REPORT TO CONGRESS

HARMFUL ALGAL BLOOMS AND HYPOXIA IN THE GREAT LAKES: AN INTERAGENCY PROGRESS AND IMPLEMENTATION REPORT

Developed pursuant to: Section 605(b) of the Harmful Algal Bloom and Hypoxia Research and Control Amendments Act, 2014 (Public Law 113-124)

Nicole R. LeBoeuf
Assistant Administrator for Ocean Services and Coastal Zone Management
National Ocean Service
National Oceanic and Atmospheric Administration

Richard W. Spinrad, Ph.D.
Under Secretary of Commerce for Oceans and Atmosphere
NOAA Administrator

THE REPORT TO CONGRESS (HARMFUL ALGAL BLOOMS AND HYPOXIA IN THE GREAT LAKES: AN INTERAGENCY PROGRESS AND IMPLEMENTATION REPORT) ACCOMPANYING THE HARMFUL ALGAL BLOOM AND HYPOXIA RESEARCH AND CONTROL AMENDMENTS ACT, 2014 (PUBLIC LAW 113-124) INCLUDED THE FOLLOWING LANGUAGE

Sec. 605. Great Lakes hypoxia and harmful algal blooms
(a) Integrated assessment.—
Not later than 18 months after the date of enactment of the Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2014, the Task Force, in accordance with the authority under section 603, shall complete and submit to the Congress and the President an integrated assessment that examines the causes, consequences, and approaches to reduce hypoxia and harmful algal blooms in the Great Lakes, including the status of and gaps within current research, monitoring, management, prevention, response, and control activities by—

(1) Federal agencies;
(2) State agencies;
(3) regional research consortia;
(4) academia;
(5) private industry; and
(6) nongovernmental organizations.

(b) Plan.—

(1) In general.—
Not later than 2 years after the date of enactment of the Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2014, the Task Force shall develop and submit to the Congress a plan, based on the integrated assessment under subsection (a), for reducing, mitigating, and controlling hypoxia and harmful algal blooms in the Great Lakes.
(2) Contents.— The plan shall—

(A) address the monitoring needs identified in the integrated assessment under subsection (a);
(B) develop a timeline and budgetary requirements for deployment of future assets;
(C) identify requirements for the development and verification of Great Lakes hypoxia and harmful algal bloom models, including—

(i) all assumptions built into the models; and
(ii) data quality methods used to ensure the best available data are utilized; and

(D) describe efforts to improve the assessment of the impacts of hypoxia and harmful algal blooms by—

(i) characterizing current and past biological conditions in ecosystems affected by hypoxia and harmful algal blooms; and
(ii) quantifying effects, including economic effects, at the population and community levels.
(3) Requirements.—In developing the plan, the Task Force shall—
(A) coordinate with State and local governments;

(B) consult with representatives from academic, agricultural, industry, and other stakeholder groups, including relevant Canadian agencies;
(C) ensure that the plan complements and does not duplicate activities conducted by other Federal or State agencies;
(D) identify critical research for reducing, mitigating, and controlling hypoxia events and their effects;
(E) evaluate cost-effective, incentive-based partnership approaches;
(F) ensure that the plan is technically sound and cost effective;
(G) utilize existing research, assessments, reports, and program activities;
(H) publish a summary of the proposed plan in the Federal Register at least 180 days prior to submitting the completed plan to Congress; and
(I) after submitting the completed plan to Congress, provide biennial progress reports on the activities toward achieving the objectives of the plan.

THIS REPORT RESPONDS TO THE U.S. SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION; U.S. HOUSE COMMITTEE ON NATURAL RESOURCES; AND U.S. HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY REQUEST.

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

For the past several decades, the Great Lakes region has experienced negative socioeconomic, public health, and environmental impacts due to harmful algal blooms (HAB) and hypoxia (low oxygen conditions) in the lakes' waters. Since the mid-1990s, there has been an increase in the size, duration, and prevalence of these scientifically-complex events in the Great Lakes region due to increased nutrient runoffs, mainly from nonpoint agricultural sources, complicated by a changing climate, resulting in increases in precipitation, runoff, flow and temperature and related changes in agricultural management practices during that time (Smith et al. 2015). HABs and hypoxia cost the Great Lakes communities millions of dollars annually (Bingham et al., 2015; EPA, 2015; Smith et al., 2019). These losses include reduced income from commercial fishing, recreation, and tourism; public health costs due to human and animal illness; and expenses related to conservation, monitoring, and management, including but not limited to water treatment (Bingham et al., 2015; Smith et al., 2019).

Per the requirements of 605(b)(3)(I) of the 2014 reauthorization of the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA 2014; Public Law (P.L.) 113-124), this biennially mandated document presents to Congress the progress made by Federal agencies to implement the recommendations laid out in the "Harmful Algal Blooms and Hypoxia in the Great Lakes Research Plan and Action Strategy: An Interagency Report" (GLRPAS), published on August 24, 2017, the first progress report, "Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation," published in March 2018, and the second progress report, "Harmful Algal Blooms and Hypoxia in the Great Lakes: An Interagency Progress and Implementation Report," published in November 2020. These reports discuss recent advancements in technology and conservation practices that allow for continued HAB and hypoxia monitoring, detection and abatement, including improvements made to instruments, modeling, and understanding of how to more effectively manage and reduce nutrient runoff. The GLRPAS and its progress reports all review developments and highlight activities taking place in the Great Lakes region that improve the understanding of the drivers of HABs and hypoxia; how long events last; the best methods for managing causes; and how HABs and hypoxia can affect human and animal health, the economy, and the ecology of the Great Lakes. The GLRPAS and its progress reports show how the Federal Government works with communities, resource managers, land owners, and other stakeholders to reduce the risk of events as well as minimize impacts during an event, and stresses the importance of preparedness through continuous monitoring, forecasting, policies, and other means.

Since the publication of the GLRPAS and the 2018 and 2020 progress reports, the Federal agencies in the Interagency Working Group-HABHRCA have made progress in addressing the causes of HABs and hypoxia in the Great Lakes, thus helping to mitigate their impacts. This progress report discusses advancements since then. Improvements in technology and conservation practices described throughout this progress report allow for real-time and near real-time HAB and hypoxia forecasting and monitoring, detection, and abatement. Some noted achievements include:

- As of 2022, Great Lakes Restoration Initiative (GLRI) Federal agencies estimate that over

2 million pounds of phosphorus have been prevented from leaving farms and entering the Great Lakes cumulatively as a result of GLRI-funded projects, including over 500,000 pounds of phosphorus reductions in fiscal years (FY) 2020-2021.

- The National Oceanic and Atmospheric Administration (NOAA) deployed a new mooring system in Lake Erie from 2017-2021 to quantify the duration, spatial extent, and thickness of the hypoxic layer, and continued the development of a Lake Erie hypoxia early warning system. NOAA Great Lakes Environmental Research Laboratory's (GLERL) Experimental Hypoxia Forecast Model provides several days of advance notice that water quality is changing, so that drinking water plant managers can be prepared to adjust their treatment processes as needed.

- United States Geological Survey (USGS) scientists continued their GLRI-funded sentinel site monitoring program in lakes Michigan, Huron, Erie, and Ontario to examine the influence of nutrient concentrations, invasive zebra and quagga mussels, and microbial ecology on *Cladophora* growth. USGS is also testing new methods to remotely sense *Cladophora* using autonomous underwater vehicles.

- The National HAB Observing Network (NHABON) implementation strategy was released in 2021, with NOAA's U.S. Integrated Ocean Observing System Office (IOOS) allocating $2.8 million in FY21 for NHABON-related activities nationwide. These activities include support of an early warning system for Lake Erie.

- Development of a pilot project funded by the USGS-National Park Service (NPS) Water Quality Partnership Program to address critical management needs related to HAB monitoring and response in four Great Lakes national parks (Apostle Islands National Lakeshore, Isle Royale National Park, Sleeping Bear Dunes National Lakeshore, and Perry's Victory & International Peace Memorial), in collaboration with NOAA, the U.S. Environmental Protection Agency (EPA), and the University of Wisconsin-Milwaukee.

- Support of 18 projects (totaling ~$14M) by the National Science Foundation (NSF) specifically related to HABs and hypoxia in the Great Lakes.

- Release of a Cyanotoxins Preparedness and Response Toolkit (CPRT) by the EPA to assist state and tribal partners with preparations for potential HABs in freshwater bodies and respond to protect public health. In addition, the EPA developed the "Tracking HABs Story Map," an interactive tool to gather information on HABs occurrences in our Nation's waters, including the Great Lakes.

- Release of a decadal national assessment of conservation practice effects on cultivated cropland by the United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS), which helps track outcomes from conservation nationally by cropland region as well as provide insight broadly into remaining conservation treatment needs.

- The Inflation Reduction Act will deliver $19.5 billion in new conservation funding to support climate-smart agriculture, including for USDA-NRCS to improve opportunities for nutrient management. NRCS recently announced it is targeting funding, increasing program flexibilities, launching a new outreach campaign to promote nutrient management's economic benefits, and expanding partnerships to develop nutrient management plans.

- In 2022, the NRCS highlighted *SMART* nutrient management planning which includes the 4Rs of nutrient stewardship (right Source, right Method, right Rate, and right Timing) and emphasizes smart activities to reduce nutrient loss by adding *Assessment* of comprehensive, site-specific conditions, recognizing that nutrient needs – as well as risks for nutrient losses – vary within a field.

ABBREVIATIONS

2G	Second-Generation
3G	Third-Generation
AERC	Agricultural Economics and Rural Communities
AFRI	Agriculture and Food Research Initiative
AMoN	Ammonia Monitoring Network
ARS	Agricultural Research Service
ART	Analytical Response Team (NOAA)
ASTHO	Association of State and Territorial Health Officials
BMP	Best Management Practice
BNRE	Bioenergy, Natural Resources, and Environment (USDA-AFRI)
CARE	Critical Agricultural Research and Extension
CBET	Chemical, Bioengineering, Environmental and Transport Systems (NSF)
CCL	Containment Candidate List (EPA)
CDC	Centers for Disease Control and Prevention
CEAP	Conservation Effects Assessment Project
CHRP	Coastal Hypoxia Research Program
CI	Cyanobacteria Index
CIG	Conservation Innovation Grants (USDA-AFRI)
CIGLR	Cooperative Institute for Great Lakes Research
CO-OPS	Center for Operational Oceanographic Products and Services (NOAA)
CPS	Conservation Practice Standards
CRM	Certified Reference Material
CyAN	Cyanobacteria Assessment Network
DHHS	Department of Health and Human Services
DO	Dissolved Oxygen
DOD	Department of Defense
DOI	Department of the Interior
DWACT	Drinking Water Advisory Communications Toolbox
ECB	Eastern Corn Belt
ECOHAB	Ecology and Oceanography of Harmful Algal Blooms
ENG	Engineering Directorate (NSF)

EPA	United States Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
ERDC	Energy Research and Development Center (USACE)
ES	Exposure Science
ESP	Environmental Sample Processor
EWS	Early Warning System
FIB	Fecal Indicator Bacteria
FDA	Food and Drug Administration
GLC	Great Lakes Commission
GLERL	Great Lakes Environmental Research Laboratory (NOAA)
GLOS	Great Lakes Observing System
GLRI	Great Lakes Restoration Initiative
GLRPAS	Great Lakes Research Plan and Action Strategy
GLWQA	Great Lakes Water Quality Agreement
HABs	Harmful Algal Blooms
HABHRCA	Harmful Algal Bloom and Hypoxia Research and Control Act
HHWQC	Human Health Water Quality Criteria
IOOS	Integrated Ocean Observing System
IWG-HABHRCA	Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act
LC-MS/MS	Liquid Chromatography Tandem Mass Spectrometry
LID	Low Impact Development
LRAUV	Long-Range Autonomous Underwater Vehicle
LTAR	Long-Term Agroecosystem Research
MBARI	Monterey Bay Aquarium Research Institute
MERHAB	Monitoring and Event Response for Harmful Algal Blooms
MPS	Mathematics and Physical Sciences Directorate (NSF)
NADP	National Atmospheric Deposition Program
NARS	National Aquatic Resource Surveys
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service (USDA)
NBOT	Nano Bubble Ozone Technology
NCCOS	National Centers for Coastal Ocean Science (NOAA)
NEMO	National Education for Municipal Officials
NEON	National Ecological Observatory Network
NIEHS	National Institute of Environmental Health Sciences
NIFA	National Institute of Food and Agriculture
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NORS	National Outbreak Reporting System
NPS	National Park Service
NRCS	Natural Resources Conservation Service (USDA)
NSF	National Science Foundation
NUE	Nitrogen Use Efficiency
NWQI	National Water Quality Initiative
OHH	Oceans and Human Health Initiative (NSF/NIEHS)

OHHABS	One Health Harmful Algal Blooms
OLCI	Ocean and Land Color Instrument
OSTP	Office of Science and Technology Policy
PCM	Prevention, Control, and Mitigation
PCMHAB	Prevention, Control, and Mitigation of Harmful Algal Blooms – Program that transitions promising PCM technologies and strategies to end users and is authorized by the Harmful Algal Bloom and Hypoxia Research and Control Act (1998, 2014)
PMN	Phytoplankton Monitoring Network
SARE	Sustainable Agriculture Research and Education
SBIR	Small Business Innovation Research program (USDA)
SDWA	Safe Drinking Water Act
SPARROW	Spatially-Referenced Regression on Watershed attributes
SPR	Surface Plasmon Resonance
SPSC	Soil Phosphorus Sorption Capacity
srRNA	Small Regulatory RNA
STEWARDS	Sustaining the Earth's Watersheds – Agricultural Research Database System (USDA-ARS)
UAS	Unmanned Air Systems
UCMR	Unregulated Contaminant Monitoring Program (EPA)
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WLEB	Western Lake Erie Basin

ABOUT THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA is an agency that enriches life through science. Our reach extends from the surface of the sun to the depths of the ocean floor as we work to keep citizens informed of the changing environment around them.

From daily weather forecasts, severe storm warnings, and climate monitoring to fisheries management, coastal restoration and supporting marine commerce, NOAA's products and services support economic vitality and affect more than one-third of America's gross domestic product. NOAA's dedicated scientists use cutting-edge research and high-tech instrumentation to provide citizens, planners, emergency managers and other decision makers with reliable information they need when they need it.

ABOUT THIS DOCUMENT

This document was developed by the Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act (IWG-HABHRCA) of the Subcommittee on Ocean Science and Technology (SOST). The report is intended to meet the statutory requirements to address HABs and hypoxia, as prescribed by the HABHRCA.

The 2022 report includes an Executive Summary that provides a general overview of the document. This summary is followed by a brief synopsis of HABs and hypoxia (low oxygen condition) events that occur in the Great Lakes. The remainder of the main body of the report contains narrative updates from a selection of IWG-HABHRCA member agencies. The list of specific activities in Appendix A provides an update on each activity that was identified in the original 2017 GLRPAS and 2020 Interagency Progress and Implementation Report. Finally, Appendix B includes new activities that were begun, expanded, or changed since the original 2017 GLRPAS and 2020 Progress and Implementation Report were written.

This report should be cited as: IWG-HABHRCA (Interagency Working Group on Harmful Algal Bloom and Hypoxia Research and Control Act) (2022). *Harmful Algal Blooms and Hypoxia in the Great Lakes: An Interagency Progress and Implementation Report*. Report to Congress. National Oceanic and Atmospheric Administration.

ACKNOWLEDGEMENTS

The IWG-HABHRCA thanks Kevin McMahon of the National Oceanic and Atmospheric Administration for his help with editing and designing this report.

Special thanks and acknowledgement to the following subject-matter experts who contributed to the writing of this report:

NOAA: Chelsea Berg, Greg Doucette, Reagan Errera, Michelle Harmon, Karen Kavanaugh, David Kidwell, Deborah Lee, Tod Leighfield, Anthony Marshak, Felix Martinez, Gladys Miles, Kaytee Pokrzywinski-Boyd, John Ramsdell, Steven Ruberg, Margo Schulze-Haugen, Richard Stumpf, Steven Thur, Tiffany Vance

Bureau of Indian Affairs: Ryan Portalatin, David Wooten

Centers for Disease Control and Prevention: Lorraine Backer

National Aeronautics and Space Administration: Bradley Doorn, Jared Entin, Laura Lorenzoni, Joel Scott

National Institute of Environmental Health Sciences: Anika Dzierlenga

National Park Service: Jamie Kilgo, Brenda Moraska Lafrancois

National Science Foundation: Stacy Aguilera-Peterson, Jeanne M. VanBriesen, Michael Sieracki

United States Army Corps of Engineers: Tony Clyde, Erich Emery, Mandy Michalsen, Jennifer Seiter-Moser, Christine Vanzomeren

United States Department of Agriculture: Lisa Duriancik, Marlen Eve, Gene Kim, Kevin King, Eric Norland, Peter Thompson, Teferi Tsegaye

United States Environmental Protection Agency: Lesley D'Anglada, Elizabeth Hinchey Malloy, Deborah Nagle, Santina Wortman

United States Food and Drug Administration: Jonathan Deeds

United States Geological Survey: Mary Anne Evans, Lisa Fogarty, Jennifer Graham, Jon Hortness, Tyler King, Kathy Lee, Keith Loftin, Jenny Murphy

II. INTRODUCTION

A. What are HABs and Hypoxia?

HABs[1] and hypoxia[2] have continued to impact the Great Lakes for the past several decades, with these events intensifying since the mid-1990s. The periodic HABs of the past have now been replaced by annual, extensive, summer-long blooms dominated by toxic cyanobacteria in the western Lake Erie basin and other areas, while the central Lake Erie basin and other areas of the Great Lakes (e.g., Green Bay, Lake Michigan; Irondequoit Bay, Lake Ontario; Saginaw Bay, Lake Huron) are experiencing summer hypoxic events (Klumb et al., 2004; Steffen et al., 2014; Reavie et al., 2016; Watson et al., 2016; Tellier et al., 2022). Excess nitrogen and phosphorus loading, driven by increases in agricultural non-point sources and urban storm water runoff, have been recognized as a key driver of HABs and hypoxic events in the Great Lakes (Steffen et al., 2014; Watson et al., 2016; Paerl et al., 2019). The drivers of these nutrient trends in the Great Lakes region are complex, and include atmospheric and climatic changes, increases in streamflow, changing agricultural management practices, and changing precipitation-runoff response due to the combination of land-use practice and drainage modifications and increasing seasonal precipitation (Choquette et al., 2019; Jabarri et al., 2021). When promoted by human-influenced ecosystem changes, such as nutrient loading, extreme weather events, and invasive organisms, HABs can form dense blooms of biomass that can disrupt the environment and local economies, and/or can produce toxins that are harmful to people and animals. Although significant effort has been made to reduce the input of nutrients into the Great Lakes, these nutrients can remain within the sediments in fields and water bodies serving as "legacy" nutrients and fueling HABs and hypoxia for years after initial input into the system (Watson et al., 2016; Arhonditsis et al., 2019; Paerl et al., 2019; Sharpley et al. 2013).

Cyanobacteria HABs occur throughout the Great Lakes, including western and central Lake Erie (Chaffin et al., 2021); Saginaw Bay in Lake Huron (Fahnenstiel et al., 2008); Green Bay in Lake Michigan (Bartlett et al., 2018); and in smaller embayments,

[1] HABHRCA, 33 U.S.C. § 4008(3), defines an HAB as "marine and freshwater phytoplankton that proliferate to high concentrations, resulting in nuisance conditions or harmful impacts on marine and aquatic ecosystems, coastal communities, and human health through the production of toxic compounds or other biological, chemical, and physical impacts of the algae outbreak."

[2] HABHRCA, 33 U.S.C. § 4008(4), defines hypoxia as "a condition where low dissolved oxygen in aquatic systems causes stress or death to resident organisms."

tributaries, and nearshore areas, such as Muskegon Lake (Mancuso et al., 2021), western Lake Superior (Sterner et al., 2020), Lake St. Clair, Sandusky Bay, the Sandusky and Maumee Rivers, Little Bay du Noc, Bay of Quinte (Canada), Hamilton Harbor (Canada), Sturgeon Bay (Canada), Honey Harbor (Canada), and Sodus Bay (New York; McKindles et al., 2020). HABs that impact the Great Lakes are often categorized into two groups; toxic cyanobacteria and non-toxic nuisance algae. Dominant cyanobacteria species in the Great Lakes that may become harmful include: *Microcystis*, *Dolichospermum*, *Aphanizomenon*, *Planktothrix*, and *Lyngbya* spp. Toxins produced by toxic cyanobacteria have the potential to kill fish, and pose risks to human health if sufficient amounts of toxins are ingested through contaminated drinking water, accidental ingestion during recreational activities, eating contaminated food, or breathing contaminated air (Wood, 2016). These toxins can also sicken or kill pets, livestock, and wildlife through ingestion of contaminated water and/or food supplies (Byappanahalli et al., 2003; Carmichael and Boyer, 2016; McKindles et al., 2020). It is important to note that blooms of cyanobacteria can be non-toxic or composed of species that do not produce toxins; however, these blooms may also be considered harmful to the ecosystem (Davis et al., 2010; Kitchens et al., 2018; Akins et al., 2020). Another category of HABs includes "nuisance" algae, which often do not produce toxins, but foul the shoreline of the Great Lakes. Extensive blooms of *Cladophora* spp., a benthic filamentous algae, occur each summer and contaminate beaches with rotting algal mats, clog water intakes, impair water quality, pose health risks to wildlife and humans, block light to bottom-dwelling plants, restructure food web dynamics, give drinking water a bad taste or odor, and harbor pathogens (Ishii et al., 2006, Lopez et al., 2008; Auer et al., 2010; Chun et al., 2013, IJC, 2014; Paerl et al., 2016). *Cladophora* blooms are found in the Grand Traverse Bay and Sleeping Bear Dunes areas of Lake Michigan, in Lake St. Clair, along the northern shorelines of Lake Erie near Ajax (Canada) and Lake Ontario (Canada), and the southern shoreline of Lake Ontario (Auer et al., 2010; IJC, 2013; Shuchman et al., 2013; Zhou et al., 2021). Mats of *Cladophora* and other green algae can be associated with pathogens, including avian botulism, which kills fish and birds, and waterborne pathogens that can harm humans (Ishii et al., 2006; Chun et al., 2013; Lan et al., 2014; Brooks et al., 2015).

Hypoxia is a condition where the concentration of oxygen dissolved within the water decreases to levels below 2 mg/L, which is the level where most macrofauna cannot survive. Hypoxia is a naturally occurring condition and forms due to physical, chemical, and biological processes that take place within the water column. As with HABs, hypoxic conditions can be exacerbated by natural and human-induced environmental changes. In the Great Lakes, hypoxia occurs in the summer when warm surface water conditions coincide with calm weather patterns, promoting stratification (layering) of the water column, limiting mixing and exposure of deeper waters to atmospherically oxygenated surface waters, and leading to oxygen-depleted bottom waters. Diatom blooms that occur during winter-spring months can potentially worsen summer hypoxic conditions, particularly in the central basin of Lake Erie (Reavie et al., 2016). Algal biomass sinks to the bottom of the water column where it decomposes, consuming the oxygen and regenerating nutrients Hypoxic conditions will persist in the lake until stratification is disrupted, which typically occurs in the fall and is a process known as

"turnover" (Vanderploeg et al., 2009a, 2009b; Kraus et al., 2015; Bocaniov and Scavia, 2016). In addition, hypoxic water can subsequently promote algal blooms by increasing phosphorus release from the sediments that may combine with external loads and regenerated nutrients (Matisoff et al., 2016, Watson et al., 2016). In this way, algal blooms, including HABs, and hypoxia sometimes may be self-perpetuating or synergistic. Hypoxic zones occur most frequently in the central basin of Lake Erie and in Lake Michigan's Green Bay (Burns et al., 2005; Hamidi et al., 2013) and episodically in western Lake Erie and Saginaw Bay (Bridgeman et al., 2006; Stow and Höök, 2013; Tellier et al., 2022). Over-winter hypoxia, associated with oxygen depletion and limited photosynthesis during thick ice and snow cover, has also been observed in Saginaw Bay (Kalejs et al., 2022; Tellier et al., 2022). Natural and human-influenced hypoxia events also occur in sinkhole regions of Lakes Huron and Michigan due to the shallowness in some parts of the Great Lakes basin (Delorme, 1982; Biddanda et al., 2009; Ruberg, 2016).

B. Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA)

Large-scale water quality issues, including HABs and hypoxia, impacting the northern Gulf of Mexico, Lake Erie, Chesapeake Bay, and Long Island Sound were identified in the 1990s. These expanding problems prompted Congress to pass HABHRCA in 1998. The continued occurrence of HABs and hypoxia in those locations and others resulted in Congress reauthorizing HABHRCA three times, mostly recently in 2019 (HABHRCA 2017, P.L. 115-423).

The 2014 HABHRCA reauthorization expands the focus of HABHRCA to include a specific emphasis on HABs and hypoxia in the Great Lakes, and in fresh waters around the country, and recognizes the need for coordinated action across the Federal sector to address these issues. In addition, the most recent reauthorization calls for Federal agencies to provide integrated assessments every 5 years identifying the causes, consequences, and approaches to reduce HABs and hypoxia nationally. The 2014 legislation also requires a progress report for national efforts, which was published in 2018, and continued progress reports for Great Lakes regional efforts every 2 years. This second biennial Great Lakes progress report fulfills this statutory requirement.

C. Proceedings of the Interagency Working Group on HABHRCA

The IWG-HABHRCA is co-chaired by representatives from NOAA (Department of Commerce), the EPA, and the White House Office of Science and Technology Policy (OSTP). In addition, it is composed of the following member agencies and departments:

- Agricultural Research Service (ARS), Natural Resources Conservation Service (NRCS), and the National Institute of Food and Agriculture (NIFA) of the Department of Agriculture (USDA);
- United States Army Corps of Engineers (USACE) and the Department of the Navy, of the Department of Defense;

- Centers for Disease Control and Prevention (CDC), Food and Drug Administration (FDA), and the National Institute of Environmental Health Services (NIEHS) of the Department of Health and Human Services;
- U.S. Coast Guard (USCG) of the Department of Homeland Security;
- U.S. Geological Survey (USGS), National Park Service (NPS), Bureau of Indian Affairs (BIA), and the Fish and Wildlife Service (FWS) of the Department of the Interior;
- National Aeronautics and Space Administration (NASA);
- National Science Foundation (NSF);
- U.S. Department of State (DOS); and
- Council of Environmental Quality (CEQ) of the White House.

D. Report Basis

HABHRCA 2014 includes a provision for the Task Force (the IWG-HABHRCA) to develop and submit "an integrated assessment that examines the causes, consequences, and approaches to reduce hypoxia and harmful algal blooms in the Great Lakes, including the status of and gaps within current research, monitoring, management, prevention, response, and control activities." Via the White House Office of Science and Technology Policy, the IWG-HABHRCA published the GLRPAS on August 24, 2017. HABHRCA 2014 requires the IWG-HABHRCA in section 605(b)(3)(I) to "provide biennial progress reports on the activities toward achieving the objectives of the plan." The first progress report, *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation* was published on March 5, 2018, and a subsequent regionally-specific progress report, *Harmful Algal Blooms and Hypoxia in the Great Lakes: An Interagency Progress and Implementation Report* was published in November 2020. The purpose of this document is to provide updates on progress toward achieving the actions outlined in the GLRPAS and 2020 Great Lakes progress and implementation report. This report is structured with narratives from Federal agencies engaged in research and activities within the Great Lakes, while also including updates to Appendix 3 from the original GLRPAS and Appendices A and B from the 2020 progress report (Appendix A of this report). A section on new activities since the 2020 progress report is also included (Appendix B of this report).

III. AGENCY UPDATES

A. Effects of the COVID-19 Pandemic on Federal Agency HAB and Hypoxia Activities in the Great Lakes Region

During the 2020-2022 COVID-19 pandemic, Federal agencies experienced slow-downs and reductions in activity while continuing to conduct research, carry out monitoring and assessments, develop forecasts, and respond to Great Lakes HAB and hypoxia events. To a degree, the inclusion of innovative approaches, virtual interfaces, and remote technologies helped to facilitate ongoing Federal HAB and hypoxia activities in the Great Lakes region. These tools also allowed for continued oversight of intra- and interagency prevention, control, and mitigation efforts. Advancements in coordination among

Federal and state agencies, and in support of internal and extramural projects and programs, continued over the past years. However, agencies generally experienced significant challenges and limitations to their HAB and hypoxia research and response capabilities during the pandemic, which resulted in constrained productivity on multiple fronts. More information regarding the effects of the COVID-19 pandemic on particular agencies' Great Lakes HAB and hypoxia efforts is provided below:

CDC: The CDC and partners experienced slow-downs in its interactions with Great Lakes states.

NOAA: Monitoring and experimental work within Lake Erie and Lake Huron conducted at GLERL was reduced in 2020 by 45.2% due to Federal and state restrictions on staff activities, which reduced fieldwork, data analysis, and experiments. Research delays and reductions continue through 2022. In 2020, GLERL postponed monitoring until late June, reduced our sampling sites and parameters, and suspended deployment of the second-generation Environmental Sample Processor (2G ESP). Reductions were due to limitations associated with access to the Laboratory, workspace restrictions, and reductions in availability of vessel crew and number of scientists allowed on vessels. Monitoring, deployment of emerging technologies including deployments of the 2G and 3G ESP, and field-based experiments resumed in 2021; however, most laboratory-based work was still suspended. In 2021, Federal and local restrictions resulted in heavier field-based workload to allow for activities to be extended while ensuring safety, which resulted in a reduction in data analysis. In addition to personnel restrictions, GLERL ran into several supply chain restraints that are expected to continue through 2022. GLERL anticipates the continued reduction in experimental work in 2022. However, operational planning at this time indicates that previously outstanding work efforts are being completed as GLERL progresses through the field season. In addition, extramurally-funded HAB and hypoxia research by NOAA was slowed. However, NCCOS and partners were successful in issuing ecological forecasts for the Great Lakes region during this period.

NASA: In response to the COVID-19 Pandemic, NASA developed and launched a dashboard website and data analysis tool (www.earthdata.nasa.gov/covid19/) to monitor the effects of the reduced activity on the environment and, in particular, water quality in the Great Lakes region. Furthermore, NASA researchers at the Glenn Research Center and their academic partners similarly evaluated the impacts of COVID-19 Pandemic-related changes on the Great Lakes and regional water quality and recently published a peer-reviewed manuscript on the subject (Bosse et al., 2021). A short summary of their findings follows:

"The states of Michigan and Ohio issued shutdown orders in mid-March 2020 in an attempt to slow the spread of COVID-19, resulting in widespread disruption to economic and human activity. NASA, in partnership with the Michigan Technical Research Institute (MTRI), conducted a study utilizing satellite remote sensing data to investigate whether these changes in activity led to any short-term changes in water quality in the Great Lakes region by comparing 2020 data to a historic baseline. The water quality

parameters examined included chlorophyll-a (CHL) and total suspended solids (TSS) concentrations, water clarity, and HAB extent. These parameters were investigated in three Great Lakes basins which experience a gradient of anthropogenic impact, including the western basin of Lake Erie (WBLE), Saginaw Bay in Lake Huron (SBLH), and Thunder Bay in Lake Huron (TBLH). TSS concentrations in April 2020 were down in all three basins, and largely remained low in WBLE and SBLH through September 2020. SBLH also experienced elevated CHL concentrations throughout 2020 and the WBLE HAB spatial extent was down in 2020 after an early end to the growing season. However, this investigation found that the COVID-19 shutdowns were likely not a primary driver of these short-term anomalies. Instead, recent trends in the indicators and co-occurring anomalies in hydrological and meteorological conditions (e.g., lake temperature, river discharge, and wind speed) appeared to be primarily responsible for the detected water quality changes. Future work will investigate whether the shutdowns have a long-term or delayed impact on Great Lakes water quality."

NSF: The scientific community has faced unprecedented challenges and experienced considerable negative impacts from the COVID-19 pandemic.[3] The forced closure of universities, research centers, and laboratories has prevented scientists from continuing their research and students from learning.

A large percentage of HABs and hypoxia research is dependent on field work. While universities and laboratories gradually re-opened in 2020 and 2021, many travel policies remained limited and restricted researchers from accessing field sites to conduct their work. This in turn has likely reduced HABs and hypoxia monitoring capabilities, particularly as sensors and other field-based technology may have missed updates and refurbishments. This is an irreplaceable data loss especially detrimental to long-term monitoring projects. Compounded by ongoing supply chain disruptions, research operations such as the Academic Research Fleet experienced limited access to vendors, creating barriers to the needed support and supplies from vendors to meet planned work schedules.

NSF plays a unique role in supporting undergraduate students, graduate students, postdocs, and early career faculty who represent the future of science, engineering, and STEM Education in the United States and throughout universities in the Great Lakes region. This support will remain a top priority for NSF as the Nation seeks to recover from the pandemic. Acknowledging the delays and challenges experienced by the research community during the COVID-19 pandemic, particularly the disruption to early career and student employment and education opportunities, NSF supported numerous supplemental funding requests. This includes support for individuals as well as institutions that serve members of historically underrepresented groups. NSF continues to offer opportunities that can help bolster early-career researchers, students and others in the scientific enterprise, including those in the Great Lakes region, who may be in a difficult situation due to the pandemic.

[3] www.ncbi.nlm.nih.gov/pmc/articles/PMC7372729/; https://sr.ithaka.org/publications/the-impacts-of-covid-19-on-the-research-enterprise/

USDA-NIFA: During the COVID-19 pandemic, USDA-NIFA experienced loss of key research/extension personnel from a NIFA-funded Great Lakes/HABs relevant project. Project leaders began the hiring process in early 2020, which was unfortunate. Not only did the pandemic impact hiring processes internally, but it also nearly halted applicants applying for open positions due to the unknown working environment conditions that resulted. New responsibilities such as COVID planning committees, adaptation to modified working conditions, and providing guidance to supervisors on effective remote supervision were extremely time consuming. There was far less time for training new hires than was anticipated. USDA-NIFA solved the issue by providing projects with No-cost Extensions (NCE) for up to 3 consecutive years. Nationwide, nearly 70% of the field- and laboratory-based water and nutrient focused projects in the Agriculture and Food Research Initiative (AFRI) Foundational and Applied Sciences Water Quantity and Quality Program requested and/or received NCEs in response to critical shocks such as university and Federal laboratory lockdowns and travel restrictions.

EPA: In 2020, disruption of field sampling due to the COVID-19 pandemic resulted in reduced temporal and spatial sampling for EPA's Lake Erie Dissolved Oxygen Monitoring Program. During the 2020 sampling season, only four of the six scheduled surveys were completed (all conducted aboard the USGS R/V Muskie), and of the 10 fixed stations, only the five stations within U.S. waters could be sampled due to the Canada-United States border restrictions.

B. Great Lakes Restoration Initiative and Great Lakes Water Quality Agreement Nutrients Annex

Multiple IWG-HABHRCA agencies collaborate on HABs projects in the region through two major geographic programs: The GLRI and the Great Lakes Water Quality Agreement (GLWQA). These cross-cutting programs provide direction and funding for many Federal agency efforts, as summarized below and detailed by particular agencies throughout this report.

1. Great Lakes Restoration Initiative

The GLRI was launched in 2010 as a nonregulatory, multi-agency program to accelerate efforts to protect and restore the largest system of fresh surface water in the world. EPA leads the implementation of the GLRI with 15 other Federal agencies. In 2022, GLRI partners will be midway through implementing the FYs 2020-2024 GLRI Action Plan III (GLRI, 2019), which identifies specific commitments and measurable objectives towards long-term goals for the Great Lakes ecosystem, one of which is to eliminate HABs (Figure 1).

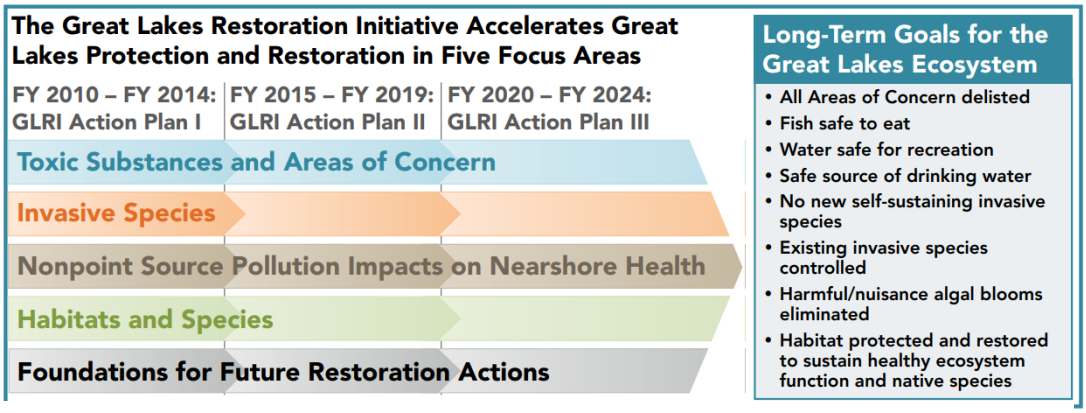


Figure 1. Focus Areas and Long-Term Goals of GLRI Action Plan III.

