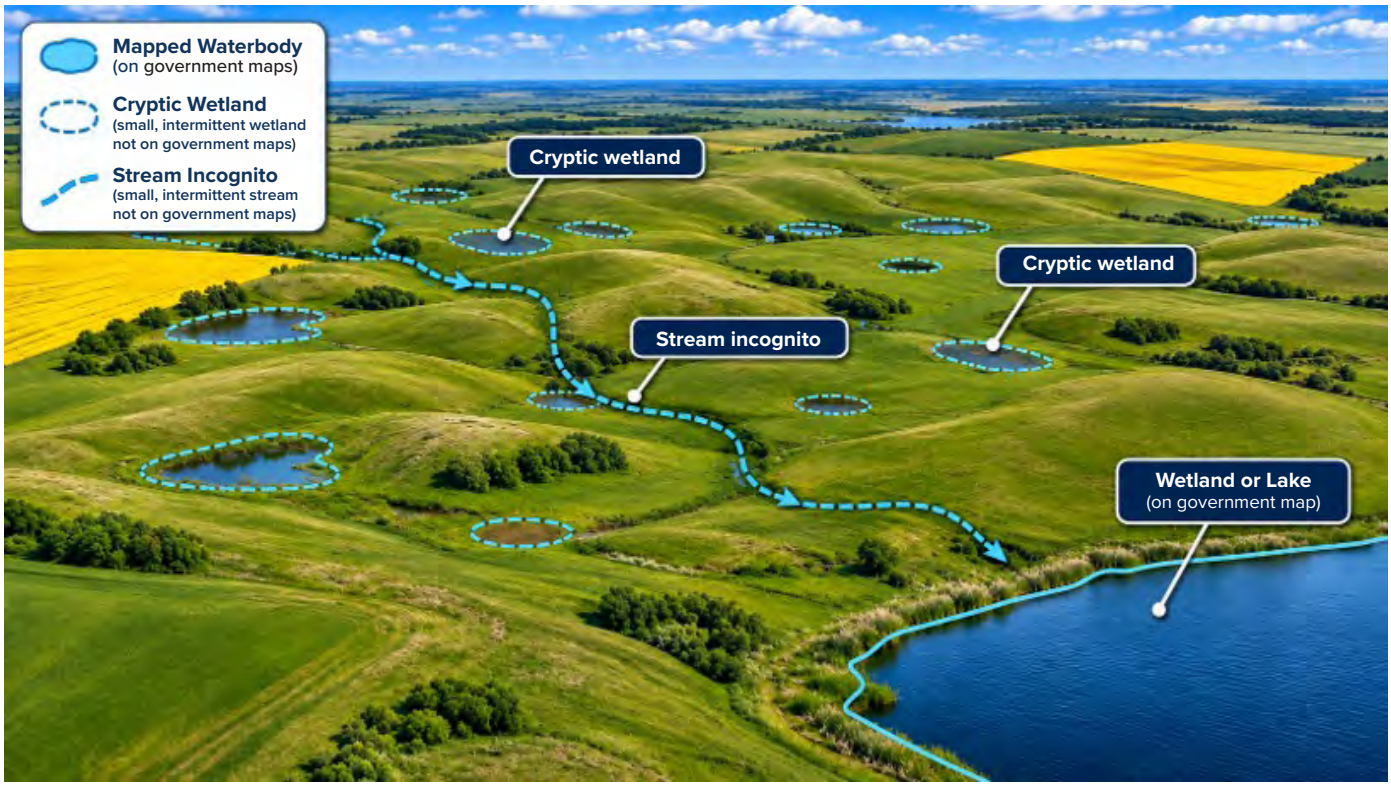
Half a century ago, policymakers, ecosystem managers, and researchers confronted a massive ecological and socioeconomic problem in the Laurentian Great Lakes. Their solution was to think big, to design experiments at appropriate scales of space, time, and ecosystem complexity. It worked. Phosphorus management reduced algal blooms in the Laurentian Great Lakes and many other lakes globally, and it has become a cornerstone of algal bloom prevention. If those policies had not been enacted, we would most certainly be in a worse place.

Today, the equivalent challenge exists for managing nutrient loads from watersheds where stakeholders have competing interests and are often geographically disconnected from the problem. What incentive structures and policies are needed to bring together a diverse group of stakeholders and enact change? Which regulations and best management practices actually reduce nutrient export under real climatic and agricultural conditions? These questions drive the features that follow in this issue.

The last generation answered the fundamental question of what causes algal blooms, and proved lakes can heal. Whether the next generation can win in the watershed—at the scale where the problem now lives—is the experiment underway right now.

This article is adapted from Scott Higgins's plenary address at the 2026 IAGLR–SCAS Joint Conference. Watch the full plenary.

Scott Higgins is a senior research scientist at the IISD Experimental Lakes Area.



Hidden hydrologic connections in prairie watersheds. Small, often unmapped wetlands (cryptic wetlands) and intermittent streams (streams incognito) form a hidden drainage network that expands and contracts with changing moisture conditions. During dry periods, these features may remain disconnected, retaining water and nutrients. As wet conditions develop, wetlands fill and spill, activating flow pathways that transport stored phosphorus, nitrogen, carbon, and other substances downstream to rivers and lakes, influencing nutrient delivery and eutrophication.

From cryptic wetlands to toxic blooms

Climate-driven shifts in watershed hydrologic connectivity—and the iron chemistry of saline lakes—shape not just how much algae grows, but which organisms dominate.

By Irena Creed

The amount and type of nutrients reaching a lake depend on how water moves through its watershed. Conventional maps poorly represent much of the hydrologic network responsible for that nutrient delivery. Early in my career, I became interested in small wetlands and intermittent streams, including features I have described as *cryptic wetlands* and *streams incognito*. Although easily overlooked, these features can influence nutrient export far beyond what their size would suggest. They retain, transform, or release organic matter, phosphorus, nitrogen, and micronutrients like iron, depending on hydrologic conditions. During dry periods, many become disconnected from the stream network and store water and nutrients. During wet periods, expanding flow pathways reconnect them, allowing accumulated nutrients to move downstream. Climatic variability and human activities on working landscapes can therefore influence nutrient delivery by changing which parts of a watershed are connected, and when.

What reaches the lake?

My research group has examined how these changes in connectivity influence eutrophication across the nearly one-million-square-kilometer Lake Winnipeg watershed. Using statistical learning models based on observations collected over decades, we found that headwater wetlands often act as nutrient gatekeepers, retaining nutrients while

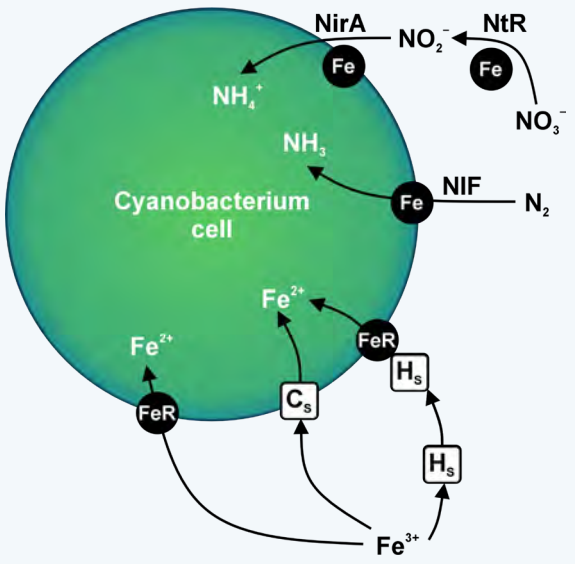
disconnected from downstream waters. As wet conditions develop, these wetlands reconnect through a process of filling and spilling, activating flow pathways that transport stored nutrients toward lakes. When more than half of the watershed becomes connected in this way, nutrient export increases sharply, coinciding with major phytoplankton blooms in Lake Winnipeg. Wetlands along larger streams were particularly influential: although they represented less than 20% of the total wetland area, their drainage by human activities was associated with disproportionately large increases in phytoplankton biomass in the network of lakes feeding Lake Winnipeg. These connections regulate the movement of phosphorus alongside other resources that influence lake productivity. The watershed therefore helps determine not only how much nutrient enrichment a lake experiences, but also the chemical conditions under which phytoplankton respond and the composition of the phytoplankton community.

What determines what grows?

Those differences in lake chemistry become important when we move from predicting total phytoplankton biomass to understanding which organisms dominate. To examine these responses, we sampled more than 100 lakes across the Lake Winnipeg watershed, spanning a gradient from freshwater to hypersaline prairie lakes. Many of these prairie lakes sit in closed basins with no outlet, so evaporation has concentrated their salts well above seawater levels.

Across these diverse conditions, we found one of limnology's most influential organizing principles still holding true. Established by Peter Dillon and Frank Rigler in the 1970s, the phosphorus–chlorophyll relationship provided a simple way to predict how algal biomass responds to phosphorus enrichment, and it helped establish the scientific foundation for managing eutrophication. More than 50 years later, it remains remarkably useful: total phosphorus continued to predict total phytoplankton biomass across the lakes studied. However, the relationship between phosphorus and phycocyanin—a pigment used as an indicator of cyanobacteria—differed markedly. The cyanobacterial response was nonlinear, with conditions favoring cyanobacterial dominance occurring within a particular range rather than increasing consistently with phosphorus. Lakes with similar phosphorus concentrations could therefore support very different phytoplankton communities. That distinction matters: chlorophyll remains a useful measure of total phytoplankton biomass, but it does not reveal which organisms dominate.

