REPORT TO CONGRESS

HARMFUL ALGAL BLOOMS AND HYPOXIA IN THE GREAT LAKES: AN INTERAGENCY PROGRESS AND IMPLEMENTATION REPORT
NOVEMBER 2020

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

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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

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

Over 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. HABs and hypoxia cost the Great Lakes communities millions of dollars annually (Bingham et al., 2015; USEPA, 2015a; 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 113-124*), this 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, and the first progress report, *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation*, published on March 5, 2018. 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 manage and reduce nutrient runoff. The GLRPAS and first progress report both 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 shows 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 progress report, 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 recent advancements since then. Improvements in technology and conservation practices described throughout the progress report allow for real-time and near real-time HAB and hypoxia forecasting and monitoring, detection, and abatement. Some noted achievements include:

- In FY19, with Great Lakes Restoration Initiative (GLRI) funding as well as other non-GLRI Federal and/or state funding, Federal and state agencies and their partners supported nutrient and sediment reduction projects on over 105,000 acres in targeted watersheds in the Great Lakes Basin.
- Federal agencies project that over 1.5 million pounds of phosphorus have been prevented from leaving farms and entering the Great Lakes as a result of GLRI-funded projects

(FY15-FY19), including over 400,000 pounds of phosphorus reductions in Fiscal Year (FY) 2019 alone.

- In 2018, the National Park Service (NPS) Regional Natural Resource Chiefs identified HABs as one of seven priority issues in the 88 ocean, coastal, and Great Lakes parks. A targeted 3-year action plan was developed to address this critical issue in parks nationwide.
- The Centers for Disease Control and Prevention (CDC) funded a partnership with the Association of State and Territorial Health Officials (ASTHO) to identify gaps in HABs preparedness, develop online HABs response resources, and incorporate HABs into state public health response plans.
- In 2015, NOAA entered into an interagency agreement with the U.S. Environmental Protection Agency (USEPA) to expand the Phytoplankton Monitoring Network (PMN) into freshwater sites. Since 2019, the PMN has been active in two of the eight U.S. states bordering the Great Lakes: Michigan and Ohio.

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 (USEPA)
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)
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 Agro-Ecosystem 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 (United States)
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 endusers 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 Phosphorous 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 (USEPA)
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WLEB	Western Lake Erie Basin

About the National Oceanic and Atmospheric Administration

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 harmful algal blooms (HABs) and hypoxia, as prescribed by that Act.

The 2020 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 Great Lakes Research Plan and Action Strategy (GLRPAS). Finally, Appendix B includes new activities that were begun, expanded, or changed since the original 2017 GLRPAS was written.

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II. Introduction

A. What are HABs and Hypoxia?

HABs[1] and hypoxia[2] have continued to impact the Great Lakes for the past two decades. The periodic HABs of the past have now been replaced by annual, extensive, summer-long blooms dominated by toxic cyanobacteria, while other areas of the Great Lakes are experiencing summer hypoxic events (Steffen et al., 2014; Watson et al., 2016). 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 changes and 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). 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, 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).

Cyanobacterial HABs occur throughout the Great Lakes, including western and central Lake Erie; Saginaw Bay in Lake Huron (Fahnenstiel et al., 2008); Green Bay in Lake Michigan; and in smaller embayments, tributaries, and nearshore areas, such as Muskegon Lake, Lake St. Clair, Sandusky Bay, western Lake Superior, 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). *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).

[1] 33 U.S. Code § 4008 under HABHRCA defines a harmful algal bloom (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] In HABHRCA, hypoxia is also defined as "a condition where low dissolved oxygen in aquatic systems causes stress or death to resident organisms."

HABs that impact the Great Lakes can be 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). 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 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 (Lopez et al., 2008; Auer et al., 2010; International Joint Commission, 2014; Paerl et al., 2016). 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 (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. 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). Additionally, hypoxic water can subsequently promote HABs by increasing phosphorus release from the sediments that may combine with external loads (Matisoff et al., 2016, Watson et al., 2016). In this way, HABs and hypoxia sometimes may be self-perpetuating or synergistic.