Since GLRI began, GLRI Federal agencies and their partners have funded multiple activities to reduce nutrient runoff and prevent nearshore HABs, with an emphasis on western Lake Erie, Saginaw Bay, and Green Bay. Under GLRI Action Plan III, GLRI Federal agencies and their partners (i.e., states, tribes, and other non-Federal stakeholders) support many activities that contribute to the prevention and monitoring objectives of HABHRCA, specifically:

1) Implementing projects on farms and in streams to reduce excess nutrient loads from agriculture watersheds, emphasizing utilization of conservation systems and increasing adoption of enhanced nutrient management practices to reduce risk of nutrient losses from farmland.
2) Implementing projects in urban areas to capture or slow the flow of untreated runoff and filter out sediment, nutrients, toxic contaminants, pathogens, and other pollutants from runoff before it enters Great Lakes tributaries, beaches, and nearshore waters.
3) Implementing coordinated monitoring and assessments to evaluate effectiveness of projects and developing new or improved approaches for reducing or preventing harmful algal blooms.

During FYs 2020-2021, GLRI Federal agencies and their partners implemented conservation activities to reduce sources of phosphorus loadings that threaten Great Lakes nearshore regions. As of 2022, GLRI Federal agencies estimate that over 2 million pounds of phosphorus have been prevented from leaving farms and

entering the Great Lakes cumulatively as a result of GLRI-funded projects, including over 500,000 pounds of phosphorus reductions in FYs 2020-2021. GLRI partners continue to encourage and accelerate implementation of green infrastructure projects and streambank improvement projects that slow and intercept runoff. Projects started in FYs 2020-2021 will capture approximately 140 million gallons of untreated urban runoff per year. These projects reduce flooding, increase green space in urban areas, reduce bacterial contamination, and return vacant properties to productive use.

In addition, GLRI supported several coordinated HABs and hypoxia research efforts, as well as performance monitoring and demonstration of innovative best management practices (BMP) for nutrient reduction. GLRI supports HABs monitoring and decision-support tools, including the Lake Erie HABs Tracker tool and biweekly forecasts; tributary and edge-of-field monitoring and nutrient load computations; and ecosystem and watershed modeling. Many of these efforts are described in the subsequent Federal agency updates. Highlights from 2020-2022 include:

- NOAA continued their weekly water quality sampling in Lake Erie, coupled with airborne hyperspectral overflights and real-time buoys. These data provide decision support tools for western Lake Erie researchers and drinking water managers, including the HABs Forecasted Bloom Position, seasonal HABs forecasts and biweekly HABs Bulletins.

- USGS scientists continued their sentinel site monitoring program in the following lakes to examine the influence of nutrient concentrations, invasive zebra and quagga mussels, and microbial ecology on *Cladophora* growth: Lakes Michigan, Huron, Erie, and Ontario. USGS is also testing new methods to remotely sense *Cladophora* using autonomous underwater vehicles.

- From 2019-2021, EPA partnered with USACE and LimnoTech to expand the Western Lake Erie Ecosystem Model to create a whole-lake ecosystem model. EPA's Office of Research and Development is collaborating with other Federal partners to use the new model to simulate the impact of various nutrient reduction scenarios.

- USACE constructed a Phosphorus Optimal Demonstration Wetland in Defiance, Ohio, that will serve as a long-term research and demonstration site under the GLRI.

- GLRI supports edge-of-field (EOF) monitoring by USGS and USDA ARS at several sites in the Great Lakes basin, to evaluate links in timing and concentrations of nutrient and sediment loads, including a robust network of sites in the western Lake Erie watershed. In 2021, the USGS published data from 85 EOF sites that were developed from five local, state, and

Federal programs. USGS is also measuring the performance of green infrastructure in cities across the Great Lakes basin, such as Gary, Indiana and Buffalo, New York.

- GLRI demonstration farm networks continue to grow, with two new networks added for a total of nine networks with 42 farms participating as of 2022. These networks are designed to showcase and demonstrate leading conservation practices that improve Great Lakes water quality by reducing phosphorus and sediment farm runoff.

- Several partners in northeast Wisconsin are collaborating on innovative conservation projects to comprehensively address nutrient reductions to Green Bay. For example, local partners piloted and monitored three Agricultural Runoff Treatment Systems (ARTS) in the Lower Fox watershed from 2017-2020. ARTS consist of a series of BMPs that capture runoff, attenuate flow, and provide nutrient reduction. In 2021, local partners added an innovative phosphorus-removal structure (PRS) to remove dissolved phosphorus at one of these systems (Penn et al., 2016). Phosphorus removal structures are planned at the other two ARTS in 2022 with GLRI funding.

- In 2022, partners completed a 5-year study of algal bloom dynamics in Lower Green Bay. Modeled after monitoring occurring in Lake Erie, the study included both continuous buoys and discrete samples to characterize the algal community. Parameters that were additionally characterized included the toxin profile, nutrients, chlorophyll *a* and phycocyanin, dissolved oxygen, and others useful in understanding bloom formation and transport. In 2020, cameras were added to the buoys to monitor surface scums. Project data were used to calibrate NOAA models generated from satellite data. NOAA is supporting continued operation of the buoys through 2023.

- To assess Saginaw Bay's nutrient dynamics and ecosystem ecology during ice-free periods, and to provide the empirical basis to develop models that will inform nutrient management scenarios, GLRI is supporting an intensive 3-year monitoring program starting in 2022. This proposed project combines shipboard sampling and real-time instrumentation on buoys and leverages NOAA's long-term research data from Saginaw Bay, led by GLERL. GLRI is also supporting NOAA's use of a combination of methods to assess primary productivity across key gradients in the Lake Huron nearshore to offshore photic zones during the 2022 Cooperative Science and Monitoring intensive (CSMI) field year in Lake Huron.

    - Methods include satellite remote sensing estimates, primary productivity experiments, and measurements from wave gliders, a shallow-water glider, and a Slocum buoyancy glider.

- Transect surveys in 2022 to assess the structure and function of the Lake Huron food web, including the impact of phosphorus from the Saginaw River, will also be conducted by EPA, NOAA, USGS, ECCC, DFO, Cornell University, Buffalo State College, and University of Minnesota Duluth in support of the 2022 CSMI.

2. Great Lakes Water Quality Agreement Nutrients Annex

The 2012 GLWQA Nutrients Annex calls for coordinating binational actions to manage phosphorus concentrations and loadings, and other nutrients if warranted, to control the growth of nuisance and toxic algae. In 2016, the United States and Canada adopted phosphorus reduction targets for Lake Erie. In 2018, each country developed 5-year implementation plans, which identify on the ground actions for meeting the new targets. The full suite of U.S., state and Canada-Ontario domestic action plans are available at www.epa.gov/glwqa/us-action-plan-lake-erie.

All jurisdictions continue to implement their respective domestic action plans and in 2023 will undertake a review of the effectiveness of these actions toward achieving Lake Erie's phosphorus targets. The United States committed to reduce phosphorus loads to Lake Erie by 40%, a reduction of 3,311 metric tons (7.3 million pounds), the bulk of which will come from agricultural sources in the western Lake Erie watershed. In response, Federal agencies have doubled the amount of cost share funding available to farmers over the past 5 years. Furthermore, the State of Ohio established a new program, the H2Ohio Initiative, and invested over $120 million to install agricultural BMPs in 2020-2023.

The U.S. continues to implement coordinated binational research and monitoring to improve our general understanding of factors driving *Cladophora* growth, HABs, and hypoxia in the Great Lakes. Agricultural research projects are underway to improve our understanding of how phosphorus moves over the landscape and how effectively BMPs can manage nutrient losses. Lake ecosystem models and watershed loading models are being applied to improve our ability to predict ecosystem response to nutrient load reduction efforts on the ground. Specific GLWQA Nutrients Annex achievements pertaining to HABHRCA during 2020-2022 include:

- Established and began implementing a Binational Adaptive Management Framework for Lake Erie. The framework outlines evaluation, coordination, and communication activities necessary to actively evaluate whether the current phosphorus targets will achieve the lake ecosystem objectives. The U.S. and Canada will conduct the first such evaluation in 2023.

- Continued implementing the binational *Cladophora* research plan, and in 2020, re-evaluated the viability of setting targets to address *Cladophora* growth in the eastern basin of Lake Erie, and confirmed scientific consensus does not support establishment of new targets at this time.

- Initiated a review of the interim nutrient targets for Lake Ontario. Recommendations due in 2022 suggest no change to the current phosphorus targets at this time.

- Hypoxia monitoring by EPA, NOAA, USGS, and others is ongoing and a workshop with partners took place in October 2021. NOAA deployed a new mooring system in Lake Erie from 2017-2021 to quantify the duration, spatial extent, and thickness of the hypoxic layer, and continued the development of a Lake Erie hypoxia early warning system. This new tool provides water intake managers with early warnings when hypoxic events are likely.

C. Department of Commerce – National Oceanic and Atmospheric Administration

1. Forecasting and Monitoring of Cyanobacterial Blooms and Hypoxia in the Great Lakes

HABs. NOAA's HAB Forecast bulletin for Lake Erie was first issued in 2008, while the first seasonal forecast was issued in 2012 and a "severity index" was used for the first time in 2014. The forecast transitioned to operations in 2017. It was operated by CO-OPS until 2021, after which it was transitioned to NCCOS prior to the June bloom season, and continues to be issued twice-weekly. The operational forecast is configured as a web-site with a bulletin option, with updates provided by email to >5000 subscribers, with no restriction. NCCOS provides analysis of bloom location and 3-day forecast conditions, including two-dimensional surface movement. NOAA issues the Western Lake Erie HAB Early Season Projection each year in early July to provide stakeholders with a general sense of how potentially disruptive the upcoming bloom season might be in severity. The seasonal forecast is an ensemble of models based largely on total available phosphorus load from the Maumee River. GLERL and NCCOS have worked to transition the Lake Erie Experimental HAB Tracker, which predicts 3D movement of blooms, to operations at NOAA NCCOS and have incorporated it into the Lake Erie Harmful Algal Bloom bulletins as an upgrade.

In 2018, NCCOS developed the Harmful Algal Bloom Monitoring System, which routinely delivers near real-time products for use in locating, monitoring and quantifying algal blooms in coastal and lake regions of the United States where satellite imagery can directly support key management concerns. This application delivers a suite of bloom detection products in the form of geographic based images. At this time, products are available for Lake Erie as well as portions of

Lake Michigan (Green Bay, Wisconsin) and Lake Huron (Saginaw Bay, Michigan).
For each location, nowcast bloom position information is available using satellite imagery including remote-sensing derived estimates of near-real-time phytoplankton cell density. Target users include land and natural resource managers, public health officials, and managers at drinking water facilities. New products are being evaluated, and new regions are being considered for incorporation into this system.

NCCOS continues to improve and develop satellite products, seasonal forecasts, and models of bloom severity for cyanobacterial blooms in HAB-impacted regions of the Great Lakes. The new Sentinel-3a and -3b satellites are being used and inter-calibrated to the previous satellites to assure a continuous time series for bloom assessment. Seasonal forecasts will continue starting with "early season" projections in early May, through the seasonal forecast made the second week of July. Moving forward, results of toxin models will be examined for incorporation into the monitoring system. Daily products for western Lake Erie, Saginaw Bay, and Green Bay will continue and be updated as needed by state and local users. In addition, an active project funded by GLRI is examining whether discharge and related phosphorus concentrations from the Saginaw River (into Saginaw Bay, Lake Huron) and Fox River (into Green Bay, Lake Michigan) can be used to predict cyanobacterial biomass and blooms in these locations, as similarly done for Lake Erie when accounting for inputs from the Maumee River.

NOAA continues to provide resource managers, public health officials, and bloom forecast models with accurate and robust information. Routine sampling and monitoring are conducted by GLERL, through traditional ship-based monitoring and deployment of advanced technologies and instrumentation to quantify biological, chemical, and the physical conditions of the lake. Weekly monitoring cruises have been conducted in Lake Erie since 2012, providing toxin and water quality data from May through October. Remote sensing platforms have also been established in Lake Erie and Lake Huron to monitor nutrients, hypoxic conditions, and HABs through real-time sensor networks, hyperspectral flyovers, and satellite remote sensing. An advanced technology within NOAA's remote sensing capabilities are GLERL's 2G ESP, supported by the Great Lakes Restoration Initiative (GLRI) and the Great Lakes Observing System (GLOS), which provide near-real time toxin data to stakeholders. The result is a long-term data set of environmental conditions to assist in the development and assessment of management actions, supporting the development of predictive tools, and providing further insight into bloom ecology. Additional improvements to the forecast are ongoing, and will include biological parameters, such as cyanobacteria growth rate and toxin probability, to provide a better forecast of the bloom dynamics.

Hypoxia. For the past 5 years, GLERL has been providing an Experimental Lake Erie Hypoxia Forecast (Figure 2) to warn public water systems serving more than

2 million residents of northern Ohio of low-oxygen upwelling events. Hypoxia – a state of low oxygen – occurs in the deep waters of Lake Erie's central basin in July through September of most years. Low-oxygen water is an unfavorable habitat for fish, and may kill bottom-dwelling organisms that provide food for fish. While the hypoxic water generally stays near the lake floor, changes in wind and water currents can create upwelling events, in which this zone of low oxygen is brought to the surface along the coast. Once it creeps into shallower parts of the lake, hypoxic water can disrupt drinking water treatment processes at water intakes along the shoreline. Hypoxic upwelling events cause rapid changes in water quality variables such as temperature, pH, dissolved organic matter, iron, and manganese. To maintain the quality of treated water, plant managers need to adjust treatment processes in response to these changes. GLERL's Experimental Hypoxia Forecast Model provides several days of advance notice that water quality is changing, so that drinking water plant managers can be prepared to adjust their treatment processes as needed.

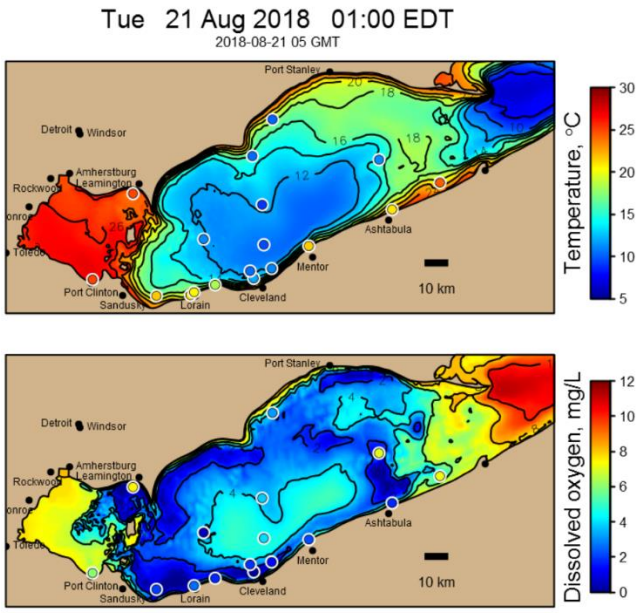


Figure 2. GLERL Experimental Lake Erie Hypoxia Forecast on August 21, 2018, showing a hypoxic upwelling event that brought low dissolved oxygen water to drinking water intakes along the Ohio shoreline of Lake Erie. The background color in the graphic shows bottom temperature and dissolved oxygen from the forecast model, with observations plotted (symbols) for comparison (Great Lakes Observing System and NOAA).

Disruptions to water treatment can be minimized if the changes in water quality are caught early. Public water systems were involved from the beginning of the project in a process to co-design experimental forecast with researchers to maximize the utility of the research for the end-users. Now in its fifth year, this forecast model has turned out to serve additional purposes that NOAA's scientists had not even considered, such as helping fisheries managers plan stock assessment surveys. The Experimental Lake Erie Hypoxia Forecast model was developed by GLERL and the Cooperative Institute for Great Lakes Research (CIGLR) as a 5-year project (2017-2021) with funding from NOAA's National Centers for Coastal Ocean Science, and is an extension of NOAA's Lake Erie Operational Forecasting System. In addition to development of the forecast model, NOAA deployed a network of sensors that gave an unprecedented view of the extent of the hypoxic zone.

2. Innovations – Models, Technologies, and 'Omics

An effort involving NOAA (NCCOS-Charleston, CIGLR) and several academic (Bowling Green State University, University of Toledo, The Ohio State University, University of Michigan), as well as industry partners (LightDeck Diagnostics, LimnoTech) aims to fully validate and integrate a rapid, portable, quantitative, multiplexed cyanotoxin detection technology into routine monitoring programs, citizen science groups, recreational beach management, and water treatment plants throughout the western Lake Erie to provide water managers with on-the-spot testing of microcystins and cylindrospermopsin. Validation of the LightDeck Cyanotoxin Detection Kit (includes sample preparation device) will compare results against a recognized 'gold standard' ELISA method, as well as mass spectrometry, and also assess ease of use for water management professionals and citizen scientist organizations. A data management system will be developed to provide an easy method for monitoring groups to upload their data through a user-friendly smartphone 'app' to a common database and ultimately to an end-user website, providing a centralized location accessible by other researchers, water plant managers, and the general public. The LightDeck system is based on a waveguide-enabled, competitive assay format capable of simultaneously testing for multiple toxins (multiplexed), providing quantitative, reproducible results in minutes, and employing a simple, user-friendly, and cost-effective workflow and platform. Field testing conducted during the 2020 and 2021 bloom seasons has led to improvements in the LightDeck system and validation efforts are ongoing.

Cyanobacteria blooms in the Great Lakes are genetically diverse, having high intraspecific variation (i.e., strain variation) which leads to phenotypic and physiological diversity within the population and bloom succession. Ultimately the physiological diversity within a bloom can influence model and forecast accuracy. GLERL with our partners at CIGLR have been able to establish a *Microcystis* culture collection isolated from Lake Erie and Lake Huron. The culture collection includes over 26 strains, with different genetic traits and capacity to produce toxins. Through establishing an extensive culture collection, we have been able to expand our understanding of bloom dynamics through controlled laboratory experiments. For example, we have been able to explore toxin production and toxin profiles based on isolates collected from the same bloom, providing a key link to toxin variability we monitor within Lake Erie blooms.

In addition, GLERL with our partners at CIGLR have begun development of the Great Lakes Atlas of Multi-Omics Research (GLAMR), a user-interface (web-based) data portal for 'Omics data across the Great Lakes with initial metadata focusing on cyanobacteria HABs. GLAMR provides a computational framework for studying the complex relationships between the many forms and dimensions of 'omics data, environmental data, and biological data (e.g., physiological,

phenotypic data). The research database provides a bioinformatics foundation for moving the field towards the promise of 'omics technologies for faster, cheaper, more sensitive, and more effective approaches to tackle NOAA missions such as revealing environmental drivers of harmful algal blooms, monitoring for pathogens and invasive and imperiled species, and identifying trophic interactions.

An ongoing collaboration between NOAA (GLERL, CIGLR, NCCOS-Charleston and AOML) and Monterey Bay Aquarium Research Institute (MBARI) has continued with development and field-testing of a long-range autonomous underwater vehicle (LRAUV) equipped with a Third Generation (3G) Environmental Sample Processor (ESP) and embedded Surface Plasmon Resonance (SPR). Successful 2-week long field campaigns were completed in 2018, 2019, and 2021 using MBARI's 3G ESP/LRAUV in Lake Erie's western basin. The 3G ESP/LRAUV has the ability of an autonomous mobile platform to perform *in situ* sample acquisition, processing, and analysis for microcystin in near-real time and sample preservation for post-deployment 'omics analysis – all accomplished while underway. During 2021 deployment, we were able to acquire near-real time toxin concentrations, employ the use of a hyperspectral imaging to direct sampling locations, and utilize an experimental patch tracking program to help determine bloom hot spots. In addition, piloting operations of a LRAUV with embedded sensors are being transitioned to NOAA from MBARI. Future work includes testing the 3G ESP in an uncrewed surface vehicle (USV) which will allow us to access nearshore, shallow-water ecosystems enhancing our ability to provide near-real time toxin data to critical stakeholder groups.

3. National HAB Observing Network

NOAA's U.S. Integrated Ocean Observing System Office (IOOS) allocated $2.8 million in FY21 for National Harmful Algal Bloom Observing Network related activities nationwide. The NHABON will efficiently and effectively integrate local, state, regional, and Federal HAB observing capabilities and deliver products operationally (IOOS Association, 2021). Implementation of the NHABON will achieve the following benefits: enable HAB forecasting and early warning; leverage economies of scale and enhance information transfer between regions; determine algal community baselines and discern patterns/trends to help assess the impacts of climate change, eutrophication, and other environmental forcing; and provide observations to support NOAA's mission of understanding and predicting changes in our oceans.

As a part of the development of NHABON, IOOS' GLOS has partnered with a broad group of stakeholders to develop and operationalize an early warning system for Lake Erie to support decision-making to take steps for public safety when facing these blooms. Funding will support testing of integration of HAB observations from hyperspectral imagery and real-time microcystin concentration and chlorophyll data. Crewed and uncrewed airborne systems will provide

sentinel observations directing the path of an Environmental Sample Processor deployed on an autonomous surface vessel. The combination of both – potentially autonomous – observational systems will help to better discern the distribution, composition, and behavior of western Lake Erie HABs. In addition, this project will enhance and expand the near real-time monitoring network in other areas of the Great Lakes, such as Green Bay, Wisconsin, to better understand the response of HABs to nutrient loads and flooding, which are two primary risks in this area. Wisconsin's Fox-Wolf basin is one of the four EPA-designated algae bloom hotspots in the Great Lakes and the Lower Green Bay and Fox River is a designated U.S. Area of Concern under the Great Lakes Water Quality Agreement. This project will instrument the two existing buoys in the lower Green Bay, which measure real-time water quality conditions related to seasonal HABs and hypoxia, to gather near real-time measurements of nutrients as well.

4. Funding Programs to Address HABs and Hypoxia in the Great Lakes

NOAA conducts HAB and hypoxia research through a combination of internal science capabilities and a suite of external programs. National external funding programs include ECOHAB (Ecology and Oceanography of Harmful Algal Blooms), MERHAB (Monitoring and Event Response for HABs), PCMHAB (Prevention, Control, and Mitigations of HABs), and CHRP (Coastal Hypoxia Research Program), all of which are congressionally authorized through HABHRCA and continue to support ongoing research in the Great Lakes. Recently funded Great Lakes projects through these programs include the following:

Two **ECOHAB** Great Lakes projects were funded between 2019-2021:

- "Linking Process Models and Field Experiments to Forecast Algal Bloom Toxicity in Lake Erie" ($251,000 total funding for 2019-2020).
- "Towards a Predictive Understanding of our Ecosystems: Microcystis Blooms and Toxin Production" ($430,000 total funding for 2019-2021).

In 2019, **MERHAB** funded a project, "Portable Toxin Detection Technology to Support Great Lakes Decision Support Tools" to create portable cyanotoxin detection technology for use by beach managers, water utilities, and charter fishing boat captains ($877,000 total funding for 2019-2023).

PCMHAB continues to fund research to move promising technologies for preventing, controlling, or mitigating HABs and their impacts through development, to demonstrations, and, finally application, culminating in widespread use in the field by end-users. This program also funds socioeconomic research to assess impacts of HAB events on economies and societies, and the costs and benefits of mitigation strategies to aid managers in devising cost-

effective management strategies. Since 2020, PCMHAB funded three projects in the Great Lakes:

- "Using Microcystin Degrading Bacteria and their Enzymes for Water Treatment" ($1.1 million total funding for 2020-2022).
- "Rapid, Portable, Multiplexed Detection of Harmful Algal Toxins in the Great Lakes" ($948,000 total funding for 2020-2022).
- PCMHAB RESCUE: "Enhancing the Capabilities of the 3rd Generation Environmental Sample Processor (3G ESP) for HAB Toxin Detection Through Integration with an Autonomous Surface Vehicle (ASV)" ($1.5 million total funding for 2021-2024).

CHRP continues to support research in the Great Lakes. In 2016, CHRP funded a project at GLERL, "Operational Lake Erie Hypoxia Forecasting for Public Water Systems Decision Support" to develop an operational dissolved oxygen forecast model for Lake Erie. This physically based model to track hypoxia development has been run successfully in 2017-2019 and provided water intake managers with early warnings when hypoxic events were likely. Three years of field and laboratory measurements to provide complementary data supporting model development have been completed. The project was expanded to include measurements to characterize manganese release into low oxygen waters, because manganese is being considered for regulation in drinking water. This coupled system will allow drinking water managers to prepare when conditions that promote hypoxic water movement into the vicinity of water intakes occur ($1.67 million total funding for 2016-2021).

5. Outreach, Education, and Research

The eight NOAA-funded, university-based, Sea Grant programs in the Great Lakes play a crucial role in supplying stakeholders with usable information and tools to further understand the causes of HABs and hypoxia and the issues they create in the region. These programs continue to fund critical research, outreach, and educational programs on HABs and hypoxia awareness, understanding, and event preparedness and response. Recent examples of this work include: 1) an ongoing collaborative research project with EPA and other agencies to look at the combined effects of hypoxia and HABs on food web processes in Lake Erie; 2) research designed to determine the value of Lake Erie beaches to the State of Ohio's overall economy and how that value is affected by HABs; and 3) creation of an interactive online dashboard (bit.ly/HABSdashboard) that visually presents data through three lenses to increase situational awareness of populations that may be vulnerable to HAB-related illnesses for five counties surrounding Western Lake Erie.

This work is in addition to the long-term efforts by these Sea Grant programs to continue to disseminate research results, reports and publications, continued work with municipalities on educational signage, brochures, and outreach materials,

and ongoing work with communities to conduct beach monitoring, develop citizen science monitoring programs with charter boat captains, and advancing HABs early warning systems. Sea Grant programs have also worked to develop tools and materials to engage stakeholders and decision makers to better understand the linkages between land uses, water quality, and municipal policies including the Watershed Game, the Tipping Point Planner and the Tackling Barriers to Green Infrastructure workbook. In addition, Ohio Sea Grant has continued to host NOAA's annual HABs Forecast event and the annual "Understanding Algal Blooms: State of the Science Conference."

D. Department of Defense – U.S. Army Corps of Engineers

The Water Resources Development Act of 2018 (WRDA, 2018) authorized the U.S. Army Engineer Research Development Center (USACE-ERDC) to implement a 5-year technology demonstration program to deliver scalable technologies for HAB detection, prevention and management intended to reduce HAB frequency and effects on our Nation's freshwater resources across scales (e.g., small lakes to river reaches), ecoregions (e.g., subtropical Florida to temperate Ohio and New York), and system types (e.g., reservoirs, riverine, lakes). Funding to support implementation of the authorized 5-year program was first received in FY19 and was executed under the USACE Aquatic Nuisance Control Research Program (ANCRP). A significant portion of research dollars appropriated in FY19, FY20, and FY21 for USACE's ANCRP were identified specifically for HAB research. The following section provides an updated summary of select HAB response, demonstration, and research activities USACE has supported since publication of the IWG-HABHRCA 2020.

1. Harmful Algae Bloom Response by USACE at USACE Managed Reservoirs

USACE water quality staff regularly monitor reservoir water quality at USACE-managed reservoirs, including those in the Great Lakes region, to document that water quality is adequate to meet the many purposes for which these Civil Works Projects were constructed. Much of the data collected through District water quality monitoring activities has been used by multiple stakeholders to inform decision makers on nutrient and eutrophication trends, as well as HABs. As HABs have increased in frequency, intensity, magnitude, and duration across the USACE portfolio, this water quality data has been useful in identifying potential bloom-driving blooms, such as nutrient inputs from watersheds.

Many Districts have developed HAB response plans, which incorporate state-developed plans where applicable. Districts continue to coordinate water quality monitoring, HAB reports, and HAB responses with local, state, Federal, and tribal stakeholders.

2. Operational Strategies for HAB Management in Inland Reservoirs

USACE-ERDC scientists are conducting a systematic study of USACE reservoir control options and their influence on HABs. In coordination with separate project "Evaluation of Historic Water Quality Information and Cyanobacteria Harmful Algal Bloom Events: Technical Guidance for Routine Monitoring Programs," this project is developing utilities to organize and visualize available water quality data from USACE reservoirs (see Figure 3), including those in the Great Lakes region, so that water quality trends and responses to operations can be assessed.

The focus is on the operational activities preceding and during HAB events, including the withholding or release of water, the use of targeted flow strategies, such as horizontal flushing or hypolimnetic withdrawals, and the corresponding observations of the effects within the lake or downstream. This analysis will be used to develop recommendations for operational management of HAB events. The project will also develop a modeling dashboard tool to enable reservoir managers to test the likely effects of operational changes on the water quality within their reservoirs or downstream of management structures. A post-processing tool will be constructed to compare modeled output for hydraulic and water quality conditions within or exiting a reservoir against stakeholder limitations to help operators place strategies they might wish to use to mitigate HABs in the context of their overall management demands.

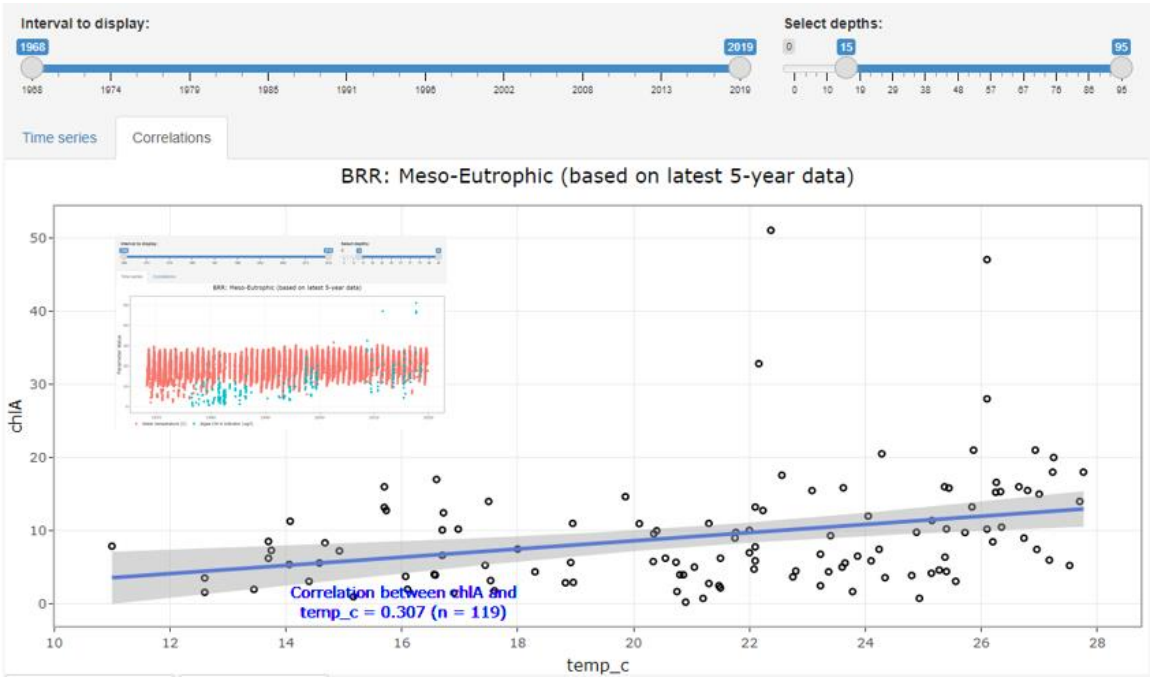


Figure 3. Data tools developed to explore relationships between key parameters influencing HAB occurrence in reservoirs.

3. Phosphorus Optimal Wetland Efficacy Demonstration Project

Phosphorus (P) reduction targets were adopted for Lake Erie to address HABs and improve regional water quality. The Maumee River watershed contributes the highest amounts of P to Lake Erie. Restoring wetlands in strategic locations within the watershed can reduce nutrient loads to improve water quality while providing habitat and other ecosystem benefits. In response, USACE is conducting research to promote the use of wetlands for nutrient load reduction in the Maumee River basin.

Construction of a pilot wetland demonstration project (18 acres) was completed in June 2021 within the Maumee River Watershed of Lake Erie in the township of Defiance, Ohio (Figure 4). The project's goals are to identify management actions and operational strategies to maximize P retention through multiple mechanisms (sediment retention, soil adsorption, plant assimilation) and investigate P reduction under a variety of scenarios (flow regimes, residence time). The project will also provide operational guidance to practitioners related to legacy P, P storage capacity thresholds, P fate within wetland systems, soil amendment effects, and associated implications for increased P removal. This will inform the improvement of water quality at multiple scales through outreach and technology transfer. To date, the project has resulted in the publication of seven peer reviewed journal papers and technical reports (Currie et al., 2017; Berkowitz et al., 2020; VanZomeren and Berkowitz, 2020; VanZomeren et al., 2020; Berkowitz et al., 2021; Lemke et al., in press; Hurst et al., in review) and over a dozen outreach engagements with the scientific community and the public.

The project demonstrates the benefits of P optimization in wetlands and promotes a methodology that may be applied as a valuable tool for reducing nonpoint source pollution from reaching the Great Lakes while enhancing other ecosystem functions provided by wetlands (habitat, flood risk reduction). USACE and project partners (City of Defiance, USGS, EPA) are conducting a 5-year field research monitoring program of the wetland demonstration project.

Figure 4. Aerial image of the completed phosphorus optimal wetland research and demonstration site in Defiance, OH.

4. Harmful Algal Bloom Indicator Estimation in Small Inland Waterbodies: Remote Sensing-based Software Tools to Assist with USACE Water Quality Monitoring

USACE Districts develop water quality programs of varying magnitudes depending upon their individual needs. Primary monitoring activities include field measurements of physical parameters and the collection and laboratory testing of water, sediment, and biological samples to ensure compliance with applicable Federal, state, and local standards, as well as examination of short- and long-term trends related to watershed management practices and regulation and operation practices in reservoirs, locks, and dams. However, these traditional approaches can be labor-intensive, often providing discrete, localized data that make it difficult to characterize a whole waterbody. This in turn can diminish the ability to detect problematic water quality conditions, such as HABs, in a timely manner. Remote sensing offers advantages for water quality monitoring of small, inland water bodies that are especially beneficial for overcoming limitations associated with traditional, field-based water sampling. Such advantages

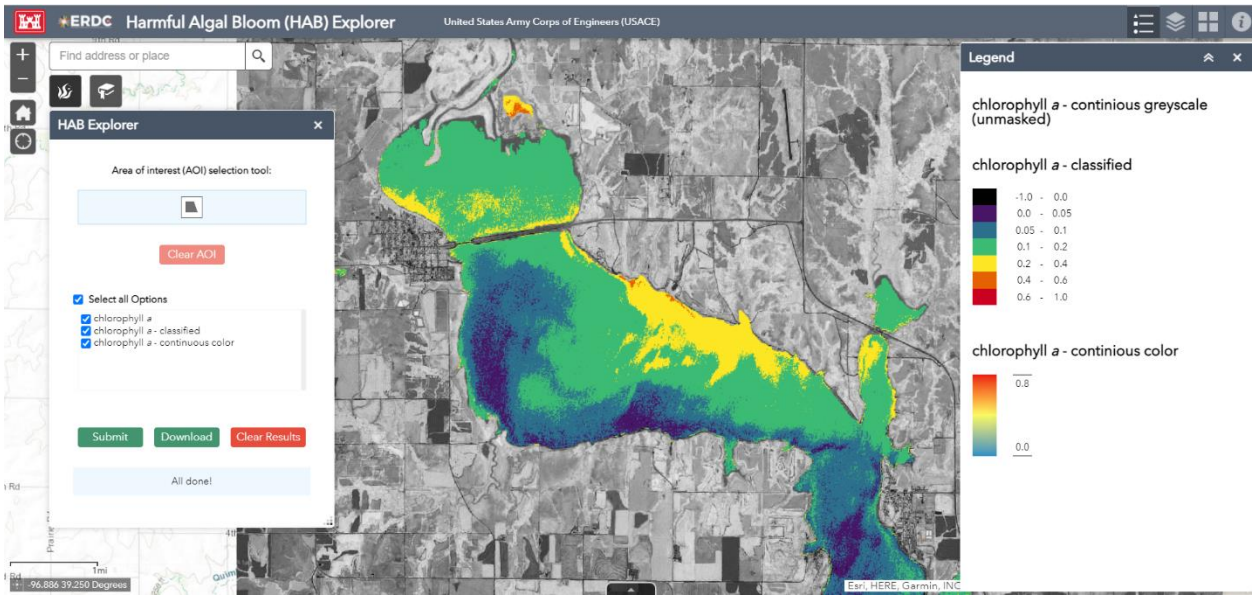


Figure 5. Sample map product showing relative estimations of surface and near-surface phytoplankton biomass generated from a chlorophyll-a index and used as a water quality indicator of HABs at Milford Lake, Kansas, using the HAB Explorer web application. Estimation values range from -1 to 1 to help quickly visualize lake conditions, in which pixel values less than 0 represent areas without algae (black), while values from 0 to 0.2 (dark blue to green) indicate relatively low chlorophyll-a concentration, and values from 0.2 to 1 (yellow to red) show relative increases in chlorophyll-a concentration that may be indicative of a HAB.

include the ability to provide recursive, satellite imagery (~ days-to-weeks temporal frequency) for routine, whole- and multi-lake monitoring of HAB water quality indicators.

The goal of this project was to build upon foundational remote sensing research, including a pilot study at Harsha (East Fork) Lake, Ohio, to develop geospatial software tools for estimating HAB water quality indicators at USACE-managed inland lakes and reservoirs, ultimately supporting proactive monitoring and management strategies. More specifically, a variety of software tools, ranging in complexity and functionality, were developed to accommodate a broad user base, skill sets, and monitoring needs. The tools make use of readily available satellite imagery and algorithms to estimate potential HAB indicators: 1) chlorophyll-a; 2) phycocyanin, a proxy for cyanobacterial or blue-green algal biomass; and 3) turbidity. Products from this research have empowered managers with characterization of lake/reservoir conditions to better enable: 1) HAB monitoring and management; 2) prioritization of field-base surveying; and 3) communication of HAB potential to managers, leadership, partners, and the public. The software tools include the following:

1. An open-source R-software package, *waterquality* and user-guide, a University of Cincinnati collaboration, is the most comprehensive option for developing image-based abundance maps of HAB indicators.
2. A Python-based ArcGIS Pro *waterquality toolbox*, designed for use in ESRI ArcGIS Pro desktop software 2.7 and greater, has pre-set menus and

limited options for a streamlined workflow to produce image-based abundance maps of HAB indicators (includes draft user-guide and sample data).