Understanding why cyanobacteria dominate requires looking beyond phosphorus to interactions among nutrients and other resources. Nitrogen influences cyanobacterial competitiveness and community composition, yet one of our more striking findings was that many lakes across the salinity gradient were neither strongly phosphorus-limited nor nitrogen-limited. If neither nutrient was limiting, something else had to be. This led us to examine other resources that might influence competition among phytoplankton, particularly iron. Iron is essential for several processes in phytoplankton, including photosynthesis, nitrogen assimilation and fixation, cellular respiration, and protection against oxidative stress. Some cyanobacteria produce siderophores, specialized iron-scavenging compounds that allow them to access iron more effectively than other phytoplankton. That competitive advantage may become increasingly important in more saline lakes, where biologically available iron declines. In our models, siderophores emerged as the strongest predictor of phycocyanin—a result none of us expected—pointing toward an important role for iron acquisition in shaping cyanobacterial communities. Dissolved organic matter adds



Iron-dependent nitrogen metabolism and iron acquisition in cyanobacteria. Iron (Fe) is an essential cofactor in enzymes involved in nitrogen fixation and nitrate assimilation. In nitrogen-fixing cyanobacteria, nitrogenase (NiF) catalyzes the reduction of atmospheric N_2 to NH_3. Nitrate assimilation involves two successive reactions: nitrate reductase (NtR) reduces NO_3^- to NO_2^-, followed by nitrite reductase (NirA), which reduces NO_2^- to NH_4^+. Given these essential metabolic functions, how do cyanobacteria obtain iron when its availability is limited? In oxygenated waters, ferrous iron (Fe^{2+}) is readily oxidized to ferric iron (Fe^{3+}), which is generally less soluble at near-neutral pH. Some cyanobacteria produce catecholate (C_s) or hydroxamate (H_s) siderophores that bind Fe^{3+} and facilitate its acquisition. Ferric reduction ($Fe^{3+} \rightarrow Fe^{2+}$), indicated by FeR, can also facilitate iron uptake, although the mechanisms vary among cyanobacteria.

another layer of complexity, influencing both nutrient supply and which organisms benefit from it.

For me, these findings illustrate an important distinction: phosphorus helps determine how much phytoplankton biomass a lake can support, but interactions among nutrients, metals, organic matter, and microbial processes help determine which organisms thrive.

What makes a bloom toxic?

Even knowing which organisms dominate and how much biomass they produce does not tell us whether a bloom will become toxic. This became particularly clear in the prairie lakes, where cyanobacterial biomass, community composition, and toxin concentrations followed different patterns across the salinity gradient. Cyanobacterial biomass peaked near the transition from freshwater to moderate salinity and then declined as salinity increased further. Community composition also changed, with turnover among different bloom-forming genera.

Yet more cyanobacteria do not necessarily mean more toxins. Instead, toxin abundance and diversity showed pronounced peaks linked to changes in both salinity and community composition, reaching their highest concentrations at higher salinities, where cyanobacterial biomass had already declined. In some lakes, microcystin and nodularin—toxins produced by some of these cyanobacteria—reached exceptionally high concentrations. Why were some lakes so much more toxic than others? Siderophores and the nitrogen-to-phosphorus ratio were among the strongest predictors of toxin concentrations in our models. These findings reinforce a distinction that deserves much greater attention: the conditions that favor algal production, cyanobacterial dominance, and toxin production are not necessarily the same.

More cyanobacteria do not necessarily mean more toxins.

One of the questions I now consider most important is what determines whether cyanobacteria with the genetic capacity to produce toxins do so. The presence of toxin-producing genes indicates potential, but not whether those genes are expressed or whether toxins are present in the water. Our findings suggest that microbial community interactions we have not yet characterized—along with nutrient availability, salinity, and iron chemistry—are important. Still, the mechanisms connecting these conditions to toxin production remain poorly understood. Addressing this question will require integrating measurements of watershed and lake conditions with information about microbial communities, genetic potential, gene expression, and measured toxins. My research group is beginning to explore these connections, with the longer-term goal of improving our ability to anticipate toxic blooms rather than detect them after they develop.

Beyond the paradigm

Taken together, these findings reveal different levels of control over eutrophication. Watershed hydrology regulates the delivery of phosphorus and other resources. Interactions among those resources influence which phytoplankton dominate. Additional ecological and physiological processes influence whether cyanobacterial communities produce toxins. These distinctions matter for monitoring and managing lakes. Phosphorus reduction remains essential for controlling eutrophication, but predicting cyanobacterial dominance and toxicity requires additional information about watershed conditions, lake chemistry, and microbial communities. As climate change alters precipitation, hydrologic connectivity, evaporation, and salinity, understanding these interactions will become increasingly important.

Scientific progress does not always require abandoning established paradigms. Often, it reveals the conditions under which they apply, the processes that modify their expression, and the questions they were never designed to answer. The phosphorus–chlorophyll relationship is an excellent example. Dillon and Rigler built something durable: a principle that still predicts algal biomass in lakes ranging from freshwater to hypersaline. What has changed is our understanding of the processes surrounding that relationship and the ecological outcomes we now need to predict. The challenge for the next generation of eutrophication science is to build on this foundation, moving beyond single-nutrient predictions toward a more integrated understanding of how changing watersheds and lakes function. Phosphorus remains fundamental, but understanding its ecological consequences requires understanding the system around it.

This article was adapted from the Frank Rigler Award plenary presented by Irena Creed at the 2026 IAGLR–SCAS Joint Conference. Watch the full plenary.

Irena Creed is a professor in the Department of Physical and Environmental Sciences at the University of Toronto Scarborough.



Scientist collects a harmful algal bloom sample in Lake Superior's Apostle Islands in 2018. Photo: Brenda Lafrancois, National Park Service.

The HABs era on Lake Superior

A new white paper urges action on tackling harmful algal blooms in the coldest Great Lake—and finds that the usual reasons for eutrophication don't hold.

By Matt Hudson

Lake Superior, long revered as the clearest, coldest, and most pristine of the Laurentian Great Lakes, is facing an emerging threat: recurring harmful algal blooms (HABs) caused by cyanobacteria. Since 2012, some nearshore and harbor areas of the lake—most commonly in southwestern Lake Superior and in the Thunder Bay region along the Canadian north shore—have seen annual or nearly annual HABs. Most observed HABs to date have been short-lived and small in area, but larger blooms in 2012 and 2018 were observed along roughly 20 and 100 kilometers of shoreline in Wisconsin, respectively. The 2018 bloom, in particular, prompted widespread concern among scientists, managers, media, and the public about what was causing such a massive bloom in pristine Lake Superior, and whether the emerging presence of HABs is a warning sign of greater shifting conditions in the lake.

A bloom with a different playbook

The blooms have so far baffled scientists and are challenging existing scientific paradigms that guide our understanding of eutrophication. Research to date shows that the more typical drivers leading to HABs, which are documented for other lakes, do not appear to be the same drivers in Lake Superior. Also unclear is the potential for generating toxins, as some blooms have had them and some have not. Not only are researchers confounded, but resource managers are left without a clear path for addressing the HABs issue in its early stages before it could become a more widespread problem. On top of that, the lake's reputation as the cleanest of the Great Lakes makes it difficult to attract investment in research at the scale needed to solve the HABs mystery and identify adaptive management solutions.



Confirmed locations of harmful algal blooms across the Lake Superior basin between 2012-2024. Credit: Sam Blackburn.

What the Duluth summit proposed

To provide more clarity and spur action, the nonpartisan, nonprofit Burke Center for Ecosystem Research convened a water summit in Duluth, Minnesota, in June 2026 with over two dozen U.S. and Canadian scientists, natural resource managers, Indigenous representatives, and tourism and public health professionals. Drawing on summit discussions, the center produced eight recommendations and published them in a white paper released in September. The recommendations aim to raise the profile of the Lake Superior HABs issue within existing policy and management frameworks, while prioritizing investments in real-time monitoring, scientific research, and stronger regional communication.

The first recommendation calls for elevating Lake Superior HABs "within existing policy frameworks, such as the Great Lakes Water Quality Agreement and the Great Lakes Restoration Initiative." Lake Superior's status in binational "State of the Great Lakes" reporting is repeatedly assessed as "good" with a trend of "unchanging," yet the emergence of HABs in the lake suggests otherwise. Adequate investment in the primary research needed at the scale necessary to pinpoint bloom drivers has lagged because the issue has yet to gain the necessary traction within existing Great Lakes policy and funding mechanisms. Greater recognition of Lake Superior HABs in these frameworks would strengthen prospects for funding the foundational science needed to develop effective, targeted management actions.

The second recommendation calls for a coordinated HABs detection network using buoys, drones, remote sensing, and other modern technologies to provide real-time information alongside existing boat-based sampling. That network would support the third recommendation, which calls for advancing research to identify the drivers of HABs in Lake Superior and determine their potential for toxin production.

The fourth recommendation calls for engaging with Indigenous communities to understand how HABs may affect culturally and spiritually significant species and the cultural lifeways tied to harvesting them. Lake Superior is home to more than 20 distinct Indigenous communities around the lake who depend on manoomin (wild rice), fish, and other culturally important beings found in embayments, estuaries, and nearshore areas most susceptible to HABs. A gap in understanding those risks was an important need identified at the summit.

Cold, deep, and warming fast

Even with adequate research funding, scientists face a fundamental challenge, which is that Lake Superior's HABs do not follow the typical playbook for HAB formation as seen in other lakes. Research to date indicates a complex set of factors, primarily linked to climate change, rather than the typical ingredients of intense human development and

excessive nutrient loading into warm, shallow waters. Lake Superior is the opposite of that paradigm, with cold, deep water, a primarily forested watershed, and little agricultural or urban development.

Yet the emergence of HABs signals that Lake Superior is changing. It is one of the fastest-warming lakes in the world, with less winter ice cover than just a few decades ago. Extreme precipitation and flooding events in recent years wash excess sediment, sediment-bound nutrients, and cyanobacterial cells into parts of the lake, potentially helping to seed blooms. These changes are linked to climate change, but how they interact with localized watershed runoff and nearshore hydrodynamic conditions to trigger blooms remains unclear.

Solving that mystery will require both greater investment in primary research and a fresh approach to studying bloom formation. Scientists must re-think the typical environmental conditions and patterns that lead to HABs, and how to measure those things in a place where blooms often appear and dissipate quickly, and where existing sensor and remote sensing technologies do not work well in the lake's crystal-clear waters. Lake Superior offers an important test case for understanding HABs and their impacts in places and ways we previously may not have considered.

An opportunity, if acted on early

The HABs era on Lake Superior has begun and the stakes could not be higher for understanding what drives its blooms. Doing so will enable the implementation of effective adaptive management strategies, risk communication strategies, and forecasting and alert systems identified in the remaining water summit recommendations.

What we are learning from Lake Superior is that our models of how lakes work are not guarantees; they are hypotheses held against emerging evidence. When a lake stops fitting the model, we should not look to force old explanations onto new observations nor to abandon our efforts at prediction altogether, but to invest in the observations themselves—monitoring networks, long-term datasets, sustained engagement with the communities closest to the water—so that understanding can catch up to change.

There is hope that the Lake Superior HABs issue has been recognized early enough for effective management to help prevent larger problems. The white paper calls for turning that opportunity into action. In the coming months, the Burke Center is engaging in binational presentations to government officials and the general public to raise awareness of the HABs threat in Lake Superior and build support for the research urgently needed to understand what drives HABs in the largest Great Lake. As Lake Superior enters its HABs era, the opportunity lies in acting now—building the knowledge needed to guide an effective response before blooms become a larger problem and it is too late.