Currently, 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).

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. Additionally, the legislation calls for Federal agencies to provide integrated assessments and progress reports every two years identifying the causes, consequences, and approaches to reduce HABs and hypoxia nationally, with particular emphasis on the Great Lakes. This 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 USEPA, and the Office of Science and Technology Policy (OSTP). Additionally, it is composed of the following member agencies and departments:

- CDC, Food and Drug Administration (FDA), and the National Institute of Environmental Health Services (NIEHS) of the Department of Health and Human Services;
- United States Army Corps of Engineers (USACE) and the Department of the Navy, of the Department of Defense;
- United States Geological Survey (USGS), National Park Service (NPS), and the Fish and Wildlife
  Service (FWS) of the Department of the Interior;
- National Aeronautics and Space Administration (NASA);
- National Institute of Food and Agriculture (NIFA), Natural Resources Conservation Service (NRCS), and the Agricultural Research Service (ARS) of the Department of Agriculture (USDA);
- State Department; and
- National Science Foundation (NSF).

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 HABs in the Great Lakes, including the state of, and gaps within, the 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. The purpose of this document is to provide updates on progress toward achieving the actions outlined in the GLRPAS. 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 (Appendix A) and new activities (Appendix B).

III. Agency Updates

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

Great Lakes Restoration Initiative (GLRI)

The multi-agency Great Lakes Restoration Initiative (GLRI) was launched in 2010 as a non-regulatory program to accelerate efforts to protect and restore the largest system of fresh surface water in the world, and to provide additional resources to make progress toward the most critical long-term goals for this important ecosystem. In October 2019, U.S. Environmental Protection Agency (EPA) Administrator Andrew Wheeler unveiled an updated an aggressive action plan under the Great Lakes Restoration Initiative (GLRI). Subject to the availability of appropriations, the GLRI Action Plan III lays out potential actions of Federal agencies and their many partners over the next 5 years to protect and restore the Great Lakes – fueling local and regional economies and community revitalization efforts across the region.

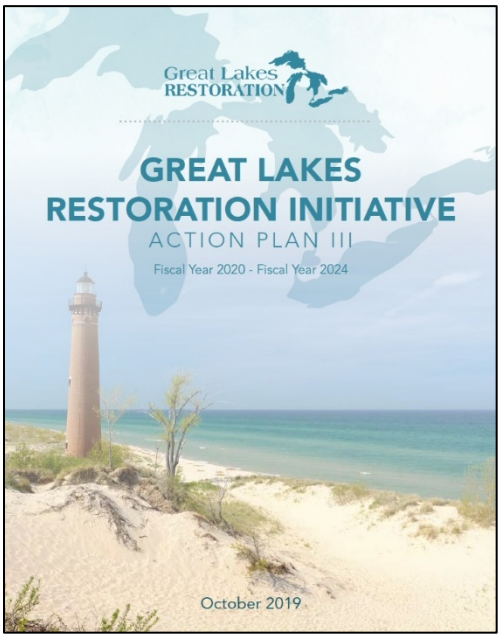


Figure 1. Cover of the Great Lakes Restoration Initiative Action Plan III for FY20-FY24 (GLRI 2019).

GLRI provides funding to: continue cleaning up and delisting Areas of Concern; reduce phosphorus contributions to HABs; prevent new invasive species, such as Asian Carp, from establishing self-sustaining populations in the Great Lakes ecosystem; remove litter, trash, and debris from beaches and waterways; and continue important water quality monitoring that will be used to inform policy decisions by environmental managers.

Through the GLRI, the Federal Government has allocated significant funds for a wide array of projects aimed at reducing nutrient and sediment loading into the Great Lakes. GLRI efforts are promoting better nutrient management and have more than doubled the number of farmland acres enrolled in agricultural conservation programs in four priority watersheds (Lower Fox River, Saginaw River, Maumee River, and Genesee River). These agriculture dominated watersheds are the watersheds most in need of phosphorus reductions to prevent excess algae growth in the Great Lakes. Federal agencies estimate that over 1.5 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 400,000 pounds of phosphorus reductions in FY19 alone. Under GLRI Action Plan III, GLRI Federal agencies and their partners (i.e., states, tribes, and other non-Federal stakeholders) will continue working on farms and in streams to reduce excess nutrient loads from agriculture watersheds, emphasizing utilization of conservation systems and work in priority watersheds.