3. An online, ESRI-based web application, *HAB Explorer* (Figure 5), to rapidly screen for potential HAB conditions with constrained algorithm and visualization options (best viewed in Google Chrome and available on the USACE uCOP Production Portal, requiring VPN or USACE network access).

5. Comprehensive Satellite-Based Algorithms for Broadscale CyanoHAB Detection and Monitoring

Remote sensing technology is another useful tool for cyanobacteria HAB (sometimes referred to as cyanoHAB or CHAB) detection and monitoring. Commonly, remote sensing involves the use of a satellite-borne optical sensor to collect imagery of a waterbody. Analysis of the spectral images yields synoptic water quality information that can support early HAB detection. However, translating these complex images into meaningful, decision-supporting information often requires specialized software skills and expertise that many USACE districts and regional water quality managers lack. The objective of this project, led by USACE-ERDC, involves the evaluation and validation of portable algorithms, which can be applied to satellite imagery to extract useful monitoring information, such as HAB presence/absence, magnitude, and extent. Outcomes of this project will include identifying a series of generalized algorithms that are effective across varying environmental, physical, geographical conditions to improve the accuracy and estimation of satellite-derived cyanoHAB algorithms and aid district managers in their monitoring efforts.

6. Rapid, Portable and Multiplexed Detection of Freshwater HAB-forming Genera (*Partnership with Bowling Green State University*)

Early detection and identification of cyanobacteria present in a waterbody is critically important for both risk management and treatment selection decisions. Water samples must be processed and analyzed in a laboratory causing delays of days to weeks before cyanobacteria and toxin results are available for decision making; delays can lead to toxin exposure while test results are pending. In this project, Bowling Green State University, in collaboration with ERDC researchers, will develop a rapid, portable, multiplexed test to simultaneously identify and quantify the presence of the seven most common bloom forming cyanobacteria using RNA based technology that can be conveniently performed on freshwater samples in the field. The method is based on the use of a taxon-specific DNA probe that hybridizes to the ribosomal RNA small subunit. Testing of candidate probes through fluorescence microscopy has produced several that are capable of detecting potentially toxic cyanobacteria with high specificity (Figure 6). This new tool will be designed to provide near real time, actionable results and will reduce cost associated with collecting critical data. This data will allow water

resource managers to make rapid decisions that will help protect human and animal health as well as reduce the time needed to determine if in-lake HAB mitigation strategies are proving effective.

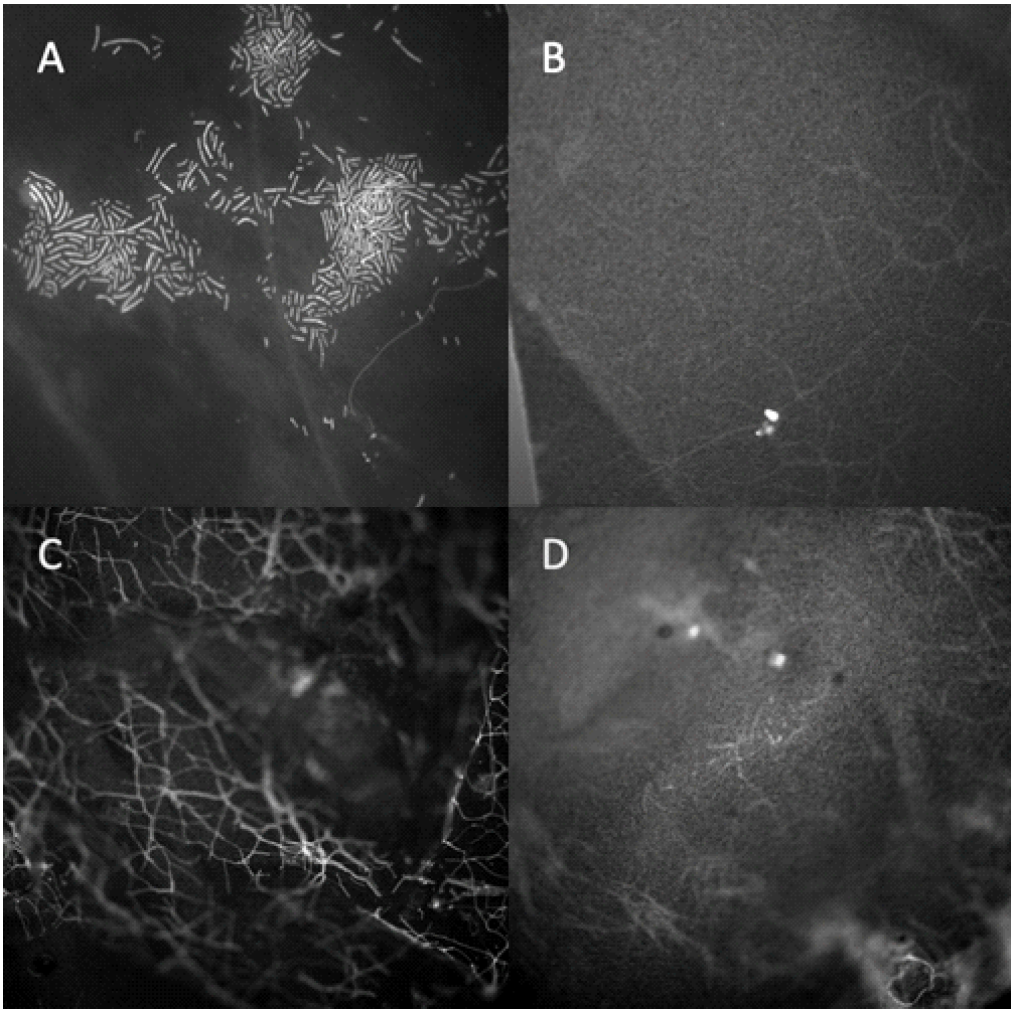


Figure 6. Example of fluorescence in situ hybridization results for *Dolichospermum* and *Cylindrospermopsis*. A. *Dolichospermum* with the *Anabaena/Dolichospermum/Aphanizomenon* (ADA) detecting probe. B. Lack of detection of *Cylindrospermopsis* with the ADA probe. C. CS-506 with universal bacterial positive control probe. D. CS-506 with universal bacterial negative control probe. The ADA probe successfully identified *Dolichospermum* (A), but did not detect the outgroup, *Cylindrospermopsis* (B). Panel D (*Cylindrospermopsis* and negative control) results are similar to results of panel B, indicating that ADA did not detect *Cylindrospermopsis.*

7. Active Early Detection and Diagnosis of HABs with Scalable Biological Treatment Strategies (*Partnership with University of Toledo*)

Real-time HAB diagnostics including novel sensors and rapid molecular tools can provide critical information to drinking water treatment utility professionals. This study, led by the University of Toledo will develop and validate cutting-edge HAB diagnostics to improve the timeliness of decision making for source-water treatment and will also evaluate effectiveness of multiple algaecides and biological treatment methods on HAB impacted reservoirs; thus, developing a

robust dataset and recommendations linking novel HAB diagnostics with treatment performance. One exciting and unique aspect of this project is the focus on multiple time scales. Novel sensors have the ability to detect catastrophic HAB cell lysis and toxin release events in source water on a scale of minutes to hours, in time for managers to respond appropriately. Meanwhile, the molecular techniques are able to characterize the microbial community and functions, related to both the cyanobacteria and the viruses that target the cyanobacteria, in the days and weeks leading up to a lysis event – providing a longer-term picture of HAB risk. Together, the approaches in this study may be able to provide real-time and longer-term assessments of bloom health in large water bodies, as well as guiding the application of biological and chemical treatment methods for optimal performance in HAB-impacted reservoirs.

8. Efficacy of Algaecides and Novel Ozone Nanobubble Technology on Prevention and Management of HABs (*Partnership with the Ohio State University*)

Effective CHAB control strategies are needed to address recreational and drinking water impacts. CHAB treatment challenges can be greater in northern climates since traditional control strategies, like algaecides, are less effective at lower water temperatures. Increased monitoring in states like Ohio has documented the occurrence of CHABs year-round (Ohio EPA, 2021), with cyanotoxin concentrations sometimes greatest in the fall and winter during colder water conditions. This project – led by the Ohio State University and in collaboration with University of Florida, Federal agencies, private industry, and local partners – is evaluating the efficacy and cost of multiple EPA-approved algaecides and an alternative innovative nanobubble ozone treatment technology (NBOT) for CHAB control, including CHABs that thrive in cooler temperatures. Preliminary results have shown variability in treatment efficacy between algaecides at lower temperatures and that some algaecides are more likely to release extracellular toxins, which is a concern for public water systems. A full-scale NBOT lake treatment trial resulted in a sharp decline in cyanobacteria at all monitoring stations following higher dose treatment. Recreational CHAB advisories were not posted, in contrast to past summers. The NBOT trial was complicated, however, by multiple major (1-4.5 inch) summer precipitation events and associated increases in nutrient loading. Additional NBOT trials are planned for 2022 that will further investigate the efficacy of algaecides and NBOTs for CHAB control and determine if NBOT can help prevent blooms by reducing nutrient bioavailability. Overall, this project is providing scientifically defensive data that water managers need to make informed reservoir management decisions.

9. Ultrasound as a Source Water Reservoir Prevention Management Strategy (*Partnership with the Ohio State University*)

This project, led by the Ohio State University (OSU), involves answering key questions about how ultrasound exposure disrupts algal cell growth and the bloom

process. The OSU team is investigating the mechanism by which ultrasound exposure changes algal cell physiology and behavior. The project is also investigating potential benefits of combining energy-efficient ultrasound with targeted hydrogen peroxide application, potentially optimizing the treatment benefits of both technologies while minimizing chemical usage in freshwater reservoirs. The project will conclude with large-scale field demonstrations in Ohio freshwater bodies, generating field scale performance data that will inform practical guidance for end users who wish to incorporate ultrasound for HAB prevention and management.

E. Department of the Interior – Bureau of Indian Affairs

The Bureau of Indian Affairs (BIA) provides funding to Federally recognized Indian Tribal Governments and Native American Organizations authorized by Indian Tribal Governments (tribes and inter-tribal organizations authorized under the Indian Self-Determination and Education Assistance Act, as amended, P.L. 93-638). Through its Invasive Species Program, BIA supports projects related to the management and control of invasive species (both plants and animals) on tribal trust lands, individual Indian allotment lands, or in areas managed by tribes through treaties or agreements, including for the Great Lakes region. This program has provided funding to the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), which represents eleven Ojibwe tribes in Minnesota, Wisconsin, and Michigan with reserved hunting, fishing and gathering rights in Treaties with the United States Government. GLIFWC provides natural resource management expertise, conservation enforcement, legal and policy analysis, and public information services in support of the exercise of treaty rights during well-regulated, off-reservation seasons throughout the treaty-ceded territories. Past efforts and outreach by the GLIFWC have included providing public information regarding invasive blue-green algae species in Muskegon Lake and other surrounding areas. While the BIA Invasive Species Program has not directly funded any Great Lakes-specific HAB-related projects, the BIA recently funded a 2-year project for blue-green algae prevention efforts by the Sisseton-Wahpeton Oyate Tribe, whose districts include western Minnesota watersheds.

F. Department of the Interior – National Park Service

1. National Strategies and Projects

Harmful Algal Blooms have been identified as a nationwide priority issue for all 88 ocean, coastal, and Great Lakes national parks. The National Park Service (NPS) Ocean and Coastal Resources Program developed a targeted action plan to provide guidance on monitoring, testing, reporting, and managing HABs in national parks. To address critical management needs related to HAB monitoring and response in national parks, NPS and USGS scientists developed a nationwide project funded by the USGS-NPS Water Quality Partnership Program, *Rapid Response Strategy for Potential Toxin Exposures from HABs in Coastal and Shoreline Areas of National Parks*. The pilot project includes four Great Lakes parks (Apostle Islands National Lakeshore, Isle Royale National Park, Sleeping

Bear Dunes National Lakeshore, and Perry's Victory & International Peace Memorial), and we are collaborating with the EPA Cyanobacteria Monitoring Collaborative, the NOAA Phytoplankton Monitoring Network, and the University of Wisconsin-Milwaukee. The Great Lakes Restoration Initiative also provided supplemental funding for project work in the Great Lakes. More information on HAB action plan progress can be found in NPS Year 2 and Year 3 Ocean and Coastal Advisory & Support Team Annual Reports.

2. Research and Coordination

Sleeping Bear Dunes National Lakeshore. NPS – in cooperation with the University of Wisconsin-Milwaukee, the University of Michigan, Michigan Department of Natural Resources, and other partners – is conducting nuisance algal monitoring and research. This is a long-term project, and the University of Wisconsin-Milwaukee is finishing up a synthesis of a 10+ year dataset. In addition, experimental work to reduce invasive mussel densities and related benthic algal biomass is underway, and sampling of benthic algal depositional areas is being conducted to analyze microbial composition and potential for botulinum toxin production.

Apostle Islands National Lakeshore. NPS and the University of Minnesota-Duluth Large Lakes Observatory deployed continuous monitoring sensors at several locations to track algal biomass, cyanobacterial pigments, and other parameters in Lake Superior (Sterner et. al., 2020). In 2021, partners from the University of Wisconsin-Milwaukee deployed a real-time temperature string and algal pigment monitoring buoy at a key nearshore monitoring site.

NPS participated in Lake Superior's Coordinated Science and Monitoring Initiative (CSMI) efforts to explore and model HAB drivers in 2021. NPS also participates in the Lake Superior Partnership Algal Bloom Work Group to improve algal bloom detection and response in western Lake Superior. NPS shared algal bloom updates with the public through presentations to diverse audiences via scientific symposia, interactions with teachers via the Lake Superior NOAA NERR's Rivers2Lake program, and interviews with regional and national media.

G. Department of the Interior – United States Geological Survey

The USGS, in collaboration with numerous partners, conducts monitoring and research activities throughout the Nation that are directly relevant, or transferrable to, harmful algal blooms and hypoxia in the Great Lakes. HABs have myriad potential harms including hypoxia, alteration of aquatic food webs, and production of toxins. Ecological imbalances such as excess nutrient loadings to water bodies are known factors that lead to algal blooms. Understanding nutrient inputs and sources, processing and fate in watersheds, transport to lakes and estuaries, and retention and cycling in lakes and estuaries is essential to developing statistical and process-based models to predict the

onset and duration of potentially harmful algal blooms and critical to the development of effective mitigation and management strategies. USGS monitoring and research activities in the Great Lakes Basin focus on a watershed approach to understand the processes driving nutrient movement from land to the lakes. Making land to lake connections is important to understanding how management strategies will change nutrient load dynamics and development of HABs in the Great Lakes and other water bodies (Figure 7). Nutrients are one key driver of algal bloom formation; however, the science relative to factors associated with algal toxin production is not well established. USGS's Toxins and HABs Science Team is actively attempting to identify and understand environmental drivers of algal toxin production and release, determine the most significant exposure routes to humans and wildlife, and develop diagnostic tools to understand if there are health impacts of algal toxins on wildlife in freshwater environments, including the Great Lakes. USGS staff are investigating relations between algal toxin exposures and potential adverse health effects on aquatic and terrestrial organisms, as well as exposure pathways to the public. Several USGS activities since the last progress report have enhanced coordination, monitoring networks, understanding of ecological processes, model development, and characterization of potential toxin exposure and risk. USGS is poised to provide new data, understanding, and decision support tools for stakeholders that need to mitigate or prevent the variety of harmful effects caused by algal blooms.

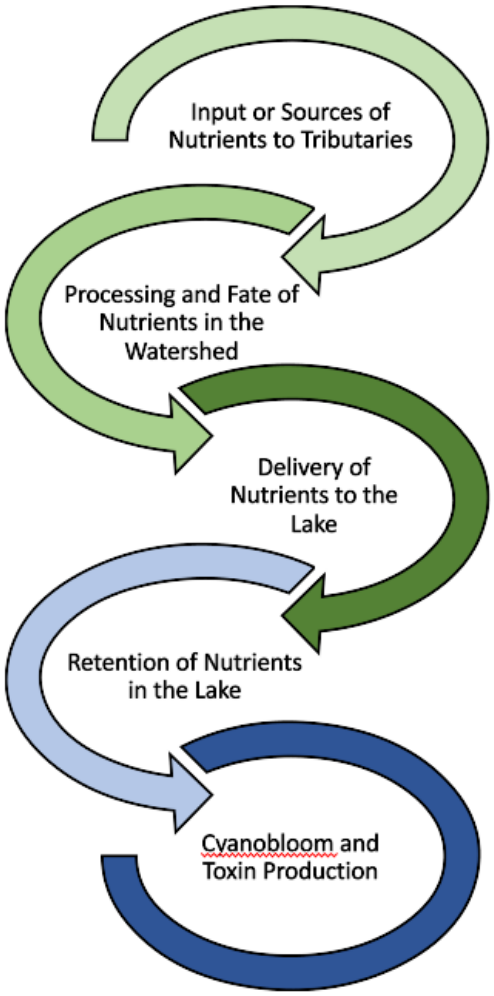


Figure 7. The USGS is conducting research that connects land and lake processes to better understand the environmental drivers of harmful algal blooms in the Great Lakes.

1. Great Lakes Science Leadership and Coordination

USGS plays a leadership role in facilitating communication and coordinating monitoring and research efforts among the many scientists, decision-makers, and stakeholders with a vested interest in the Great Lakes. In 2015, USGS, in partnership with the Great Lakes Commission, established the Great Lakes HABs Collaborative to develop a common knowledge base about the state of the science, identify future science needs, and build a regional network that works

together to better prevent and manage HABs. A summary of Great Lakes HABs knowledge gaps published by the Collaborative in 2021 identified general and lake-specific knowledge gaps under the broad categories of watershed runoff and tributary nutrient loading processes, in-lake processes and bloom development, bloom toxicity, and negative impacts to humans, the ecosystem, and the economy. In 2020, the USGS led a Great Lakes Science Forum to assess data gaps and science needs across the Great Lakes ecosystem (Carl et al., 2021). The forum included numerous partners and stakeholders including EPA, NOAA, the International Joint Commission, several tribes and tribal consortiums, academic researchers, and non-government organizations. The outcomes of this assessment lay the foundation for the development of an integrated Great Lakes science plan and some of the most significant gaps have direct implications to HABs and hypoxia. Key gaps indicated that:

a. Expanded data collection or monitoring would provide basic ecosystem, social, and public health data to manage the Great Lakes system and to develop and test models and decision support tools; and
b. New science and advanced technologies would improve the understanding of critical threats, such as harmful algal blooms.

USGS also plays a key role in supporting the GLWQA Nutrients Annex with Canada. USGS staff participate on subcommittees, task teams, and working groups and often serve in leadership roles including as U.S. Co-chairs of the Lake Erie Adaptive Management Task Team and the Lake Ontario *Cladophora* Working Group.

2. Watershed Activities

Monitoring. Monitoring and assessment are integral to the evaluation of ecosystem change, understanding ecosystem processes, and developing and evaluating models and decision support tools. Existing USGS monitoring stations in the Great Lakes Basin represent approximately 50% of the U.S. drainage area and measure an estimated 45% of all nutrient loads to the Lakes. This monitoring network is funded through a variety of local, state, and Federal sources. Connecting waters of the Great Lakes have not received the same level of focus as

other key tributaries and the lakes. USGS has expanded nutrient monitoring in the St. Clair, Detroit, Niagara, and St. Lawrence Rivers, including targeted assessments of nutrient sources, cycling, and transport to begin to fill this gap. The USGS is also developing a Next Generation Water Observing System (NGWOS) that includes innovation sites used to advance emerging monitoring technologies (Figure 8). For example, non-contact methods for monitoring streamflow and sensor-based methods for monitoring nutrients are being evaluated in the Detroit and Niagara Rivers.

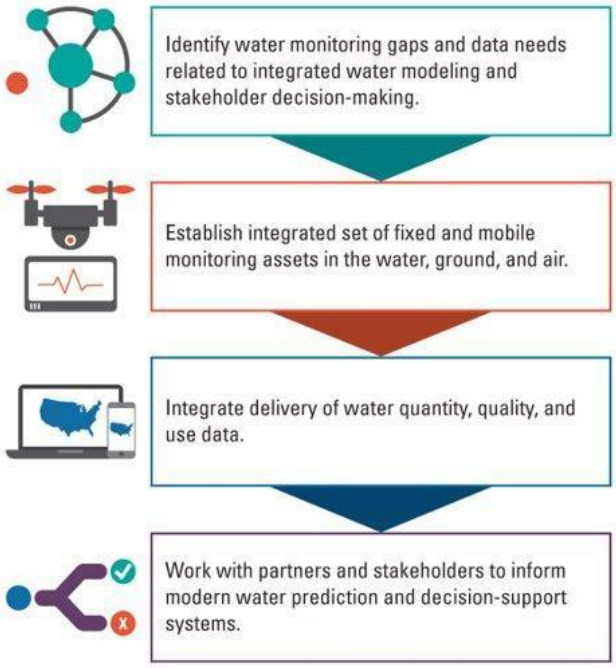


Figure 8. The USGS is developing a Next Generation Water Observing System that will integrate fixed and mobile monitoring assets in the water, ground, and air.

Understanding Ecological Processes. Significant efforts have been made to reduce nutrient inputs to tributaries of the Great Lakes. While these efforts are likely to have a positive effect on overall nutrient loading, change is difficult to quantify, and it is uncertain how long it will take to achieve the reduction goals for priority areas in the Great Lakes. To support restoration and actions to reduce nutrient delivery to the Great Lakes, the USGS is providing a more complete understanding of the sources, sinks, and transport of water, nutrients, and sediment. Recent research has emphasized the transport and fate of legacy (field soils, streambanks, groundwater, and channel-stored) sediment and nutrients in these watersheds, which have the potential to mask the effects of best management practices. Riverbed sediments throughout the Fox River Basin were saturated with phosphorus across a gradient of land uses, suggesting that river sediments in this watershed may act as a legacy source of phosphorus (Kreiling et al., 2019). A follow-up study in the Maumee River Basin is assessing in-stream phosphorus and nitrogen sources and sinks throughout the Basin. As part of the 2021 Cooperative Science and Monitoring Initiative (CSMI), the USGS is part of a multi-institution collaborative effort aimed at addressing the drivers of cyanobacterial blooms in Lake Superior. USGS is monitoring nutrient and suspended sediment loads, examining nutrient cycling potential in bed and suspended sediments, characterizing the microbial community in sediment and water, and screening for presence of cyanotoxins in locations spanning from tributaries to the nearshore of Lake Superior. The overarching goal of the Lake Superior studies is to characterize relationships between storm frequency and

magnitude; nutrient, sediment, and cyanobacteria loading; and bloom development and toxicity, in hopes of better understanding the conditions and processes that lead to algal bloom formation.

Modeling. USGS has developed a surrogate regression approach to estimate continuous tributary loading at 26 major tributaries to the Great Lakes and provided nutrient loading information through 2018 (Robertson et al., 2018; Koltun, 2021). USGS is now developing ways to use these techniques to estimate real-time loads at each of these sites to better understand the timing of nutrient delivery and quantify nutrient load reductions to the Great Lakes. Process-based models are also being developed to evaluate ecosystem-level responses to remediation and restoration projects, including those targeting nutrient reduction. For example, a predictive, mechanistic, three-dimensional hydrodynamic model for the St. Louis River Estuary of Lake Superior was developed to simulate flow and water temperatures, and provide a framework for future nutrient modeling under various remediation scenarios (Smith et al., 2020). Development of watershed models is underway for nine locations in the New York portion of the Lake Erie Basin to help focus future water-quality improvement efforts in the basin and aid in regional target-setting efforts for nutrient reduction; these models will be used to estimate potential nutrient and sediment load reductions under various management practices across a gradient of land uses. Field-scale watershed models are being developed for three locations in the Wisconsin portion of the Lake Michigan Basin to better understand the changes in nutrient and sediment processing associated with various agricultural best management practices.

3. Open-Water Activities

***Monitoring*.** USGS is conducting sentinel site assessments of *Cladophora* in Lakes Michigan, Huron, Erie, and Ontario as part of a binational effort to understand the conditions that lead to *Cladophora* overgrowth throughout the Great Lakes. Sentinel site assessments have been conducted each year since 2018 (Przybyla-Kelly et al., 2020a; Przybyla-Kelly et al., 2020b). New methods to remotely sense *Cladophora* presence and abundance utilizing autonomous underwater vehicles are being tested. These efforts will help support management of this HAB species through nutrient control, especially in Lake Erie where *Cladophora* control remains the biggest unknown in attempts to set nutrient management targets. EPA has assisted with field data collections on Lake Ontario. NPS has assisted with logistical support on Lakes Michigan and Huron.

Understanding Ecological Processes. USGS is using advanced methods to develop a better understanding of the environmental conditions which promote cyanotoxin production and bloom toxicity. Results will inform ongoing efforts to assess the impact of nutrient reductions and lay the foundation for development and improvement of cyanotoxin models and forecasts. Ongoing research is characterizing the ecological and food-web impacts of hypoxia and cyanotoxins.

Recent studies have contributed to the understanding of the effects of hypoxia on Great Lakes fish communities, including distribution of fish in the water column and aggregation near the edges of the hypoxic zone (Chamberlin et al., 2020), and habitat availability use by cisco in Lake Erie based on oxythermal conditions (Schmitt et al., 2020); led to the development of a spatio-temporal geostatistical interpolation framework to estimate hypoxia extent in the Central Basin of Lake Erie (Xu et al., 2021); and explored the utility of miniature temperature and depth sensors implanted in fish as a tool to enhance monitoring data (Kraus et al., 2021). Research by the USGS's Toxins and HABs Science Team on understanding the effects of algal toxin exposures is directly relevant to the Great Lakes. Algal toxin exposures on reserved Federal lands and among trust species have been described (Laughrey et al., 2021). The team has also completed research focused on understanding the relation between algal toxins and seabird die offs in the Bering and Chuckchi Seas (Van Hemert et al., 2021), the acute toxicity of saxitoxin on waterfowl (Dusek et al., 2021), and the mechanisms by which algal toxins cause inflammatory responses in vertebrates, including fish, wildlife, and humans (Hansen et al., 2021).

Models. Tools for timely and accurate estimates of algal toxin occurrence, and concentration, are needed to identify when levels pose a threat to recreational and drinking-water resources. Ongoing research is focused on using real-time water-quality and other data available in near-real time to develop proxies, predictive models, nowcasts, and forecasts of potential harmful algal bloom and cyanotoxin occurrence in lakes and rivers. USGS is leading ground to space verification for the Cyanobacteria Assessment Network (CyAN) developed in partnership with NOAA, EPA, and NASA. A field tool is being created for Lake Erie to query water quality samples. The field tool will be able to access data through maps, charts, tables, and validate algal bloom algorithms based on a spectral satellite data. Nowcast models to determine potential for cyanotoxin exposure at recreational beaches in western Lake Erie and Ohio have been developed (Francy et al. 2019, 2020a). In addition, real-time models to predict microcystin concentration action-level exceedances at recreational beaches and drinking-water intakes in western Lake Erie and Ohio have also been developed (Francy et al., 2020b). Cyanotoxin mixture models, rather than predictive models focused on a single cyanotoxin, show potential in evaluating potential human health risks associated with cyanobacterial blooms containing multiple toxins (Christensen et al., 2021).

4. Adaptive Management and Decision Support

Decision analysis is used to inform complex decisions regarding natural resource management, and the USGS has worked with decision-makers and stakeholders to help frame and analyze many types of natural resources decision problems, including those associated with HABs. A Binational Lake Erie Nutrient Adaptive Management Framework is being developed by the GLWQA Nutrients Annex Adaptive Management Task Team. USGS tools such as the SPARROW model

and the Exploration and Graphics for RivEr Trends (EGRET) statistical package will be used in the adaptive management evaluation process.

H. National Science Foundation

In FY20 and FY21, the National Science Foundation (NSF) supported 18 projects (totaling ~$14M)[4] focused on fundamental research and specifically related to HABs and hypoxia in the Great Lakes.

NSF Directorates and Divisions who funded HABs and hypoxia research in FY20 and FY21 include the: Engineering Directorate (ENG) Chemical, Bioengineering, Environmental and Transport Systems (CBET); ENG Electrical, Communications and Cyber Systems (ECCS); Geosciences Directorate (GEO) Division of Ocean Sciences (OCE); Mathematical and Physical Sciences Directorate (MPS) Division of Mathematical Sciences (DMS); Biological Sciences Directorate (BIO) Division of Biological Infrastructure (DBI); BIO Division of Environmental Biology (DEB); Office of the Director (OD) Office of International Science and Engineering (OISE); and Computer and Information Science and Engineering Directorate (CISE) Division of Advanced Cyberinfrastructure (OAC).

Much of NSF's HAB and hypoxia related research contributes to increasing our understanding of the direct and indirect causes of HABs and their ecological consequences through research on: a) the physiological and ecological bases for algal bloom formation; b) the physical and chemical attributes of coastal oceans that facilitate blooms; c) the population attributes of bloom species; and d) the long-term consequences of ecosystem changes due to blooms. Each of the projects described below contributes to intellectual merit and broader impacts (that can include education, training, broadening, broadening participation, public outreach, and collaboration with policy and management agencies), consistent with NSF's mission and merit review criteria. In collaboration with the National Institute of Environmental Health Sciences (NIEHS), NSF continued to support the Lake Erie Center for Fresh Waters and Human Health (OCE-1840715). This 5-year (since 2018) multi-institutional Center investigates the environmental factors that determine growth and toxicity of cyanobacteria HABs in Lake Erie. The Center's Community Engagement Core recruits charter boat captains as citizen scientists in the collection of water samples, provides real-time data to researchers, and develops communication campaigns about HABs targeted for a variety of audiences around the Great Lakes region. Partnering institutions in this Center include Bowling Green State University, State University of New York Environmental Sciences and Forestry School, Ohio State University, Michigan State University, University of North Carolina, University of Michigan, University of Toledo, and NOAA. Other continuing HAB and hypoxia-related NSF-funded projects include *The role of heterotrophic bacteria in protecting cyanobacteria from hydrogen peroxide in coastal systems* (OCE-1736629), an effort by the University of Michigan to study the sources, fate, and effects of hydrogen

[4] This total is the full amount allocated to projects active in FY20 and FY21, not necessarily the amount of funds that were distributed only in FY20 and FY21. This total does not include the funding allocated to the NEON program, which nation-wide received $130 million between FY20 and FY21.

peroxide in Lake Erie, which is a potentially important control on the toxicity and species present within toxic cyanobacteria HABs. NSF also continued to support the project *Leveraging Hydro-climatic Processes to Advance Season-ahead Cyanobacteria Prediction and Beach Management*, a HABs-related CAREER[5] award that continued throughout FY20 and FY21 (CBET-1845783). This research and education project explores methods to better predict cyanobacteria abundance from hydroclimatic variables (such as temperature, precipitation, and streamflow) to enable better lake management.

New awards in FY20/21 include the EAGER[6] award, *Synchronization Across Terrestrial and Aquatic Ecosystems*, which is applying new analysis tools to better understand changes in water, nutrients, and organic carbon synchronize from watersheds to lakes (OAC-2121896). NSF also funded the University of Wisconsin-Milwaukee in FY20 to demonstrate the practicality of a new technique (using radionuclide lead-210 (210Pb) and its daughter bismuth-210 (210Bi)) to measure particle dynamics in Lake Michigan to better understand shallow water chemical cycling, potentially improving scientific information available to better manage for HABs and hypoxic events (OCE-2023454). Another new NSF FY20 award funded Bowling Green State University to provide U.S. graduate students the opportunity to expand their research on water quality and HABs in Lake Erie to Lake Victoria (OISE-1953468). This research will fill knowledge gaps on the similarities and differences between the blooms that occur in each lake to better understand the ecological strategies that *Microcystis* uses to form blooms in fresh waters across the globe.

NSF is enhancing sustainability in the Great Lakes by advancing and integrating environmental and socio-economic modeling. For example, NSF continues to support the University of Michigan project, *Coastal SEES: Enhancing sustainability in coastal communities threatened by HABs by advancing and integrating environmental and socio-economic modeling* (OCE-1600012). This project addresses the effect of climate on the biophysical dynamics of freshwater ecosystems and ecosystem services, and how scientist and stakeholder co-projection of information can enhance coastal decision-making in the context of responding to HABs outbreaks in the Great Lakes. Another NSF-funded project, *Dynamics of Phytoplankton in Water Columns: Persistence, Competition, and Evolution*, uses mathematical models to understand the competition among phytoplankton and help design more effective hydrologic control strategies for HAB events (DMS-1853561).

In FY20 and FY21, NSF supported several new collaborative research projects on HABs and hypoxia for which investigators from two or more organizations collaborate on a unified research project. One example is the collaborative effort *Treatment of Cyanotoxins by UV/Chlorine: Optimizing Removal While Developing Strategies to*

[5] The Faculty Early Career Development Program (CAREER) is a Foundation-wide activity that offers the National Science Foundations' most prestigious awards in support of early-career faculty who have the potential to serve as academic role models in research and education and to lead advances in the mission of their department or organization.

[6] NSF's EAGER awards are funding mechanisms intended for short-term, proof-of-concept projects with high-payoff prospects.

Minimize Disinfection Byproducts and Toxicity among the University of Cincinnati, University of South Carolina at Columbia, and Baylor University (begun in FY21) to evaluate and optimize the performance of a new water treatment process that combines UV light with chlorine (UV/chlorine) to break down cyanotoxins present in drinking water (CBET-2042060). Another new FY20 NSF collaborative research award is using fish chemical biomarkers in otoliths (i.e., fish ear bones) to directly assess lifetime hypoxia exposure to better understand how hypoxia affects fish and their food webs, contaminant transfers, and ecosystem services including economic impacts. This project, *Shifting the Hypoxia Paradigm-New Directions to Explore the Spread and Impacts of Ocean/Great Lakes Deoxygenation*, is a joint effort between the State University of New York and Texas A&M University (OCE-1923965). The project, *Cyanobacteria, Nitrogen Cycling, and Export Production in the Laurentian Great Lakes*, serves as another new FY20 collaborative research project (OCE-1948787). This collaboration between Wright State University, University of Minnesota Duluth, University of Minnesota-Twin Cities, and University of Pittsburgh is evaluating modern and historical cyanobacterial productivity in Lakes Erie and Superior. The NSF collaborative research project, *Biogeochemistry of diurnal vertical migration in microbial mats of Lake Huron's sinkholes*, is an effort started in FY21 between University of North Florida and Grand Valley State University to examine cyanobacteria daily vertical migration processes in hypoxic microbial mats in Lake Huron (OCE-2045972).

In addition to shorter term projects, NSF recognizes the value in funding long-term research efforts. For example, the NSF-supported National Ecological Observatory Network (NEON) provides environmental data for studies of HABs and hypoxia (DBI-1724433). This program provides aquatic remote sensing and measurement infrastructure for aquatic ecological research, which supports further research on HABs. NSF also continues to support the Lamont-Doherty Core Repository (LDCR), particularly for the long-term curation and archiving of samples and cores collected by the geoscience community to ensure their preservation and usefulness to current and future generations of Earth scientists. Samples preserved by LDCR include sediment cores in Lake Superior from multiple sources which can be used to study historical HAB and hypoxic events and improve predictions for future events (OCE-2115638). The NSF-funded North Temperate Lakes Long-Term Ecological Research site explores the ecology and management of lakes in the Great Lakes region from a long-term perspective, particularly how the biophysical setting, climate, and changing land use and cover interact to shape lake characteristics and dynamics over time (DEB-2025982). Another long-term investment by NSF is through its support of the R/V Blue Heron, an 86-foot coastal research vessel owned by the University of Minnesota and operated by the Large Lakes Observatory as part of the U.S. Academic Research Fleet (ARF) (e.g., OCE-1916124). R/V Blue Heron is part of the University National Oceanographic Laboratory System and is available for charter by research scientists on any of the Great Lakes. Cruises from the R/V Blue Heron are used for water chemistry studies to examine algal toxins in the area and cyanobacteria populations and dynamics.

Infrastructure acquisition and technology development are other areas that NSF supports the HABs and hypoxia research communities. For example, NSF-funded the acquisition

of a next-generation sequencing System for Grand Valley State University's Annis Water Resources Institute to in part characterize microbial communities associated with HABs across freshwater lakes ascribed to different trophic scales (DBI-1828451). Another example is the NSF-funded project, *Multiplexing Detection of Extracellular and Intracellular Toxins in Water by GaN Field Effect Transistors*, is supporting researchers at Ohio State University to develop biosensors for detection of extracellular and intracellular cyanotoxins in water and environmental samples (ECCS-1809570).

I. United States Department of Agriculture – National Institute of Food and Agriculture

The National Institute of Food and Agriculture (NIFA) is the extramural science-funding agency within USDA's Research, Education, and Economics mission area. NIFA invests in and advances agricultural research, education, and extension to help solve national challenges in agriculture, food, the environment, and communities. These efforts are accomplished through the Nation's Land-Grant Universities (LGU), other universities and organizations, and Federal science agencies. NIFA and its partners utilize an integrated approach to create knowledge and to ensure that it makes its way into communities, working lands, and classrooms. This approach includes research to provide solutions to complex issues that challenge the Nation and its citizens; extension to translate knowledge gained through research and education and extend it to stakeholders and decision-makers who can use it; and education to strengthen schools and universities in their efforts to train the next generation of scientists, educators, agricultural, rangeland and forest producers, and citizens. NIFA provides capacity and competitive funding to eligible institutions, organizations, and agencies to pursue research, education, and extension programs in the agricultural, food, and environmental sciences. Several NIFA programs support research, education, and extension programs that address HABs and hypoxia. These include:

- Smith-Lever (extension capacity).
- Hatch and Hatch Multi-State (research capacity).
- Evans-Allen (1890 LGU research capacity).
- McIntire-Stennis Cooperative Forestry Research Program (research capacity).
- Small Business Innovation Research (research competitive).
- Agriculture and Food Research Initiative (research, education, and extension competitive).