To read the white paper and see the companion video produced from the Burke Center water summit, visit www.burkectr.org/water-summits.

Matt Hudson is associate director- Great Lakes at the Burke Center for Ecosystem Research.



Harmful algal bloom in Lake Superior's Portage Canal Waterway in Houghton, Michigan, in 2021. This was the first reported bloom in Michigan waters of Lake Superior, appearing in the cold of November, further adding to the mystery of Lake Superior HABs. Photo: Gordon Paterson.



Aerial view of heavy industy along Hamilton Harbour on Lake Ontario.

Unmasking the iron shield

Why Hamilton Harbour's sediments are still releasing legacy phosphorus

By Alex Neumann, Tao Xu, Maria Dittrich, Yasasi Fernando, John Gibson, Ramin Farnood, David Depew, and George B. Arhonditsis

For decades, lake managers worked from a reassuring premise: reduce the phosphorus entering a lake, and the water should gradually clear. That logic still holds, but Hamilton Harbour shows why recovery can be far more complicated. Like many enriched freshwater systems, the harbor carries an ecological memory. Phosphorus that accumulated in bottom sediments during earlier decades can continue to influence water quality long after external pollution controls are in place.

Hamilton Harbour—a deeply industrialized embayment at the western end of Lake Ontario and a Great Lakes Area of Concern since 1987—offers a striking example of this "eutrophication paradox." Through the Remedial Action Plan process, external phosphorus loading was cut by more than 50% between 1987 and 2016. Yet phosphorus concentrations in the harbor did not decline as expected. Instead, they leveled off, while phosphorus release from bottom sediments rose sharply.

The question was simple but puzzling: why would sediments that retained phosphorus during the harbor's most polluted years begin releasing it after external inputs were reduced? To investigate, our research team developed a model of sediment diagenesis—the slow chemical and microbial transformation of deposited material—to reconstruct three decades of changing chemistry at the sediment–water interface (Xu et al., 2026a and Xu et al., 2026b). The answer points to a hidden player in the harbor's recovery story: industrial iron.

The industrial "rust shield"

For much of the 20th century, local steel production added an unusual chemical subsidy to Hamilton Harbour. Stelco and Dofasco discharged iron-rich effluents, with iron inputs reaching up to 34,000 kilograms per day and still averaging nearly 5,000 kilograms daily by 1985. In oxygenated surface waters, that iron formed reactive iron oxyhydroxides, essentially rust-like minerals. Once deposited at the sediment surface, they acted as a chemical sponge, binding

phosphate released during organic matter decomposition before it could escape back into the water column.

In the 1980s and 1990s, this iron-rich layer was so effective that internal phosphorus loading was close to negligible, at only 0.09 to 0.26 milligrams per square meter daily. The lakebed was not simply burying phosphorus; it was locking away large stores of redox-sensitive, iron-bound legacy phosphorus while shielding the water column above.

When the shield began to fail

As environmental regulations strengthened, industrial iron discharges fell dramatically—by more than 90%—to 442 kilograms per day by 2016. This was, in many respects, an environmental success. But in the sediments, the loss of this iron supply weakened the very chemical barrier that had been trapping phosphorus.

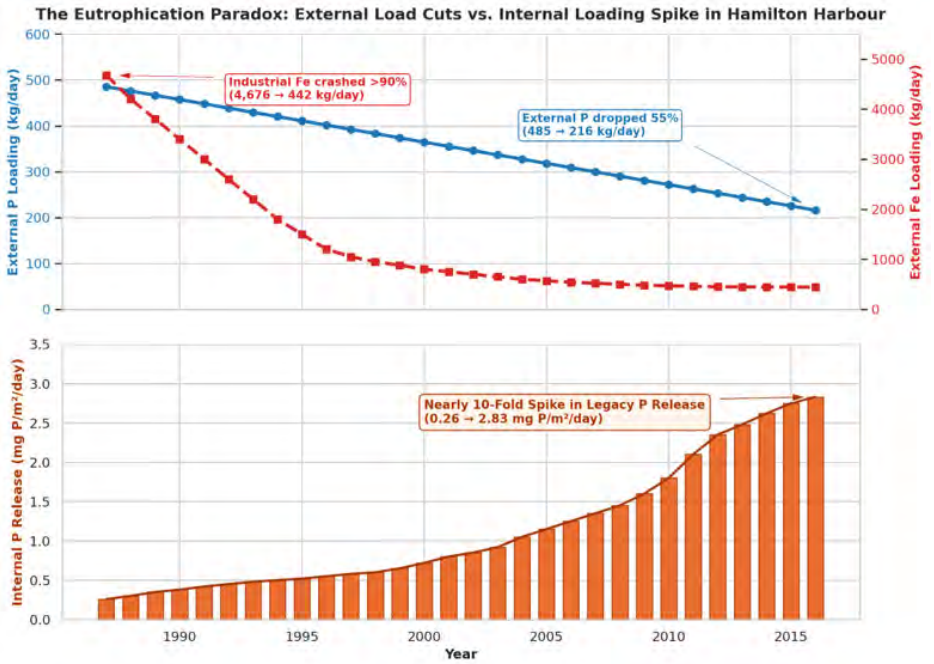
As the iron supply dwindled, the sediment surface lost its capacity to rebuild the binding layer. One measure of this capacity is the ratio of dissolved iron to phosphorus in the water within the sediment. Generally, there needs to be more than twice as much iron as phosphorus for iron to bind the upward-moving phosphate as it reacts with oxygen near the sediment surface. In 1987, Hamilton Harbour's surface sediments were heavily buffered, with ratios between 20 and 50 within the upper 3 centimeters. By 2016, the ratio in the uppermost oxidized layer (0 to 2 millimeters) had fallen to 1.4, below the commonly cited threshold for effective iron-mediated phosphorus retention.

Once that surface barrier weakened, phosphate diffusing upward from the sediments could escape into the hypolimnion—the cold, stagnant bottom layer of water that forms when the lake stratifies each summer and stays sealed off from the surface until fall overturn. By 2016, the modeled internal phosphorus flux—phosphorus released from the sediments themselves—had climbed to 2.83 milligrams per square meter daily during stratification, with summer monthly values reaching approximately 3.7. For comparison, the harbor's annual-average external phosphorus loading of 216 kilograms per day in 2016 corresponds to approximately 10 milligrams per square meter daily when normalized by its surface area (21.5 square kilometers). In other words, in the summer, the sediments released phosphorus at a rate equal to roughly 30% of what the harbor received from all external sources averaged over the entire year, and all of it was pooled in the bottom waters waiting for fall turnover to spread it through the harbor.

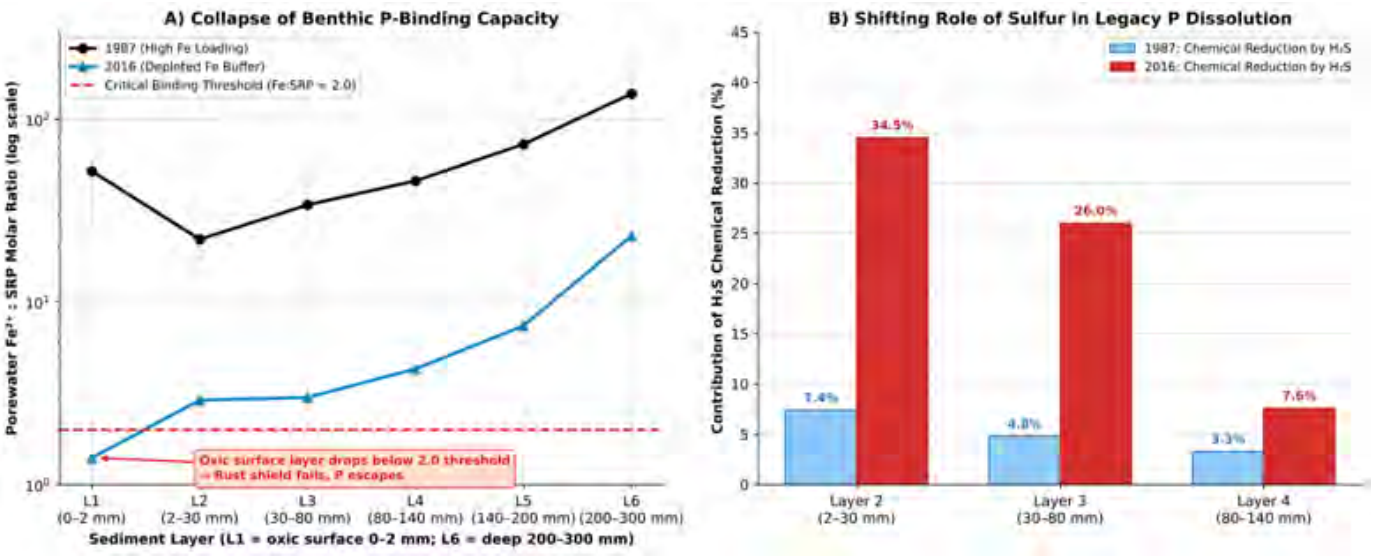
Enter the iron–phosphorus–sulfur triangle

The model also revealed a second shift. As iron became less abundant, sulfur chemistry became more important. Historically, plentiful iron oxyhydroxides helped suppress microbial sulfate reduction. With less iron available, sulfate-reducing bacteria became more active, producing hydrogen sulfide. That sulfide then reacted with iron, forming iron sulfide minerals and effectively removing iron from the phosphorus-binding system.

In 1987, biological iron reduction was responsible for more than 92% of deep-sediment phosphorus release. By 2016, chemical reduction driven by hydrogen sulfide accounted for up to 34.5% of phosphorus release in the upper anaerobic layers. In practical terms, sulfur was helping strip away the iron buffer, leaving more legacy phosphorus mobile.



The Hamilton Harbour Eutrophication Paradox. (Top) Decadal trends showing a 55% reduction in external phosphorus loading alongside a >90% drop in industrial iron inputs from local steel mills. (Bottom) Internal soluble reactive phosphorus (SRP) diffusive flux surging nearly tenfold post-2012 as sediment binding capacity failed.



Breakdown of Benthic Binding Capacity and the Shift to Sulfidic Release. (Panel A) Porewater Fe^{2+}:SRP molar ratio across sediment layers in 1987 vs. 2016, showing the oxic surface layer falling below the critical 2.0 binding threshold. (Panel B) Percentage contribution of H_2S chemical reduction to legacy phosphorus dissolution in upper anaerobic layers.