Under GLRI Action Plan III, GLRI Federal agencies and their partners will also continue to encourage and accelerate implementation of green infrastructure projects to reduce the impacts of polluted runoff on nearshore water quality. These projects will 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. The GLRI Action Plan III also lays out watershed management projects, such as streambank improvement projects identified in watershed plans that slow and intercept runoff. In FY19, Federal agencies and their GLRI partners worked collaboratively in urban areas to prevent over 70 million gallons of polluted storm water from entering the Great Lakes. GLRI Action Plan III continues to specify objectives with related commitments and measures of progress for each Focus Area. Under Focus Area 3: Nonpoint Source Pollution Impacts on Nearshore Health, *Objective 3.1: Reduce nutrient loads from agricultural watersheds*, a new commitment was developed for the USDA Natural Resources Conservation Service (NRCS), *3.1.2: Increase adoption of enhanced nutrient management practices to reduce risk of nutrient losses from farmland*. All of these efforts continue to advance progress toward achieving long-term Great Lakes goals.

In FY20, USEPA selected 21 organizations to receive $11.5 million in GLRI funding to address nutrient runoff from agriculture and storm water nonpoint sources in the Great Lakes and included five innovative water-quality trading projects that will promote cost-effective and market-based approaches to reducing excess nutrients to surface waters. Other projects included riparian restoration to reduce runoff to the Maumee River, green infrastructure to reduce storm water runoff, manure management to reduce nutrient runoff from farms, and accelerating the adoption of nutrient management through farmer-led outreach and education.

In FY18, NOAA's Great Lakes Environmental Research Laboratory (GLERL) used GLRI funding to conduct weekly flights over Lake Erie using an airplane equipped with a hyperspectral camera to assess the presence of HABs. The resulting images are

hyperspectral, which means they contain many more bands of discrete wavelengths of light than a typical spaceborne satellite image. The hyperspectral camera has the unique capability to assess HAB conditions, while satellite-based sensors are unable to see through clouds or resolve nearshore areas. The additional coverage and enhanced spatial scale of the hyperspectral data (approximately 1 meter) compared to the satellite data (300 m to 1km, depending on the satellite used) is a key resource for drinking water managers by providing a 24- to 48-hour rapid response notice of cyanobacteria levels within their vicinity. Based on the compilation of the data from these flights, cyanobacteria level maps were assembled and shared with the Ohio Environmental Protection Agency and the City of Monroe's drinking water managers.

In FY18/19/20, the US Geological Survey (USGS) Great Lakes Science Center (GLSC) conducted basin-wide assessments of *Cladophora* throughout the Great Lakes basin to understand the environmental conditions that have led to increased *Cladophora* growth in nearshore areas of the Great Lakes. Overgrowth of *Cladophora* in nearshore environments has negatively impacted fisheries, wildlife, and coastal areas by altering food webs, harboring pathogens, and fouling shorelines. During the 2019 Cladophora growth season, USGS scientists and divers collected samples each month 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. The data will be used to populate models that can assist agencies in the development of *Cladophora* management strategies. This broad-scale, logistically-complex effort was made possible with the help of multiple GLRI partners, including USEPA, National Park Service, State agencies and universities.

Figure 2. USGS scuba divers collect *Cladophora* algae and zebra and quagga mussels at the bottom of Lake Huron. Photo credit: Meredith Nevers, USGS.