The Farm Bill provides most of the authorizing legislation and most existing programs are renewed with every new 5-year Farm Bill. Most legislation does not specifically call for HAB and hypoxia projects but many state partners use capacity funds and submit for competitive funding to address these issues. Competitively awarded grants support science on working agricultural lands which can be the significant sources of nutrient and sediment runoff into waterways in the five-state Lake Erie basin. The primary competitive grants program at NIFA is the Agriculture and Food Research Initiative (AFRI). NIFA provides AFRI grants, through a competitive process, to support research, education, and extension activities in six Farm Bill priority areas:

1) Plant Health and Production and Plant Products.
2) Animal Health and Production and Animal Products.
3) Food Safety, Nutrition, and Health.
4) Bioenergy, Natural resources, and Environment.
5) Agriculture Systems and Technology.
6) Agriculture Economics and Rural Communities.

In addition to Farm Bill language, NIFA science programs will be aligned with the "USDA SCIENCE BLUEPRINT: A Roadmap for USDA Science from 2020 to 2025." The science themes most relevant to HABs and hypoxia are: Sustainable Agricultural Intensification, Agricultural Climate Adaptation, and Agricultural Science Policy Leadership. Some examples of funded projects that apply research, education, and/or extension to work towards solution of Great Lakes HABs and hypoxia include:

1. **A multi-scale and regional approach to cold season hydrology and nutrient dynamics in agroecosystems for water quality protection (AFRI Competitive Grant)** (AM Thompson and others, University of Wisconsin)

The non-growing season is a critical period for nutrient loss in cold agricultural regions. However, soil and water nutrient dynamics during the wintertime and transition periods between frozen and non-frozen conditions are poorly understood. This study integrates hydrology, soil physics, and nutrient measurements with process-based modeling to understand frozen and non-frozen hydrologic processes to protect water quality at the watershed scale in upper Midwest agroecosystem. Given potential changes to nutrient and soil dynamics from climate change, knowledge on how nutrient dynamics are affected by soil temperature gradients and freeze-thaw processes is needed so that stakeholders are aware of adaptation challenges and options. Cold regions contribute to pervasive national and regional water quality issues, such as Gulf Hypoxia and Great Lakes harmful algal blooms. While the critical period for these issues is generally summer, when conditions are conducive to excess algal growth, nutrient loading to waterways throughout the year contributes to summer eutrophication. Wisconsin's work fills knowledge gaps in hydrologic and nutrient cycling processes of frozen/partially frozen soil to develop better guidance to reduce nonpoint source pollution in cold regions.

2. **Integration of diversity with tillage for sustainable field crop production on coarse soils (Hatch Act Capacity Grant)** (SI Snapp, Michigan State University)

Michigan field crop rotations, the Midwest Corn Belt, and similar crop systems globally are reliant on substantial inputs to optimize productivity. The need for frequent and high doses of soluble nutrients is most apparent in crops grown on coarse soils with low to moderate organic matter levels and limited nutrient

supply capacity. Concerns are growing regarding the production costs associated with high input row cropping, and the environmental costs that put water and air quality at risk. Reliance on use of inorganic fertilizers as the primary source of fertility has long-term ecological effects. Loading agricultural systems with reactive nitrogen and soluble phosphorus plays a role in groundwater contamination, hypoxia related issues and global climate change. This project focuses on how to incorporate cover crops into field crop production with reduced disturbance, to ensure that nutrient immobilization and potential disease issues are minimized while soil carbon sequestration and timely nutrient supply are maximized. Farmers, rural communities and consumers in the Great Lakes region and all producers on coarse soils will benefit from the findings of this work.

3. Digital agriculture to design and scale sustainable and resilient agricultural systems (Hatch Act Capacity Grant)

(BR Basso, Michigan State University)

The balance between producing more food for a growing population and protecting the environment is becoming increasingly precarious. As a result, sustainable practices that use soil, water, and other resources more efficiently, and are able to adapt to increased climate variability, are critical. Excessive use of Nitrogen (N) fertilizer over a large area releases significant amounts of nitrous oxide. N is a potent greenhouse gas, and can cause harmful algal blooms and hypoxia. Farmers know that any fertilizer that isn't used by crops can be lost from their fields, thereby lowering profits. Optimal application rates should vary across space and time to match the variability of crop growth conditions and soil properties. Applying fertilizer at a variable rate across a field is challenging because it requires understanding detailed variability across each field and the relationship of that variability to weather. MSU's research advances the science needed to achieve that goal by developing and enabling solutions to improve the economic and environmental efficiency of U.S. agricultural systems given the knowledge of spatial and temporal variability of corn and soybean yields related to climate variability, landscape characteristics, and management.

J. United States Department of Agriculture – Natural Resources Conservation Service

1. Farm Bill Conservation Practice Standards Review

Section 2502 of the 2018 Farm Bill (P.L. 115-334) required expedited review of all 169 national conservation practice standards (CPS) by the Natural Resources Conservation Service (NRCS) by December 19, 2019. In keeping with the review requirement, NRCS evaluated opportunities to increase flexibility in the CPS in a manner that ensures equivalent natural resource benefits, including for the Great Lakes region. NRCS additionally provided the optimal balance between meeting site-specific conservation needs and minimizing risks of design failure and associated costs of construction and installation. To the maximum extent

practicable, the completeness and relevance of the CPS to local agricultural, forestry, and natural resource needs was ensured, including specialty crops, native and managed pollinators, bioenergy crop production, forestry, and such other needs as determined by NRCS. NRCS completed this 2018 Farm Bill review of all CPS in 2019.

NRCS standardizes its conservation practices to integrate science-based solutions into farm planning, which are available to all states (including the eight Great Lakes Region States). NRCS continues to review and revise CPS on a five-year rotation. This ensures applicability of standards to address current issues, including climate resiliency and urban agriculture, as well as consideration of conservation innovations and new scientific and technological advancements.

2. USDA NRCS Great Lakes Restoration Initiative

Through the GLRI, NRCS provides additional assistance to farmers and landowners to combat invasive species, protect watersheds and shorelines from non-point source pollution, and restore wetlands and wildlife habitat. Since 2010, NRCS has funded more than 3,600 conservation contracts, utilizing over $157.3 million in GLRI financial assistance, to help farmers implement agricultural conservation practices on over 803,500 acres within the Great Lakes Basin priority watersheds. As a result of accelerating conservation practice implementation in the Great Lakes Region under GLRI, over 1.75 million pounds of phosphorus losses have been reduced in priority areas. NRCS GLRI efforts also target wildlife habitat and invasive species control. Over 9,575 acres of wildlife habitat has been protected, restored and/or enhanced by implementing 137 contracts totaling $816,000. Over 3,600 acres of aquatic/terrestrial invasive species were controlled by GLRI funded projects on 109 sites, totaling over $832,500.

In addition to financial assistance, NRCS utilizes technical assistance funding for conservation planning, conservation practice designs, and partnership agreements. GLRI-funded Demonstration Farm Networks, created through agreements with conservation partners, showcase cutting edge water quality and soil health practices on participating farms. The farms host field days and tours for farmers and conservation professionals to share successes and lessons learned in adopting new practices and techniques, including no-till planting, cover crops, low disturbance manure applications, and prescribed grazing. Nine networks involving dozens of farms in four states are motivating other farmers to try these new approaches to benefit their operations and reduce phosphorus losses to the Great Lakes.

NRCS continues to work with the USGS through edge-of-field monitoring to assess water quality benefits of conservation practices in priority watersheds located in Wisconsin, Ohio, Michigan, New York, and Indiana. Through GLRI funding, the University of Wisconsin-Green Bay, Purdue University, the USGS

and the NRCS are assessing in-field soil health benefits of conservation practices as well as sediment and nutrient losses in surface water and tile runoff from select farm fields in four Great Lakes priority watersheds. A paper was published analyzing initial results of the study in 2022 (Fermanich et al., 2022). In addition, NRCS has developed a unique collaborative partnership with the Great Lakes Commission (GLC) to reduce nutrient and sediment loss, with an emphasis on a significant reduction of phosphorus loads in the Great Lakes Region via their Great Lakes Sediment and Nutrient Reduction Program. To date, GLC has successfully supported 133 projects in the Great Lakes Basin.

3. NRCS National Water Quality Initiative

USDA National Water Quality Initiative (NWQI), is a partnership among NRCS, the EPA, and state water quality agencies to improve and protect water quality through on-farm, voluntary, conservation. NWQI was launched in 2012 to reduce nonpoint sources (runoff) of agriculture-related nutrients, sediment, and pathogens to impaired or threatened surface water bodies, using a small watershed approach (12-digit Hydrologic Unit Code, or generally an average 10,000-40,000 acres). This small watershed approach provides targeted funding for financial and technical assistance, accelerates funding, and increases the likelihood that water quality improvements are detected in a shorter timeframe. NWQI considers a combination of avoiding, controlling, and trapping (ACT), to reduce the runoff of sediment, nutrients, and pathogens into surface waters where water quality is a critical concern. A primary goal of NWQI is to reduce pollutant or impairment levels so that water quality standards are met or surpassed, and waters can therefore be removed from a state's list of impaired and threatened waters (e.g., stream/river segments, lakes).

From NWQI's start in 2012 thru 2021, NRCS has worked with more than 5,600 producers to adopt conservation practices on more than 1,190,000 acres in priority watersheds across the Nation, with a financial investment of $272.9 million. Within these watersheds, cropland sediment erosion has been reduced by over 1.1 million tons, phosphorus loss and nitrogen loss has been reduced by 3.1 million and 13.5 million pounds, respectively. At least 16 impaired water bodies have been improved and subsequently scheduled for de-listing or otherwise removed from NWQI due to successful water quality improvements. As of FY 2016, state water quality agency partners report that 27% of NWQI monitoring watersheds show an improvement in water quality in at least one of the NWQI-monitored pollutants. Furthermore, 81% of these improvements can be attributed to, or associated with, agricultural conservation practices implemented by farmers and ranchers.

In 2019, NRCS expanded NWQI to include Source Water Protection (SWP), to target conservation practices that protect drinking water sources and provide benefits to agricultural producers. SWP is delivered in coordination with the states, state technical committees, and community water utilities to identify

priority areas to target source water efforts. States further refine the source water priority areas using a variety of risk factors and other characteristics based on HUC12 watersheds. The Farm Bill mandates at least 10% of total funds available for all conservation programs (excluding the Conservation Reserve Program (CRP), are to be used for SWP. In FY 2021, NRCS determined that $376 million in financial assistance, and $124 million in technical assistance from covered programs was devoted to SWP.

In November 2022, NRCS committed to extend NWQI beyond FY23. NWQI is a partnership program with USDA, EPA, and state water quality agencies to select priorities in each state that address impaired waters and/or protect source water for drinking. Watershed assessments or source water protection plans guide efforts to address the identified water quality concerns by targeting vulnerable areas for conservation practices that can have the greatest impact. Since 2012, NWQI has obligated $11.7 million to treat over 36,500 acres within the Great Lakes basin to help improve water quality.

4. Conservation Effects Assessment Project

Conservation Effects Assessment Project (CEAP) studies help to determine current impact, remaining conservation needs, and strategies for increasing effectiveness to achieve benefits from additional conservation. In March 2022, NRCS released a new report of a decadal assessment of conservation effects on cultivated croplands across the U.S., including the Great Lakes Region. Nationally, the report shows use of no-till, crop rotations, more efficient irrigation methods and advanced technologies have climbed in recent years. The "Conservation Practices on Cultivated Cropland: A Comparison of CEAP I and CEAP II Survey Data and Modeling" was developed by USDA's CEAP using surveys, land use and soils data and modeling techniques. It found significant gains for soil health and soil carbon storage, while also identifying areas where additional and targeted nutrient management strategies are needed. The full report (USDA-NRCS, 2022) or a four-page summary of findings are available for download on the agency website.

Key findings nationally include:

- Farmers increasingly adopted advanced technology, including enhanced-efficiency fertilizers and variable rate fertilization to improve efficiency, assist agricultural economies and benefit the environment.
- More efficient conservation tillage systems, particularly no-till, became the dominant form of tillage, improving soil health and reducing fuel use.
- Use of structural practices increased, largely in combination with conservation tillage as farmers increasingly integrated conservation treatments to gain efficiencies. Structural practices include terraces, filter and buffer strips, grassed waterways and field borders.

- Irrigation expanded in more humid areas, and as irrigators shifted to more efficient systems and improved water management strategies, per-acre water application rates decreased by 19% and withdrawals by 7 million-acre-feet.
- Nearly 70% of cultivated cropland had conservation crop rotations, and 28% had high-biomass conservation crop rotations.

Because of this increased conservation, the report estimates:

- Average annual water (sheet and rill) and wind erosion dropped by 70 million and 94 million tons, respectively, and edge-of-field sediment loss declined by 74 million tons.
- Nearly 26 million additional acres of cultivated cropland were gaining soil carbon, and carbon gains on all cultivated cropland increased by over 8.8 million tons per year.
- Nitrogen and phosphorus losses through surface runoff declined by 3% and 6%, respectively.
- Average annual fuel use dropped by 110 million gallons of diesel fuel equivalents, avoiding associated greenhouse gas emissions of nearly 1.2 million tons of carbon dioxide equivalents.

In addition to the large-scale CEAP Cropland modeling analysis, NRCS and partners (USDA ARS), universities, landowners and agencies) continue work under the CEAP Watershed Assessment Study network to document measurable effects of conservation practices on water quality at edge-of-field and small watershed scales. In April 2022, NRCS released a new video showcasing collaborative partnerships driving innovative water quality assessment and conservation in the Western Lake Erie Basin (Figure 9). This film shows how the CEAP watershed studies in the Western Lake Erie Basin bring researchers, farmers, government agencies and nonprofit organizations together to develop science-based solutions and strategically place them where they can deliver the greatest conservation benefits. In October 2021, USDA released a new glossy publication featuring the CEAP Watershed Assessment Studies Network, project descriptions, and key findings and outcomes from each active site including several in the Great Lakes region. A special issue and synthesis study reviews measured water quality conservation outcomes from 15 years of assessment (Moriasi et al., 2020). Four NRCS Outcomes Webinars were prepared and delivered for the public highlighting science and insights on topics including conservation effects in watersheds, innovative watershed assessment planning tools, conservation for climate resilience in the WLEB, and SMART Nutrient Management and outcomes.

Assessment continues in a paired watershed study in the Blanchard River Watershed in Ohio, which drains into the Maumee River Basin. In 2021 a new Pilot Watershed Project was funded by NRCS to The Ohio State University and other partners for over $6.8 million under the Regional Conservation Partnership

Program Alternative Funding Arrangement in the Western Lake Erie Basin. The project will enhance conservation planning and implementation in the Blanchard River CEAP Watershed and elsewhere in the Western Lake Erie Basin and be coupled with CEAP assessment to document outcomes. Findings from CEAP on practice effectiveness and effective conservation strategies are communicated via the Blanchard River Demonstration Farm Network and various science forums in the region, such as the Sea Grant Understanding Algal Blooms: State of the Science workshop. CEAP conservation insights are used to inform and evaluate NRCS conservation applications and to inform adaptive management strategies, USDA, GLRI, and the GLWQA Nutrients Annex.

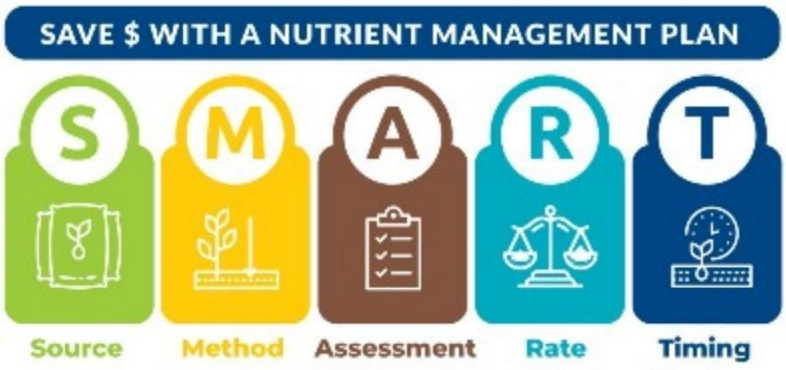
Also, under CEAP Watersheds, NRCS and ARS partner to fund and conduct edge-of-field water quality research at 46 sites of existing as well as innovative conservation practice standards. An assessment of a system of stacked conservation practices for avoiding, controlling, and trapping nutrient and sediment reductions in-fields, at the edges-of-fields, and instream is ongoing within the Western Lake Erie Basin (WLEB). In addition, a new assessment of legacy phosphorus was initiated in 2020 in the WLEB and in 2021, NRCS provided $2.5 million of funding to initiate a national assessment of legacy phosphorus to build on the basin-specific project. Results are expected in 2023 from an USDA assessment quantifying lag time in watersheds in the Maumee River Basin and in other locations around the Nation.

Figure 9. Image of USDA Edge-of-field monitoring sites in Indiana, from USDA's film, *Science-Based Solutions: Leveraging Partnerships to Protect the Western Lake Erie Basin*, which details efforts from CEAP.

5. USDA Increases Assistance and Encourages SMART Nutrient Management Planning 2

SMART Nutrient Management Planning helps farmers save money on fertilizer costs – which have increased significantly in the past year – with the added

benefit of healthier soils, fewer greenhouse gas emissions, and cleaner water. The Natural Resources Conservation Service (NRCS) recently highlighted *SMART* nutrient management planning which includes the 4Rs of nutrient stewardship (right Source, right Method, right Rate and right Timing) and emphasizes smart activities to reduce nutrient loss by adding ***Assessment*** of comprehensive, site-specific conditions, recognizing that nutrient needs – as well as risks for nutrient losses – vary even within a field. Producers could save an average of nearly $30 per acre on fertilizer costs if they implemented a nutrient management plan. Nutrient management not only improves water quality, but also is an important part of climate-smart agriculture. Excess nutrients on the land can lead to nitrogen losses to the atmosphere. Nutrient management maximizes crop-nitrogen uptake and has a compelling and cost-effective role to play in mitigating greenhouse gas emissions from agriculture. The Inflation Reduction Act will deliver $19.5 billion in new conservation funding to support climate-smart agriculture, including for NRCS to improve opportunities for nutrient management. USDA recently announced it is targeting funding, increasing program flexibilities, launching a new outreach campaign to promote nutrient management's economic benefits, and expanding partnerships to develop nutrient management plans. NRCS is highlighting why SMART nutrient management planning is a win-win for farmers.



To share the science behind SMART nutrient management and the outcomes it can achieve, in October 2022, NRCS Conservation Outcomes Webinar Series focused on *Achieving Water Quality Outcomes Through Nutrient and Water Management*, and a webinar recording and additional resources are available online. Despite many successes from farmer-led conservation efforts documented in a March 2022 NRCS report, data revealed national increases in subsurface nitrogen and soluble phosphorus lost to the environment over a 10-year period. CEAP Watershed Studies have recommended that agrichemical loss, a function of source and transport mechanisms, must be addressed with a two-pronged approach. This includes both nutrient and water management, especially as shifts in climate patterns complicate efforts to reduce agricultural nutrient sources.

K. United States Environmental Protection Agency

EPA has taken several actions to protect public health from HABs. EPA works with states, territories and authorized tribes to ensure that Clean Water Act programs and authorities are leveraged to protect human health, in the following ways:

- Swimming advisories for cyanotoxins are issued to protect public health in recreational waters.
- Waters are listed as not meeting water quality standards related to nutrients, eutrophication, and HABs, either for already adopted applicable numeric criteria, or for applicable narrative criteria.
- For impaired waters, a pollution diet or Total Maximum Daily Load (TMDL) is developed and implemented to mitigate HABs.
- Permits are written that will not cause or contribute to this problem.
- Funding for effective BMPs is directed to mitigate HABs.

EPA developed drinking water health advisories for two cyanotoxins, microcystins and cylindrospermopsin, and recommendations for managing algal toxins in drinking water, in 2015. EPA issued Recommended Recreational Ambient Water Quality Criteria or Swimming Advisories for microcystins and cylindrospermopsin, for the protection of human health while swimming or participating in other recreational activities in and on the water, in 2019. EPA is working to assess the presence of HAB-related organisms and toxins in public water systems nationally, characterize the effectiveness of drinking water treatment techniques in reducing toxin concentrations, and assist drinking water treatment facilities in optimizing their existing facilities for toxin control while maintaining compliance with other Safe Drinking Water Act finished drinking water standards.

In addition to these activities, EPA conducts research and monitoring to better understand the causes of HABs and hypoxia and mitigate their impacts – and has a lead coordination role to work with other Federal agencies and Canada on actions to prevent HABs and hypoxia in the Great Lakes basin under the GLWQA and the GLRI. Specific accomplishments during 2021-22 are highlighted below and in Section B of this report.

1. Clean Water Act and Safe Drinking Water Act programs

In 2021, EPA published a technical support document, *Implementing the 2019 National Clean Water Act Section 304(a) Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin*, to assist states and authorized tribes in implementing these recommended criteria.

In 2021, EPA published new recommended ambient water quality criteria to address nutrient pollution in lakes and reservoirs under section 304(a) of the Clean Water Act (CWA). These criteria replace ecoregional nutrient criteria for lakes and reservoirs released in 2000-01. The updated criteria are based on data from EPA's National Aquatic Resource Surveys and include stressor-response models linking protection of designated uses to nutrient concentrations.

In May 2021, EPA posted a Cyanotoxins Preparedness and Response Toolkit (CPRT) online. The CPRT helps EPA's state and tribal partners prepare for potential HABs in freshwater bodies and respond to protect public health. The CPRT includes a template to develop a Cyanobacteria/Cyanotoxins Management Plan, including worksheets and checklists to assist before and during a bloom event; frequently asked questions; links to tools relevant to the development of management plans and effective communication during cyanotoxin events; an incident response questionnaire to use when a cyanotoxins event is suspected or confirmed; and a post-incident technical support questionnaire to evaluate the effectiveness of the response.

The Ohio EPA is developing a TMDL for the Maumee River to address impairments in western Lake Erie due to HABs. The draft TMDL report is planned to be submitted to EPA for approval by the end of 2022. The TMDL will include phosphorus load allocations for point source and nonpoint source pollution occurring throughout Ohio's portion of the Maumee drainage basin to meet the reduction goals established under the GLWQA. The Maumee River TMDL work follows on the heels of methods Ohio EPA developed in 2020 to assess portions of Lake Erie for recreational impairment from HABs under the CWA.

In 2022, Michigan proposed designating Saginaw Bay as impaired for nutrients, due to repeated, persistent, and extensive cyanobacteria blooms impacting the inner portion of Saginaw Bay, as evidenced by both NOAA satellite imagery as well as shoreline monitoring data.

EPA encourages States to enable water quality trading and adaptive management as permit compliance options for nutrient dischargers. In the Great Lakes basin, Wisconsin, developed a state-wide water quality trading framework after phosphorus water quality standards were approved in 2010. Three successful trades, of 32 total trades approved in Wisconsin, occurred in the Great Lakes basin from 2019-2021. Project locations and associated documents are available online. Notably, NEW Water (Green Bay Metropolitan Sewage District) recently completed a multiyear pilot project to consider the feasibility of incorporating adaptive management (AM) in their wastewater permit as a method for compliance. AM is a unique permitting strategy in Wisconsin that catalyzes efforts among watershed partners to reduce non-point source pollutants and achieve water quality criteria in a receiving watershed. Based on their experience, NEW Water submitted an AM Plan for inclusion in the 2022 permit reissuance.

2. Great Lakes Monitoring and Assessments

EPA Great Lakes National Program Office annually monitors temperature and dissolved oxygen concentration at 10 sampling stations in the central basin of Lake Erie throughout the stratified season. This program continues a time series

that was initiated in 1983 to monitor and track hypoxic conditions in response to the phosphorus reduction programs implemented by the 1978 GLWQA. Oxygen and temperature profiles are collected every three weeks in order to determine the annual oxygen depletion rate and duration of hypoxia/anoxia in the Central Basin of Lake Erie. This sampling is conducted with cooperation from the USGS Lake Erie Biological Station R/V Muskie. EPA's Lake Erie Dissolved Oxygen Monitoring Program technical reports are available at www.epa.gov/great-lakes-monitoring.

EPA Great Lakes National Program Office conducts long-term monitoring of the Great Lakes, which includes annual water quality and lower food web monitoring surveys in Great Lakes open waters in spring and summer. Due to COVID restrictions, monitoring did not occur in 2020, but resumed in 2021. EPA expects to release a technical report in 2022 that presents the results of long-term trend analyses of water quality data for each of the Great Lakes from 1983 through 2018.

Every 3 years, EPA in partnership with Environment and Climate Change Canada, conducts a comprehensive assessment of the Great Lakes ecosystem for nutrient and algae status and trends using a suite of indicators. The next binational State of Great Lakes report will be released in 2022.

In August 2021, EPA released a new National Coastal Condition Assessment (NCCA) report showing that eutrophication is a persistent problem in Great Lakes nearshore waters, and that Lake Erie experienced the most eutrophication, with 67% of the nearshore waters in fair or poor condition. The NCCA is a national coastal monitoring program with rigorous quality assurance protocols and standardized sampling procedures designed to produce national and regional estimates of the quality of the nation's coastal waters. A collaborative program between EPA, states, and tribes, the NCCA provides critical and nationally-consistent data on the nation's coastal waters.

3. Satellite Remote Sensing and Early Warning Systems

The Cyanobacteria Assessment Network (CyAN) is a multi-agency project among EPA, NASA, NOAA, and the USGS to develop an early warning indicator system using historical and current satellite data to detect algal blooms in U.S. freshwater systems. EPA maintains a project website that summarizes progress by each fiscal year.

In 2021, there was a major public release of CyAN data along with a web-based app. WDNR staff collaborated on developing and beta testing the CyAN web app for identifying cyanobacteria blooms in Green Bay. CyAN is one of the tools used by the states to track algal blooms and to respond to illnesses reported. So far, four Great Lakes states are using CyAN data (Wisconsin, Ohio, Pennsylvania, and New York).

IV. CONCLUSION

Since the release of the 2020 Interagency Progress and Implementation Report, much progress has been made in the Great Lakes on partnership efforts to address nutrient pollution and other stressors to the Great Lakes ecosystem, as well as on the science of HABs and hypoxia. The Federal agencies have provided updates (Appendix A) to the original activities listed in the Harmful Algal Blooms and Hypoxia in the Great Lakes Research Plan and Action Strategy: An Interagency Report and the new activities (post-2017) listed in the Harmful Algal Blooms and Hypoxia in the Great Lakes Interagency Progress and Implementation Report. They have likewise included new activities (post-2020) in Appendix B. Some important advancements include:

- HAB forecasts continue to be operational, together with the refinement of an experimental Lake hypoxia forecast.
- Continued enhancement and expansion of a near real-time monitoring network in western Lake Erie and other parts of the Great Lakes.
- Continued advancements to better detect HABs and toxins.
- Coordination with stakeholders through outreach, education, and citizen science efforts.
- Enhancement of models and tools allowing drinking water managers the ability to prepare for when HABs or hypoxia are in the vicinity of water intakes and to potentially treat blooms.
- Numerous publications on the fate and transport of nutrients that may support HABs or hypoxia, on the evaluation of management strategies for nutrient reduction, and on the expansion of frameworks and models to advance these efforts.

The programs, policies, and other activities highlighted in this progress report continue to further our collective understanding of the causes and effects of HABs and hypoxia, to better monitor and detect HABs and hypoxia, and to improve preparedness. The Federal agencies involved have also been working since the publication of the aforementioned reports to increase and improve collaborations with stakeholders. Uncertainties and research challenges with predictive abilities, management options, and ability to protect the health of communities in the Great Lakes through mitigation efforts continue to be addressed as technologies and capabilities improve. This progress report promotes and highlights collaboration between Federal and non-Federal organizations to reduce HABs and hypoxia in the Great Lakes.

V. REFERENCES

Akins, L., J. Ortiz, and L.G. Leff. "Strain-specific responses of toxic and non-toxic Microcystis aeruginosa to exudates of heterotrophic bacteria." *Hydrobiologia* 847(2020): 75-89. DOI: 10.1007/s10750-019-04073-4.

Arhonditsis, G.B., A. Neumann, Y. Shimoda, D.K. Kim, F. Dong, G. Onandia, C. Yang, A. Javed, M. Brady, A. Visha, F. Ni, and V. Cheng. "Castles built on sand or predictive limnology in action? Part B: Designing the next monitoring-modelling-assessment cycle of adaptive management in Lake Erie." *Ecological Informatics* 53(2019): 100969. DOI: 10.1016/j.ecoinf.2019.05.015.

Auer, M.T., L.M. Tomlinson, S.N. Higgins, S.Y. Malkin, E.T. Howell, and H.A. Bootsma. "Great Lakes Cladophora in the 21st Century: Same Algae-Different Ecosystem." *Journal of Great Lakes Research* 36(2010): 248-255. DOI: 10.1016/j.jglr.2010.03.001.

Bartlett S.L., S.L. Brunner, J.V. Klump, E.M. Houghton, and T.R. Miller. "Spatial analysis of toxic or otherwise bioactive cyanobacterial peptides in Green Bay, Lake Michigan." *Journal of Great Lakes Research* 44(2018): 924-933. DOI: 10.1016/j.jglr.2018.08.016.

Berkowitz, J.F., D.A. Schlea, C.M. VanZomeren, and C.M. Boles. "Coupling watershed modeling, public engagement, and soil analysis improves decision making for targeting P retention wetland locations." *Journal of Great Lakes Research* 46(2020): 1331-1339. DOI: 10.1016/j.jglr.2020.06.016.

Berkowitz, J.F., C.M. VanZomeren, N.R. Hurst, and K.J. Sebastian. (2021). An evaluation of soil phosphorus storage capacity (SPSC) at proposed wetland restoration locations in the western Lake Erie Basin. ERDC/EL TR-21-6. DOI: 10.21079/11681/42108.

Biddanda, B.A., S.C. Nold, S.A. Ruberg, S.T Kendall, T.G. Sanders, and J.J. Gray. "Great Lakes sinkholes: a microbiogeochemical frontier." *Eos, Transactions American Geophysical Union* 90(2009): 61-62. DOI: 10.1029/2009EO080001.

Bingham, M., S.K. Sinha, and F. Lupi. Economic Benefits of Reducing Harmful Algal Blooms in Lake Erie. Environmental Consulting & Technology, Inc., Report, 66 pp., October 2015.

Bocaniov, S.A., and D. Scavia. "Temporal and Spatial Dynamics of Large Lake Hypoxia: Integrating Statistical and Three-Dimensional Dynamic Models to Enhance Lake Management Criteria." *Water Resources Research* 52(2016): 4247-4263. DOI: 10.1002/2015WR018170.

Bosse, K.R., M.J. Sayers, R.A. Shuchman, J. Lekki, and R. Tokars. "Measuring the Impact of the COVID-19 Shutdown on Great Lakes Water Quality Using Remote Sensing." *Frontiers in Marine Science* 8(2021). DOI: 10.3389/fmars.2021.673989.

Bradley, P.M., D.R. LeBlanc, K.M. Romanok, K.L. Smalling, M.J. Focazio, M.C. Cardon, J.M. Clark, J.M. Conley, N. Evans, C.E. Givens, J.L. Gray, L.E. Gray, P.C. Hartig, C.P. Higgins, M.L. Hladik, K.A. Loftin, R.B. McCleskey, C.A. McDonough, E.K. Medlock-Kakaley, C.P. Weis, and V.S. Wilson. "Public and private tapwater: comparative analysis of contaminant exposure and potential risk, Cape Cod, MA, USA." *Environment International* 152(2021): 106487. DOI: 10.1016/j.envint.2021.106487.

Brahney, J., G. Wetherbee, G.A. Sexston, C. Youngbull, P. Strong, and R.C. Heindel. "A new sampler for the collection and retrieval of dry dust deposition." *Aeolian Research* 45(2020): 100600. DOI: 10.1016/j.aeolia.2020.100600.

Bridgeman, T.B., D.W. Schloesser, and A.E. Krause. “Recruitment of Hexagenia mayfly nymphs in western Lake Erie linked to environmental variability.” *Ecological Applications* 16(2006): 601-611. DOI: 10.1890/1051-0761(2006)016[0601:ROHMNI]2.0.CO;2.

Brooks, P., J. Chorover, S. Godsey, J. McNamara, and C. Tague. “Hydrological Partitioning in the Critical Zone: Recent Advances and Opportunities for Developing Transferable Understanding of Water Cycle Dynamics.” *Water Resources Research* 51(2015): 6973-6987. DOI: 10.1002/2015WR017039.

Burns, N.M., D.C. Rockwell, P.E. Bertram, D.M. Dolan, and J.J. Ciborowski. “Trends in temperature, Secchi depth, and dissolved oxygen depletion rates in the central basin of Lake Erie, 1983–2002.” *Journal of Great Lakes Research* 31(2005): 35-49. DOI: 10.1016/S0380-1330(05)70303-8.

Byappanahalli, M., M. Fowler, D. Shively, and R. Whitman. “Ubiquity and Persistence of *Escherichia coli* in a Midwestern Coastal Stream.” *Applied Environmental Microbiology* 69(2003): 4549-4555. DOI: 10.1128/AEM.69.8.4549-4555.2003.

Carl, L.M., J.E. Hortness, and R.M. Strach, U.S. Geological Survey Great Lakes Science Forum – Summary of remaining data and science needs and next steps: U.S. Geological Survey Open-File Report 2021-1096(2021), 4 p., DOI: 10.3133/ofr20211096.

Carmichael, W.W., and G.L. Boyer. “Health Impacts from Cyanobacteria Harmful Algae Blooms: Implications for the North American Great Lakes.” *Harmful Algae* 54(2016): 194-212. DOI: 10.1016/j.hal.2016.02.002.

Chaffin, J.D., J.F. Bratton, E.M. Verhamme, H.B. Bair, A.A. Beecher, C.E. Binding, J.A. Birbeck, T.B. Bridgeman, X. Chang, J. Crossman, W.J.S. Currie, T.W. Davis, G.J. Dick, K.G. Drouillard, R.M. Errera, T. Frenken, H.J. MacIsaac, A. McClure, R.M. McKay, L.A. Reitz, J.W. Santo-Domingo, K. Stanislawczyk, R.P. Stumpf, Z.D. Swan, B.K. Snyder, J.A. Westrick, P. Xue, C.E. Yancey, A. Zasterpa, and X. Zhou. “The Lake Erie HABs Grab: A binational collaboration to characterize the western basin cyanobacterial harmful algal blooms at an unprecedented high-resolution spatial scale.” *Harmful Algae* 108(2021): 102080. DOI: 10.1016/j.hal.2021.102080.

Choquette, A.F., R.M. Hirsch, J.C. Murphy, L.T. Johnson, and R.B. Confesor, Jr. “Tracking changes in nutrient delivery to western Lake Erie: Approaches to compensate for variability and trends in streamflow.” *Journal of Great Lakes Research* 45(2019): 21-39. DOI: 10.1016/j.jglr.2018.11.012.

Chamberlain, D.W., C.T. Knight, R.T. Kraus, A.M. Gorman, W. Xu, and P.D. Collingworth. “Hypoxia augments edge effects of water column stratification on fish distribution.” *Fisheries Research* 231(2020): 105684. DOI: 10.1016/j.fishres.2020.105684.

Christensen, V.G., E.A. Stelzer, B.C. Eikenberry, H.T. Olds, J.F. LeDuc, R.P. Maki, A.M. Saley, J. Norland, and E. Khan. “Cyanotoxin mixture models: relating environmental variables and toxin co-occurrence to human exposure risk.” *Journal of Hazardous Materials* 415(2021): 125560. DOI: 10.1016/j.jhazmat.2021.125560.

Christensen, V.G., H.T. Olds, J. Norland, and E. Khan. “Phytoplankton community interactions and cyanotoxin mixtures in three recurring surface blooms within one lake.” *Journal of Hazardous Materials* 427(2022): 128142. DOI: 10.1016/j.jhazmat.2021.128142.

Chun, C.L., U. Ochsner, M.N. Byappanahalli, R.L. Whitman, W.H. Tepp, G. Lin, E.A. Johnson, J. Peller, and M.J. Sadowsky. “Association of toxin-producing Clostridium botulinum

with the macroalga Cladophora in the Great Lakes." *Environmental Science and Technology* 47(2013): 2587-2594. DOI: 10.1021/es304743m.

Cloern, J.E., T.S. Schraga, E. Nejad, and C. Martin. "Nutrient status of San Francisco Bay and its management implications." *Estuaries and Coasts* 42(2020): 1299-1317. DOI: 10.1007/s12237-020-00737-w.

Coffer, M.M., B.A. Schaeffer, K. Foreman, A. Porteous, K.A. Loftin, R.P. Stumpf, P.J. Werdell, E. Urquhart, R.J. Albert, and J.A. Darling. "Assessing cyanobacterial frequency and abundance at surface waters near drinking water intakes across the United States." *Water Research* 201(2021b): 117377. DOI: 10.1016/j.watres.2021.117377.