From slow burial to fast diagenesis

Together, these changes mark a shift in how the harbor's sediments function. In the earlier "slow diagenesis" state, phosphorus was captured and gradually buried beneath an iron-rich surface layer. In the newer "fast diagenesis" state, organic matter is mineralized more quickly, and the phosphorus released during that process can cycle back into the water column with much less resistance.

The model's sensitivity analysis—a stress test that ranks which of its 56 parameters most strongly control internal loading—confirmed this transition. In 1987, iron sedimentation ranked only 17th in importance. By 2003, as iron became scarce, iron deposition had become the second-most sensitive factor in the system, while sediment-water sulfate concentrations rose from 23rd to 4th place.

Lessons for lake restoration and management

Hamilton Harbour offers several practical lessons for Great Lakes restoration:

1. **Recovery is not linear.** Reducing external phosphorus is essential, but sediment response can lag for years or decades. In systems with strong ecological memory, internal loading may increase before long-term recovery becomes visible.
2. **Look beyond phosphorus alone.** Iron, sulfur, oxygen, and organic matter all shape whether sediments retain or release phosphorus. Restoration targets need to account for this broader chemical context.
3. **Watch for unintended chemical consequences.** Reducing one pollutant can change the behavior of another. In Hamilton Harbour, lowering industrial iron inputs improved one aspect of water quality but also reduced sediment phosphorus-binding capacity.
4. **Use predictive tools adaptively.** Dynamic sediment models can help managers test potential interventions, such as oxygenation strategies, organic matter controls, or targeted amendments, before making costly restoration decisions.

Hamilton Harbour reminds us that lakes do not forget their past. Beneath the sediment surface, decades-old pollution legacies continue to interact with today's management choices. By understanding the coupled chemistry of iron, phosphorus, and sulfur, restoration practitioners can set more realistic expectations, and design recovery strategies that work with the lake's internal timeline, not against it.

Alex Neumann, Tao Xu, Maria Dittrich, Yasasi Fernando, and George B. Arhonditsis are affiliated with the Department of Physical and Environmental Sciences at the University of Toronto. John Gibson and Ramin Farnood are part of the Department of Chemical Engineering and Applied Chemistry at the same institution. David Depew is with the Canada Centre for Inland Waters at Environment and Climate Change Canada.



A dense network of ditches and drains moves water through the Red River Valley landscape to the waters of Lake Winnipeg. Photo: Adam Yates.

Intercepting the flow

The journey of nutrients through the Red River Valley, and the hidden places we can intervene.

By Adam Yates and Robert Brua

To look at the Canadian Red River Valley today is to see a landscape engineered to move water: ditches and drains criss-crossing flat farmland, fields graded to shed water as efficiently as possible—a network that functions like gutters on a roof, all draining toward Lake Winnipeg. That is certainly how we thought about it when we began studying nutrient transport in the valley more than 15 years ago. Then we measured what happens in those drains and found they don't behave like gutters at all.

It is spring melt in the Red River Valley. The accumulated snow of the winter past is melting, and across the valley the ditches and streams are filled to the top of the banks with water. As the water rushes downstream, it carries with it tons of nitrogen and phosphorus, nutrients essential for plant growth, but also prized by algae. Headed for Lake Winnipeg, these excess nutrients have been feeding massive algal blooms for more than 20 years. But the journey of these nutrients did not start here. And, as we were to learn, it does not run uninterrupted to the lake either.

Our own journey as researchers studying the transport and fate of nutrients in the Red River Valley began with a workshop in early 2009. The lakewide algal blooms in Lake Winnipeg—Canada's sickest lake—had been garnering national media attention for several years, and efforts to generate solutions were intensifying. Scientists from government and academia convened to discuss what we did and didn't know about nutrient transport from the valley lands to the lake. Key questions emerged. What are the primary sources and locations of those nutrients? What controls the amount and timing of nutrients being delivered to the lake? They were big questions that didn't have a lot of answers. We couldn't wait to get started.

Before the drains

Water has always taken its time crossing the Red River Valley. Two hundred years ago, the valley plain was an immense, wet tallgrass prairie ecosystem. Stream water flowing in from the Manitoba escarpment to the west and the Canadian Shield to the east combined with rainwater captured in large wetlands. The abundant plant life of those wetlands readily filtered

nutrients from the water as it trickled to the meandering tributaries on a slow, circuitous path to the Red River.

Water still flows slowly most of the year, but the path it follows is much shorter. The vast wetlands and meandering channels have mostly been replaced by a dense network of ditches and drains. A landscape rebuilt to move water quickly is also, unfortunately, a landscape that transports nutrients efficiently—and today's Red River Valley has plenty of nutrients to move. The region is now a checkerboard of farms and cultivated fields interspersed with villages, towns, and a couple small cities. Those communities generate significant quantities of nutrients as sewage, and while municipal wastewater treatment lagoons capture some of it, much passes directly to local waterways during short annual or biannual releases. In addition, people are greatly outnumbered by livestock, especially on the eastern side of the valley where millions of pigs are reared every year, producing immense amounts of nutrient-rich manure. That manure, as well as synthetic fertilizers, is applied to the land to enhance crop growth. Under the wrong circumstances, these nutrients are also lost to waterways.

When the water moves

The quantity of these nutrients ultimately reaching the lake follows precipitation patterns. Typically, the greatest amount is transported during the snowmelt, as meltwater carries away the nutrients accumulated on the land over the previous year. Yet rainstorms account for a growing proportion of nutrient loads as climate change increases the frequency and intensity of storms. And the amount and timing of precipitation in the Red River Valley varies greatly from year to year. Some years there is so much water that we struggle to safely collect samples; other years there is almost no water to sample. In the dry years, loss of nutrients may be low. But in wet years, the snowmelt and rain—encouraged by a drainage network that connects hundreds of farm yards, fields, and urban lands to a single waterway system—funnel the nutrients all these activities produce toward Lake Winnipeg.

Streams as living filters

A network like that sounds like plumbing. But drains and streams aren't gutters. They are ecosystems teeming with life—and life needs nutrients. We were nonetheless surprised when, in one instance, all the nitrogen and 80% of the phosphorus from a single municipal wastewater lagoon release was captured by the stream. We maybe shouldn't have been. The biota are remnants of the wetlands that have been filtering nutrients since the last ice age. The native sediments attract and hold onto nutrients the way a magnet attracts iron. And the slowly flowing water gives both plenty of time to act. The effectiveness of these natural filters does vary—it slows in colder weather, and the filters can clog with overuse, as we saw from successive sewage effluent releases in a single summer. Overall, though, these ecosystems work.

But then what happens? It appears that significant amounts of the captured nutrients are stored, at least until the next large snowmelt. We found acesulfame—a common artificial sweetener that enters waterways in significant quantities only with human wastewater—in under-ice



Ditches and drains in the Red River Valley have an abundance of life and fine sediments that filter nutrients from the water. Photo: Robert Brua.



Captured nutrients are often flushed downstream to Lake Winnipeg during the spring melt. Photo: Kristin Painter.

sediments and in stream water during snowmelt. Its presence there means that wastewater-borne material from summer releases was still sitting in the stream months later, waiting for the spring flush. By examining the relative amounts of the lighter and heavier versions (isotopes) of nitrogen, we also found indications that nutrients from the previous summer's effluent releases were still in the stream during snowmelt. Both are strong signals that nutrients are being stored when streamflow levels are lower. More work is needed to understand the extent of this storage.

A second chance

Despite the filtering services waterways provide, it is a guarantee that nutrients won't be retained forever, so the priority is to keep the nutrients out of the waterways in the first place. But some waterways may give us a second chance to reclaim these nutrients before they can reach Lake Winnipeg and contribute to the algal bloom problem. The opportunity lies in the fact that every year, numerous kilometers of ditches and drains are "cleaned"—a process in which the accumulated sediments are removed from the bed of the ditch. Because these sediments can capture large amounts of nutrients, especially phosphorus, their removal may prevent further transport downstream while also returning a valuable resource to neighboring fields. We have only just started researching this question, so there are few answers yet as to how much drain cleanouts can contribute to the solution.

Given the scope of the nutrient problem, and that nutrient losses to the Red River are still increasing, solutions large and small will be needed to reduce nutrient losses to Lake Winnipeg and give the lake the opportunity to recover. What our years following nutrients through this landscape have taught us is that the journey matters as much as the destination. The water moving downstream is not simply delivering nutrients to their fate. Every ditch and streambed along the way holds some of those nutrients in reserve—and every one of those stops is a place where we might intervene. By understanding the full journey, we can begin to manage the destination.

Adma Yates is an associate professor at the University of Waterloo. Robert Brua is a research scientist with Environment and Climate Change Canada.



Drain "cleanouts" are an opportunity to reclaim nutrients that have been trapped in sediments and decaying plant material by returning these nutrients to the land and keeping them out of Lake Winnipeg. Photo: Allyza Tabirara.

Are the wetlands working?

What we're learning about restored wetlands and water quality.

By Kenneth Anderson, Mary Ellen Klukow, and Olivia Schloegel

When officials told almost half a million people in and around Toledo not to consume their water in 2014—even after boiling, even just for brushing teeth—the cause wasn't hard to find. Dangerously high microcystin toxins from a harmful algal bloom (HAB) in Lake Erie's western basin had reached the city's water intake, and all one had to do was look upstream for the reason why. The Maumee Watershed's heavy agricultural use, combined with the shallow, warm waters of the western basin, had made the area a hotspot for blooms. The link between nutrient runoff and eutrophication had been clear for decades.

Identifying the solution wasn't as simple.