Great Lakes Water Quality Agreement (GLWQA) Nutrients Annex

The 2012 Great Lakes Water Quality Agreement (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 domestic action plans, which outline strategies for meeting the new targets. The U.S. Action Plan presents a summary of each state's efforts, coupled with Federal activities, which together comprise the overarching U.S. strategy to achieve the phosphorus reduction goals in the basin. In addition, more detailed state action plans were developed by Indiana, Michigan, Ohio, and Pennsylvania. The full suite of U.S., state and Canada-Ontario domestic action plans are available at https://www.epa.gov/glwqa/us-action-plan-lake-erie. Implementation of the domestic action plans will advance efforts toward the phosphorus load reduction targets set as a result of the 2012 GLWQA. The GLRI will continue to implement activities in the U.S. to reduce and monitor excess phosphorus in support of Nutrient Annex goals.

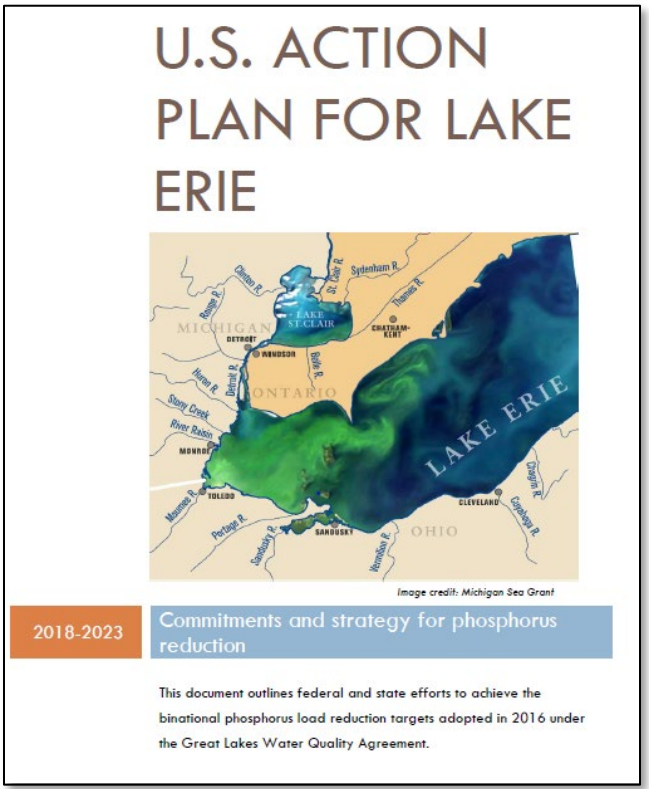


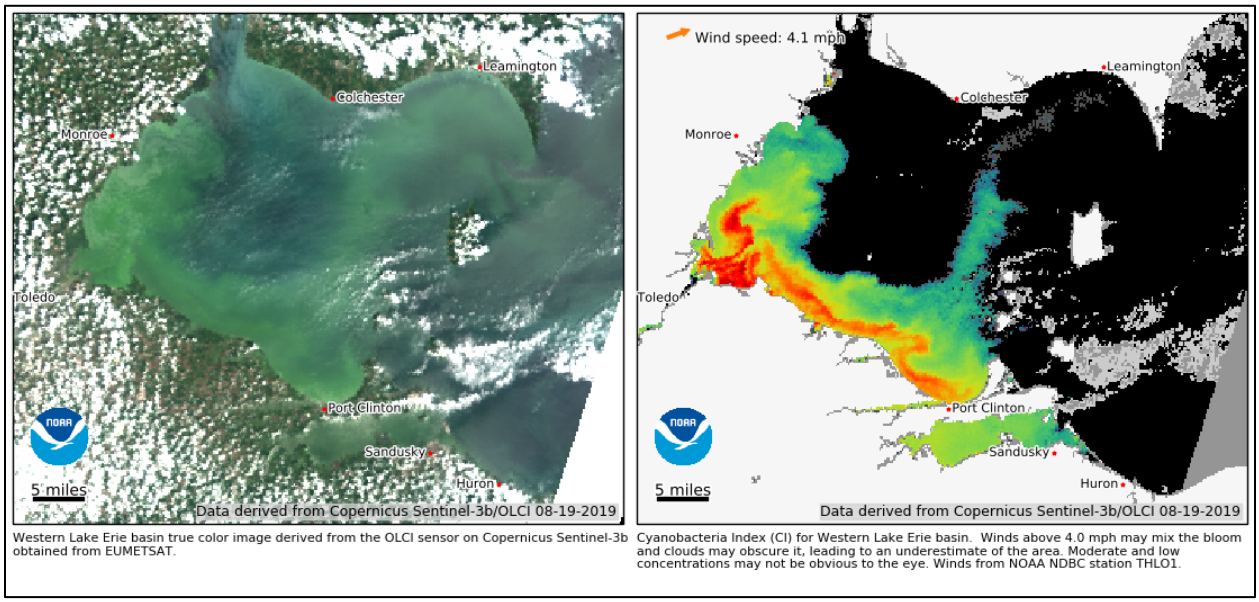
Figure 3. Cover of the 2018-2023 U.S. Action Plan for Lake Erie (USEPA 2018).