Coffer, M.M., B.A. Schaeffer, W.B. Salls, E. Urquhart, K.A. Loftin, R.P. Stumpf, P.J. Werdell, and J.A. Darling. Satellite remote sensing to assess cyanobacterial bloom frequency across the United States at multiple spatial scales. *Ecological Indices* 128(2021a): 107822. DOI: 10.1016/j.ecolind.2021.107822.

Currie, S.J., C.M. VanZomeren, and J.F. Berkowitz. (2017). Utilizing wetlands for phosphorus reduction in Great Lakes watersheds: A review of available literature examining soil properties and phosphorus removal efficiency. ERDC/EL SR-17-4. DOI: 10.21079/11681/24838.

Davis, T.W., M.J. Harke, M.A. Marcoval, J. Goleski, C. Orano-Dawson, D.L. Berry, and C.J. Gobler. "Effects of nitrogenous compounds and phosphorus on the growth of toxic and non-toxic strains of Microcystis during cyanobacterial blooms." *Aquatic Microbial Ecology* 61(2010): 149-162. DOI: 10.3354/ame01445.

Del Giudice, D., S. Fang, D. Scavia, T.W. Davis, M.A. Evans, and D.R. Obenour. "Elucidating controls on cyanobacteria bloom timing and intensity via Bayesian mechanistic modeling." *Science of The Total Environment* 755(2021): 142487. DOI: 10.1016/j.scitotenv.2020.142487.

Delorme, L.D. "Lake Erie oxygen; the prehistoric record." *Canadian Journal of Fisheries and Aquatic Sciences* 39(1982): 1021-1029. DOI: 10.1139/f82-137.

Dusek, R.J., M.M. Smith, C. Van Hemert, V.I. Shearn-Bochsler, S. Hall, C.D. Ridge, D.R. Hardison, R.S.A. Kaler, B. Bodenstein, E.K. Hofmeister, and J.S. Hall. "Acute oral toxicity and tissue residues of saxitoxin in the mallard (Anas platyrhynchos)." *Harmful Algae* 109(2021): 102109. DOI: 10.1016/j.hal.2021.102109.

Fahnenstiel, G.L., D.F. Millie, J. Dyble, R.W. Litaker, P.A. Tester, M.J. McCormick, R. Rediske, and D. Klarer. "Microcystin Concentrations and Cell Quotas in Saginaw Bay, Lake Huron." *Aquatic Ecosystem Health & Management* 11(2008): 190-195. DOI: 10.1080/14634980802092757.

Fermanich, Kevin, Molly Meyers, Luke Loken, Marianne Bischoff-Gray, Ronald Turco, Karen Stahlheber, Lisa F. Duriancik, Mathew Dornbush, Matt Komiskey. 2022. Challenges in Linking Soil Health to Edge-of-Field Water Quality across the Great Lakes Basin. J. Environ. Qual. 2022;1–15., http://dx.doi.org/10.1002/jeq2.20364

Francy, D.S., A.M. Brady, and T.M. Zimmerman. Real-time assessments of water quality – A nowcast for Escherichia coli and cyanobacterial toxins: U.S. Geological Survey Fact Sheet 2019-3061(2019), 4 p. DOI: 10.3133/fs20193061.

Francy, D.S., A.M.G. Brady, B.L. Ash, and W.R. Midden. Pilot-scale testing of dairy manure treatments to reduce nutrient transport from land application, northwest Ohio, 2015-17: U.S. Geological Survey Scientific Investigations Report 2020-5015(2020a), 31 p. DOI: 10.3133/sir20205015.

Francy, D.S., A.M.G. Brady, J. Cicale, H. Dalby, and E.A. Stelzer. "Nowcasting methods for determining microbiological water quality at recreational beaches and drinking-water source waters." *Journal of Microbiological Methods* 175(2020a): 105970. DOI: 10.1016/j.mimet.2020.105970.

Francy, D.S., A.M.G. Brady, E.A. Stelzer, J. Cicale, C.P. Hackney, H. Dalby, P. Struffolino, and D.F. Dwyer. "Predicting microcystin concentration action-level exceedances from cyanobacterial blooms in selected lake sites in Ohio." *Environmental Monitoring and Assessment* 192(2020b), article 513. DOI: 10.1007/s10661-020-08407-x.

Graham, J.L., N.M. Dubrovsky, K.A. Loftin, B.H. Rosen, and E.A. Stelzer. Cyanotoxin, chlorophyll-a, and cyanobacterial toxin genetic data for samples collected at eleven large river sites throughout the United States, June through October 2018. U.S. Geological Survey Data Release (2021). DOI: 10.5066/P98RPC1E.

Great Lakes Restoration Initiative (GLRI). Great Lakes Restoration Initiative Action Plan III. Fiscal Year 2020 – Fiscal Year 2024. (2019). www.epa.gov/sites/default/files/2019-10/documents/glri-action-plan-3-201910-30pp.pdf. Last accessed: March 21, 2022.

Hamidi, S., H. Bravo, and J. Klump. "Evidence of Multiple Physical Drivers on the Circulation and Thermal Regime in the Green Bay of Lake Michigan." *World Environmental and Water Resources Congress* (2013): 1719-1726. DOI: 10.1061/ 9780784412947.169.

Hansen, J.D., K.A. Loftin, Z. Laughrey, and O. Adamovsky. "Neither microcystin, nor nodularin, nor cylindrospermopsin directly interact with human toll-like receptors." *Chemosphere* 274(2021): 129623. DOI: 10.1016/j.chemosphere.2021.129623.

Hurst, N.R., C.M. VanZomeren, and J.F. Berkowitz. "Temperature, redox, and amendments alter wetland soil phosphorus retention capacity in a Laurentian Great Lakes priority watershed." *Journal of Great Lakes Research* (in review).

Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act (IWG-HABHRCA). (2020). Harmful Algal Blooms and Hypoxia in the Great Lakes: An Interagency Progress and Implementation Report. Report to Congress. National Oceanic and Atmospheric Administration.

International Joint Commission (IJC). *Human Health Effects from Harmful Algal Blooms: A Synthesis*. Submitted by the Health Professionals Advisory Board (HPAB). 9 (2013). 55p. https://legacyfiles.ijc.org/publications/Attachment%202%20Human%20Health%20Effects%20from%20Harmful%20Algal%20Blooms.pdf. Last accessed: March 20, 2020.

International Joint Commission (IJC). *A Balanced Diet for Lake Erie: Reducing Phosphorus Loadings and Harmful Algal Blooms.* A Report of the Lake Erie Ecosystem Priority. (2014). ISBN: 978-1-927336-07-6. https://legacyfiles.ijc.org/publications/2014%20IJC%20LEEP%20REPORT.pdf. Last accessed: March 20, 2020.

IOOS Association. 2021. Implementation Strategy for a National Harmful Algal Bloom Observing Network (NHABON). IOOSassociation.org. 10p. www.ioosassociation.org/NHABON. Last accessed: March 20, 2022.

Ishii, S., T. Yan, D.A. Shively, M.N. Byappanahalli, R.L. Whitman, and M.J. Sandowsky. "Cladophora (Chlorophyta) spp. harbor human bacterial pathogens in nearshore water of Lake Michigan." *Applied and Envrionmental Microbiology* 72(2006): 4545-4553. DOI: 10.1128/AEM.00131-06.

Jabbari, A., J.D. Ackerman, L. Boegman, and Y. Zhao. “Increases in Great Lake winds and extreme events facilitate interbasin coupling and reduce water quality in Lake Erie.” *Scientific Reports* 11(2021). DOI: 10.1038/s41598-021-84961-9

Johnson, H.M., and E.G. Stets. “Nitrate in streams during winter low-flow conditions as an indicator of legacy nitrate.” *Water Resources Research* 56(2020): e2019WR026996. DOI: 10.1029/2019WR026996.

Kalejs, N.I., M.T. Zischke, J.S. Beugly, P.D. Collingsworth, E.F. Roseman, R.D. Hunter, D.G. Fielder, and T.O. Höök. “An evaluation of fish spawning on degraded and remnant reefs in Saginaw Bay, Lake Huron.” *Journal of Great Lakes Research* 48(2022): 593-605. DOI: 10.1016/j.jglr.2022.01.010.

Kitchens, C.M., T.H. Johengen, and T.W. Davis. “Establishing spatial and temporal patterns in Microcystis sediment seed stock viability and their relationship to subsequent bloom development in Western Lake Erie.” *PLoS One* 13(2018): e0206821. DOI: 10.1371/journal.pone.0206821.

Klumb, R.A., K.L. Bunch, E.L. Mills, L.G. Rudstam, G. Brown, C. Knauf, R. Burton, and F. Arrhenius. “Establishment of a metalimnetic oxygen refuge for zooplankton in a productive Lake Ontario embayment.” *Ecological Applications* 14(2004): 113-131. DOI: 10.1890/02-5054.

Koltun, G.F. Estimated total phosphorus loads for selected sites on Great Lakes tributaries, water years 2014–2018: U.S. Geological Survey Open-File Report 2020-1145(2021), 13 p., DOI: 10.3133/ofr20201145.

Komiskey, M.J., T.D. Stuntebeck, L.C. Loken, K.A. Hood, M.E. Danz, C.M. Rachol, C.A. Toussant, E.G. Dobrowolski, A.J. Kowalczk, R.P. Ennis, S.A. Snarski, and M.J. Hardebeck. Nutrient and sediment concentrations, loads, yields, and rainfall characteristics at USGS surface and subsurface-tile edge-of-field agricultural monitoring sites in Great Lakes States. U.S. Geological Survey data release (2021). DOI: 10.5066/P9LO8O70.

Kraus, R.T., H. Bontrager, C.S. Vandergoot, and M.D. Faust. “Expanding freshwater biologger studies to view fish as environmental sensing platforms.” *Marine & Freshwater Research* 73(2021): 133-139. www.publish.csiro.au/mf/MF21046. Last accessed: March 20, 2020.

Kraus, R.T., C.T. Knight, T.M. Farmer, A.M. Gorman, P.D. Collingsworth, G.J. Warren, P.M. Kocovsky, and J.D. Conroy. “Dynamic hypoxic zones in Lake Erie compress fish habitat, altering vulnerability to fishing gears.” *Canadian Journal of Fisheries and Aquatic Sciences* 72(2015): 797-806. DOI: 10.1139/cjfas-2014-0517.

Kreiling, R.M., M.C. Thoms, L.A. Bartsch, W.B. Richardson, and V.G. Christensen. “Complex response of sediment phosphorus to land use and management within a river network.” *Journal of Geophysical Research Biogeosciences* 124(2019): 1764-1780. DOI: 10.1029/2019JG005171.

Krempa, H.M. Periphyton biomass and community compositions as indicators of water quality in the Lower Grand River hydrologic unit, Missouri and Iowa, 2011–18: U.S. Geological Survey Scientific Investigations Report 2021-5012 (2021). 51 p., DOI: 10.3133/sir20215012.

Lan, C.C., C.I. Kahn, A.J. Borchert, M.N. Byappanahalli, R.L. Whitman, J. Peller, C. Pier, G. Lin, E.A. Johnson, and M.J. Sandowsky. “Prevalence of Toxin-Producing Clostridium botulinum Associated with the Macroalga Cladophora in Three Great Lakes: Growth and

Management." *Science of the Total Environment* 511(2015): 523-529. DOI: 10.1016/j.scitotenv.2014.12.080.

Larson, J., W.F. James, F.A. Fitzpatrick, P.C. Frost, M.A. Evans, P.C. Reneau, and M.A. Xenopoulos. "Phosphorus, nitrogen and dissolved organic carbon fluxes from sediments in freshwater rivermouths entering Green Bay (Lake Michigan; USA)." *Biogeochemistry* 147(2020a): 179-197. DOI: 10.1007/s10533-020-00635-0.

Larson, J., E. Hlavacek, N. DeJager, M.A. Evans, and T. Wynne. "Preliminary analysis to estimate the spatial distribution of benefits of P load reduction: Identifying the spatial influence of phosphorus loading from the Maumee River (USA) in western Lake Erie." *Ecology and Evolution* 10(2020b): 3968-3976. DOI: 10.1002/ece3.6160.

Larson, J.H., M.A. Evans, F.A. Fitzpatrick, P.C. Frost, M.A. Xenopoulos, W.F. James, and P.C. Reneau. "Benthic and planktonic inorganic nutrient processing rates at the interface between a river and lake." *Biogeochemistry* 155(2021): 189-203. DOI: 10.1007/s10533-021-00821-8.

Laughrey, Z.R., V.G. Christensen, R.J. Dusek, S.S. Senegal, J.S. Lankton, T.A. Ziegler, L.C. Jones, D.K. Jones, B.M. Williams, S. Gordon, G.A. Clyde, E.B. Emery, and K.A. Loftin. "A review of algal toxin exposures on reserved Federal lands and among trust species in the United States." *Critical Reviews in Environmental Science and Technology* (2021). DOI: 10.1080/10643389.2021.2010511.

LeDuc, J.F., V.G. Christensen, and R.P. Maki. "Rapid-assessment test strips: effectiveness for cyanotoxin monitoring in a northern temperate lake." *Lake and Reservoir Management* 36(2020): 444-453. DOI: 10.1080/10402381.2020.1805531.

Legleiter, C.J., and S.W. Hodges. "Mapping benthic algae and cyanobacteria in river channels from aerial photographs and satellite images: a proof-of-concept investigation on the Buffalo National River, AR, USA." *Remote Sensing* 14(2022): 953. DOI: 10.3390/rs14040953.

Lemke, A.M., K.G. Kirkham, M.P. Wallace, C.M. VanZomeren, J.F. Berkowitz, and D.A. Kovacic. "Nitrogen and phosphorus removal using tile-treatment wetlands: A 12-year study from Midwestern USA." *Journal of Environmental Quality* (in press, 2022): 1-14. DOI: 10.1002/jeq2.20316.

Lopez, C.B., E.B. Jewett, Q. Dortch, B.T. Walton, and H.K. Hudnell. "Scientific Assessment of Freshwater Harmful Algal Blooms." Washington, D.C.: Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. (2008). http://aquaticcommons.org/14920/1/assess_12-08.pdf. Last accessed: March 20, 2020.

Mancuso, J.L., A.D. Weinke, I.P. Stone, S.E. Hamsher, M.M. Woller-Skar, E.B. Snyder, and B.A. Bibbdanda. "Bloom and bust: Historical trends of harmful algal blooms in Muskegon Lake, Michigan, a Great Lakes estuary." *Freshwater Science* 40(2021): 463-477. DOI: 10.1086/716236.

Matisoff, G., E.M. Kaltenberg, R.L. Steely, S.K. Hummel, J. Seo, K.J. Gibbons, T.B. Bridgeman, Y. Seo, M. Behbahani, W.F. James, L.T. Johnson, P. Doan, M. Dittrich, M.A. Evans, and J.D. Chaffin. "Internal loading of phosphorus in western Lake Erie." *Journal of Great Lakes Research* 42(2016): 775-788. DOI: 10.1016/j.jglr.2016.04.004.

McKindles, K., T. Frenken, R.M. McKay, and G.S. Bullerjahn. "Binational efforts addressing cyanobacterial harmful algal blooms in the Great Lakes." In: Crossman J., and C.

Weisener (eds) *Contaminants of the Great Lakes. The Handbook of Environmental Chemistry*, vol 101. Springer, Cham. DOI: 10.1007/698_2020_513.

Miller, M.P., B.R. Clark, S.M. Eberts, P.M. Lambert, and P. Toccalino. Water priorities for the Nation – U.S. Geological Survey Integrated Water Availability Assessments: U.S. Geological Survey Fact Sheet 2020-3044 (2020). 2 p. DOI: 10.3133/fs20203044.

Mishra, S., R.P. Stumpf, B. Schaeffer, J. Werdell, K.A. Loftin, and A. Meredith. "Evaluation of a satellite-based cyanobacteria bloom detection algorithm using field-measured microcystin data." *Science of the Total Environment* 774(2021): 145462. 10.1016/j.scitotenv.2021.145462.

Moriasi, D.N., Duriancik, L.F., E.J.Sadler, T. Tsegaye, J.L. Steiner, M.A. Locke, T. C. Strickland and D.L. Osmond. 2020. Quantifying the impacts of the Conservation Effects Assessment Project watershed assessments: The first fifteen years. Journal of Soil and Water Conservation, 75 (3) 57A-74A; DOI: https://doi.org/10.2489/jswc.75.3.57A

Murphy, J.C. "Changing suspended sediment in United States rivers and streams: linking sediment trends to changes in land use/cover, hydrology and climate." *Hydrolology and Earth Systems Sciences* 24(2020): 991-1010. DOI: 10.5194/hess-24-991-2020.

Ohio EPA. (2021). Harmful Algal Blooms: Public Water System and Ohio EPA Surface Water Monitoring. www.epa.ohio.gov/gis/mapportal/HAB_Monitoring.html. Last accessed: March 16, 2022.

Paerl, H.W., W.S. Gardner, K.E. Havens, A.R. Joyner, M.J. McCarthy, S.E. Newell, B. Qin, and J.T. Scott. "Mitigating Cyanobacterial Harmful Algal Blooms in Aquatic Ecosystems Impacted by Climate Change and Anthropogenic Nutrients." *Harmful Algae* 54(2016): 213-222. DOI: 10.1016/j.hal.2015.09.009.

Paerl, H. W., K.E. Havens, H. Xu, G. Zhu, M.J. McCarthy, S.E. Newell, J.T. Scott, N.S. Hall, T.G. Otten, and B. Qin. "Mitigating eutrophication and toxic cyanobacterial blooms in large lakes: The evolution of a dual nutrient (N and P) reduction paradigm." *Hydrobiologia* (2019): 1-17. DOI: 10.1007/s10750-019-04087-y.

Papenfus, M., B. Schaeffer, A.I. Pollard, K. Loftin. "Exploring the potential value of satellite remote sensing to monitor chlorophyll-a for U.S. lakes and reservoirs." *Environmental Monitoring and Assessment* 192(2021): 808. DOI: 10.1007/s10661-020-08631-5.

Pearce, N.J.T., J.H. Larson, M.A. Evans, P.C. Frost, and M.A. Xenopoulos. "Episodic Nutrient Addition Affects Water Column Nutrient Processing Rates in River-to-Lake Transitional Zones." *JGR Biogeosciences* 126(2021): e2021JG006374. DOI: 10.1029/2021JG006374.

Peller, J., M.B. Nevers, M. Byappanahalli, C. Nelson, B.G. Babu, M.A. Evans, E. Kostelnik, M. Keller, J. Johnston, and S. Shidler. "Sequestration of microfibers and other microplastics by green algae, Cladophora, in the US Great Lakes." *Environmental Pollution* 276(2021): 116695. DOI: 10.1016/j.envpol.2021.116695.

Przybyla-Kelly, K., M.B. Nevers, D.A. Shively, S.P. Benson, G.M. Carter, S.C. Dwyer, M.E. Lewan, K.R. Picard, L.C. Richards, D.S. Sopovski, A.M. Spoljaric, D.R. Szymkowski, A.D. Welninski, E.E. Wimmer, and M.A. Evans. Cladophora biomass and supporting data collected in the Great Lakes, 2018 (ver 1.1). U.S. Geological Survey data release (2020a). DOI: 10.5066/P9E570JS.

Przybyla-Kelly, K., M.B. Nevers, D.A. Shively, S.P. Benson, G.M. Carter, S.C. Dwyer, M.E. Lewan, K.R. Picard, D.S. Sopovski, A.M. Spoljaric, D.R. Szymkowski, A.D. Welninski, E.E. Wimmer, and M.A. Evans. Great Lakes Cladophora biomass and supporting data

collected in 2019. U.S. Geological Survey Data Release. (2020b). DOI: 10.5066/P99O4QXB.
Reavie, E.D., M. Cai, M.R. Twiss, H.J. Carrick, T.W. Davis, T.H. Johengen, D. Gossiaux, D.E. Smith, D. Palladino, A. Burtner, and G.V. Sgro. Winter–spring diatom production in Lake Erie is an important driver of summer hypoxia. *Journal of Great Lakes Research* 42(2016): 608-618. DOI: 10.1016/j.jglr.2016.02.013.
Robertson, D.M., L.E. Hubbard, D.L. Lorenz, and D.J. Sullivan. "A surrogate regression approach for computing continuous loads for the tributary nutrient and sediment monitoring program on the Great Lakes." *Journal of Great Lakes Research* 44(2018): 26-42. DOI: 10.1016/j.jglr.2017.10.003.
Ruberg, S. Personal email communication. Great Lakes Environmental Research Laboratory. April 25, 2016.
Sadler E.J., J.L. Steiner, J.L. J.L. Hatfield, D.E. James, B.C. Vandenberg, T. Tsegaye. "STEWARDS: A decade of increasing the impact of Agricultural Research Service watershed research programs." *Journal of Soil and Water Conservation* 75(2020): 50A-6A. DOI: 10.2489/jswc.75.3.50A
Seegers, B.N., P.J. Werdell, R.A. Vandermeulen, W. Salls, R.P. Stumpf, B.A. Schaeffer, T.J. Owens, S.W. Bailey, J.P. Scott, and K.A. Loftin. "Satellites for long-term monitoring of inland U.S. lakes: The MERIS time series and application for chlorophyll-a." *Remote Sensing of Environment* 266(2021): 112685. DOI: 10.1016/j.rse.2021.112685.
Schmitt, J.D., C.S. Vandergoot, B.P. O'Malley, and R.T. Kraus. "Does Lake Erie still have sufficient oxythermal habitat for cisco Coregonus artedi"? *Journal of Great Lakes Research* 46(2020): 330-338. DOI: 10.1016/j.jglr.2020.01.019.
Shuchman, R.A., M.J. Sayers, and C.N. Brooks. "Mapping and Monitoring the Extent of Submerged Aquatic Vegetation in the Laurentian Great Lakes with Multi-Scale Satellite Remote Sensing." *Journal of Great Lakes Research* 39(2013): 78-89. DOI: 10.1016/j.jglr.2013.05.006.
Slonecker, T., B. Bufford, J. Graham, K. Carpenter, D. Opstal, N. Simon, and N. Hall. "Hyperspectral Reflectance Characteristics of Cyanobacteria" *Advances in Remote Sensing* 10(2021): 66-77. DOI: 10.4236/ars.2021.103004.
Smith, D.R., King, K.W., Williams, M.R. 2015. What is causing the harmful algal blooms in Lake Erie? Journal of Soil and Water Conservation. 70(2):27A-29A. http://handle.nal.usda.gov/10113/60955
Smith, E.A., R.L. Kiesling, and E.J. Hayter. Simulation of discharge, water-surface elevations, and water temperatures for the St. Louis River estuary, Minnesota-Wisconsin, 2016-17. U.S. Geological Survey Scientific Investigations Report 2020-5028(2020), 31 p., DOI: 10.3133/sir20205028.
Smith, R.B., B. Bass, D. Sawyer, D. Depew, and S.B. Watson. "Estimating the economic costs of algal blooms in the Canadian Lake Erie Basin." *Harmful Algae* 87(2019): 101624. DOI: 10.1016/j.hal.2019.101624.
Steffen, M.M., B.S. Belisle, S.B. Watson, G.L. Boyer, and S.W. Wilhelm. "Status, Causes, and Controls, of Cyanobacterial Blooms in Lake Erie." *Journal of Great Lakes Research* 40(2014): 215-225. DOI: 10.1016/j.jglr.2013.12.012.
Sterner, R.W., K.L. Reinl, B.M. Lafrancois, S. Brovold, and T.R. Miller. "A first assessment of cyanobacterial blooms in oligotrophic Lake Superior." *Limnology and Oceanography* 65(2020): 2984-2998. DOI: 10.1002/lno.11569.

Stets, E.G., L.A. Sprague, G.P. Oelsner, H.M. Johnson, J.C. Murphy, K. Ryberg, A.V. Vecchia, R.E. Zuellig, J.A. Falcone, and M.L. Riskin. "Landscape drivers of dynamic change in water quality of U.S. Rivers." *Environmental Science and Technology* 54(2020): 4336-4343. DOI: 10.1021/acs.est.9b05344.

Stow, C., and T. Höök. Saginaw Bay Multiple Stressors Summary Report. Department of Commerce, NOAA Technical Memorandum GLERL-160. (2013). https://repository.library.noaa.gov/view/noaa/11142. Last accessed: March 20, 2020.

Tellier, J.M., N.I. Kalejs, B.S. Leonhardt, D. Cannon, T.O. Höök, and P.D. Collingsworth. "Widespread prevalence of hypoxia and the classification of hypoxic conditions in the Laurentian Great Lakes." *Journal of Great Lakes Research* 48(2022): 13-23. DOI: 10.1016/j.jglr.2021.11.004.

United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS). Conservation Practices on Cultivated Cropland: A Comparison of CEAP I and CEAP II Survey Data and Modeling. Conservation Effects Assessment Project. (2022). www.nrcs.usda.gov. Last accessed: May 9, 2022.

United States Environmental Protection Agency (EPA). Algal Toxin Risk Assessment and Management Strategic Plan for Drinking Water. EPA 810R04003. (2015). www.epa.gov/sites/default/files/2018-11/documents/algal-risk-assessment-strategic-plan-2015.pdf. Last accessed: March 15, 2022.

United States Environmental Protection Agency (EPA). Ambient Water Quality Criteria to Address Nutrient Pollution in Lakes and Reservoirs. EPA-822-R-21-005. (2021). www.epa.gov/system/files/documents/2021-08/nutrient-lakes-reservoirs-report-final.pdf. Last accessed: May 9, 2022.

Van Hemert, C., R.J. Dusek, M.M. Smith, R. Kaler, G. Sheffeld, L.M. Divine, K.J. Kuletz, S. Knowles, J.S. Lankton, D.R. Hardison, R.W. Litaker, T. Jones, H.K. Burgess, and J.K. Parrish. "Investigation of algal toxins in a multispecies seabird die-off in the Bering and Chukchi Seas." *Journal of Wildlife Diseases* 57(2021): 399-407. DOI: 10.7589/JWD-D-20-00057.

Van Hemert, C., S.K. Schoen, W.R. Litaker, M.M. Smith, M. Arimitsu, J.F. Piatt, W.C. Holland, D.R. Hardison, and J.M. Pearce. "Algal toxins in Alaskan seabirds: Evaluating the role of saxitoxin and domoic acid in large-scale die-off of Common Murres." *Harmful Algae* 92(2020): 101730. DOI: 10.1016/j.hal.2019.101730.

Vanderploeg, H. A., S.A. Ludsin, J.F. Cavaletto, T.O. Höök, S.A. Pothoven, S.B. Brandt, J.R. Liebig, and G.A.Lang. "Hypoxic zones as habitat for zooplankton in Lake Erie: refuges from predation or exclusion zones"? *Journal of Experimental Marine Biology and Ecology* 381 (2009a): S108-S120. DOI: 10.1016/j.jembe.2009.07.015.

Vanderploeg, H. A., S.A. Ludsin, S.A. Ruberg, T.O. Höök, S.A. Pothoven, S.B. Brandt, G.A. Lang, J.R. Liebig, and J.F. Cavaletto. "Hypoxia affects spatial distributions and overlap of pelagic fish, zooplankton, and phytoplankton in Lake Erie." *Journal of Experimental Marine Biology and Ecology* 381 (2009b): S92-S107. DOI: 10.1016/j.jembe.2009.07.027.

VanZomeren, C.M., J.F. Berkowitz, M. Lemke, and K. Kirkham. "Soil P sorption capacity in agricultural treatment wetlands: Can a system designed for N reduction also retain P"? *Wetlands* 40(2020): 503-514. DOI: 10.1007/s13157-019-01205-3.

VanZomeren, C.M., and J.F. Berkowitz. (2020) Evaluating Soil Phosphorus Storage Capacity in Constructed Wetlands: Sampling and Analysis Protocol for Site Selection. ERDC/EL TN-20-3.

Walker, J.T., G. Beachley, H.M. Amos, J.S. Baron, J. Bash, R. Baumgardner, M.D. Bell, K.B. Benedict, X. Chen, D.W. Clow, A. Cole, J.G. Coughlin, K. Cruz, R.W. Daly, S.M. Decina, E.M. Elliot, M.E. Fenn, L. Ganzeveld, K. Gebhart, S.S. Isil, B.M. Kerschner, R.S. Larson, T. Lavery, G.G. Lear, T. Macy, M.A. Mast, K. Mishoe, K.H. Morris, P.E. Padgett, R.V. Pouyat, M. Puchalski, H.O.T. Pye, A.W. Rea, M.F. Rhodes, C.M. Rogers, R. Saylor, R. Scheffe, B.A. Schichtel, D.B. Schwede, G.A. Sexstone, B.C. Sive, R.P. Sosa- Echeverría, H. Templer, T. Thompson, D. Tong, G.A. Wetherbee, T.H. Whitlow, Z. Wu, Z. Yu,, and L. Zhang. "Toward the improvement of total nitrogen deposition budgets in the United States." *Science of the Total Environment* 691(2019a): 1328-1352. DOI: 10.1016/j.scitotenv.2019.07.058.

Walker, J.T., G.M. Beachley, H.M. Amos, J.S. Baron, J Bash, R. Baumgardner, M.D. Bell, K.B. Benedict, X. Chen, D.W. Clow, A. Cole, J.G. Coughlin, K. Cruz, R.W. Daly, S.M. Decina, E.M. Elliott, M.E. Fenn, L. Ganzeveld, K. Gebhart, S.S. Isil, B.M. Kerschner, R.S. Larson, T. Lavery, G.G. Lear, T. Macy, M.A. Mast, K. Mishoe, K.H. Morris, P.E. Padgett, R.V. Pouyat, M. Puchalski, H.O.T. Pye, A.W. Rea, M.F. Rhodes, C.M. Rogers, R. Saylor, R. Scheffe, B.A. Schichtel, D.B. Schwede, G.A. Sexstone, B.C. Sive, P.H. Templer, T. Thompson, D. Tong, G.A. Wetherbee, T.H. Whitlow, Z. Wu, Z. Yu,, and L. Zhang. Science needs for continued development of total nitrogen deposition budgets in the United States. U.S. Environmental Protection Agency, Washington, DC, EPA 601/R-19/001. (2019). https://nadp.slh.wisc.edu/white-paper/. Last accessed: May 11, 2022.

Walker, J.T., M.D. Bell, D. Schwede, A. Cole, G. Beachley, G. Lear, and Z. Wu. "Aspects of uncertainty in total reactive nitrogen deposition estimates for North American critical load applications." *Science of the Total Environment* 690(2019c): 1005-1018. DOI: 10.1016/j.scitotenv.2019.06.337.

Watson, S. B., C. Miller, G. Arhonditsis, G.L. Boyer, W. Carmichael, M.N. Charlton, R. Confesor, D.C. Depew, T.O. Höök, S.A. Ludsin, G. Matisoff, S.P. McElmurry, M.W. Murray, R.P. Richards, Y.R. Rao, M.M. Steffen, and S.W. Wilhelm. "The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia." *Harmful Algae* 56 (2016): 44-66. DOI: 10.1016/j.hal.2016.04.010.

Wherry, S.A., A.J. Tesoriero, and S. Terziotti. "Factors affecting nitrate concentrations in stream base flow." *Environmental Science and Technology* 55(2021): 902-911. DOI: 10.1021/acs.est.0c02495?ref=pdf.

Williamson, T.N., K.H. Shaffer, D.L. Runkle, M.J. Hardebeck, E.G. Dobrowolski, J.W. Frey, N.T. Baker, K.M. Collier, C.A. Huitger, S.P. Kula, R.J. Haefner, L.M. Hartley, H.F. Crates, D.P. Finnegan, N.J. Reithel, C.A. Toussant, and T.L. Weaver. "Nutrient and suspended-sediment concentrations in the Maumee River and tributaries during 2019 rain-induced fallow conditions." *Journal of Great Lakes Research* 47(2021a): 1726-1736. DOI: 10.1016/j.jglr.2021.10.004.

Williamson, T.N., E.G. Dobrowolski, and R.M. Kreiling. "Phosphorus sources, forms, and abundance as a function of streamflow and field conditions in a Maumee River tributary, 2016–2019." *Journal of Environmental Quality* (2021):1-16: DOI: 10.1002/jeq2.20290.

Wood, R. “Acute animal and human poisonings from cyanotoxin exposure – A review of the literature.” *Environment International* 91(2016): 276-282. DOI: 10.1016/j.envint.2016.02.026.

Xu, W., P.D. Collingsworth, R. Kraus, and B. Minsker. “Spatio-temporal analysis of hypoxia in the central basin of Lake Erie of North America.” *Water Resources Research* 57(2021): e2020WR027676. DOI: 10.1029/2020WR027676.

Zhou, X., M.T. Auer, and P. Xue. “Open Lake Phosphorus Forcing of Cladophora Growth: Modeling the Dual Challenge in Great Lakes Trophic State Management.” *Water* 13(2021): 2680. DOI: 10.3390/w13192680.

Zuellig, R.E., J.L. Graham, J.L., E.A. Stelzer, K.A. Loftin, and B.H. Rosen. Cyanobacteria, cyanotoxin synthetase gene, and cyanotoxin occurrence among selected large river sites of the conterminous United States, 2017-2018: U.S. Geological Survey Scientific Investigations Report 2021-5121. (2021), 22 p. DOI: 10.3133/sir20215121.