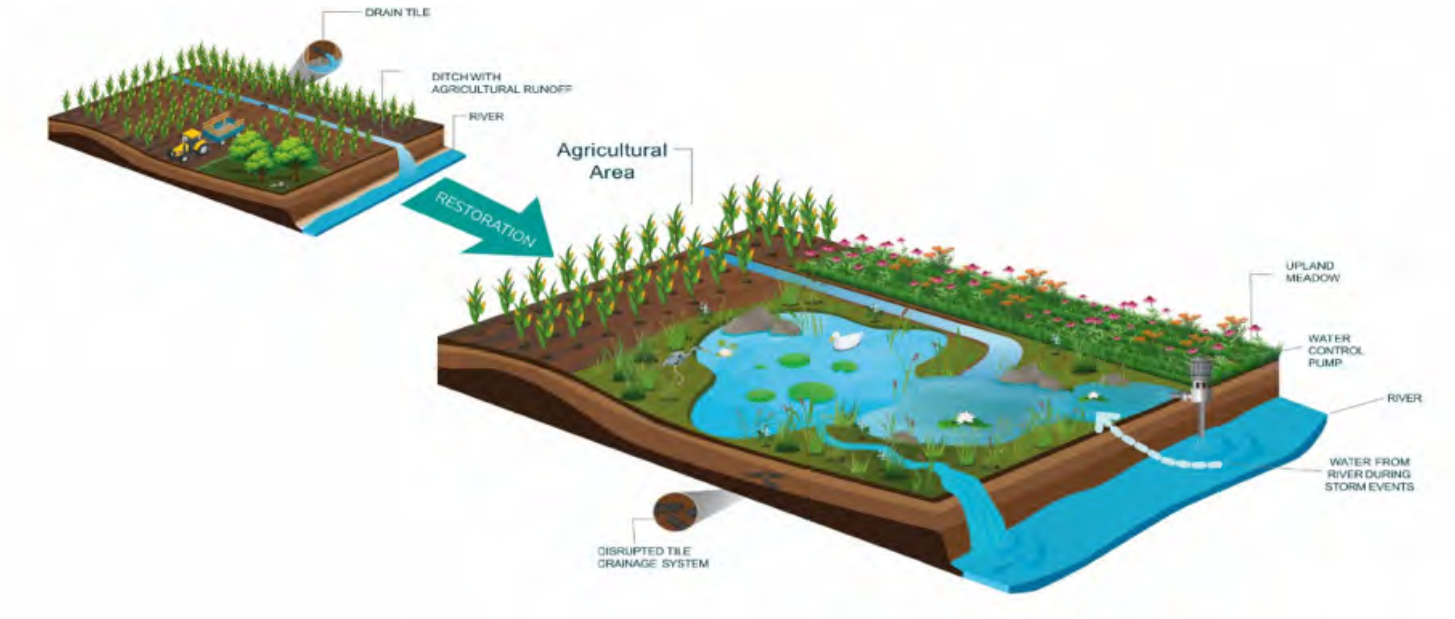
In response to Ohio's failing water quality, the H2Ohio initiative emerged in 2019 to empower individuals and organizations across the landscape to be good water stewards. It promised remediation of degraded water infrastructure, implementation of best management practices for farming, and dam removal. It also promised to create and restore wetlands as nutrient retention tools. That last promise is where our story begins, because it asked something new of an old practice.

Wetland restoration in the United States, especially the construction of mitigation banks, has been common since the Clean Water Act passed in 1972. But most of that restoration—and the laws guiding it—was geared toward habitat improvement. The nonprofits, conservation groups, and restoration companies with long histories of building and monitoring wetlands to meet biodiversity goals were suddenly tasked with creating wetlands for a new purpose: capturing nutrients before they could fuel the next bloom.

The question then became ours to answer: Are these wetlands working for water quality?

Watching the water

Answering that question is the objective of the H2Ohio Wetland Monitoring Program (WMP). This research group spans six academic institutions and works collaboratively to collect and analyze hydrological and nutrient data across 50 restored Ohio wetlands. As WMP researchers, we use these data to calculate nutrient budgets, which essentially



Wetlands constructed on former agricultural land are designed to capture high nutrient water from a variety of sources including agricultural ditches and streams. Stream water is delivered passively to some wetlands during storms, and actively pumped into others.



Floodplain wetland under construction in Williamsburg, Ohio. Repurposed drinking water reservoir in the foreground which drains into the meandering wetland (background). Credit: Ohio State University Stormwater Management Program.

are an account of the mass of phosphorus and nitrogen in the water flowing into and out of each wetland. If less leaves than enters, the wetland is retaining nutrients. Mass loads offer a policy-relevant, scalable metric, allowing us to assess not only whether wetlands are working, but how their performance compares to other best management practices implemented through H2Ohio.

By analyzing trends across 24 wetlands over two to four years—a total of 528 monthly nutrient retention values—we can say that these restored wetlands are working right now. Our data show that their retention is meaningful enough to contribute to the watershed-scale nutrient reduction goals outlined by the Maumee River Total Maximum Daily Load Project. But when we dug deeper into the data, we found important patterns around timing, placement, and uncertainties.

Working when we need them most

Late summer and early fall HAB severity in Lake Erie is determined by nutrient loading from March through July. That makes the spring and early summer a critical window, and, perhaps not coincidentally, the period when the wetlands do their best work. WMP data suggest that roughly 70% of annual total nutrient retention across wetlands occurs during those months.

Part of this is biology: spring and summer are times of active plant growth and dissolved nutrient uptake. But wetlands also physically slow water down, shifting the timing of nutrient transport so that a portion of what would have rushed downstream during the loading period arrives later instead. For the management of large lakes, this may be the most encouraging finding: wetlands can help right when we need them most.

Connectivity matters

A clear pattern across all our sites was that the more water a wetland received, the more nutrients it retained. Storm events carry great potential, bringing large volumes of high-nutrient water into a wetland. But they also carry risk. High flows can exit the wetland before nutrient processing occurs,



Aerial shot of Magee Marsh Wetland. Photo: Dave Dean and Ricky Becker.



Collecting long-term data is crucial for understanding how constructed wetlands develop and perform across different climate conditions. Photo: Lauren Kinsman-Costello.



Native plant species like the pickerelweed, arrowhead, and bulrush pictured here are well suited for taking up nutrients. Photo: Lauren Kinsman-Costello.

or resuspend and mobilize stored nutrients. We observed that individual wetlands did sometimes release nutrients. But what surprised us was that, across all wetlands we studied, those releases were dramatically outweighed by retention over the course of the year.

Surface water connectivity has emerged as the bridge between the habitat-based restoration designs of the past and the surface-water-focused designs called for today. Our findings are already informing shovel-ready projects. Anecdotal evidence about relative elevation compared to adjacent streams, and the role of pumps in connectivity has been passed from researchers to agency staff, who use it to inform the next round of wetland grants. That feedback loop—science informing design decisions as the program matures—is an important part of what H2Ohio has built. Upstream practitioners and funders have better information to build wetlands that meaningfully contribute to water quality of downstream lakes.

What we don't know yet

We want to be clear about the limits of what five years of data can tell us. Ohio's wetlands currently are net retainers of nutrients, but we don't know if that will change as they develop. There is a gap in the scientific literature on how constructed wetlands evolve, and what drives their ability to retain nutrients in the coming decades. Additionally, our dataset spans multiple drought years. It therefore has limited power to predict nutrient retention in normal or wet years, posing a challenge in the face of a shifting climate.

The long-term success of wetlands also depends on management, not just construction. Soils can become saturated with nutrients, accumulated sediment may need to be dredged, and plant communities will change over time as vegetation establishes and gives way to new species. Meeting those demands, through long-term monitoring paired with adaptive management, is what will turn a promising intervention into one with real and consistent impacts on downstream lakes.

Building better wetlands

For restoration professionals and managers looking to increase the potential of future and existing wetlands, our 2025 Annual Report points to several practical levers:

- **Slow the water down.** Build wetland features that slow incoming water, support sedimentation, and extend the time water is in contact with wetland soils.
- **Plant for uptake.** Incorporate the native plant species the WMP has identified as particularly efficient at taking up nutrients.
- **Expect surprises.** Understand how constructed wetlands develop and perform across different climate conditions to reduce the risk of nutrient release.
- **Feed the filter.** Divert water into wetlands when nutrient concentrations in the source water are high.

The wide variety of wetland designs built under H2Ohio means there are still open questions about which types retain nutrients best. But the bigger lesson may be the process itself. In responding to a public health crisis, H2Ohio and its Wetland Monitoring Program built something larger than a set of wetlands. It built a collaborative research and management partnership that can keep answering water quality questions for decades to come.

Kenneth Anderson is a postdoctoral scholar, and Mary Ellen Klukow and Olivia Schloegel are research coordinators for the H2Ohio Wetland Monitoring Program at Kent State University.



Cyanobacterial bloom on the shore of Dunga Beach, one of the major landing sites for fishing boats in Kisumu, Kenya.
Photo: Jessica Corman on Flickr.

As Lake Victoria turns green, community knowledge meets the science of HABs

For communities around Winam Gulf, Lake Victoria's changing waters raise questions that measurements alone cannot answer. New monitoring of cyanobacterial toxins offers some clarity—and exposes how much remains unknown.

By Dorine Were

During a focus group discussion with people living around Lake Victoria, one participant offered these words when asked about cyanobacteria and changes in water quality in Africa's largest lake:

> "We don't know its meaning; we don't know how it started. We just woke up one morning and it was all over the water. We don't know if it can be removed, or if ever it will disappear."
>
> — 45-year-old woman
> Dunga, Kisumu County

Her response captured something that scientific measurements alone cannot fully express: the uncertainty and frustration of living alongside a lake whose waters are changing. Why is it happening? What does it mean? Can anything be done?

For communities around the Winam Gulf in western Kenya, Lake Victoria is much more than a body of water. It supports fishing, trade, transport, food security, and everyday livelihoods. Yet the same waters that sustain these activities are under increasing pressure. Unusual water color, floating algal growth, and concerns about water quality raise difficult questions for people who depend on the lake.



A cyanobacterial harmful algal bloom on Lake Victoria in Kenya, captured during a 2022–2023 research survey. Photos: George Bullerjahn.

What the water tells us

Between June 2022 and July 2023, water samples collected from 20 stations in Winam Gulf, Lake Victoria, were analyzed for microcystins, toxins produced by some cyanobacteria. The research was conducted under the NSF-IRES Lake Victoria Research Consortium, a multidisciplinary collaboration involving Kenyan, Canadian and U.S. institutions, and was partly supported by the National Science Foundation, IRES Track II: *Advanced Studies Institute on Water Quality and Harmful Algal Blooms in Lake Victoria* project, led by George Bullerjahn, Kefa Otiso and R. Michael McKay. Microcystin concentrations ranged from 0.01 to 1.34 micrograms per liter, with a mean of 0.149. The highest measurement, at Homa Bay Pier, exceeded the 1 microgram per liter threshold set by the World Health Organization in its guidelines for drinking water safety. This finding raises important questions about the quality of water in the Gulf and the potential risks facing communities that depend on the lake.