B. Department of Commerce – National Oceanic and Atmospheric Administration

Forecasting and Monitoring of Cyanobacterial Blooms in the Great Lakes

NOAA's HAB Forecast bulletin for Lake Erie transitioned to operations in 2017, and the National Centers for Coastal Ocean Science (NCCOS) will continue to improve and develop similar products for other HAB impacted regions of the Great Lakes. The Lake Erie HAB Seasonal Forecast predicts the likely conditions two months in advance, helping drinking water managers and the tourism industry plan for the season. The forecast has been accurate within about 15 percent (1.5 on the ~10 point scale) since it was issued and continues to improve. NCCOS issues an early seasonal "rolling" outlook in May, called the "NCCOS Early Season Forecast," in response to managers who

wanted more lead-time to make necessary preparations (e.g., ordering the right amount of water treatment chemicals). NCCOS also automated daily satellite imagery of cyanobacterial blooms for western Lake Erie, Saginaw Bay, and Green Bay in 2019. These images are uploaded on a daily basis to the Harmful Algal Bloom Monitoring System webpage.



Western Lake Erie basin true color image derived from the OLCI sensor on Copernicus Sentinel-3b obtained from EUMETSAT.

Cyanobacteria Index (CI) for Western Lake Erie basin. Winds above 4.0 mph may mix the bloom and clouds may obscure it, leading to an underestimate of the area. Moderate and low concentrations may not be obvious to the eye. Winds from NOAA NDBC station THLO1.

Figure 4. Daily satellite imagery of western Lake Erie basin during an August 2019 cyanobacterial bloom, including an Ocean and Land Color Instrument (OLCI)-derived true color image (left) and with concentrations depicted by the Cyanobacteria Index (CI; right).

To provide resource managers, public health officials, and bloom forecast models with accurate and robust information, routine sampling and monitoring is conducted by NOAA Great Lakes Environmental Research Laboratory (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 our remote sensing capabilities are GLERL's second generation Environmental Sample Processor (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. Pending any COVID-19 related rescheduling, the stationary ESP network, located near Toledo, Ohio, and Monroe, Michigan, is currently planned for deployment in 2020 to provide twice-daily reports of toxin concentrations in the area. 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. For example, the Lake Erie Experimental HAB Tracker is a three-dimensional model developed at GLERL, which locates the HAB within the water column, both

vertically and horizontally, and forecasts the short-term movement of blooms (Rowe et al., 2016). The location of the cyanobacterial bloom within the water column is important for different stakeholders. At the surface, for example, the bloom is more problematic for boaters, swimmers, and fishers. A bloom lower in the water column would be located close to water intakes, in which case, water treatment managers will need to take action to protect drinking water. In 2020, this capability is anticipated to be added to the Lake Erie Harmful Algal Bloom Operational Forecast System (HAB-OFS). Additional improvements to the forecast are currently ongoing, and will include biological parameters, such as cyanobacteria growth rate, to provide a better forecast of the bloom dynamics. However, current COVID-19 related shelter-in-place orders may disrupt FY20 summer field season plans, in addition to those for analytical labs and on board vessels, with lake sampling of toxins potentially reduced to the minimum required to support the western Lake Erie HAB forecast.