APPENDIX A

Updates to HABHRCA Federal Agency HABs and Hypoxia Program Activities

This appendix includes updates to Federal agency activities and research efforts that were originally included in Appendix 3 of the 2017 *Harmful Algal Blooms and Hypoxia in the Great Lakes Research Plan and Action Strategy: An Interagency Report* and Appendices A and B of the 2020 *Harmful Algal Blooms and Hypoxia in the Great Lakes: An Interagency Progress and Implementation Report*. The table below follows the format of Appendix 3 in the 2017 report, and Appendices A and B in the 2020 report, with new information regarding the status and progress of each original program activity.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
DHHS	Great Lakes Restoration Initiative, CDC	HABs	HAB-associated case and outbreak surveillance	CDC initiated waterborne and foodborne disease outbreak surveillance systems in the 1970s. U.S. states and territories voluntarily report to these systems via the electronic NORS, which receives aggregate data on human cases and their exposures, including exposures to harmful algal blooms (HABs) or HAB toxins. The One Health Harmful Algal Bloom System (OHHABS) launched in June 2016 and collects single case-level reporting of human and animal illness, and relevant environmental data. OHHABS will inform restoration activities in the Great Lakes but is accessible to all states via NORS.	Ongoing	CDC continues to conduct health surveillance through NORS and OHHABS. CDC provides data for both systems through publicly accessible websites. NORS data are available through www.cdc.gov/norsdashboard/ and OHHABS data summaries are available through www.cdc.gov/habs/data/index.html.
DHHS	CDC	HABs	Great Lakes State Health Surveillance Capacity	CDC has partnered with the Council of State and Territorial Epidemiologists (CSTE) since 2013 to place and provide technical support for epidemiology fellows in Great Lakes states, including Indiana, Illinois, Michigan, Minnesota, New York,	Completed	CDC now provides support to states, inclusive of some Great Lakes states, through a different mechanism, as detailed in this CDC web page: Building Public Health Capacity for Harmful Algal Blooms | CDC. This new activity is supported by a congressional appropriation to

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				Ohio, and Wisconsin. The activity is supported by the Great Lakes Restoration Initiative. Fellows focus on waterborne disease detection, investigation, response and reporting. The fellowship has expanded state waterborne disease reporting and analytic capacity; improved state health surveillance for HABs; and ensured dedicated staff time for waterborne disease surveillance and coordination activities.		CDC, rather than through GLRI. More details are included in Appendix B.
DHHS	CDC	HABs	Health Communications	CDC's health communications activities related to HABs include the launch of a HAB-Associated Illness website with information for public health practitioners, clinicians, and the public, and the expansion of the Drinking Water Advisory Communications Toolbox (DWACT) to include information about HAB-related drinking water advisories. The DWACT was created through a collaborative effort among CDC, EPA, the American Water Works Association, the Association of State and Territorial Health Officials, the Association of State Drinking Water Administrators (ASDWA), and the National Environmental Health Association (NEHA).	Ongoing	CDC continues to conduct health communications activities. CDC has increased its efforts to work directly with state health departments on health communications related to HABs since the last report. CDC completed an extensive update of the HAB-Associated Illness website in 2021, increased the availability of printed health communications materials, and provided Spanish versions of web and print materials.
DHHS	CDC	HABs	Research	CDC is investigating electronic health records to assess whether these databases would be valuable in determining the level of public health impact from HAB- and CyanoHAB-associated illnesses.	Ongoing	

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
DHHS	CDC	HABs	Preparing state and local health departments to respond to HABs	CDC has a funded partnership with Association of State and Territorial Health Officials (ASTHO) to identify gaps in HAB preparedness, develop HAB response resources and post online, and incorporate HABs into state public health response plans. Efforts include drafting a HAB response tool for health departments and supporting states with preparing HAB response resources.	Ongoing	Since 2020, the HAB response tool has been created. Efforts now include communicating public health experiences and lessons learned during HAB responses and developing HAB-focused health training resources.
Multiple	CDC, EPA, NOAA	HABs	Interagency Analytic Workgroup	Additional research is needed to fully characterize and understand the health risks from drinking water provided by public water systems when that water is contaminated with cyanobacterial toxins. There is a need to establish standardized biological sample collection and analysis protocols to support assessment of toxin-associated health effects. Multiple Federal agencies are working together to assess sampling and analytical capabilities related to analysis of biological specimens collected from human and animals exposed to cyanobacteria toxins via contaminated water, including drinking water. The goal is to combine expertise to develop robust analytic methods to detect biological evidence of exposure to cyanobacterial toxins, to optimize laboratory and emergency response capacity in the collection, analysis, and response to HAB-related illnesses.	Ongoing	The Certified Reference Material (CRM) workgroup was an IWG subgroup on CRMs/Analytical Methods, which was dissolved in May 2019. Its accomplishments remain the same as those listed in the 2020 Great Lakes Progress Report. Since 2019, the IWG-HABHRCA has worked with CDC and other member agencies to finalize an inventory and information repository of laboratories that measure human and animal biospecimens related to HABs. This information will be published on agencies' websites in 2022.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
DHHS	CDC	HABs		Method development, refinement, and validation for detecting human exposures to HAB toxins through the detection of toxins and specific biomarkers in clinical samples. Current methods approved for use include the detection of saxitoxin, neosaxitoxin, tetrodotoxin, and gonyautoxins (1-4), which have been applied to individual cases to confirm suspected HAB exposures.	Ongoing	CDC has added microcystins and brevetoxins to the suite of toxins the laboratory can detect in clinical specimens.
DHHS	FDA	HABs		Method development, refinement, and validation for detecting HAB toxins in FDA-regulated products. Improving understanding of HAB toxin sources and vectors that impact seafood and dietary supplement safety.	Ongoing	FDA has evaluated multiple methods for screening and/or confirmation of cyanobacterial microcystin contamination in blue-green algae (BGA)-based dietary supplements; including antibody-based surface plasmon resonance (SPR), polymerase chain reaction (PCR)-based detection of toxin-producing genes, in-vitro protein phosphatase inhibition assays (PPIA), and liquid chromatography tandem mass spectrometry (LC-MS/MS). FDA is in the process of expanding these detection capabilities to additional commodities such as beverages with added BGA and seafood.
DOC	NOAA	HABs	Airborne Hyperspectral Remote Sensing for Detection of HABs in Lake Erie and Saginaw Bay, Lake Huron	The Resonon Pika II hyperspectral camera is flown weekly over the western basin of Lake Erie and biweekly over Saginaw Bay during the HAB growing season. A report with processed hyperspectral images of cyanobacteria levels from municipal drinking water locations are sent 24-48 hours post flight directly to the Ohio	Ongoing	NOAA GLERL scientists coordinated crewed hyperspectral flights over Lake Erie and Saginaw Bay. Processed cyanobacteria HAB images alerted drinking water municipalities and also aided with directing the LRAUV missions directed by MBARI, NOAA GLERL, and NCCOS. Continued efforts are focused on deriving phytoplankton community

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				Environmental Protection Agency, Michigan DNR, and Ohio and Michigan municipal drinking water managers.		composition and refining atmospheric correction methods for hyperspectral data.
DOC	NOAA	HABs	Analytical Response Team	The NOAA Analytical Response Team (ART) provides a formal framework through which coastal managers may request immediate coordinated assistance during harmful algal blooms (HABs) and related health incidents. ART acts as one of the primary responders to HABs and associated mortality events, providing rapid and accurate identification of harmful algae and their associated toxins. This identification and analytical capability provides support for management agencies that can then make timely and informed decisions impacting stakeholders involved in coastal wildlife, human health and commerce.	Ongoing	The NOAA Analytical Response Team (ART) provides a formal framework through which coastal managers may request immediate coordinated assistance during harmful algal blooms (HABs) and related health incidents. ART acts as one of the primary responders to HABs and associated mortality events, providing rapid and accurate identification of harmful algae and their associated toxins. This identification and analytical capability provides support for management agencies that can then make timely and informed decisions impacting stakeholders involved in coastal wildlife, human health and commerce. ART is designed on the principles of a sense-and-respond unit. The team is comprised of early event listeners, a multidisciplinary team of event assessors from diverse scientific backgrounds, and a team leader responsible for designing an event-specific solution. Key to the success of the team is that the response is based upon the unique expertise and experience of each individual rather than a pre-designed response, and that all team members work together on a daily basis in a mission-based Program. This approach represents a revolutionary design in business in which "business is an adaptive system for responding

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						to unanticipated requests in unpredictable environment."
DOC	NOAA	HABs	National Phytoplankton Monitoring Network	The PMN was established to monitor phytoplankton and HABs and promote environmental stewardship through the use of citizen volunteers. The NOAA PMN, in partnership with EPA Office of Water, expanded the use of citizen scientist to monitor HABs in Lake Erie. Volunteer monitors on the west coast of Lake Erie are monitoring potentially toxic cyanobacteria biweekly and reporting results to NOAA through an online data portal. Environmental conditions and HAB species information can be visualized using an internet map service. PMN volunteers are trained by NOAA staff on sampling techniques and identification methods for over 50 genera, including 10 potentially toxin producing genera of dinoflagellates and diatoms on the volunteers' watch list. 250 sites in 22 states and American territories, including 52 schools, 15 universities, 298 civic groups and 40 state and Federal agencies, collect phytoplankton and environmental data. Since the inception of the program in 2001, more than 275 algal blooms and 15 toxic events have been reported by PMN volunteers.	Ongoing	NOAAs Phytoplankton Monitoring Network (PMN) was established in 2001 to monitor potentially harmful phytoplankton and HABs. In 2015, PMN entered into an interagency agreement with EPA Office of Water to establish a freshwater cyanobacterial monitoring program in the Great Lakes, and it rapidly expanded from there. As of 2021, there are 47 total active sites in 14 states monitoring freshwater sites. Of these, there are two active sites in Lake Erie (Ohio) and four active sites in Lake Michigan (Michigan). Up to present, PMN sites have collected 109 samples, with only one report of any cyanobacteria, but not at elevated concentrations.
DOC	NOAA	HABs	HAB Forecasting Branch	The National Centers for Coastal Ocean Science (NCCOS) has provided base	Ongoing	The Lake Erie HAB Bulletin was first issued in 2008, while the first seasonal forecast was

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				funding (labor and operational funds) for development of HAB forecasts for Lake Erie. NOAA NCCOS develops an annual HAB severity forecast for Lake Erie that is distributed in early July, and reports the seasonal bloom severity in October, as well as the forecast accuracy. Also, the twice-weekly Lake Erie Harmful Algal Bloom Bulletin is set to transition to operations in 2017. NOAA NCCOS will continue to improve the Lake Erie bulletin and will develop similar products for other HAB impacted regions of the Great Lakes, including Saginaw Bay, Lake Huron and Green Bay, Lake Michigan. Furthermore, NOAA NCCOS will begin to develop a Lake Erie HAB toxicity forecasting model in collaboration with NOAA GLERL.		issued in 2012 and "severity index" was used for the first time in 2014. The forecast went operational in 2017 and was operated by CO-OPS until 2021, after which it was transitioned to NCCOS. NOAA issues the Western Lake Erie HAB Early Season Projection in early July to provide stakeholders with a general sense of how potentially disruptive the upcoming bloom season might be in severity. The seasonal forecast is an ensemble of models based largely on total available phosphorus load from the Maumee River. NCCOS continues to improve and develop similar products for HAB impacted regions of the Great Lakes. In 2018, NCCOS developed the Harmful Algal Bloom Monitoring System, which routinely delivers near real-time products for use in locating, monitoring and quantifying algal blooms in coastal and lake regions of the U.S. where satellite imagery can directly support key management concerns. This application delivers a suite of bloom detection products in the form of geographic based images. At this time, products are available for Lake Erie as well as portions of Lake Michigan (Green Bay, Wisconsin) and Lake Huron (Saginaw Bay, Michigan). For each location, nowcast bloom position information is available using satellite imagery including remote-sensing derived estimates of near-real-time phytoplankton cell density. Target users include natural resource and land managers, public health officials, and managers at drinking water facilities. New products are being evaluated, and new regions

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						are being considered for incorporation into this system.
DOC	NOAA	HABs		NOAA GLERL, in collaboration with NOAA NCCOS will continue to develop a three-dimensional Lagrangian particle transport model to effectively predict HAB advection (HAB Tracker) as part of the Lake Erie Operational Forecasting System, which is set to go operational in fiscal year 2015. The Lake Erie Experimental HAB Tracker is set to be transitioned to operations by 2018. Furthermore, the HAB Tracker will continue to be improved to incorporate vertical mixing. Furthermore, NOAA GLERL plans to develop this bloom forecasting system in other HAB impacted areas, including Saginaw Bay, Lake Huron and Green Bay, Lake Michigan.	Ongoing	NOAA GLERL and NCCOS have successfully transitioned the Lake Erie Experimental HAB Tracker, which predicts 3D movement of blooms, to operations at NOAA NCCOS and have incorporated it into the Lake Erie Harmful Algal Bloom bulletins as an upgrade. The Lake Erie Experimental HAB Tracker continues to be refined and improved.
DOC	NOAA	HABs	Great Lakes Sea Grant Network collaboration	NOAA Sea Grant programs have funded research, outreach, and education programs to understand the causes of HABs and to help the public understand the risks associated with them. Sea Grant's Great Lakes programs partner with GLERL to support research, and transfer research results to stakeholders in the region and were integral to public understanding of the Toledo water crisis. Website learning pages, HAB webinars, and stakeholder meetings are among the tools used by Sea Grant to inform decision-makers and the	Ongoing	The eight NOAA Sea Grant programs in the Great Lakes continue to fund critical research, outreach, and educational programs on HABs and hypoxia awareness, understanding, and event preparedness and response. Recent examples of this work include (1) an ongoing collaborative research project with EPA and other agencies to look at the combined effects of hypoxia and HABs on food web processes in Lake Erie; (2) research designed to determine the value of Lake Erie beaches to the state of Ohio's overall economy and how that value is affected by HABs; and (3) creation of an interactive online dashboard, (https://tabsoft.co/3UhJWth) that visually presents data through three lenses to increase

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				public on HAB topics of relevance to their lives.		situational awareness of populations that may be vulnerable to HAB-related illnesses for five counties surrounding Western Lake Erie. This work is in addition to the long-term efforts by these Sea Grant programs to continue to disseminate research results, reports and publications, continued work with municipalities on educational signage, brochures, and outreach materials, and ongoing work with communities to conduct beach monitoring, develop citizen science monitoring programs with charter boat captains, and advancing HABs early warning systems. Sea Grant programs have also worked to develop tools and materials to engage stakeholders and decision-makers to better understand the linkages between land uses, water quality, and municipal policies including the Watershed Game, the Tipping Point Planner and the Tackling Barriers to Green Infrastructure workbook. In addition, Ohio Sea Grant has continued to host NOAA's annual HABs Forecast event and the annual "Understanding Algal Blooms: State of the Science Conference." Sea Grant programs have also leveraged funds from the Oceans and Human Health portfolio funding from National Science Foundation and National Institute of Environmental Health Sciences, and are conducting community engagement trainings for HABs scientists and continue to assess their outreach, engagement, and science communication needs, as part of the Great Lakes Center for Freshwater and Human Health.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
DOC	NOAA	HABs	Ecology and Oceanography of Harmful Algal Blooms (ECOHAB)	National, competitive extramural research program developing a better understanding of HAB causes and impacts that form the basis for better management to reduce HABs and their impacts throughout the U.S. regions, including the Great Lakes.	Ongoing	ECOHAB continues to support ongoing research in the Great Lakes. Two projects were funded between 2019-2021: Linking Process Models and Field Experiments to Forecast Algal Bloom Toxicity in Lake Erie ($251K total funding for 2019-2020); Towards a Predictive Understanding of our Ecosystems: Microcystis Blooms and Toxin Production ($430,000 total funding for 2019-2021)
DOC	NOAA	HABs	GLERL 'Omics Program	The GLERL and Cooperative Institute for Great Lakes Research (CIGLR) have developed a comprehensive 'omics program that will use the approaches of: (1) targeted 'omics research to study ecosystem change, and (2) developing monitoring tools and technologies. Both approaches will be applied to the critical issues of HABs and the status of rare, endangered and invasive species. Our current program includes three main research projects in the area of HAB research. These include linking genes to microbial traits which are key to the rise and demise of HABs, this project will provide critical information on HAB diversity, biology, and toxicity and will be incorporated into biophysical models and advance our knowledge of bloom ecology (timing and geographical extent). In an effort to develop monitoring tools and	Ongoing	In order to support a healthy, productive, and resilient Great Lakes ecosystem the Great Lakes Environmental Research Laboratory (GLERL), with our partners at the Cooperative Institute for Great Lakes Research (CIGLR), continue to leverage new technologies and scientific tools, employ a diverse and inclusive workforce, and invest in future scientific and operational needs through investment in 'Omics based tools and research. The goals of GLERL's 'Omics program are to use multidimensional 'omics tools to study ecosystem change and develop monitoring tools and technologies specifically targeting harmful algal blooms, food web dynamics, invasive species, and fisheries to better serve Great Lakes managers and stakeholders. Since 2020, we have established a Microcystis culture collection with Lake Erie and Lake Huron isolates. These cultures represent a range of different genetic traits that we can

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				technologies we have partnered with Monterey Bay Aquarium Research Institute (MBARI) to test and validate the third generation Environmental Sample Processor (3G ESP), which has been incorporated into a long-range autonomous underwater vehicle. This mobile device is capable of collecting essential environmental and toxin concentrations data and transmitting the information to shore in near-real time, the device also determines algal populations using membrane-based DNA and protein probe arrays. In concurrence with these projects and in an effort to fully explore strain diversity during Microcystis blooms and potential toxicity of the bloom, we are conducting a retrospective analysis to distinguish toxin-producing from non-toxin producing cyanobacteria. Using 'omics techniques, we aim to connect the presence of the microcystin gene (mcyE) with microcystin concentration and environmental conditions.		explore further to advance our understanding of bloom dynamics. In 2021, we successfully deployed a LRAUV-3G ESP (further details provided below) capable of providing near-real time toxin data and collect archival 'omics samples. Results from our retrospective study suggest the microcystin gene (mcyE) could be used as an early warning for toxin presence within the environment.
DOC	NOAA	HABs	HAB Forecasting Products	The NOAA National Centers for Coastal Ocean Science (NCCOS) will continue improving satellite products, seasonal forecasts, and models of bloom severity for cyanobacterial blooms in the Great Lakes. The new Sentinel-3a and 3b satellites are being used, and they are being inter-calibrated to the previous satellites to assure a continuous time	Ongoing	The NOAA National Centers for Coastal Ocean Science (NCCOS) continues to improve satellite products, seasonal forecasts, and models of bloom severity for cyanobacterial blooms in the Great Lakes. The new Sentinel-3a and 3b satellites are being used, and they are being inter-calibrated to the previous satellites to assure a continuous time series for bloom assessment. Seasonal forecasts will continue

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				series for bloom assessment. Seasonal forecasts will continue starting with "early season" projections in early May, through the seasonal forecast made the 2nd week of July. Results of toxin models will be examined for incorporation into the monitoring system. Daily products for western Lake Erie, Saginaw Bay, and Green Bay will continue and be updated as needed by state and local users.		starting with "early season" projections in early May, through the seasonal forecast made the 2nd week of July. Results of toxin models will be examined for incorporation into the monitoring system. Daily products for western Lake Erie, Saginaw Bay, and Green Bay will continue and be updated as needed by state and local users.
DOC	NOAA	HABs	Lake Erie Harmful Algal Bloom Bulletin	During a bloom, the Center for Operational Oceanographic Products and Services (CO-OPS) issues the twice-weekly Lake Erie Harmful Algal Bloom Bulletin, providing analysis of bloom location and 3-day forecast conditions, including two-dimensional surface movement. NOAA CO-OPS and NOAA NCCOS provide base funds to support the Lake Erie Harmful Algal Bloom Bulletins, with NOAA GLERL providing operational support for field sample collection. NOAA NCCOS collaborates with NOAA CO-OPS to improve the Lake Erie bulletin and will also develop similar products for other HAB impacted regions of the Great Lakes, including Saginaw Bay, Lake Huron and Green Bay, Lake Michigan. NOAA GLERL, NCCOS, and CO-OPS have worked to transition the Lake Erie Experimental HAB Tracker, which predicts 3D movement of	Ongoing	The Lake Erie Harmful Algal Bloom Bulletin was transitioned to NCCOS as of 2020, which continues to be issued twice-weekly. NCCOS provides analysis of bloom location and 3-day forecast conditions, including two-dimensional surface movement. NOAA NCCOS works to improve the Lake Erie bulletin and is developing similar products for other HAB-impacted regions of the Great Lakes, including Saginaw Bay, Lake Huron and Green Bay, Lake Michigan. NOAA GLERL and NCCOS have worked to transition the Lake Erie Experimental HAB Tracker, which predicts 3D movement of blooms, to operations at NOAA NCCOS and have incorporated it into the Lake Erie Harmful Algal Bloom bulletins as an upgrade.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				blooms, to operations at NOAA CO-OPS by 2020 and incorporate it into the Lake Erie Harmful Algal Bloom bulletins as an upgrade.		
DOC	NOAA	HABs	Monitoring and Event Response for Harmful Algal Blooms (MERHAB)	National, competitive extramural research program that builds capacity for enhanced HAB monitoring and response in state, local, and tribal governments, including the Great Lakes.	Ongoing	MERHAB continues to support research in the Great Lakes. In 2019, MERHAB funded a project to create portable cyanotoxin detection technology for use by beach managers, water utilities, and charter fishing boat captains ($877,000 total funding for 2019-2023).
DOC	NOAA	HABs	Prevention and Control of Biological and Chemical Threats	NCCOS research has applied Nano Bubble Ozone Technology (NBOT) as an environmentally acceptable technology for direct intervention of ongoing HAB events to eliminate harmful algae and their toxins. Working under a Cooperative Research and Development Agreement (CRADA) with American Marine University and several industrial partners, NBOT equipment is being engineered to address water quality issues found in small ponds to larger lakes. Pilot tests in 2019 at Lake Okeechobee's Port Mayaca (Florida) Lock, Lake Newport (Ohio), and Constitutional Gardens (Washington, DC), have demonstrated that NBOT need only treat a small percentage of the total water volume to obtain effective results in algae (microbial) mitigation.	Ongoing	NBOT equipment has been engineered and re-engineered through an interactive process evaluating more than a dozen prototypes and reengineering of proprietary components to address water quality issues found in waters ranging from small ponds to larger lakes. Open water studies have indicated that treatment a small percentage of the total water volume to obtain effective results in algae (microbial) mitigation. Updated data suggest that NBOT may be applicable as both a control and prevention method for certain harmful algal blooms. For 2022 an open water research collaboration with Ohio EPA, the Ohio Department of Natural Resources, EPA, Ohio State University, and local lake managers will determine the efficacy of nanobubble ozone technology (NBOT) to reduce nutrients and eliminate cyanobacteria and their toxins in Ohio's Grand Lake in the Maumee River watershed. A parallel line of research in the laboratory NCCOS scientists will initiate

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						chemical analysis will examine the fate of nutrients after treatment by ozone-impregnated nanobubbles to determine where these nutrients go (as well as various associated metals such as iron) and whether these altered nutrient forms continue to be bioavailable to reinitiate blooms or can themselves return to harm the environment. In addition, a second independent evaluation of NBOT as a ship ballast water treatment method for invasive species control in the Great Lakes has been conducted by The Great Waters Research Collaborative at the University of Wisconsin-Superior Lake Superior Research Institute. Expanding a 2020 technical report on a bench-scale evaluation of a scaled-up evaluation of multiple larger units capable of operating on millions of gallons of water completed in 2021. In combination with open water demonstrations, independent testing of NBOT has accelerated improved designs and propelled this NCCOS innovation to environmental applications beyond harmful algal blooms.
DOC	NOAA	HABs	Prevention, Control, and Mitigation of Harmful Algal Blooms (PCMHAB)	National, competitive extramural research program that develops new methods of HAB prevention, control, and mitigation. It also addresses the socioeconomic impact of HABs and efforts to reduce HAB impacts.	Ongoing	PCMHAB continues to fund research to move promising technologies for preventing, controlling, or mitigating HABs and their impacts through development, to demonstrations, and, finally application, culminating in widespread use in the field by end-users. This program also funds socioeconomic research to assess impacts of HAB events on economies and societies, and

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						the costs and benefits of mitigation strategies to aid managers in devising cost-effective management strategies. Since 2020, PCMHAB funded three projects in the Great Lakes: Using Microcystin Degrading Bacteria and their Enzymes for Water Treatment ($1.1 million total funding for 2020-2022); Rapid, Portable, Multiplexed Detection of Harmful Algal Toxins in the Great Lakes ($948,000 total funding for 2020-2022); PCMHAB RESCUE: Enhancing the Capabilities of the 3rd Generation Environmental Sample Processor (3G ESP) for HAB Toxin Detection Through Integration with an Autonomous Surface Vehicle (ASV) ($1.5 million total funding for 2021-2024).
DOC	NOAA	HABs	Event Response	Provides immediate assistance for managing HAB events and advancing the understanding of HABs when they occur, including the Toledo water crisis.	Ongoing	The NCCOS HAB Event Response Program continues to provide immediate assistance to help Federal, state, and local officials manage events and advance the understanding of HABs as they occur. Recently funded events in the Great Lakes included the 2014 Toledo water crisis, and during a September 2017 cyanobacterial bloom in the Maumee River (Ohio) to support initial testing and toxins monitoring by state and academic institutions.
DOC	NOAA	Hypoxia	Coastal Hypoxia Research Program (CHRP)	National, competitive extramural research program that develops understanding of hypoxia causes and impacts that form the basis for better management to reduce hypoxia and its ecological and socioeconomic impacts. Through CHRP, NOAA hopes to develop a hypoxia warning	Ongoing	CHRP continues to support research in the Great Lakes. In 2016, CHRP funded a project at GLERL to develop an operational dissolved oxygen forecast model for Lake Erie. This physically-based model to track hypoxia development has been run successfully in 2017-2019 and provided water intake

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				system for the central basin of Lake Erie. It includes all coastal systems except the large hypoxic zone along the northern Gulf of Mexico continental shelf.		managers with early warnings when hypoxic events were likely. Three years of field and laboratory measurements to provide complementary data supporting model development have been completed. The project was expanded to include measurements to characterize manganese release into low oxygen waters, because manganese is being considered for regulation in drinking water. This coupled system will allow drinking water managers to prepare when conditions that promote hypoxic water movement into the vicinity of water intakes occur ($1.67M total funding for 2016-2021).
DOC	NOAA	Hypoxia/ HABs	Outreach and Education	Continue to work with Sea Grant and other partners to engage stakeholders to drive research prioritization and disseminate advanced knowledge and tools for HAB and hypoxia mitigation to regional managers, fishing industry, state and Federal leadership and citizens to name a few.	Ongoing	Sea Grant programs in the Great Lakes continue to work with NOAA and other partners to develop outreach products and decision support tools that engage stakeholders, drive research prioritization, and assist communities in preventing and mitigating HABs and hypoxia across the region. Examples include the Sea Grant Watershed Game, the Tipping Point Planner and the Tackling Barriers to Green Infrastructure workbook. In addition, Ohio Sea Grant continues to facilitate forums for sharing information and research collaboration by hosting events such as NOAA's annual HABs Forecast event and the annual "Understanding Algal Blooms: State of the Science Conference." Sea Grant programs are also

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						conducting community engagement trainings for HABs scientists and continue to assess outreach, engagement, and science communication needs, as part of the Great Lakes Center for Freshwater and Human Health.
DOC	NOAA	HABs	NOAA's Great Lakes HAB monitoring and experiment program	Studies molecular ecology of HABs in the Great Lakes to further understand the drivers of bloom growth and toxin production as well as the interaction of HAB-forming species with other microbes to better understand bloom impacts on western Lake Erie ecosystem services. Key regions of focus include Lake Erie, Saginaw Bay, Lake Huron and Green Bay, Lake Michigan. GLERL monitors eight routine stations in the western basin of Lake Erie and five sites in Saginaw Bay while collaborating with academic and state partners to study Green Bay. GLERL samples Lake Erie and Saginaw Bay on a weekly and bi-weekly basis, respectively, during blooms season. At four sites in Lake Erie, GLERL deploys real-time water quality monitoring instrumentation that measures several key parameters, including pigments, temperature, dissolved oxygen, nitrate and dissolved reactive phosphorus. NOAA GLERL supplies critical data, including toxicity, to stakeholders via the NOAA GLERL HABs and Hypoxia website and that supports the NCCOS and GLERL predictive HAB models	Ongoing	Research continues to be multidisciplinary and includes both experimental and monitoring initiatives to further understand the drivers of cyanobacteria bloom growth and toxin production within the Great Lakes. GLERL, in collaboration with Cooperative Institute for Great Lakes Research (CIGLR), continues monitoring efforts focused on western basin of Lake Erie and Lake Huron (Saginaw Bay). Due to COVID delays, monitoring begun in June during the 2020 season includes a reduced number of parameters. In 2021, we were able to reestablish monitoring in April. Both years monitoring continued through October. Weekly sampling occurs at eight established sites in the western basin of Lake Erie. In 2021, we also began monitoring a monthly transect which stretched from non-bloom area to a bloom dominated area. In Saginaw Bay, sampling occurred every other week at five sites, starting in July in 2020 and June in 2021. Sampling within both systems spans a gradient of nutrient concentrations as well as drinking water intake locations (e.g., Toledo, OH and Monroe, MI). Real-time data are still collected at four of the sites within Lake Erie. NOAA GLERL supplies critical data, including toxicity,

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				in Lake Erie and elsewhere in the Great Lakes (described above). Using the monitoring data, NOAA GLERL works with Federal, state and academic partners to conduct experiments to understand the response of HAB communities to future environmental conditions (i.e., extreme weather events). Furthermore, NOAA GLERL, in collaboration with NOAA NCCOS-HML and academic partners, will deploy the first ever Environmental Sample Processor in Lake Erie during the 2016 field season to begin to develop an autonomous, high-frequency bloom toxicity monitoring network. Finally, GLERL, in collaboration with NASA and other state and academic partners, will continue to use hyperspectral flyovers intended to further develop the resolution of remote sensing imaging to distinguish phytoplankton functional groups which will allow for more accurate forecasting products. Developing a three-dimensional Lagrangian particle transport model to effectively predict HAB advection as part of the Lake Erie Operational Forecasting System, which is set to go operational in fiscal year 2017.		to stakeholders via the NOAA GLERL HABs and Hypoxia website, GLOS HAB portal, and supports the NCCOS and GLERL predictive HAB models in Lake Erie and elsewhere in the Great Lakes (described elsewhere). NOAA GLERL in collaboration with NOAA NCCOS-HML has developed a second-generation Environmental Sample Processors (2G ESPs) network in Lake Erie. Deployments were postponed in 2020 due the ongoing pandemic but resumed in 2021, with an ESP station was established near the Toledo Water Intake (Ohio) from July - September. Near real-time toxin data was available through the NOAA GLERL HABs and Hypoxia website. Experimental work has been on hold since the beginning of the pandemic but will continue in 2022, focusing on bloom resting cells and resuspension events as well as exploration of the role of dressined mussels on the development of cyanobacteria blooms. Work continues on a probability toxin forecast, providing the risk associated with microcystin toxin levels exceeding the recreational limits. A portion of this work is supported through GLRI.
DOC	NOAA	HABs and hypoxia	GLRI	Investigating links between land-use changes and in-lake algal blooms; GLRI-funded research led by NOAA's Great Lakes Environmental Research Lab, in collaboration with partners from the	Ongoing	In 2019, Investigating links between land-use changes and in-lake algal blooms continued. GLRI-funded research led by NOAA's Great Lakes Environmental Research Lab, in collaboration with partners from the University

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				University of Michigan's Cooperative Institute for Limnology and Ecosystems Research, is investigating impact of land use changes and algal bloom development in the western basin of Lake Erie and in Lake Huron's Saginaw Bay. Measurements of total phosphorus, total dissolved phosphorus, and dissolved reactive phosphorus will contribute to the GLRI's goal of reducing algal bloom growth through reductions in phosphorus.		of Michigan's Cooperative Institute for Great Lakes Research, is investigating impact of land use changes and algal bloom development in the western basin of Lake Erie and in Lake Huron's Saginaw Bay. Measurements of total phosphorus, total dissolved phosphorus, and dissolved reactive phosphorus will contribute to the GLRI's goal of reducing algal bloom growth through reductions in phosphorus. Additional details are provided in NOAA's Great Lakes HAB monitoring and experiment program.
DOC	NOAA	HABs	Third generation Environmental Sample Processor (3G ESP) long-range autonomous underwater vehicle (LRAUV)	NCCOS-HML, GLERL, AOML, CIGLR, and MBARI scientists are leading a major advance in HAB monitoring technology via development and prototype testing of MBARI's 3G-ESP integrated with a Tethys-class long-range autonomous underwater vehicle (LRAUV). Engineering advances for the 3G-ESP/LRAUV included miniaturizing the 2G-ESP to fit into a LRAUV payload to provide in situ sample acquisition, processing, and analysis. The fully autonomous device is capable of interrogating marine and freshwater algal populations while underway using a novel, self-contained sample preparation cartridge system and a surface plasmon resonance (SPR)-based toxin sensor. Data are transmitted on-the-fly to shore- or ship-based operators in near-real time. Samples can also be preserved and	Ongoing	NCCOS, GLERL, AOML, CIGLR, and MBARI scientists achieved the first real-time HAB toxicity assessment by an uncrewed, Long-Range Autonomous Underwater Vehicle (LRAUV) carrying the 3G-ESP during a toxic cyanobacterial bloom in western Lake Erie (4-17 August, 2021). NCCOS-HML (HAB Monitoring & Reference Branch)-fabricated, microcystin (MC)-specific toxin sensors, coupled with MBARI's newly redesigned embedded surface plasmon resonance SPR module integrated with 3G-ESP, produced these first 'on-the-fly' quantitative MC measurements onboard the LRAUV, confirming the relatively low toxicity nature of the bloom. Highly coordinated, vessel-assisted water quality sampling and airborne hyperspectral imagery contributed by GLERL and CIGLR, as well as satellite imagery from the NCCOS Lake Erie HAB Bulletin, provided critical paired validation data and information on bloom

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				archived for post-deployment recovery and laboratory-based 'omics analyses.		location, intensity, and trajectory, respectively. A second MBARI sentinel LRAUV deployed during the first week of the mission served to map the bloom distribution and guide sampling by the 3G-ESP/LRAUV. NOAA personnel, trained by MBARI, successfully piloted the LRAUV and adaptively executed bloom patch tracking and sampling missions during field operations. This key step towards transferring MBARI's LRAUV technology will significantly enhance NOAA's uncrewed systems (UxS) capabilities. Archived samples collected and preserved by the 3G-ESP/LRAUV are being used by GLERL, AOML, and CIGLR scientists for post-deployment 'omics-based analyses of the bloom population. Together, all of this information will improve our understanding of factors contributing to bloom toxicity in Lake Erie.
DOC	NOAA	HABs	Upgrading and Planning for the Transition of the Lake Erie HABs Early Warning System to a sustainable Operational Form	GLOS with partners from NOAA (GLERL), LimnoTech, The Ohio State University, Cleveland Water Alliance, and CIGLR are developing a HAB early warning system (EWS) in western Lake Erie. The development of GLERL's 2G ESP network within the western basin of Lake Erie has provided autonomous, high-frequency bloom toxicity monitoring (described in detail in NOAA's Great Lakes HAB monitoring and experiment program). Data collected from the ESP network is being incorporated into the HABs portal and Early Warning System (EWS). In years	Completed	GLOS with partners from LimnoTech, Cleveland Water Alliance, Ohio State University and NOAA partners from the GLERL, National Centers for Coastal Ocean Science (NCCOS), and the Cooperative Institute for Great Lakes Research (CIGLR) have worked towards the development of a Western Lake Erie HAB Early Warning System (EWS). From 2017 through 2021, work focused on understanding and advancing the monitoring network in western Lake Erie, engaging stakeholders in a needs assessment, and developing GLOS IT platform to support the EWS. The team: 1) upgraded and supported existing drinking water

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				2 and 3 of the project, GLOS is enhancing the data network and the backend technology necessary to take in data and present clear, actionable information through a new online EWS application, which will be released in the fall of 2020.		treatment plant water quality monitoring assets; 2) expanded the in-situ real time monitoring capabilities of the network by expanding the number of drinking water treatment plants contributing water quality data to the EWS monitoring network; 3) procured and deployed a Monterey Bay Aquarium Research Institute (MBARI) Second Generation (2G) Environmental Sample Processor (ESP); and 4) developed GLOS IT platform to ingest relevant data and incorporate an alert and warning system to provide feedback to users in real time.
DOC	NOAA	HABs and hypoxia	U.S. Integrated Ocean Observing System (IOOS) and Great Lakes Observing System (GLOS)	GLOS is a certified Regional Information Coordination Entity under the U.S. IOOS. GLOS aggregates data from Federal and non-Federal data sources and makes it more easily discoverable and accessible to a broader stakeholder audience, including researchers, policy-makers, and resource managers. This is evidenced most directly through the GLOS Data Portal as well as the customized HABs Portal: http://habs.glos.us/map/ As a regional association of IOOS, GLOS also helps coordinate Federal and non-Federal observing activities across the region and supports operation of several nearshore buoys, including two buoys used for hypoxia monitoring by Cleveland, Ohio.	Ongoing	Thanks to a grant through the U.S. Integrated Ocean Observing System's Ocean Technology Transition project, GLOS partnered with NOAA GLERL and NCCOS, LimnoTech, The Ohio State University, and Cleveland Water Alliance to build a HAB early warning system (EWS) in western Lake Erie. As a response to what is increasingly becoming a regional public health concern, the project combined existing data streams from in-water sensors and incorporated new technology into a system that allows water managers and the public to anticipate HABs and react effectively. See www.glos.org/ and www.frontiersin.org/articles/10.3389/fmars.2019.00731/full for more details. As a capstone to this multi-year project, the "Lake Erie Harmful Algal Bloom Early Warning System Operational Plan" documents the current EWS from collecting the water quality observations

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						to delivering HABs information to the public. The Operational Plan charts a course for improvements to the EWS in coming years. For the past several decades, scientists, citizens, and policy makers have worked creatively to address Great Lakes challenges, including the spread of invasive species, aging water infrastructure, and a changing economy and climate. Today, the Great Lakes region continues to work towards greater collaboration and a better understanding of the lakes. It is now understood that a connected information ecosystem could help address a broad variety of challenges facing the region. The Smart Great Lakes Initiative (SGLi) is working to build an information ecosystem based on smart technologies that improve the understanding, use, and management of the lakes. This ecosystem will connect the region with advanced data management and analysis, leveraging technology innovations that get people more high-value information, on demand. See www.glos.org/ for more details.
DOD	USACE	HABs		Responding to HABs in response to public reports/complaints in close coordination with state water quality/public health agencies. Response programs developed by individual USACE Divisions/Districts. USACE Engineer Research and Development Center available to support Divisions/Districts in assessing HAB impacts to USACE Civil Works Projects	Ongoing	No updates

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				(e.g., water quality modeling, remote sensing, and technical assistance). General water quality monitoring and HAB response to meet authorized project purposes and recreation mission requirements.		
DOD	USACE	HABs and Hypoxia		The U.S. Army Engineer Research and Development Center (ERDC) provides support to Great Lakes Restoration Initiative Partners, and the U.S.-Canada Great Lakes Water Quality Agreement (GLWQA) Nutrients Annex by developing technical guidance for locating and implementing wetland restoration/construction projects to reduce excess nutrient inputs to surface waters. This is completed through a combination of modeling, laboratory analysis, and field data collection in conjunction with the publication of peer reviewer literature and engagement with the scientific community and the public.	Ongoing	Construction of a pilot wetland (18 acres) was completed in June 2021 within the Maumee River Watershed of Lake Erie in the township of Defiance, Ohio. Project goals are to identify management actions and operational strategies to maximize P retention through multiple mechanisms (sediment retention, soil adsorption, plant assimilation) and investigate P reduction under a variety of scenarios (flow regimes, residence time). The project will also provide operational guidance to practitioners related to legacy P, P storage capacity thresholds, P fate within wetland systems, soil amendment effects, and associated implications for increased P removal. USACE and project partners (City of Defiance, USGS, EPA) are conducting a 5-year field research monitoring program of the wetland demonstration project.
DOD	USACE	HABs		The U.S. Army Engineer Research and Development Center (ERDC) provides support for the Great Lakes & Ohio River Division's water quality monitoring program, including assessment and development of remote sensing software tools to identify water quality indicators of HABs.	Ongoing	Building on the foundational pilot study at Harsh (East Fork) Lake, OH, this project developed a series of software tools that make use of available satellite imagery and algorithms to estimate potential HAB indicators (e.g., chlorophyll-a, phycocyanin, turbidity). Products from this research include:

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						1. An open-source R-software package, *waterquality*, a University of Cincinnati collaboration and the most comprehensive option for developing image-based abundance maps of HAB indicators, with accompanying user-guide. 2. A Python-based ArcGIS Pro *waterquality toolbox* with user-guide and sample data, designed for use in ESRI ArcGIS Pro desktop software 2.7 and greater, has pre-set menus and limited options for a streamlined workflow to produce image-based abundance maps of HAB indicators. 3. An online, ESRI-based web application, *HAB Explorer*, to rapidly screen for potential HAB conditions with constrained algorithm and visualization options (USACE network-only access as of spring 2022, public access forth coming later 2022).
DOI	NPS	HABs and hypoxia	Outreach and Education	Of the 411 NPS units, there are 88 units that are considered ocean, coastal, or Great Lake parks, in addition to other park units that have extensive surface water bodies. HABs have the potential to influence all of these park units at various levels, and it is therefore important to prepare for these events in order to preserve our resources. The National Park Service is creating a Sharepoint website containing a public health and ecological HAB events reporting system. It also provides a point of contact for park managers to partner with local, state, and Federal health and environmental agencies	Ongoing	NPS Regional Natural Resource Chiefs identified HABs as one of seven priority issues in the 88 ocean, coastal, and Great Lakes parks. A targeted action plan was developed to address this critical issue in parks nationwide. The action plan includes continued updates and improvements to the internal NPS website with information on monitoring, testing, reporting, responding to, and managing HABs. Additional outreach materials on HABs, their causes, the effects on the ecosystem, and the many ways to reduce or stop nonpoint source pollution will continue to be developed. More information on HAB action plan progress can be found in our Year 1 and Year 2 Ocean and

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				that can provide park personnel with technical assistance for the management of HAB events. Outreach materials (brochures, interpretive displays, and materials) on HABs, their causes, the effects on the ecosystem, and the many ways to reduce or stop nonpoint source pollution, are being created by the NPS.		Coastal Advisory & Support Team Annual Reports.
DOI	USGS	HABs and hypoxia	National Water Quality Program, National Water Quality Network, and Cooperative Matching Funds	USGS conducts long-term monitoring of nutrients and other water quality characteristics in surface and groundwater networks, nationally. The sources and quantities of nutrients delivered by streams and groundwater to the Great Lakes are monitored at several sites and locations throughout the Great Lakes watersheds. Annual updates from National Water Quality Network monitoring sites are made available to the public, including nutrient concentrations, loads, and yields. These data, along with data aggregated from numerous other agencies, are used to evaluate trends in critical water quality parameters, including nutrients and sediment. Trends in nutrient loading to the Gulf of Mexico from the Mississippi River, measured through the National Water Quality Network, are used each year to track progress toward nutrient reduction targets set by the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. NWQN (usgs.gov)	Ongoing	The National Water Dashboard contains data for over 13,000 USGS real-time stream, lake, reservoir, precipitation, water quality, and groundwater stations in context with current weather and hazard conditions. Annual updates on streamflow, nutrient and sediment concentrations and loads, and pesticide concentrations from river and stream sites in the National Water Quality Network are made available to the public through an online web tool that visualizes changes over time and allows for downloading data. Decadal changes in the water-quality of the Nation's surface water and groundwater can also be visualized through online web tools. Several nutrient and sediment studies that have direct relevance or transferability to the Great Lakes have been completed, including: Landscape drivers of dynamic change in water quality of U.S. Rivers (Stets et al., 2020). Nitrate in streams during winter low-flow conditions as an indicator of legacy nitrate (Johnson and Stets, 2020).