Brown et al. (2024) identified cyanobacteria carrying genes associated with the potential to produce microcystins and cylindrospermopsin in different parts of the Gulf. Zepernick et al. (2024) also documented spatial variation in cyanobacterial communities, identifying *Dolichospermum* as a dominant bloom-forming genus, with *Microcystis* also present. Even though the presence of these genes indicates the potential for toxin production, it does not confirm that toxins are actively being produced.

Monitoring cyanobacterial blooms is challenging. Their occurrence and distribution can change across locations and seasons, and blooms may develop or disappear between sampling visits. A sample collected at one station may therefore not capture conditions elsewhere in the Gulf nor reflect short-lived changes in water quality. Visible algal growth also does not necessarily indicate the presence of toxins. This makes repeated sampling, direct toxin measurements, and continuous water-quality monitoring important. More information is also needed on how toxin concentrations vary over time, which environmental conditions favor their production, and how these changes affect people, fish, and other aquatic organisms.

Why the waters are changing

Eutrophication happens when excessive nutrients like nitrogen and phosphorus enter an aquatic ecosystem and stimulate biological production. In Lake Victoria's basin, these nutrients can come from inadequately treated wastewater, agricultural fertilizers, livestock waste, and soil erosion. Research tracing environmental changes in the basin over the past century has linked shifts in land use and nutrient inputs with the lake's increasing eutrophication. Nutrient enrichment can favor dense cyanobacterial growth. When this organic matter dies and decomposes, microorganisms consume dissolved oxygen. Where oxygen becomes depleted, aquatic organisms may struggle to survive, and fish habitats can be affected. These processes are not uniform across the lake; conditions vary with location,

season, water movement and local sources of pollution. The Winam Gulf, with its shallow waters and river-influenced environments, illustrates why local monitoring matters.

Beyond the shoreline

The scale of the challenge means that the problem cannot be solved at the shoreline alone. Rivers carry materials from settlements, farms and other parts of the catchment into the lake. Pollution entering upstream environments can affect ecosystems and communities downstream. While removing accumulated algal growth may improve the appearance of affected shorelines, lasting improvement depends on addressing the nutrient pollution that fuels the blooms.

Yet, efforts to improve the health of Lake Victoria are already underway. Across the Lake Victoria Basin, governments, researchers, and development partners are working toward better sanitation, water-quality monitoring, and catchment management. The Lake Victoria Basin's Lakewide Inclusive Sanitation strategy, developed through regional cooperation, is one example. Assessments in 57 urban settlements across the five basin countries have helped identify sanitation needs and inform plans for reducing pollution through improved sanitation, drainage, and waste management. These are important steps, although strategies and plans must be matched by sustained investment, implementation and maintenance.

The first to notice

Communities must also be part of the response. People living and working around the lake are often the first to notice changes in water color, fish availability, odor, or the condition of familiar fishing grounds. Their observations can help researchers identify where and when to investigate, while accessible information can help communities understand potential risks and make informed decisions. This requires more than asking people to participate in research: it means sharing findings, listening to local experience, and involving communities in decisions about the lake's future.

The participant's question remains with me: could the unfamiliar growth covering the water ever disappear? There is no simple promise that the lake will return to an earlier condition, or that recovery will happen quickly. But neither should the scale of the challenge lead us to accept degradation as inevitable. Reducing nutrient pollution, expanding effective wastewater treatment, protecting wetlands and riverbanks, improving agricultural practices and strengthening long-term monitoring can all contribute to healthier waters. Scientific research can identify emerging risks and measure progress; regional institutions and governments can support coordinated action; and communities can help shape and sustain solutions.

For those whose lives are tied to Lake Victoria, hope must be more than reassurance. It must be visible in cleaner rivers, better-managed waste, reliable water-quality information, and meaningful action to protect the lake. We may not yet have every answer to the questions raised during that discussion. But we know enough to begin addressing the causes of the changes. The future of Winam Gulf will depend not only on what we learn about its waters, but on what we do with that knowledge.

Dorine Were is a research intern at the Kenya Marine and Fisheries Research Institute and a 2026 African Women in Science cohort member.



Young boys helping load nets onto fishing boats before their fathers set sail for a night fishing in Lake Victoria. Dunga Beach, Kisumu, Kenya. Photo: Evans Dims on Unsplash.

Beyond delisting: Understanding ecosystem recovery in Severn Sound

By Alana Tyner, Aisha Chiandet, Olena Volik, and Andrea Kirkwood

In 2003, Severn Sound became one of the first Great Lakes Areas of Concern (AOC) to be delisted. But that official turning point marked not just an end, but also a beginning that prompted a new set of questions: once the designation is gone, does the ecosystem recover? Does it last? And how would we know?

Severn Sound, located in southeastern Georgian Bay on Lake Huron, was designated a Great Lakes Area of Concern in 1987, mainly due to eutrophication and associated water quality issues. Anthropogenic nutrient inputs contributed to excessive algal growth, prompting decades of nutrient management and restoration efforts. The Severn Sound Remedial Action Plan (RAP) coordinated the response: upgrades to numerous wastewater treatment plants, stormwater and septic system improvements, tributary riparian tree planting, and a variety of agricultural projects, such as livestock exclusion fencing. As a result, water quality improved, algae declined, and the designation was removed.

To understand how the ecosystem responded over the course of restoration efforts, we went beyond water chemistry and turned to the base of the food web.



Celebrating Severn Sound's delisting as a Great Lakes Area of Concern in 2003. From left: Mayor Anita Dubeau, Town of Penetanguishene; Dunc McLaren, Severn Sound Public Advisory Committee Chair; Hon. Paul DeVillers, MP for Simcoe North; Hon. David Anderson, Minister of the Environment; Rt. Hon. Herb Gray, IJC Canadian Section Chair; Garfield Dunlop, MPP for Simcoe North; Coun. Bill Thompson, Town of Midland & SSEA Chair; and Keith Sherman, SSRAP Coordinator.

Four decades of phytoplankton change

Using phytoplankton data collected by the Severn Sound Environmental Association (SSEA) from 1973 to 2016, we examined long-term trends and shifts in phytoplankton communities before, during, and after AOC listing. The record covers five stations and more than 200 samples, collected across the four Severn Sound embayments, making it one of the longer continuous phytoplankton datasets in the Great Lakes, and one that covers both the degradation and recovery phases of an AOC.

Over the study period, total phytoplankton biovolume declined significantly across Severn Sound, with decreases being seen at all stations. Phytoplankton community composition also shifted between the pre- and post-listing periods. Bacillariophyta was a major component of the phytoplankton community before restoration efforts, however, over the study period Bacillariophyta biovolume heavily decreased. Although not as large of a component as Bacillariophyta, Cryptophyta and Dinophyta also experienced a decline. Which division took over varies from station to station, however Chrysophyta and Cyanophyta were commonly seen to increase.

Environmental drivers such as water temperature, total phosphorus, and total nitrate/nitrite were significantly associated with this variation. However, their impact on the seven major phytoplankton divisions differed. Total phosphorus was a significant explanatory variable for all divisions, however, total nitrate/nitrite was an explanatory variable for Bacillariophyta, Chlorophyta, Chrysophyta, and Dinophyta, and water temperature was an explanatory variable for Cryptophyta and Euglenophyta. This highlights the complexity of phytoplankton responses and the importance of considering multiple environmental drivers when assessing long-term ecological change.

A recovery with local variability

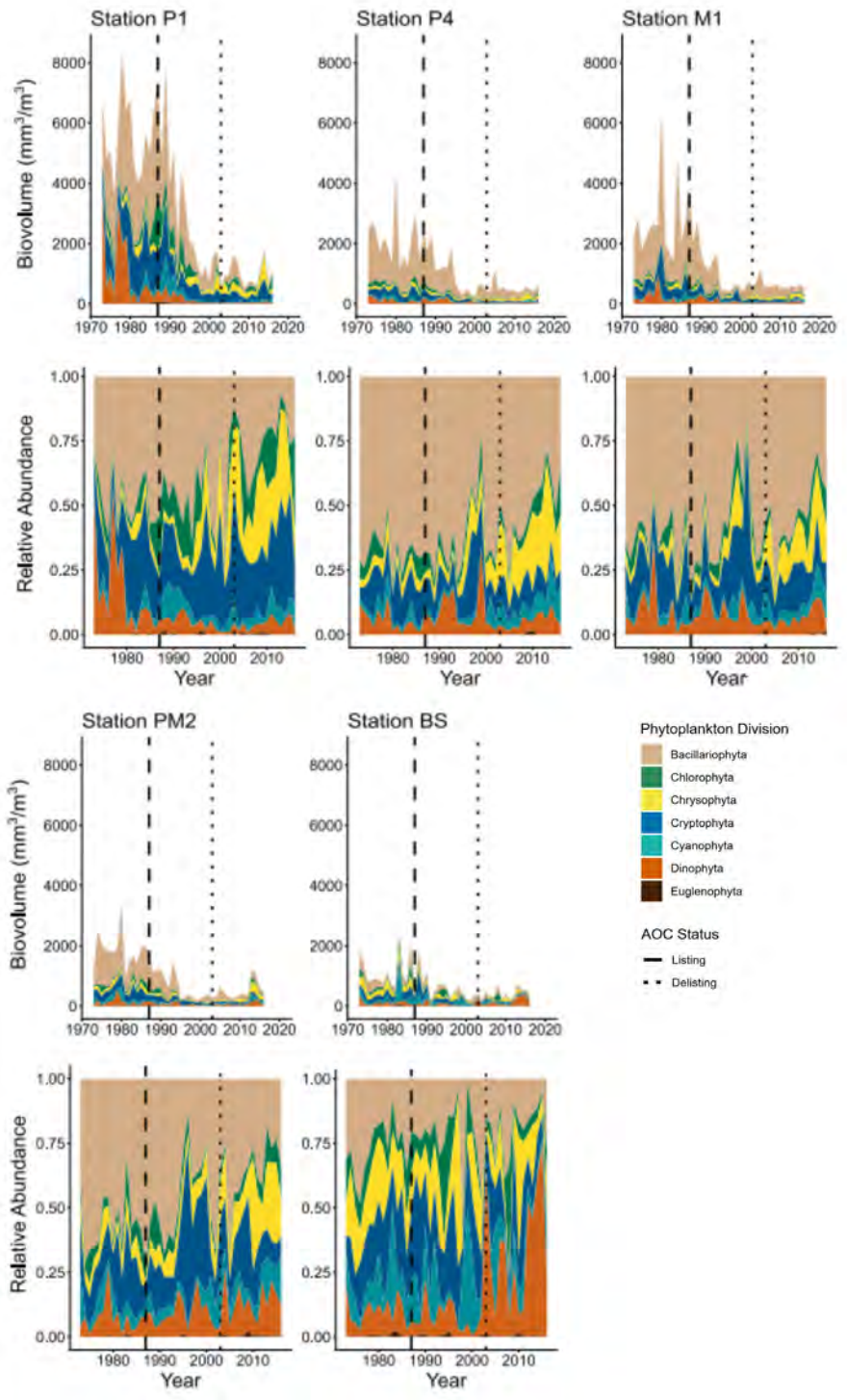
Phytoplankton communities also did not respond uniformly across Severn Sound. Variation among monitoring stations suggests that local conditions—basin morphometry, water movement, land use, and nutrient point sources—shaped community composition over time.