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				These loads are also used by NOAA to generate a prediction of the size of the hypoxic zone in the Gulf each year.		Linking sediment trends in U.S. rivers and streams to changes in land use, hydrology, and climate (Murphy, 2020). Pilot-scale testing of dairy manure treatments to reduce nutrient transport from land application (Francy et al., 2020a). Nutrient status of San Francisco Bay and its management implications (Cloern et al., 2020). Factors affecting nitrate concentrations in stream base flow (Wherry et al., 2021).
DOI	USGS	HABs and hypoxia	National Water Quality Program/ Matching Funds; Groundwater and Streamflow Information Program (GWSIP)/Water Observing Systems	USGS collects fish, aquatic macroinvertebrate, and algae-community samples, and conducts stream physical habitat surveys to assess the effects of multiple stressors, including algal toxins, on aquatic organisms in streams in several ecoregions.	Ongoing	USGS studies include those focused on better understanding the relations between environmental conditions, the development of attached (benthic) and open-water (planktonic) cyanobacteria HABs, and cyanotoxin production. Recent emphasis has been placed on cyanobacteria and cyanotoxin occurrence in streams and large rivers (e.g., Graham et al., 2020; Krempa, 2021; Zuellig et al., 2021).
DOI	USGS	HABs	National Water Quality Program/ Cooperative Matching Funds and HAB Directed Cooperative Matching Funds.	USGS Water Science Centers (WSC) work with more than 1,600 partners to address local priorities and meet goals of national interest. Cooperative Matching Funds (CMF) support much of this work and are required to have at least a 1:1 match by state, local, or tribal partners. Since 2019, a subset of CMF has been directed towards HAB-related projects that advance real-time monitoring, remote sensing, and use of molecular techniques to identify and	Ongoing	During 2019-2022, HAB Directed Cooperative Matching Funds have supported 40 projects in 19 geographic areas. Combined, these studies will provide locally relevant and transferable information that inform the development of early indicators for HABs, assist water-treatment plant operators in decision-making, and build knowledge of cyanobacterial communities that cause HABs and the cyanotoxins they produce.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				predict the occurrence of HABs and the cyanotoxins they produce.		There are two projects in the Lake Superior Watershed focused on better understanding the land to lake drivers of cyanotoxin production and the influence of sediment, nutrient loading, and hydrology on cyanobacterial bloom initiation in the nearshore environment. Recently completed studies that have direct relevance or transferability to the Great Lakes include: The development of nowcast models (Francy et al., 2019) to determine potential for cyanotoxin exposure at recreational beaches in western Lake Erie and Ohio (Francy et al., 2020b). Real-time models to predict microcystin concentration action-level exceedances at recreational beaches and drinking-water intakes in western Lake Erie and Ohio (Francy et al., 2020c).
DOI	USGS	HABs	National Water Quality Program/Water Availability and Use	Various water-quality process studies will inform assessment of HABs and have direct relevance or transferability to the Great Lakes. Integrated Water Availability Assessments (IWAAs) will provide nationally consistent assessments of water availability for human and ecological needs and identify factors that limit water availability, which will improve forecasting at multiple temporal and spatial scales (Miller et al., 2020).	Ongoing	There are three Regional IWAAs studies, selected to leverage information being collected by NGWOS: Delaware River Basin, Upper Colorado River Basin, and the Illinois River Basin. Studies in the IWAAs Basins will evaluate new ways to assess and model algal communities and use this information, along with models of water quality, to estimate the likelihood of HAB occurrences.
DOI	USGS	HABs	National Water Quality Program/Water	Various water-quality process studies will inform assessment of HABs and have direct relevance or transferability to the	Ongoing	There are three Regional IWAAs studies, selected to leverage information being collected by NGWOS: Delaware River Basin,

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
			Availability and Use	Great Lakes. Integrated Water Availability Assessments (IWAA) will provide nationally consistent assessments of water availability for human and ecological needs and identify factors that limit water availability, which will improve forecasting at multiple temporal and spatial scales (Miller et al., 2020).		Upper Colorado River Basin, and the Illinois River Basin. Studies in the IWAAs Basins will evaluate new ways to assess and model algal communities and use this information, along with models of water quality, to estimate the likelihood of HAB occurrences.
DOI	USGS	Hypoxia	National Water Quality Program	The USGS SPARROW (SPAtially Refrerenced Regressions on Watershed attributes) model quantifies nutrient and sediment sources and loads to the Great Lakes. USGS modeled groundwater/surface water interactions at the hydrologic unit code (HUC) 8 scale throughout the U.S., including part of the Great Lakes Basin, which provides key information on travel times for recharging water to flow to a receiving surface water.	Ongoing	Interactive SPARROW mappers are available for the entire binational Great Lakes watershed, the U.S. part of the Great Lakes basin, and the rest of the CONUS.
DOI	USGS	HABs	National Wildlife Health Center	The USGS National Wildlife Health Center (NWHC) advances wildlife health science for the benefit of animals, humans, and the environment. The NWHC conducts applied wildlife health research, field investigations and disease ecology studies, and investigations into the causes of wildlife mortality events. The National Wildlife Health Center has response resources available for wildlife mortalities, including those associated with HABs. The NWHC developed the Wildlife Health Information Sharing Partnership event reporting system (WHISPers), which includes information about HAB-related events.	Ongoing	Several studies focused on saxitoxin effects on seabirds in the Gulf of Alaska, Bering Sea, and Chukchi sea have been completed including: Acute and oral toxicity and tissues residues of saxitoxin in the mallard (Dusek et al., 2021). An investigation of algal toxins in a multispecies seabird die-offs that occurred between 2014 and 2017 (Van Hemert et al., 2021). An evaluation of the role of saxitoxin and domoic acid in a die-off of Common Murres (Van Hemert et al., 2020)

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
DOI, USDA	USGS, USDA-NRCS	HABs and hypoxia	GLRI	USGS GLRI projects are assessing HABs and hypoxia control, prevention, and mitigation from a landscape perspective, and in close consultation with USDA-Natural Resources Conservation Service (NRCS), monitoring at edge-of-field (21 sites) and small watershed (6 sites) locations in the GLRI priority watersheds to help quantify phosphorus, nitrogen, and sediment reductions from GLRI projects on agricultural lands. Rapid sharing of edge-of-field monitoring results with local stakeholders allows for adaptive management processes to occur. The USGS has installed GLRI-funded edge-of-field monitoring stations on farms in the Maumee River basin, the Fox River basin, the Saginaw River basin and the Genesee River basin. These stations gather weather data and sample runoff water during storm events. The water samples are analyzed for their phosphorus, nitrogen, and sediment content. NRCS staff assist the cooperating farmer with installing conservation practices in the field above the stations. This analysis helps quantify the value of conservation practices in reducing sediment and nutrient delivery from these fields, under these conditions, in order to improve water quality.	Ongoing	The results from the first set of edge-of-field sites have been reported (Komiskey et al., 2021). Several reports quantifying the amount of nutrient and sediment reductions as a result of GLRI projects will be released in 2022. In addition, new sites have been added to evaluate the effectiveness of bioreactors for improving water quality.
DOI	USGS	HABs and Hypoxia	GLRI	USGS monitoring near the outlets of 26 major tributaries to the Great Lakes helps to assess the impacts of management practices, extreme weather events, and land use change on the timing and magnitude of delivery of nutrients and sediments to the Great Lakes.	Ongoing	USGS has developed a surrogate regression approach to estimate continuous tributary loading at these sites and provided nutrient loading information through 2018 (Robertson et al., 2018; Koltun, 2021). USGS is now developing ways to use these techniques to estimate real-time loads at each of these sites

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				Watershed nutrient monitoring helps to identify sources, impacts of management practices, and influence on loadings to the Great Lakes.		and present these data to the public at more frequent intervals (annually or less). This information will be used to better quantify nutrient load reductions to the Great Lakes. The extensive monitoring network in the Maumee basin has provided valuable data set to understand nutrient dynamics under different climate conditions and improving ability to understand sources contributing the nutrient loads to the Great Lakes (Williamson et al., 2021a; Williamson and others 2021b).
DOI	USGS	HABs and Hypoxia	GLRI	USGS works collaboratively with NOAA, EPA, states, universities, and NGOs on several projects to better understand how nutrient and sediment loading from Great Lakes watersheds affect hypoxia, HABs, and biological communities in the river mouths and open lake environments.	Ongoing	USGS investigations have contributed to the understanding of rivermouth nutrient retention and transformation (Larson et al., 2020a; Larson et al., 2021; Pearce et al., 2021), the spatial distribution of benefits of nutrient load reductions (Larson et al., 2020b), and the interactions of nuisance macro algae and microplastic pollution in nearshore environments (Peller et al., 2021). Modeling studies combining field data from USGS, NOAA, and other agencies have shown insights into controls of cyanobacterial bloom timing in western Lake Erie (Del Giudice et al., 2021).
DOI	USGS	HABs	Environmental Health: Toxic Substances Hydrology and Contaminants Biology Programs	Cause, Controls, and Fate of Algal Toxin Production: Investigations are made into the origins, occurrence, transport/fate, effects, and mitigation of HABs and associated toxin mixtures. These investigations have transfer value to the Great Lakes. In doing so, new methods are being pioneered including toxin-specific	Ongoing	The USGS's Toxins and HABs Science Team is continuing to develop tools to evaluate algal toxin production in waters across the Nation, including the Great Lakes. The team is advancing methods for algal toxin detection in a variety of matrices (water, sediment, tissue, and aerosols) and also

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				analytical methods and development of targeted and non-targeted ground-to-space field and laboratory methods. Current and planned research, which includes investigations of metabolites and related biota, characterizes the spatial/temporal extent of understudied aspects of toxins associated with HABs; evaluates environmental controls responsible for HAB proliferation and associated toxin production; and evaluates environmental health implications and impacts. In addition to contributing to basic understandings of the biogeochemical underpinnings of algal toxin occurrence and associated environmental health threats, this information can be utilized to assist with standardization of study designs, field, laboratory, and interpretative techniques and to inform mitigation activities. Current and planned collaboration is ongoing with multiple Federal and State agencies and tribes as well as through outreach efforts, such as participation on the Inland HAB Discussion Group. Industry collaborations are fostered to facilitate acquisition of lower cost, higher throughput screening assays, and more advanced interpretative capabilities where the program provides validation support for the benefit of program research and stakeholder collaboration.		making advances on high-resolution mass spectrometry methods to add metabolomic and proteomic capabilities to genomic approaches to support mechanistic understanding of toxin expression. They are using a polyphasic approach to assess the morphology, genetics, pigments (to aid ground to space characterization of uncertainty for the Cyanobacteria Assessment Network (CyAN; Papenfus et al., 2020; Coffer et al., 2021a; Coffer et al., 2021b; Mishra et al., 2021; Seegers et al., 2021), toxin chemistry of potentially toxic cyanobacteria cultures collected from algal blooms in waterbodies across the country (Graham et al., 2021, Zuellig et al., 2021), toxin mixtures and interactions of the microbial community (Christensen et al., 2021; Christensen et al., 2022). The team completed a historical review of cyanotoxin and other algal toxin occurrence on Reserved Federal Lands and effects on DOI Trust species (Laughrey et al., 2021), a pilot study that analyzed potential toxin exposure from tapwater (Bradley et al., 2021), and effects of cyanotoxin exposure in mallards (Dusek et al., 2021).

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				Pioneer new field monitoring methods (sensors), assessment techniques, and laboratory methods needed to address HAB issues in freshwaters. New methods include a multi-toxin method that can quantify cyanotoxin mixtures, and DNA- and RNA-based molecular methods for detecting microcystin and microcystin producers.		
DOI	USGS	HABs and hypoxia	Ecosystems	USGS has ongoing research characterizing ecological and food web impacts of cyanotoxins and hypoxia. For example, USGS studies in Lake Erie are exploring fish behavior mediated by effects of western basin HABs. Research is being done in the central basin of Lake Erie to measure effects of hypoxia on prey and game fish recruitment.	Ongoing	USGS research has contributed to the understanding of the effects of hypoxia on Great Lakes fish communities, including distribution of fish in the water column and aggregation near the edges of the hypoxic zone (Chamberlin et al., 2020) and habitat availability use by cisco in Lake Erie based on oxythermal conditions (Schmitt et al., 2020); led to the development of a spatio-temporal geostatistical interpolation framework to estimate hypoxia extent in the Central Basin of Lake Erie (Xu et al., 2021); and explored the utility of miniature temperature and depth sensors implanted in fish as a tool to enhance monitoring data (Kraus et al., 2021).
DOI	USGS	HABs	GLRI	Great Lakes *Cladophora* Assessment: The USGS is conducting sentinel site assessments of *Cladophora* in Lakes Michigan, Huron, Erie, and Ontario as part of a binational effort to understand the conditions that lead to *Cladophora* overgrowth throughout the Great Lakes. This effort will help support management of this HAB species through nutrient control. EPA assists with field data collections on Lake Ontario and the NPS	Ongoing	Sentinel site assessments have been conducted each year since 2018, and the data are publicly available (Przybyla-Kelly et al., 2020a; Przybyla-Kelly et al., 2020b). Project data have been used by Great Lakes Water Quality Agreement Task Teams and multiple ecosystem modeling groups. This assessment has also led to insights about the interactions of nuisance macro algae and

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				assists with logistical support on Lakes Michigan and Huron.		microplastic pollution in nearshore environments (Peller et al. 2021).
DOI	USGS	HABs and hypoxia	Groundwater and Streamflow Information Program (GWSIP)/Water Observing Systems	The USGS is enhancing observing networks, including new sensor and satellite-based monitoring of selected water-quality properties and constituents in a Next Generation Water Observing System (NGWOS). The USGS NGWOS will provide real-time data on water quantity, quality, and use, including data directly related to assessing HABs, in more efficient and rapid ways than previously possible, and in more locations (Eberts et al., 2019). When fully implemented, the USGS NGWOS will intensively monitor at least 10 watersheds and underlying aquifers that represent larger regions across the Nation.	Ongoing	There are four NGWOS locations: Delaware River Basin, Upper Colorado River Basin, Illinois River Basin, and the Willamette River Basin. Observing networks in all Basins are evaluating new sensor and satellite-based monitoring approaches for HABs, including the potential for identifying cyanobacteria based on hyperspectral reflectance characteristics (Slonecker et al., 2021). In the Illinois River Basin, there is a focus on better understanding the influence of the magnitude and timing of nutrient delivery on HAB development and predicting HAB events.
DOI	USGS	HABs and hypoxia	Water Resources Research Act	The Water Resources Research Act Program is a Federal-state partnership that plans, facilitates, and conducts research that helps resolve state and regional water problems; promotes technology transfer; promotes dissemination and application of research; trains scientists through participation in research; and awards competitive grants to Water Resource Research Institutes or Centers under the Water Resources Research Act. This program routinely funds HAB- and hypoxia-related research through National Competitive Grants and Annual Base Grants.	Ongoing	There are four ongoing National Competitive Grant projects and six ongoing Annual Base Grants projects focused on HABs. The research being conducted by these studies represents freshwater and marine environments in eight states, and is focused on developing tools to monitor and predict HABs, enhancing mechanistic understanding of HAB development and toxin projection, and managing and mitigating the effects of HABs.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
DOI	USGS, NPS	HABs	National Water Quality Program/USGS-NPS Water Quality Partnership Program	The USGS/NPS Water-Quality Partnership has supported research to address critical water-quality issues in National Parks since 1998. A competitive selection process is used to fund projects that address issues including contaminants and human-health concerns and vulnerability of national park resources.	Ongoing	There are four ongoing projects focused on 18 National Parks. Four Great Lakes Parks – Isle Royale National Park, Apostle Islands National Lakeshore, Sleeping Bear Dunes National Lakeshore, and Perry's Victory and International Peace Memorial – are included in these projects. Ongoing projects are focused on the development of tools and strategies that Parks can use to monitor, assess, and mitigate the effects of harmful algal blooms in their freshwater and marine resources. Recently completed projects include remote sensing of benthic algal blooms (Legleiter and Hodges, 2022), influence of internal nutrient loading on bloom development and hypoxia, physicochemical and biological conditions associated with *Pseudo-nitzschia* bloom development, accumulation of cyanotoxins in fish, understanding cyanobacteria and cyanotoxin occurrence in lake (Christensen et al., 2022), river, and cave ecosystems, developing cyanotoxin mixture models to understand exposure risks (Christensen et al., 2021), and evaluating rapid assessment test strips for cyanotoxin monitoring (LeDuc et al., 2020).
Multiple agencies	Multiple agencies	HABs and hypoxia	GLRI	Nutrient and sediment reduction projects in targeted watersheds: Through the GLRI, Federal agencies and their partners are reducing nutrient loads into the Great Lakes. During FY 2015, Federal agencies and their partners funded nutrient and sediment reduction projects on over 100,000 acres of targeted watershed in the Great Lakes Basin using GLRI funding	Ongoing	As of 2022, GLRI Federal agencies estimate that over 2 million pounds of phosphorus have been prevented from leaving farms and entering the Great Lakes cumulatively as a result of GLRI-funded projects including over 500,000 pounds of phosphorus reductions in FYs 2020-2021. In addition, green infrastructure projects started in FYs 2020-2021 will capture approximately 140 million gallons of untreated urban runoff per year.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				which are projected to prevent over 160,000 pounds of phosphorus from entering the Great Lakes annually. During FY 2015, Federal agencies and their partners also funded urban runoff projects that are anticipated to capture an average annual volume of more than 37 million gallons of untreated urban runoff per year. These projects reduce flooding, increase green space in urban areas, and return vacant properties to productive use.		
Multiple agencies	Multiple agencies	HABs and hypoxia	GLRI	Conservation demonstration farms for watershed farmers: The GLRI is funding the implementation of conservation practices including cover crops, nutrient management, no-till planting, and the conversion of cropland to prescribed grazing on conservation demonstration farms in the Great Lakes basin. The farms are open to field days, tours, and mentoring opportunities where other farmers in the watershed can view the installed practices, hear farmers' opinions on the value that conservation farming practices can add to their farming operations, and ask questions.	Ongoing	USGS Update: USGS performs some monitoring on some of these Demonstration Farms, but NRCS does most of the coordination. USDA NRCS update – USDA NRCS update: A total of 8 GLRI demonstration farm networks in Wisconsin (6), Ohio (1), and New York (1) are now partnering with dozens of producers to showcase cutting edge conservation systems. Demo farms have led to very robust GLRI Nearshore EQIP (conservation program) sign-ups and observable increases in living winter cover and crop residue, evidenced with satellite imagery. They are leading the way on conservation innovation and sharing their knowledge and success with farms in their neighborhood and across the states in the Great Lakes region.
Multiple agencies	Multiple agencies	HABs and hypoxia	GLRI	Real-time continuous water quality observation buoys and forecasting: During FY 2015, GLRI partners established a network of four real-time continuous observing buoys to track detailed water	Ongoing	NOAA: Airborne hyperspectral imaging observations were conducted over GLERL weekly monitoring stations and over water intakes; these observations were flown under clouds and near shore where satellite observations were unavailable. Results were

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				quality conditions to support modeling, forecasting, and public warnings of HAB conditions throughout western Lake Erie. The observing buoys are capable of tracking water quality and bloom conditions and measuring dissolved phosphorus concentrations at hourly intervals. During the 2015 bloom season, these buoys collected over 7,000 in-lake nutrient and water quality measurements, providing unprecedented spatial and temporal details of internal lake dynamics and bloom development. In addition to providing real-time tracking of HABs conditions for water intake managers and recreational users, the observing data will be used to improve ongoing forecasting efforts covering a range of spatial and temporal scales, including seasonal HABs forecasts, 5-day forecasts, and vertical distribution forecasts.		reported to water intake managers from 32 flights over western Lake Erie and Saginaw Bay. A seasonal HAB areal extent report developed from the NOAA GLERL/MTRI Color Producing Agents (CPA) algorithm was provided to EPA/GLNPO. Weekly optical property data was collected to improve this algorithm and to begin the development of a general purpose phytoplankton functional type algorithm in anticipation of the launch of the NASA PACE hyperspectral satellite in 2024. Real-time continuous water quality observation buoys and forecasting: GLERL and CIGLR partners established a network of four real-time continuous observing buoys to track detailed water quality conditions to support modeling, forecasting, and public warnings of HAB conditions throughout western Lake Erie. The observing buoys are capable of tracking water quality and bloom conditions and measuring dissolved phosphorus and nitrate concentrations at hourly intervals. During the 2021 bloom season, these buoys collected in-lake nutrient and water quality measurements, providing unprecedented spatial and temporal details of internal lake dynamics and bloom development. In addition to providing real-time tracking of HABs conditions for water intake managers and recreational users, the observing data will be used to improve ongoing forecasting efforts covering a range of spatial and temporal scales, including seasonal HABs forecasts, 5-day forecasts, and vertical distribution forecasts. This project is supported by GLRI.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
Multiple agencies	Multiple agencies and partners, including but not limited to EPA, FWS, NOAA, NPS, USACE, USDA, USGS	HABs and hypoxia	Water Quality Portal	Participants in the Water Quality Portal, a cooperative data service that makes data publicly available. The data are derived from the USGS National Water Quality Information System (NWIS), the EPA Storage and Retrieval data warehouse (STORET), and the USDA ARS Sustaining the Earth's Watersheds – Agricultural Research Database System (STEWARDS). With data from over 400 Federal, state, tribal, and local agencies, this effort will improve understanding of the progress of nutrient reduction efforts.	Ongoing	Data submissions continue to grow; the WQP serves data from 2.6 million monitoring locations representing data from over 400 organizations. Many WQP users have shifted data retrieval methods to automated data retrieval via APIs. The WQP's APIs have become more stable and extensive to serve users EPA plans to continue including cyanotoxins data as data are available. To explore the data, go here: www.waterqualitydata.us/portal/ Data from the Water Quality Portal have are now used in the new How's My Waterway Tool from the EPA; this tool is intended to help the public better understand water quality and impairments in their local area. USACE WQ data are available through Access to Water (A2W), the public mirror to our Corps Water Management System (CWMS). USDA – Since 2020, 8.1 million records were added to STEWARDS as well as the Water Quality Portal. In May 2020, USDA published an analysis of the impact of the STEWARDS data portal (Sadler et al., 2020).
Multiple agencies	Multiple agencies and partners, including but not limited to USDA ARS, NOAA, NPS,	HABs and hypoxia	National Atmospheric Deposition Program	The National Atmospheric Deposition Program (NADP), a consortium of Federal and non-Federal partners, monitors precipitation chemistry and publicly provides information on atmospheric nitrogen deposition.	Ongoing	The NADP established a network in 2010 to measure ammonia gas deposition called the Ammonia Monitoring Network (AMoN); this network has been expanding rapidly and now has more than 100 sites across the United States, many in the Great Lakes Region.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
	NSF, EPA, USFS, USGS					NADP partners have been collaborating with Utah State University to develop improved sample collection methods to capture atmospheric dry deposition of phosphorus and other nutrients. A new dry deposition sampler is described in Brahney et al., 2020. NADP developed total atmospheric nitrogen deposition data sets and maps for the U.S. These data and maps are available for the years 2000-2016. Science needs for continued development of total atmospheric nitrogen deposition budgets in the United States were identified, and the results are described in two papers (Walker et al., 2019a and Walker et al., 2019c, and a report (Walker et al., 2019b). A new sampler attachment that will allow analysis of total nitrogen and total phosphorus in wet atmospheric deposition is under development and being tested by NADP personnel. It is anticipated that this sampler will be ready for beta testing at NADP sites in the latter half of 2022.
Multiple agencies	Multiple agencies: CDC, NASA, NOAA, NSF, USDA, and USGS	HABs	Exposure Science (ES)21 Federal Working Group on Exposure Science	Exposure assessment is instrumental in helping to forecast, prevent, and mitigate exposure that leads to adverse human health or ecological outcomes. This vision expands exposures from source to dose, over time and space, to multiple stressors, and from the molecular to ecosystem level. HAB exposure assessment is addressed by ES21 Working Groups on Biomonitoring, Citizen Engagement/Citizen Science and Sensors/Dosimeters.	Completed	This effort was completed as of 2020. NOAA took lead roles to represent HABHRCA in three workgroups: Biomonitoring, Sensors/Dosimeters, and Citizen Science. Outputs included increased awareness of HABs to other science disciplines though webinars, case studies, harmonization of terminology and updating of agency contacts and activities. Reorganization of the workgroups shifted to key areas of national interest including sensors and research preparedness.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
Multiple agencies	Multiple Agencies, EPA and NOAA	HABs	Volunteer Freshwater Phytoplankton Monitoring Program	Volunteer monitoring program that collects baseline data on harmful algal species and builds capacity by providing data to NOAA Phytoplankton Monitoring Network and EPA. Volunteers are trained to identify algae, collect water samples, conduct basic water quality analyses, and preserve samples for further analysis by the NOAA Analytical Response Team. Network became operational in 2015 with stations in the Western Basin of Lake Erie, and in seven lakes in EPA Region 8 with plans to expand to Lakes Michigan, Superior, Huron, and Grand Lake St. Mary in 2016.	Ongoing	NOAAs Phytoplankton Monitoring Network (PMN) was established in 2001 to monitor potentially harmful phytoplankton and HABs. In 2015, PMN entered into an interagency agreement with EPA Office of Water to establish a freshwater cyanobacterial monitoring program in the Great Lakes, and it rapidly expanded from there. As of 2021, there are 47 total active sites in 14 states monitoring freshwater sites. Of these, there are two active sites in Lake Erie (Ohio) and four active sites in Lake Michigan (Michigan). Up to present, PMN sites have collected 109 samples, with only one report of any cyanobacteria, but not at elevated concentrations.
NASA	NASA	HABs	The Ocean Biology and Biogeochemistry Program	Basic HABs research resulting in publications and new retrieval algorithms.	Ongoing	NASA has worked with several universities and other government partners in the Great Lakes area to develop new capabilities for remote sensing of water quality, primarily focused on Harmful Algal Blooms in freshwater ecosystems. The research team has completed the documentation of the research project and contributed 10 papers to a special issue of the Journal of Great Lakes Research, released in June 2019. The team documented many advances generated during this project. Data acquired from 2014 to 2020, including 92 flights of airborne hyperspectral imagery, is being organized to match up with in-situ sampling and other remotely sensed data to support the NASA PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) mission.
NASA	NASA (and NOAA)	HABs	Health and Air Quality	Monitoring and surveillance of cyanobacterial HABs in drinking and recreational water supplies. Satellite	Completed (NASA component);	The NASA-led component of this project is completed and is no longer supported through NASA funding. NOAA continues to utilize

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
			Applications Program	derived products that were developed for western Lake Erie are being analyzed for their use in other regions (e.g., Chesapeake Bay and inland lakes in Ohio and Florida). This project has established methods to identify environmental thresholds that indicate the potential for cyanobacterial blooms to form or persist, and these data sets are also being made available to CDC.	Ongoing (NOAA applications)	satellite data for HAB monitoring in Lake Erie, without NASA funding. Thus, this activity is ongoing – however without direct NASA support.
NSF	Joint initiative between NSF and NIEHS	HABs	Centers for Oceans and Human Health Initiative, a collaboration between NSF's Division of Ocean Sciences, and the National Institute for Environmental Health Sciences	Centers support collaborations among oceanographic/aquatic sciences and biomedical sciences to research the nature of ocean and Great Lakes exposures (including HABs) and the impact on human and community health. Examples of supported studies included those that examine the effects of HAB toxins on human and mammalian physiology, develop biomarkers for chronic toxin exposure, and design and test novel technologies for *in situ* detection of algal toxins in fresh- and salt-water environments, etc. Centers include a Community Engagement Core for active involvement of local partners to facilitate translation of research findings and implementation of mitigation and communication strategies.	Ongoing	NSF and NIEHS have funded the Lake Erie Center for Fresh Waters and Human Health since 2018. Ongoing activities include: integrating detection and sampling technologies to improve monitoring of cyanoHABs; identification of other microbes in bloom populations to determine which organisms encourage cyanoHAB development, persistence, and decline; and discovery and characterization of new toxins in genomes and metagenomes of bloom-forming cyanobacteria. The Center's Community Engagement Core actively facilitates participation of citizen scientists (including charter boat captains) in routine sampling, and interacts with community groups to strategize new opportunities for research translation to the general public, and improved risk communication with communities around the Great Lakes.
NSF	NSF	HABs	Division of Ocean Sciences (OCE), NSF Ocean Observatories Initiative	Observational capabilities for research in marine systems.	Ongoing	

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
NSF	NSF	HABs	Directorate for Geosciences, Prediction and Resilience Against Extreme Events (PREEVENTS)	Focused interdisciplinary research projects.	Completed	
NSF	NSF	HABs	Division of Biological Infrastructure, National Ecological Observatory Network (NEON)	Observational capabilities for ecological research.	Ongoing	
NSF	NSF	HABs	Division of Ocean Sciences	Research Support, unsolicited proposal in marine ecology.	Ongoing	
NSF	NSF	HABs and hypoxia	Divisions of Mathematical Sciences (DMS) and Chemical, Bioengineering, Environmental & Transport Systems (CBET)	Modeling to predict and understand HABs/Hypoxia dynamics	Ongoing	
NSF	NSF	HABs and hypoxia	Collaboration between NSF GEO, SBE, and ENG directorates, as well as USDA NIFA.	Program supporting interdisciplinary research to understand and predict the interactions between the water system and extreme weather events, land use, the built environment, and ecosystem function and services through research and models. Several research projects are focused on nutrient movement and hypoxia mitigation strategies.	Completed	
NSF	NSF	HABs and hypoxia	Division of Chemical, Bioengineering,	Research grants in Environmental Engineering & Sustainability cluster on	Ongoing	

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
			Environmental, and Transport Systems	HABs/hypoxia – prediction, detection, mitigation, and environmental impacts.		
USDA	USDA/Multiple agencies, led by USDA NRCS, Partner with ARS, FSA, and NASS.	HABs and hypoxia	Conservation Effects Assessment Project (CEAP) - Cropland National Assessment	The CEAP is a collaborative, multi-agency effort to quantify the environmental effects of conservation practices and programs and develop the science base for managing the agricultural landscape for environmental quality. Project findings are used to guide USDA conservation policy and program development, and help conservationists, farmers, and ranchers make more informed conservation decisions. The CEAP National Cropland Assessment combines information from NASS producer surveys, land use, soils and conservation practice data as inputs into two models [Agricultural Policy EXtender field-scale model and Soil and Water Assessment Tool (SWAT/SWAT+) watershed model] to estimate the environmental benefits of conservation practices and conservation treatment needs within major cropland production regions of America, including the Great Lakes region.	CEAP 2 Completed; analysis ongoing	USDA update: The CEAP Cropland 2.0 producer survey, administered by the USDA National Agricultural Statistics Service (NASS), was completed and data analysis was recently completed. A full national scale technical report of the APEX modeling results and a summary report were released by NRCS in 2022 and are available for download on the NRCS CEAP webpage. Watershed modeling by USDA ARS, NRCS and partners is ongoing. The SWAT model enhancement to SWAT+ was completed and is available online. SWAT is one of the most widely used watershed models to evaluate conservation, nutrients and sediment in watersheds.
USDA	Multiple agencies, led by USDA NRCS. Partner with ARS, NASS and FSA	HABs and hypoxia	CEAP Cropland Western Lake Erie Basin Special Study	In 2012, NASS worked with NRCS to administer a "Special Study" CEAP Cropland-survey focused on the Western Lake Erie Basin. Data from 2003-06 and 2012 cropland surveys and other sources was used to assess conservation effects in the Western Lake Erie Basin and compare trends and progress in conservation as well as evaluate additional treatment	Completed	Edge-of-Field APEX model report released in 2016. Watershed SWAT model report released in October 2017.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				needs in that region. The edge-of-field assessment report was released March 2016; the SWAT modeled delivery estimations will be released later this year.		
USDA	USDA NRCS, ARS, universities, private landowners, NIFA, and FSA., Also includes USGS, NOAA, EPA.	HABs and Hypoxia	CEAP – Watershed Assessment Studies	The Watershed Assessment Studies Component of CEAP conducts small watershed scale assessments across the United States to quantify water and soil resource outcomes of conservation practices and systems and enhance understanding of processes. Interactions among practices are investigated as well as modeling enhancements, watershed targeting approaches, and socioeconomic factors. Practice standards are developed or updated to improve effectiveness and address gaps.	Ongoing	A new CEAP Watersheds video on the Western Lake Erie Basin was released in April 2022. This USDA video provides a closer look at the collaborative partnerships driving innovative water quality assessment and conservation in the Western Lake Erie Basin. This film shows how USDA's CEAP watershed studies in the Western Lake Erie Basin bring researchers, farmers, government agencies and nonprofit organizations together to develop science-based solutions and strategically place them where they can deliver the greatest conservation benefits. A new CEAP Watershed Assessment Study was established in 2018 as a paired watershed study in the Blanchard River Watershed in Ohio, which drains into the Maumee River Basin. This assessment is led by Heidelberg University and the USDA Agricultural Research Service, with USGS and other universities as partners. New assessments of legacy phosphorus sources on conservation outcomes in watersheds. Western Lake Erie Basin assessment funded in 2020 to USDA ARS and partners. New National Assessment funded in 2021 to ARS and university partners. National assessment of watershed lag time ongoing, initiated in 2018 in over 40

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						watersheds nationally with USDA NRCS and ARS and university partners. An assessment of a system of stacked conservation practices to treat and quantify reductions in-field, edge-of-field and instream is ongoing within the WLEB. Edge-of-field assessment under CEAP by ARS of existing and innovative conservation practice standards is ongoing in an extensive network in the WLEB consisting of 20 paired sites (40 fields) on farms. Watershed assessment of cumulative effects of conservation is also ongoing in St. Joseph River and Blanchard River CEAP Watersheds.
USDA	USDA	Hypoxia	Small Business Innovation Research program (SBIR)	The USDA SBIR program supports the research and development of technologies that contribute to the protection and conservation of air, water, and soils resources. This program has supported (among others) the development of technologies involved in the monitoring and measurement of nutrients such as N and P. The USDA SBIR Program provided support to the Nitrate Elimination Company, Inc., which has developed a portable nitrate biosensor system for quantitative nitrate detection.	Ongoing	Progress through 3/2019 – Feasibility of building a phosphate sensor was shown by detecting and quantifying phosphate by electrochemical analysis using Standard Phosphate of known concentration and phosphate content of a foraged sample which was equivalent to that found using NECi Phosphate Test Kit (Kopiec et al., 2018). The company designed the electrode system for the NECi Phosphate Sensor. Direct detection of phosphate by electrochemistry is not possible since it is electrochemically silent. Therefore, NECi recombinant PNP and natural nucleoside Inosine as substrate was used. PNP catalyzes reaction of Inosine with Inorganic Phosphate to yield Hypoxanthine and Ribose-1-Phosphate (R-1P), in equal amounts with the R-1-P in proportion to the phosphate in the sample.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						Objective 2 was accomplished by the design and manufacture of NECi Prototype Nitrate Meter with app running in the smart phone. Essentially, the current prototype Meter is capable of running the Phosphate Sensor once the software app is updated to include both analyte analysis. Smartphone is connected to prototype NECi Nitrate Meter wired via USB port of phone. Smartphone runs NECi Nitrate Biosensor app, which provides controlled direct current for colorimetric analysis of nitrate and collects data from the analysis. Raw data are automatically baseline corrected and area under curve is integrated to calculate charge Q. Based on Standard calibration for Nitrate content of the sample, the result of the nitrate analysis is displayed on a smartphone and stored.
USDA	NIFA	Hypoxia	Agriculture and Food Research Initiative (AFRI) Water for Agriculture Challenge Area	This program focuses on solutions for conserving higher quality water and understanding human behavior and its influence on decision making for agricultural water use. The program will focus on developing solutions for water management that link food, water, climate, energy, and environmental issues.	Terminated	The AFRI Program was restructured and the use of Challenge Areas was discontinued. Water quality and quantity was incorporated into two other AFRI Programs: Sustainable Agricultural Systems, and Foundational and Applied Science. Requests for Applications (RFA) were released and proposals were reviewed with recommendations for NIFA funding.
USDA	NIFA	Hypoxia	Agriculture and Food Research Initiative (AFRI) Foundational	Bioenergy, Natural Resources and Environment (BNRE): This program area supports research on healthy agro-ecosystems and their underlying natural resources. Program areas focuses on the physical and biogeochemical processes affecting the flow, fate and transport, transformation, movement, and storage of	Ongoing	The BNRE Program – Water for Agriculture awarded funding to 14 projects that address the program priorities for a total of $5,683,967.00

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				nitrogen (N) and phosphorus (P) and innovative agro-ecosystem management practices with the potential to enhance ecosystems services. Agricultural Economics and Rural Communities (AERC): This program supports projects related to interactions between agriculture, environment and communities in rural areas; demographic changes and impacts; consumer preferences or behavior; decision-making under uncertainty; market structure and performance; policy design and impact; or agricultures impact on the environment. Critical Agricultural Research and Extension (CARE): This program area addresses critical challenges and opportunities to improve the Nation's agricultural and food systems. It focuses on critical problems that, despite prior investments in basic and applied research, continue to impede the efficient production of agriculturally-important plants and animals, producing safe and nutritious foods, and to meet environmental challenges for agriculture. Projects are expected to produce results that lead to practices that are rapidly adopted by end-users.		
USDA	NIFA	Hypoxia	Climate and Corn-based Cropping Systems CAP (CSACP) (also known as the	This USDA-NIFA funded project gathers data from 35 field sites and thousands of farmers in 9 Midwestern states, with the goal of creating a suite of practices for corn-based systems that:	Completed	The results of this project are found at: https://sustainablecorn.org/. Some key findings include: NITROGEN – Controlled drainage can reduce offsite nitrate loss to surface water from drained cropland.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
			Sustainable Corn Project	a. retain and enhance soil organic matter and nutrient and carbon stocks b. reduce off-field nitrogen losses that contribute to greenhouse gas emissions and water pollution c. better withstand droughts and floods d. ensure productivity under different climatic conditions. This program has developed a vast number of tools and resources that can be helpful for researchers, farmers, extension agents, and policy makers. Examples include the Nitrogen Rate calculator, Decision Support Tools, and several reports, videos, a YouTube Channel, blogs and publications in all topics related to extreme weather events, nutrient management, water and soil quality, crop production, resiliency and others. It received $4 million USD per year up to 2015 (it is in a no-cost extension in 2016).		The drainage systems do not reduce the nitrate concentration in tile drains; rather a reduction in nitrate loss is a result of reduced drain flow from the land. Cover crops are effective for reducing nitrate and sediment losses from a variety of cropland landscapes. Models of extensive adoption of cover crops across the Corn Belt region confirm that wider cover crop adoption by producers in the study region would be of value. GREENHOUSE GAS – To reduce nitrous oxide (a greenhouse gas) emissions in a corn-soybean system, replacement of corn with another crop, such as soybean or wheat, can achieve a greater reduction than what can be achieved solely through improved crop management practices. The cover crop and drainage experiments showed no consistent effect on nitrous oxide emissions from the soil surface. More research is needed. CARBON – Losses and gains in soil organic carbon, soil nitrate, and soil water holding capacity are site specific. These changes reflect soil characteristics, position on the landscape, and tillage practices. For example, soil organic carbon in the root zone (0-20 cm) is eroded over time on slopes and summits, causing crop yields to go down in those locations. The results from this project have wide applicability to regions beyond the Corn Belt and can be used to inform soil and water management

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						decisions by producers in the Great Lakes Basin.
USDA	NIFA	Hypoxia	Sustainable Agriculture Research and Education (SARE)	A significant portion of the broad research and extension portfolio funded by the SARE program contributes to hypoxia solutions. Significant topic areas where SARE has provided funding include cover crops, nutrient management, and systems diversification to include use of more perennial forage crops. The SARE Professional Development Program is a trainer program that has focused on training agricultural professionals, especially in the Midwest, about using cover crops to improve soil health. The SARE program funds multiple grant types and sizes ranging from Research and Extension Grants which go primarily to academic institutions to smaller research grants that go directly to farmers. Funding for the overall SARE program is $22.667 million per year.	Ongoing	Projects addressing cover crops, nutrient use efficiency, soil health, water quality, and tillage practices (particularly no-till) were funded in FY 2019 and FY 2020.
USDA	NIFA	Hypoxia	Hatch Multi-State Projects	NIFA provides financial assistance to multistate projects addressing issues with Hypoxia. Some project examples are: ● Framework for Nutrient Reduction Strategy Collaboration: The Role for Land Grant Universities (SERA-46); ● Organization to Minimize Nutrient Loss from the Landscape (SERA-17); ● Drainage Design and Management Practices to	Ongoing	NIFA provides financial assistance to agricultural research stations at land-grant universities for the purpose of developing new knowledge and technologies in the agricultural, food, and environmental sciences. Several formally chartered multi-state committees are studying hypoxia and HAB. The most relevant are: Framework for Nutrient Reduction Strategy Collaboration: The Role for Land Grant Universities (SERA-46) NOTE: The work of this committee is applicable to both the Great Lakes Basin and the Gulf of Mexico.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				Improve Water Quality (NCERA-217); ● Enhancing Nitrogen Utilization in Corn-Based Cropping systems to Increase Yield (NC-1195); ● Southern Region Integrated Water Resources Coordinating Committee (SERA-43); and Catalysts for Water Resources Protection and Restoration: Applied Social Science Research (NC-1190).		For more information about the committee and its accomplishments, go to: www.nimss.org/projects/18666 Organization to Minimize Nutrient Loss from the Landscape (SERA-17) – SERA-17 is a resource for research and extension on issues related to agricultural management that affect nutrients, runoff, conservation, and water quality. Drainage Design and Management Practices to Improve Water Quality (NCERA-217) – Nitrogen (N) and phosphorus (P) pollution of surface water from nonpoint sources is a serious problem nationwide, particularly in the Midwest. Much of this region is characterized by land use dominated by row crop agriculture (i.e., corn, soybean, small grains), and by the extensive use of subsurface drainage systems (a.k.a., tile drainage) and maintained ditches to manage soil water conditions. Enhancing Nitrogen Utilization in Corn-Based Cropping systems to Increase Yield (NC-1195) – The dilemma facing US corn producers and policy makers today is that the steady increase in corn yield realized over the past 50 years, and needed in the future, can be partially attributed to the intensive and increasing use of N fertilizer. Unfortunately, after nearly a century of research to develop precise N fertilizer recommendations and efficient N management systems, fertilizer N use efficiency (NUE) worldwide is still less than 50%.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						<u>Committee Outcomes or Projected Impacts</u> Scientific papers and presentations from the committee will substantially improve scientific understanding related to one or more project objectives. Farmers and farm advisors will have a better understanding of nitrogen dynamics and management due to committee research and outreach. Nitrogen management practices will improve in at least some agricultural sectors due to increased understanding, or due to the development or refinement of N decision tools. Foster multi-state, multi-disciplinary collaboration to address high priority water resource; Regularly convene to communicate ideas, projects, and proposals to establish and improve collaborative relationships built to address complex transdisciplinary water issues. Also, a regional conference will be planned to share research, extension, and education resources, and to facilitate broader interaction among faculties and external partners. Update and expand a web-based portal for LGU water programs, curricula, and resources to enhance technology transfer among institutions and to external partners and clientele.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
USDA	NRCS	HABs and Hypoxia	USDA NRCS Farm Bill Programs: Regional Conservation Partnership Program and Conservation Innovation Grant Program	● This NRCS-funded program promotes coordination between NRCS and its partners to deliver conservation assistance to producers and landowners. RCPP combines the authorities of several Farm Bill programs such as the Environmental Quality Incentives Program (EQIP), the Conservation Stewardship Program (CSP), and the Agricultural Conservation Easement Program (ACEP). Half of all RCPP funding must be allocated to eight Critical Conservation Areas (CCAs) — the Great Lakes watershed is one of the CCAs. Conservation Innovation Grants (CIG): These are competitive grants that stimulate the development and adoption of innovative approaches and technologies for conservation on agricultural lands. CIG uses Environmental Quality Incentives Program (EQIP) funds to award competitive grants to non-Federal Governmental or nongovernmental organizations, American Indian Tribes, or individuals.	Ongoing	Under the 2018 Farm Bill, a total of $51 million has been allocated for Great Lakes CCA projects in the Regional Conservation Partnership Program (RCPP). For more information on RCPP, visit: www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/rcpp/ For more information including project listings on CIG, including 2 projects funded in the WLEB in 2021, visit: www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/cig/
USDA	ARS and NRCS	HABs	St. Joe Watershed CEAP Study	● Nested (edge-of-field to headwater stream-scale) research to quantify the effects of conservation practices on surface runoff and subsurface (tile) drainage nutrient transport. Develop novel conservation practices (i.e., blind inlets) to	Ongoing	Updates provided in bullets under CEAP entry above

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				minimize the water quality impacts of agricultural management.		
USDA	ARS and NRCS	HABs and Hypoxia	Western Lake Erie Basin	● CEAP and Long-Term Agro-Ecosystem Research (LTAR) edge-of-field research to quantify effects of in-field conservation practices (e.g., 4Rs) as well as novel field edge practices (e.g., drainage water management, blind inlets and steel slag filters) on nutrient transport in surface and subsurface (tile) drainage pathways	Ongoing	Updates provided in bullets under CEAP entry above
USDA	NIFA and ARS	HABs and Hypoxia		● Support of extramural and intramural research on the effects of HABs and HAB toxins on food safety, aquaculture, and livestock.	Ongoing	
USDA	ARS	HABs and hypoxia		● Research on nutrient management, nutrient contribution to hypoxia, and aquaculture. LTAR and Watershed Research Centers.	Ongoing	As part of the LTAR Common Experiment, the Eastern Corn Belt (ECB) node is leading plot and field and watershed scale assessments to quantify the water quality impacts of a suite of conservation practices aimed at reducing the extent and toxicity of HABs in Lake Erie. The field scale research is conducted on ~40 private fields within the Lake Erie Basin. The ECB node is developing and testing innovative and aspirational phosphorus removal structures to capture phosphorus at the field edge. The ECB is leading a new project aimed at understanding the relationships between

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						legacy and incidental phosphorus in the basin. This project will investigate in-field and in-stream sources as well as methodologies for quantifying sources of phosphorus.
USDA	NIFA and ARS	HABs and hypoxia		• Supports research on best management practices for nutrient management, aquaculture, and plant breeding, among others. Specific concerns addressed by this research include manure management from animal feeding operations and water use and conservation on cropland.	Ongoing	As of 2016 (most recent data available) many of the research projects have been completed. Findings document best management practices to prevent direct deposit of livestock manure into streams; feed additives to reduce N excretion; polymer coated urea and stabilized nitrogen products use in crop production to increase nitrogen use efficiency and reduce nitrate leaching; nitrogen [N] and irrigation [IRR] best management practices to meet environmental goals, as well as improve input use efficiency and producer profitability; and quantification of the effect of incorporating broiler litter with conservation tillage practices on N, P, and sediment loads in surface runoff water and ammonia volatilization compared to applications to no-tillage systems. Findings also demonstrate that at multiple locations and on multiple soil types that conservation-tillage technology can be successfully used to reduce N and P losses from manure fertilized grain production fields. Recently awarded research grants were made in 2019 by NIFA to: improve nutrient use efficiency and water quality be developing slow-release fertilizers; reclaiming water, energy and nutrients from livestock wastewater; accelerating water and nutrient recycling: evaluating risk trade-offs to develop best management practices for nontraditional agricultural waste stream use; and biological

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						nitrogen removal in sediment plumes - a critical but missing component of watershed models.
USDA	NRCS, ARS (partnership with The Nature Conservancy)	HABs and hypoxia	CEAP — Wildlife — Western Lake Erie Basin	● The ongoing Nature Conservancy-led Western Lake Erie Basin CEAP-Wildlife project is being conducted to assess and forecast benefits of NRCS conservation practices to stream fish communities, to help advance strategic conservation of riverine ecosystems. A similar project for the Saginaw Bay was already completed. In this WLEB CEAP Wildlife project, using pre-existing water quality and stream fish community data, the effort is linking SWAT modeling with fish community condition at small watershed scales (NHD+ scale) to reveal relationships between conservation practice implementation and fish community response within the streams. The effort will provide science-based estimates of the priorities, scope and costs of restoring stream fish communities throughout the Western Lake Erie Basin watershed. Coordination with other groups in evaluating connections to Lake Erie water quality.	Completed	Final report released 10/2016 CEAP Conservation Insight released 12/2017
USDA		HABs and hypoxia	Nonpoint Education for	● The National NEMO Network is a collection of outreach programs	Ongoing with other funding sources.	The National NEMO program, housed at the University of Connecticut Extension, no longer

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
			Municipal Officials (NEMO)	across the U.S. that educate local (town/city/county) land use decision-makers about protecting water quality as communities grow. There are NEMO programs in 30 states, most led by either University-based Extension (USDA.gov) and/or Sea Grant programs.		receives NIFA funding to coordinate the National NEMO Network. However, many of the programs that were a part of the Network are still operating and maintain occasional contact, sharing resources and new approaches to addressing the land use and water quality connection. Several of the tools developed through the Network, such as the National Low Impact Development (LID) Atlas and the Rain Garden smartphone app, also continue to be used.
EPA	EPA	HABs and hypoxia	Water Quality Management	● Diversified approach to better understand cyanobacterial HABs ecology and the development of watershed and source water management techniques, including the development of models for nutrient loading, the optimization of watershed placement of phosphorus and sediment BMPs, and the use of water quality trading (WQT) to cost-effectively reduce nutrient loadings. It also includes an assessment of the impact of land use and infrastructure on watershed changes, and the evaluation of ecological contributors to cyanobacterial HAB development and toxin production. This research program also includes the use of molecular methods to characterize the risk for toxin and algal blooms, and the analysis of the impact of HABs on	Ongoing	This work has produced a series of webinars, oral presentations at National meetings and conferences, and peer reviewed journal submissions. In 2021, EPA published a peer reviewed paper on the effects of HABs on regulated disinfection byproducts. The paper summarizes the findings of a study done in 2018 during the bloom season in 5 public water systems.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				creating disinfection by-products (DBPs) precursors.		
EPA	EPA	HABs	Human and Ecological Health	• Research support to address data gaps associated with health, ecosystem, and economic effects of HABs. Research activities include the characterization of cyanobacteria and their toxins and allergic components, the evaluation of the toxicity of multiple congeners of microcystins, and identification of biomarkers of exposure for human health risk assessments. EPA is also assessing occurrence and health information for the inclusion of cyanotoxins in the Contaminant Candidate List (CCL) and the Unregulated Contaminant Monitoring Rule (UCMR) program. In addition, EPA is developing Human Health Water Quality Criteria (HHWQC) for cyanotoxins in recreational waters.	Ongoing	This work has produced a series of oral presentations in national meetings and conferences and peer reviewed journal submissions. From March 2018 through November 2020, EPA collected cyanotoxin monitoring data in public water systems under EPA's Fourth Unregulated Contaminant Monitoring Rule (UCMR 4) Program. EPA coordinated with drinking water utilities on the collection and reporting of collected nationally-representative finished drinking water cyanotoxin occurrence data from approximately 6,000 public water systems. In May 2019, EPA issued final "Recommended Recreational Ambient Water Quality Criteria" or Swimming Advisories for Cyanotoxins, Microcystins and Cylindrospermopsin for the protection of human health while swimming or participating in other recreational activities in and on the water. States, territories, and authorized tribes can consider adopting these recommended criteria into their water quality standards and using them for Clean Water Act purposes, or alternatively, can use these same values as the basis of swimming advisories for public notification purposes at recreational waters. In 2021, EPA released a technical support document to assist states, tribes, and territories in implementing these recommended criteria.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						In 2021, EPA published new recommended ambient water quality criteria to address nutrient pollution in lakes and reservoirs under section 304(a) of the Clean Water Act (CWA). These criteria replace ecoregional nutrient criteria for lakes and reservoirs released in 2000-2001. The updated criteria are based on data from EPA's National Aquatic Resource Surveys and include stressor-response models linking protection of designated uses to nutrient concentrations. Lastly, in 2021 EPA's Water Infrastructure and Resiliency Finance Center (WIRFC) conducted a 2-day virtual forum titled Federal Funding for the Prevention, Monitoring, and Treatment of Harmful Algal Bloom to provide state agencies and coastal and inland communities experiencing HABs related issues with an overview of Federal funding programs available to prevent, monitor, and treat HABs and case examples of communities that have utilized those funds.
EPA	EPA	HABs	Monitoring and Analytical Methods Development	A collaborative effort of EPA, NASA, NOAA, and USGS to provide an approach for mainstreaming satellite ocean color capabilities into U.S. fresh and brackish water quality management decisions. The Cyanobacteria Assessment Network (CyAN) for freshwater systems will develop approaches to relate nutrient loads and land use to the frequency, location, and severity of cyanobacterial blooms in lakes of the United States. It will include assessing risk to human health from satellite multispectral data to assess	Ongoing	This work has produced peer reviewed journal articles, a series of webinars, a database and software, assessment models, training methodology, satellite data, and an U.S. Patent. EPA maintains a project website that summarizes progress by each fiscal year. In 2021, there was a major public release of CyAN data along with a web-based app.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				biological conditions and risk to human health in lakes and reservoirs in the United States. EPA also provides nationally consistent and scientifically defensible assessments of aquatic resources through the National Aquatic Resource Surveys (NARS), including indicators associated with cyanotoxin exposure. EPA and its regions are also working on monitoring efforts including the Great Lakes Restoration Initiative projects and Phosphorus Reduction Strategy. EPA is also working on monitoring projects to improve identification and removal of HAB toxins in drinking water, and evaluating the impact of temperature on bloom development. ● EPA is developing analytical tools, including the use of real-time sensors, quantitative polymerase chain reaction and fluorescence based technologies of micro spectrophotometer and flow cytometry to detect cyanobacteria organisms in source water.		CyAN satellite efforts were incorporated into the World Health Organization guidance in Chpt 11 and Interstate Technology Regulatory Council.
EPA	EPA	HABs	Drinking Water Treatment	EPA is working to characterize the effectiveness of drinking water treatment techniques in reducing toxin concentrations, with a focus on powdered activate carbon, investigating the recovery of toxins from water treatment plant residuals. EPA is also working to assist drinking water treatment in facilities responding to bloom events and	Ongoing	It is anticipated that this work will produce a series of webinars, oral presentations, and peer-reviewed journal submissions.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
				optimizing their existing facilities for toxin control while maintaining compliance with other SDWA finished drinking water standards.		
EPA	EPA	HABs	Outreach	EPA conducts webinars and provides online resources to promote public awareness and information sharing.	Ongoing	As part of this work, the EPA has conducted Regional HABs workshops around the EPA Regions, and developed websites (CyanoHABs in Water Bodies website, HABs Research website, Nutrients Research Website), outreach material and videos (Tracking HABs Story Map, CyAN app website with outreach material (including a CyAN app overview video and CyAN app Training video), CyAN Project, Fact Sheets), and webinars and workshops (Water Research Webinars, EPA Annual Drinking Water Workshop). More specifically, since 2021, EPA gathers information on possible HABs in both fresh and marine waters through its EPA's *Sanitary Survey App for Marine and Fresh Waters* and in the Story Map entitled *Tracking CyanoHABs*, an user-friendly online resource to compile the incidence of reported cyanobacterial HABs in freshwater across the United States, and to use maps to illustrate HABs occurrences in the United States since 2015 and major HABs events that have impacted drinking water systems and affected recreational activities. EPA also published the *Cyanotoxins Preparedness and Response Toolkit (CPRT)*, a compilation of the tools and resources, both recreational and drinking tools, needed to

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)	Updates
						prepare for and respond to potential HABs in freshwater bodies. EPA continues conducting national webinars and publishing the monthly HABs newsletters. For example, in 2021, in collaboration with NOAA and the Sitka Tribe of Alaska, EPA hosted a three-part national webinar series on the impacts of marine and freshwater HABs and their toxins. In 2022, EPA conducted a national webinar on the occurrence of HABs and their toxins in fish and shellfish and the possible adverse effects to human health and the environment. These resources could be found here: www.epa.gov/cyanohabs/epa-newsletter-and-collaboration-and-outreach-habs.
EPA	EPA	Hypoxia	Monitoring	EPA GLNPO annually monitors the DO concentration at 10 sampling stations in the central basin of Lake Erie throughout the stratified season. This program continues a time series that was initiated in 1983 to monitor and track hypoxic conditions in response to the phosphorus reduction programs implemented by the 1978 GLWQA. Oxygen and temperature profiles are collected in order to determine the annual oxygen depletion rate and duration of hypoxia/anoxia in the Central Basin of Lake Erie.	Ongoing	In 2017, a pilot study was initiated to add DO and temperature loggers to the monitoring program design. The loggers collect data from 1 m above the lake bottom every hour through the season, providing enhanced temporal measurements of oxygen conditions at two GLNPO monitoring stations in Lake Erie's central basin. EPA will release a Lake Erie Dissolved Oxygen Monitoring Program technical report in 2022 with data reported through 2021. Based upon the success of the pilot study, USGS has incorporated data logger deployments on a network of fish tracking devices throughout the central basin of Lake Erie, and these data are revealing hypoxia dynamics at the edge of thermocline and providing ground-truth information for hypoxia forecasting efforts by NOAA-GLERL.

APPENDIX B

HABHRCA Federal Agency HABs and Hypoxia Program New Activities

This appendix includes new activities and research that have been initiated since the publication of the 2020 *Harmful Algal Blooms and Hypoxia in the Great Lakes Research Plan and Action Strategy: An Interagency Report*.

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
DHHS	CDC	HABs	Building Public Health Capacity for Harmful Algal Blooms	CDC provides financial support and technical assistance to state, local, and territorial health departments annually through the Epidemiology and Laboratory Capacity (ELC) Cooperative Agreement. As part of the ELC program, CDC supports public health surveillance, response, and mitigation of HAB-associated illnesses. This funding helps recipients to improve surveillance, response, and reporting of HABs and HAB-associated human and animal illness, as well as implement public health interventions and tools to prevent HAB-associated illness. CDC also coordinates the One Health HAB Community of Practice (CoP) to increase communication and collaboration among state and Federal partners with interest in public health activities related to HABs. The One Health HAB CoP meets regularly to share knowledge and activities related to surveillance, response, and mitigation of HAB-associated illnesses. More information is available here: www.cdc.gov/habs/public-health-capacity.html	Ongoing
DOC	NOAA	HABs	National Harmful Algal Bloom Observation Network (NHABON)	As a part of the development of a NHABON GLOS has partnered with a broad group of stakeholders to develop and operationalize an early warning system for Lake Erie to support decision making to take steps for public safety when facing these blooms. Funding will support testing of integration of HAB observations from hyperspectral imagery and real-time microcystin concentration and chlorophyll data. Crewed and uncrewed airborne systems will	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
				provide sentinel observations directing the path of an Environmental Sample Processor deployed on an autonomous surface vessel. The combination of both – potentially autonomous – observational systems will help to better discern the distribution, composition, and behavior of western Lake Erie HABs. In addition, this project will enhance and expand the near real-time monitoring network in other areas of the Great Lakes, such as Green Bay, Wisconsin, to better understand the response of HABs to nutrient loads and flooding, which are two primary risks in this area. Wisconsin's Fox-Wolf basin is one of the four EPA-designated algae bloom hotspots in the Great Lakes and the Lower Green Bay is one of the International Joint Commission-designated Areas of Concern. This project will instrument the two existing buoys in the lower Green Bay, which measure real-time water quality conditions related to seasonal HABs and hypoxia, to gather near real-time measurements of nutrients as well.	
DOC	NOAA	Hypoxia	NOAA GLERL Experimental Hypoxia Lake Erie Forecast	For the past 5 years, NOAA GLERL has been providing an Experimental Lake Erie Hypoxia Forecast to warn public water systems serving more than 2 million residents of northern Ohio of low-oxygen upwelling events. NOAA GLERL's Experimental Hypoxia Forecast Model provides several days of advance notice that water quality is changing, so that drinking water plant managers can be prepared to adjust their treatment processes as needed. Since its development, this forecast model now serves additional purposes, including helping fisheries managers plan stock assessment surveys. The Experimental Lake Erie Hypoxia Forecast model was developed by the NOAA GLERL and the Cooperative Institute for Great Lakes Research (CIGLR) as a 5-year project (2017-2021) with funding from NOAA NCCOS, and is an extension of NOAA's Lake Erie	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
				Operational Forecasting System. In addition to development of the forecast model, NOAA deployed a network of sensors that gave an unprecedented view of the extent of the hypoxic zone.	
DOC	NOAA	HABs	GLOS Autonomous Holographic Imaging System (AUTOHOLO)	GLOS to execute a contract with University of WI to test a novel autonomous holographic imaging system (AUTOHOLO) and to generate observations of phytoplankton community composition needed for scientific research and environmental management of cyanobacteria harmful algal blooms (cHABs) in the Great Lakes. GLOS to execute a contract with Florida Atlantic University, to establish IoT Networking and Remote Environmental Monitoring in Green Bay's Hypoxic-Prone Waters. Expenses are for deployment of AUTOHOLO, field work and post-processing and expanding the plankton database	Ongoing
DOC	NOAA	HABs	NCCOS Expanded Climatology of Harmful Algal Blooms	Monitoring and modeling can help limit water outages associated with toxic cyanobacterial blooms, which result in detrimental economic impacts, as well as cause the public to perceive the lake to be "polluted". This GLRI-funded effort (2016-2023) is creating a climatology of these products, which will aid in neutralizing these detrimental impacts. NOAA will produce a climatology that potentially will extend from 2000 through the present and can be added to with every additional year of available data. The climatology will be useful to check climatic conditions affecting cyanobacteria blooms. The project will also help to ensure safe drinking water supplies. In the Laurentian Great Lakes, three primary catchments are particularly susceptible to cyanobacterial blooms. Green Bay (off Lake Michigan's western shore); Saginaw Bay (on Lake Huron's western shore); and the western basin of Lake Erie. All three catchments are relatively warm, shallow, and	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
				anthropocentrically affected, and are hence capable of producing significant cyanobacteria blooms. This project will examine when the blooms start, where they start and when they end. In addition, all three catchments have a river flowing into the shallowest and warmest portions. It has been shown that the Maumee River discharge and related phosphorus concentrations can be used to predict cyanobacteria blooms in western Lake Erie. This hypothesis will be tested to determine if the Saginaw River discharge can be used to predict the Saginaw Bay cyanobacteria biomass and if the Fox River can be used to predict the cyanobacteria bloom in Green Bay. The goal is to see when and where blooms begin in Saginaw Bay and Green Bay.	
DOC	NOAA	HABs	Community health dashboard	Relevance: Western Lake Erie is vulnerable to seasonal population surges of cyanobacteria species, some of which may produce toxins that affect human and animal health. These HABs can interrupt drinking water supplies, sicken pets, and harm the wellbeing of people who live or recreate in or near affected waterways. Response: Michigan Sea Grant (MISG) and partners developed an online dashboard to help scientists, policymakers, and the public understand HABs water quality and community health data. The dashboard covers census tracts in five Michigan and Ohio counties along western Lake Erie. The dashboard illuminates a tract's risk of experiencing HABs, the likelihood that residents may be vulnerable to HAB-related illnesses due to underlying health sensitivities, and residents' resource capacity to adapt if a HAB occurs. Results: Until nutrient management programs can eliminate HABs from Lake Erie, this tool will help equip communities to weather them. The	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
				results of this tool may inform existing Lake Erie community engagement efforts, such as the Great Lakes Center for Fresh Waters and Human Health. The tool can help community organizers target outreach and education campaigns, and identify locations where individuals may be in need of emergency water supplies if a HAB affects municipal water systems.	
DOC	NOAA	HABs	Stone Lab Offers Water Testing to Keep Lake Erie Island Residents' Drinking Water Safe	Relevance: Most Lake Erie shoreline communities draw at least some of their drinking water from the lake, and for the Lake Erie islands, not doing so would often mean having no easily accessible water at all. Being able to detect any contamination, such as toxins from HABs, is essential to keeping island residents safe. Ohio EPA now requires that water treatment plants that use surface water as their main source of drinking water test both raw water and treated water for microcystins, the type of toxin produced by most harmful algal blooms in Lake Erie, weekly during the summer and every other week during the winter months. Response: Because smaller water treatment plants like those on the Lake Erie islands aren't set up to run the required tests themselves, they have to find a lab to provide them with this important safety information. The Stone Lab Algal and Water Quality Lab on South Bass Island performs microcystin testing for four water treatment plants on South Bass, Middle Bass and Kelleys Islands. Results: Samples are tested at Stone Lab right on the island, instead of having to send the water to a lab on the mainland. The main toxins of concern are microcystin. This information is critical to water treatment plant operators who may need to adjust their treatment processes to maintain safe drinking water for area residents.	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
DOC	NOAA	HABs	Great Lakes Harmful Algal Bloom Observing Network Pilot Project	GLOS in collaboration with regional partners from NOAA Great Lakes Environmental Research Laboratory (GLERL), National Centers for Coastal Ocean Science (NCCOS-HML), the Cooperative Institute for Great Lakes Research (CIGLR), Monterey Bay Aquarium Research Institute (MBARI), University of Wisconsin, Florida Atlantic University, University of Minnesota and Michigan Technology Research Institute are working to support the development, testing and deployment of platforms and technologies that provide real time data and information to characterize the presence and toxicity of freshwater HABs to further develop an early warning system. The work is contributing to improve monitoring, prediction, and communication of cyanoHABs formation and toxicity by: 1) supporting the deployment of 2G ESPs in western Lake Erie; 2) supporting the development and deployment of UxS for the autonomous monitoring of HABs biomass and toxicity in Lake Erie; 3) supporting the testing of an autonomous, in-situ holographic imaging system for HAB monitoring; 4) expanding the real time collection of HAB data in the lower Green Bay; and 5) making corresponding data and data products available in the GLOS IT platform.	Ongoing
DOD	USACE	HABs	USACE-ERDC HAB R&D Program	The Water Resources Development Act of 2018 (WRDA 2018) authorized the U.S. Army Engineer Research Development Center (USACE-ERDC) to implement a 5-year technology demonstration (R&D) program to deliver scalable technologies for HAB detection, prevention and management intended to reduce HAB frequency and effects on our Nation's freshwater resources. Funding was first appropriated for the program in Fiscal Year 2019 (FY19) and executed under the USACE Aquatic Nuisance Control Research Program (ANCRP). A significant portion of funding in FY19,	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
				FY20 and FY21 for USACE's ANCRP were identified specifically for HAB research, which supported initiation of 19 new-start HAB R&D projects in FY20. HAB R&D projects led by university partners in the Great Lakes Region (GLR), or that feature USACE projects or demonstration in the GLR, are highlighted in section 5 of this report with select projects also summarized in Appendix A. All HAB R&D sponsored by the USACE ANCRP is intended to produce technology that is scalable and applicable for HAB prevention, detection and management in the GLR and in freshwater resource development projects nationwide. Examples of in-progress R&D include development of sensors and field-deployable molecular tools for HAB detection; novel biological methods for HAB prevention; and multiple chemical, biological and physical tools for HAB management. A comprehensive list of all in-progress USACE ANCRP-sponsored HAB R&D projects may be found on our website.	
DOD	USACE	HABs	HAB Technology Demonstration Program	WRDA 2020 Sec 128 authorized USACE to implement a HAB technology demonstration program intended to produce cost and performance data for HAB prevention, detection and management technologies. No funding has been appropriated, as February 2022 report preparation, to implement this program. Please see WRDA 2020 Sec 128 USACE Implementation Guidance for more information.	
DOD	USACE	HABs	Phosphorus Optimal Wetland Efficacy Demonstration Project	The U.S. Army Engineer Research and Development Center (ERDC) provides support to Great Lakes Restoration Initiative Partners, and the U.S.-Canada GLWQA Nutrients Annex by developing technical guidance for locating and implementing wetland restoration/construction projects to reduce excess nutrient inputs to surface waters. This is completed	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
				through a combination of modeling, laboratory analysis, and field data collection in conjunction with the publication of peer reviewer literature and engagement with the scientific community and the public. Construction of a pilot wetland (18 acres) was completed in June 2021 within the Maumee River Watershed of Lake Erie in the township of Defiance, Ohio. Project goals are to identify management actions and operational strategies to maximize P retention through multiple mechanisms (sediment retention, soil adsorption, plant assimilation) and investigate P reduction under a variety of scenarios (flow regimes, residence time). The project will also provide operational guidance to practitioners related to legacy P, P storage capacity thresholds, P fate within wetland systems, soil amendment effects, and associated implications for increased P removal. USACE and project partners (City of Defiance, USGS, EPA) are conducting a 5-year field research monitoring program of the wetland demonstration project.	
DOI	USGS	HABs	National Water Quality Program/Water-Quality Processes Program	The USGS is working to improve estimation and forecasting of algal blooms in rivers and streams. To support these efforts a suite of proxies for algal blooms that can be used to estimate occurrence at monitored and unmonitored locations are being developed. Proxies that function across a range of scales, from specific sites to multiple locations will be evaluated, and ultimately provide estimates of algal biomass and probabilities that thresholds of concern will be exceeded. In addition, a nationwide dataset of chlorophyll *a* is being compiled that will include discrete measurements from inland waters (i.e., rivers and lakes) collected by the USGS and other national, state, and regional monitoring	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
				organizations. These data will be harmonized and reviewed for quality.	
DOI	USGS	HABs	Remote Sensing of Water Quality; a task within the Next Generation Water Observing System's Remote Sensing R & D project	The USGS is estimating water quality using moderate resolution earth observing satellite imagery of inland, freshwater waterbodies. Water quality retrieval includes remotely sensing aquatic chlorophyll-a, a pigment typically associated with algal blooms, including HABs. Using published approaches this project is focused on: 1) retrieving chlorophyll-a estimates from historic Landsat and Sentinel-2 earth observing satellite imagery; and 2) operationally producing near-real time estimates of algal bloom extent on a pixel-by-pixel basis. Historical trends and patterns in algal bloom development and progression are extracted from satellite imagery archives to inform process-based understanding of the drivers of HABs. Near-real time estimates of bloom progression are produced from contemporary satellite imagery to inform algal toxin monitoring to protect public health. Using moderate resolution imagery (pixels less than 100 ft. by 100 ft.), this project has the potential to provide observations for approximately 75% of freshwater surface area within the United States (excluding Alaska). In addition, this project is researching and developing methods for discerning between algal types using hyperspectral remote sensing approaches including laboratory, field and spaceborne sensors. Initial results show that distinctions can be made between benign and potentially toxigenic algal genera.	Ongoing
DOI	USGS	HABs	Environmental Health/ Toxic Substance Hydrology	Toxin Exposure and Effects: The USGS's Toxins and HABs Science Team is identifying environmental drivers of	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
			and Contaminant Biology Programs	algal toxin production and release, determining the most significant exposure routes to humans and wildlife, and developing diagnostic tools to understand if there are health impacts of algal toxins on wildlife in freshwater environments, including the Great Lakes. New efforts include linking bloom and cyanotoxin variability with toxin production and resultant migratory bird exposure. Additional efforts to quantify cyanotoxin socioeconomic impacts will enhance the understanding of the impacts of these types of blooms and support direction/prioritization of research and communication of the significance of the issue.	
Multiple partners	EPA, NOAA, USGS, and academic partners	Hypoxia	Lake Erie Hypoxia Summit	In October 2021, EPA and partners organized an innovative virtual summit entitled Status and Approaches to Assess Lake Erie Central Basin Hypoxia, sponsored by the Cooperative Institute for Great Lakes Research (CIGLR). This summit convened an international group of university scientists and Federal and state agency representatives to review the state of knowledge with respect to hypoxia in Lake Erie and evaluate methods and measures to assess and quantify hypoxia on a routine basis, pursuant to the objectives of the 2012 U.S.-Canada Great Lakes Water Quality Agreement.	Complete
Multiple partners	USACE, EPA	HABs and hypoxia	Lake Erie Ecosystem Model	From 2019-2021 EPA partnered with USACE and LimnoTech to expand the Western Lake Erie Ecosystem Model to create a whole-lake ecosystem model. In 2022-23, EPA ORD is collaborating with other Federal partners to use the new model to simulate the impact of various nutrient reduction scenarios.	Ongoing
NASA	NASA	HABs	The Ocean Biology and Biogeochemistry and the Terrestrial Hydrology programs	NASA announced ten new awards in early 2022, amounting to a $6.1 million USD investment, spread over three years, with projects starting in mid-2022. These awards will work to advance the remote sensing of water quality including basic HAB research to	Ongoing

Office/ Dept.	Agency	HABs/ Hypoxia/ Both	Program Title (brief description)	Program Activities	Status (Completed, Ongoing, Postponed, Terminated)
				improve and advance remote detection and monitoring of harmful algal blooms. Four of these awards are focused on better characterizing the remote retrieval of water quality in and around the Great Lakes, specifically in the western basin of Lake Erie and the Ohio and Illinois river basins.	

THIS PAGE INTENTIONALLY LEFT BLANK