Phytoplankton abundance and community structure were also likely affected not only by changes in nutrients, but also by climate warming and the dreissenid mussel invasion, illustrating the complex ecosystem dynamics within this system.

What this means for the Great Lakes basin

The experience in Severn Sound demonstrates the value of examining phytoplankton communities when assessing the effects of restoration efforts. Declining algal abundance and shifting community composition provide information about ecological change, while differences among phytoplankton groups and monitoring stations highlight the complexity of lake responses. These findings emphasize the importance of long-term monitoring that considers biological communities alongside water quality indicators.

Although delisting represents an important restoration milestone, continued monitoring can help determine how communities respond to changing environmental conditions and inform future eutrophication management across the Great Lakes. This is particularly important as blue green algae blooms in nearshore and offshore areas are being reported more often despite overall phytoplankton decline. Future work should seek to examine nearshore algae communities and how they are responding to environmental change.



Biovolume (mm³/m³) and relative abundance of phytoplankton divisions across long-term sampling sites in Severn Sound from 1973 to 2016. Note the shifts between the pre- and post-AOC listing periods indicated by the vertical lines.

Alana Tyner is an aquatic ecologist at Ontario Tech University; Aisha Chiandet a project manager with Water First Education & Training Inc.; Olena Volik a water scientist at Severn Sound Environmental Association; and Andrea Kirkwood a professor of biological science at Ontario Tech University.

From eutrophication modeling to real time: Forecasting water quality risks

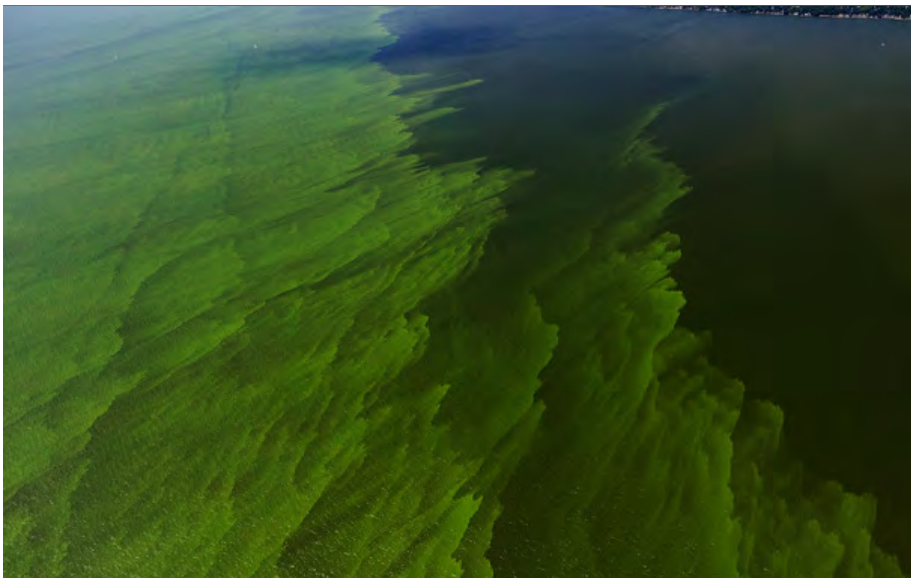
By Mark Rowe

Eutrophication models

In the 1960s and 1970s, eutrophication science linked adverse water quality outcomes, such as harmful algal blooms (HABs) and hypoxia, to nutrient pollution. Whole lake experiments showed the importance of phosphorus as a limiting nutrient and pointed toward phosphorus control as an important tool in lake management. Researchers introduced phosphorus mass balance models and empirical relationships between phosphorus loading and chlorophyll levels as important predictors of lake trophic status.

Such tools were the underpinning of phosphorus loading targets under the Great Lakes Water Quality Agreement (1972, 1978, 2012), which were credited with largely controlling eutrophication in the Great Lakes by the 1990s.

However, harmful algal blooms and hypoxia re-emerged in Lake Erie in the early 2000s, pointing to the need for an adaptive management approach whereby the status of nutrient loading targets and ecosystem response indicators are updated periodically. Applying phosphorus-based eutrophication principles, NOAA's National Centers for Coastal Ocean Science issues a forecast of the seasonal maximum HAB extent in Lake Erie based on the spring cumulative phosphorus load from the Maumee River.



Aerial image of a cyanobacterial harmful algal bloom in Lake Erie. Photo: Zachary Haslick, Aerial Associates Photography Inc.

The technologies that made forecasts possible

Traditional eutrophication modeling approaches continue to be useful for lake management, but for some applications, additional information on when and where adverse water quality outcomes are likely to occur can mitigate risks and point to additional management strategies.

In the 1990s and 2000s, advancements made in computing power and numerical models capable of simulating three-dimensional water currents and temperature made real-time forecasts a possibility. Early applications occurred in the Great Lakes, with the demonstration of a real-time forecast system in 1994. In the 2010s, unstructured grid models enabled realistic depictions of shoreline morphologies and currents in coastal areas, providing the basis for NOAA's Great Lakes Operational Forecast System.

At the same time, satellite-based ocean color sensors became increasingly available. Remote sensing retrievals specific to cyanobacteria were developed, enabling detailed tracking of harmful algal blooms.

Turning predictions into action on Lake Erie

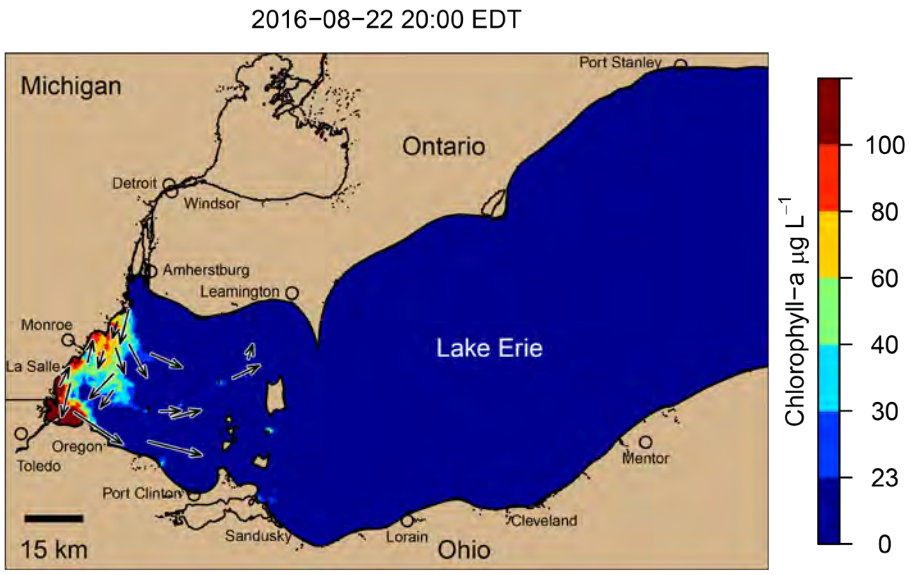
With advance notice of when and where water quality hazards are likely to occur, users of Lake Erie can direct activities toward less affected areas. Drinking water treatment operators can prepare staff, equipment, and supplies to adjust testing and treatment methods to ensure continuous delivery of high-quality drinking water.

With this goal in mind, researchers have developed real-time water quality forecasts. As early as 2009, NOAA began to produce a Lake Erie bloom transport forecast, combining satellite imagery of bloom location with a hydrodynamic forecast to predict movement of the bloom over coming days. While earlier versions of the transport model focused on surface currents, a subsequent version showed improved performance by simulating three-dimensional vertical mixing of buoyant cyanobacterial colonies.

Further development demonstrated capability to predict the risk of exceeding the recreational public health advisory level of microcystin toxin. This was made possible by combining the bloom transport forecast with a statistical model calibrated over a 10-year hindcast period that incorporates weekly monitoring of microcystins and chlorophyll-a, a measurement supported by reliable, sensitive immunoassay techniques that became readily available in the 1990s.

While HABs can be tracked using satellite imagery, hypoxia also causes risks to drinking water but is not directly visible. By tracking a mass budget for dissolved oxygen, similar in principle to eutrophication models based on a phosphorus budget, researchers demonstrated a real-time hypoxia forecast that predicts coastal upwelling events that cause rapid changes in water quality at drinking water intakes.

These technological and research advances provided the basis for operational real-time HAB and hypoxia forecasts produced by NOAA. With continued advances in computing power, numerical modeling, remote sensing, and new technologies such as AI and machine learning, opportunities abound for continued research and advancement of real-time water quality prediction to enable coastal communities to mitigate risks and maximize the use of freshwater resources.



An experimental Lake Erie harmful algal bloom forecast from 2016, showing predicted movement of the HAB out of Maumee Bay past water intakes on the Ohio coast.

Mark Rowe is a research physical scientist with NOAA Great Lakes Environmental Research Laboratory.

GREAT LAKES FISHERY COMMISSION

Call for proposals

The Great Lakes Fishery Commission is soliciting pre-proposals and pilot project proposals for the **Fishery Research** and **Sea Lamprey Research** programs.

www.glfc.org/call-for-proposals.php



Fishery Research special topics

- Indigenous-led research
- Effects of emerging contaminants and pollutants

Sea Lamprey Research special topics

- Impacts of extreme weather on sea lamprey control
- Population-level effects of lampricides on non-target organisms
- Improved understanding of granular Bayluscide effectiveness
- Human dimensions of sea lamprey control

PROPOSALS DUE

January 15, 2027

Questions? Contact **research@glfc.org**

View our informational webinars to learn more about research needs and the funding process.

To access, scan the QR code or visit **www.glfc.org/call-for-proposals.php.**

Photo: Aerial shot of the St. Marys River. Zak Allon, GLFC
This product contains content generated with the assistance of artificial intelligence (AI), and has been evaluated for accuracy.

Great Lakes Fishery Commission
PROTECTING OUR FISHERY

An inconvenient bloom

By Steven W. Wilhelm, R. Michael McKay, and George S. Bullerjahn



A worker assesses algae from the Lincoln Memorial Reflecting Pool in Washington, D.C., in June 2026. Photo: SWinxy via Wikimedia Commons / CC BY 4.0.

Reports earlier this year about renovations and an algal takeover of the Reflecting Pool in Washington, D.C., made international headlines. Millions of dollars were spent in an attempt to keep this iconic tourist destination looking blue and attractive to visitors.

But the Reflecting Pool is far from the only water body dealing with algae problems. Water bodies of every size—from small ponds in neighborhood parks and on farms to vast systems like the Laurentian and African Great Lakes—have experienced recurring algal blooms for decades. So why did this particular bloom capture so much attention, and what should we take from it?

The Lincoln Memorial Reflecting Pool is part of the National Mall, one of the most visible and visited places in the country. The larger National Mall complex attracts roughly 24 million visitors each year and contributes an estimated $1.1 billion annually to the regional economy. In that context, spending millions to maintain such a prominent public feature may seem justified.

Still, it is striking that this event received so much media attention when harmful algal blooms are a much broader international problem. Consider Lake Erie: toxin-producing cyanobacterial blooms can stretch up to 2,000 square miles (>5,000 km^2) and have become a recurring feature of summer. Yet Lake Erie supports about $20 billion annually in tourism, a commercial freshwater fishery with an estimated regional economic impact of $244 million coupled to a massive recreational charter boat fishery whose impact alone is over $1 billion. This is not to mention the drinking water that serves around 11 million people. Equally concerning is the spread of blooms to sites where they were never imagined to occur. Indeed, Lake Superior is susceptible to bloom events since they were first reported in 2012. Even Great Slave Lake in Canada's remote Northwest Territories has seen regular blooms throughout the 21st century. If an artificial reflecting pool is worth major investment and concern, surely natural systems of this scale deserve at least equal attention and protection.

Understanding and managing harmful algal blooms in the Great Lakes is already a priority for several agencies, with the National Oceanic and Atmospheric Administration and various state agencies playing a leading role in bloom monitoring and forecasting in the United States, with Environment and Climate Change Canada and provincial counterparts serving similar roles across the border. Yet these programs are often vulnerable to budget cuts even as environmental protections are weakened. From both an environmental and economic standpoint, that is a risky choice.

Algal bloom control is not simple. In highly managed, people-centered water features like the Reflecting Pool, it may be acceptable and feasible to use aggressive treatments such as hydrogen peroxide or nanobubble-based systems that indiscriminately suppress much of the biology in the water. But those approaches are far less appropriate in natural lakes, where scalability and ecology come into play. Unless a treatment is highly selective, it can harm the broader plankton community as well as the problem species. That leaves behind an empty ecological space that harmful algae can quickly reclaim.

In both Lake Erie and the Reflecting Pool, eutrophication caused by excess nutrients from urban and agricultural sources remain the main underlying cause of the problem. In a small, engineered water body, controlling those inputs may be relatively straightforward. In natural lakes and reservoirs, however, nutrient management is far more challenging. Although we have made real progress in recent decades, we are still not where we need to be.

Maybe this story is best understood as more than just a local nuisance. The problems in the Washington Reflecting Pool may be a "convenient bloom": a highly visible reminder that water bodies across the globe provide enormous public and economic value—but only if we are willing to invest in their care and protection. Let's not waste the lesson it offers.

Steven W. Wilhelm is Mossman Professor and distinguished professor at the University of Tennessee. R. Michael McKay is director of the Great Lakes Institute for Environmental Research and professor at the University of Windsor. George S. Bullerjahn is director emeritus of the Great Lakes Center for Freshwater Waters and Human Health and distinguished professor emeritus at Bowling Green State University.

Building a better infrastructure for science communication

By John C. Besley

Editor's note: Throughout this issue, we've traced what scientists have learned about eutrophication, and where that understanding continues to evolve. But research benefits lakes only when it reaches and resonates with the people whose decisions affect them. In our closing Perspective, science communication scholar John C. Besley argues that the gap between research and society is not primarily a failure of individual scientists, but of infrastructure: the lasting relationships, support, and institutional commitment that allow insights to flow both ways between scientists and society. For scientists wondering where their next decade of work should lead, his question is a fitting place to start: who, if not scientists, will take the lead in building and sustaining the two-way exchange that research and the lakes depend on?

Not every scientist needs to communicate with every audience. But every scientist should identify a role they want to play in ensuring that society has access to the insights research generates. The science communication infrastructure we need must connect research with those who need it and bring societal needs back to researchers. If scientists do not take the lead in building and maintaining that infrastructure, who will?

My use of the term "infrastructure" is intentional. It includes the people, organizations, channels, resources, and processes that make high-quality communication possible. Science communication requires more than individual effort; it needs this infrastructural support for sustained engagement.

Too many science communication discussions focus on training individual scientists to choose, plan, implement, and evaluate their own communication efforts. Many of my colleagues and I increasingly recognize that this places an unnecessary burden on scientists. It can also lead to poor-quality communication and research programs that fail to address stakeholders' true needs. Weak stakeholder relationships make these challenges harder to overcome.

Focusing on relationships offers a useful way to ensure that time spent on communication is well spent. It also clarifies what science communication infrastructure must accomplish: support sustained, two-way exchange of ideas.

Relationships that support two-way sharing of insight

The "strategic science communication" that I propose through my work emphasizes helping scientists and their organizations identify priority behavioral goals for specific audiences and then building a communication program to achieve those goals. From this perspective, relationships are not the end goal. Rather, positive relationships support two complementary goals:

- Helping key stakeholders consider scientific insights in their decision making—a goal scientists consistently tell us they prioritize.
- Integrating stakeholder insights into research and communication decisions—a goal we encourage scientists to prioritize, but one they sometimes neglect.

But relationships do not just happen. Building relationships that enable scientists to share and seek insights takes deliberate effort and support. Well-managed businesses, nonprofits, and government agencies typically have specialist communication staff who help subject-matter experts manage relationships. Indeed, relationships are at the heart of public relations specialties such as media relations, community relations, and stakeholder relations. Too few scientific organizations have people in such roles.

Building trusting relationships requires more than expertise

As a science communication researcher who focuses on trust, I often find myself reminding scientists that demonstrating expertise is rarely enough to motivate or sustain relationships. Trustworthiness research suggests that people almost always also want to understand scientists' character as part of deciding whether to consider such scientists' advice or put time into sharing information about their community's needs and concerns. And learning about character—including the degree to which experts are motivated by a desire to help, act with integrity, and are open to the views of others—takes time.

It also takes sustained effort to reassure potential stakeholders that trusting scientists with their time

and energy is worthwhile, given their own goals. Moreover, even if people are open to engaging, they may face a range of constraints that make such interaction difficult to sustain, including competing personal and professional priorities. They may also—sometimes justifiably—worry that engaging with scientists will put them in an uncomfortable position in which scientists treat them more like students than colleagues or neighbors.

What help looks like

In a recent interview study of communication through Long-Term Ecological Research (LTER) sites, we found that the organizations with the most advanced communication efforts had created ways for scientists to collaborate with engagement professionals. *Engagement professionals* is a broad term meant to describe communication experts who help scientists participate in substantive, sustained discussions with stakeholders and other societal actors. In some cases, such efforts included internal sharing of resources across projects and grants to support one or more communication experts who could help sustain the type of broad communication that relationships require. Some LTERs, however, partnered with organizations such as museums and environmental education centers that are in better positions to manage relationships with key stakeholders. In such cases, scientists had opportunities to participate in or support communication but did not have to take primary responsibility for relationship management.

In other ongoing research, we are finding that scientists appreciate communication support of many kinds. This includes logistical and implementation support, as well as more strategic help identifying priorities and designing ethical paths toward achieving them. This is also consistent with our past research at two LTER sites that highlighted how much scientists valued having an engagement professional to help manage communication. In one case, for example, this engagement professional helped create and run a community advisory board that gave scientists opportunities to interact with stakeholders that they might not otherwise have had.

Across these studies, the pattern is consistent. Scientists value both strategic and practical support, and shared responsibility can make sustained engagement more feasible. The question, then, is not whether every scientist should communicate more, but how scientific organizations can create the support needed for sustained engagement.

The question, then, is not whether every scientist should communicate more, but how scientific organizations can create the support needed for sustained engagement.

Going forward

Given the current funding environment, it would be naïve to expect every scientific organization to create the type of robust communication infrastructure that professionals in other sectors of society have built. That said, if scientists want to ensure their research has impact and serves societal needs, they need to look for ways to build and maintain the trusting relationships that can enable experts to share and seek insights. One option is to ask scientists to do more on their own, but a better option is to allocate meaningful resources to communication support. Depending on their circumstances, organizations might hire communication professionals, share expertise across projects, or partner with museums, education centers, and other organizations equipped to sustain stakeholder relationships. Scientific organizations already invest in specialized support for accounting, grant management, and human resources. They should likewise treat communication support as a core organizational capacity, scaled to their missions, audiences, and resources, rather than as an optional burden placed on individual scientists. The goal is not to separate scientists from stakeholders, but to provide the support that allows scientists to participate effectively without asking them to manage every aspect of communication themselves.

John C. Besley is the Ellis Brandt Professor of Public Relations in the College of Communication Arts and Science at Michigan State University and co-author of Strategic Science Communication (2022) and Science Communication for Scientists (2026).

This material is based upon work supported by USDA NIFA (MICL02758). Any opinions, findings, conclusions, or recommendations expressed in this article are the author's and do not necessarily reflect the views of the USDA.

IAGLR

International Association
for Great Lakes Research

CONNECT. LEARN. COLLABORATE. LEAD.

Science for lakes. Connections for life.

GLOBAL COMMUNITY

Connect with a diverse network of individuals passionate about large lakes worldwide.

LEARN & GROW

Access cutting-edge science, webinars, and leadership opportunities.

COLLABORATE

Find partners and opportunities to work together on local and global challenges.

AMPLIFY YOUR VOICE

Share your research, contribute ideas, and help shape the future of lake science.







Renew Your Membership

or Join Today!

VISIT IAGLR.ORG →

COLLABORATION • DIVERSITY & INCLUSION • EXCELLENCE • LEARNING • STEWARDSHIP