Similarly, real-time measurements of dissolved oxygen near the lakebed of Lake Erie give early warnings to drinking water treatment-plant managers in Cleveland, Ohio. Coupled to an existing real-time, fine-scale hydrodynamic model, the dissolved oxygen forecast model developed at GLERL will allow drinking water managers to prepare when conditions that promote hypoxic water occur in the vicinity of water intakes. These managers then know to initiate additional water-treatment procedures to remove contaminants that tend to accumulate during hypoxic events, such as manganese and iron, which can turn drinking water yellow and affect taste or corrosion.

Innovations – Model and Equipment Development

In August 2018, NOAA and its partners at the Monterey Bay Aquarium Research Institute (MBARI) initiated testing of MBARI's third generation ESP prototype, onboard a Long-Range Autonomous Underwater Vehicle (LRAUV), for measuring cyanobacterial bloom toxicity in western Lake Erie. The mobile, autonomous third-generation (3G) ESP/LRAUV uses an NCCOS-designed sensor to detect the potent liver toxin, microcystin, while underway and transmits results to operators in near-real time, as well as archiving samples for later genomic analyses. This successful initial deployment included pre-programmed sampling at GLERL's real-time observing buoys, and sampling guided by satellite and hyperspectral imagery provided by NCCOS and GLERL, respectively, enabling interrogation of high biomass and bloom boundary areas. A second deployment in August 2019 fielded two LRAUVs at the same time. One for continuous mapping of bloom biomass and distribution, providing information used to guide a second carrying the 3G ESP for monitoring microcystin concentrations on-the-fly. Sampling by the 3G ESP/LRAUV was coordinated with toxin detection by the 2G ESP positioned near the Toledo, Ohio, water intake crib in the western basin of Lake Erie, which is the city's drinking water source, and GLERL's boat-based sampling to allow comparison. Overall, the ability to detect areas of high bloom toxicity will help drinking and recreational water managers make timely decisions about water safety, and the observations collected on bloom biology and ecology will improve toxicity forecasts being developed by NOAA and its partners. Field testing will continue over the next several years, with the long-term goal of permanently integrating the ESPs into NOAA's monitoring and forecasting system for HABs in the Great Lakes.

Figure 5. Scientists from NOAA and Monterey Bay Aquarium Research Institute (MBARI) aboard a NOAA research vessel deploying a long-range autonomous underwater vehicle (LRAUV) in Lake Erie's HAB. This LRAUV's mission is to map algae concentrations throughout the bloom and tell the 3rd generation environmental sample processor (3GESP) where to measure microcystin toxin levels. Image credit: David J Ruck, Great Lakes. Outreach Media.

To provide a better understanding of HAB initiation, progression, and decline, as well as their potential to adapt to changing conditions, advanced biological tools are used to explore organisms at the molecular level. Often referred to as "'omics," these tools allow for the study of DNA, RNA, proteins, and metabolites. 'Omics technologies advance our understanding of HAB dynamics and their responses to environmental conditions. Through the use of 'omics, GLERL is exploring the relationship between genomic

information and physiological traits (i.e., growth, toxin, and metabolites production). NOAA scientists are able to improve HAB predictions and forecasts by investigating shifts in *Microcystis aeruginosa* strains during a bloom and identifying key traits that may determine bloom magnitude and toxicity. These efforts will yield insights into HAB life history strategies fundamental to our understanding of their dynamics in the Great Lakes.

Improvement of HAB forecast products is vital for protecting human health and key to advancing these forecasts is furthering our understanding of the possible connection between toxin potential, bloom toxicity, and environmental conditions. The presence of cyanobacteria is not correlated with toxin concentrations. Through 'omics techniques, NOAA is exploring the possibility of connecting the presence of the toxin gene (mcyE) with microcystin concentration and environmental conditions. Results from this unique long-term dataset collected through our monitoring efforts allow us to explore bloom conditions during distinct climate conditions, such as dry, normal, and wet years. Offering us the ability to explore the connection between the toxin potential (presence of the gene), toxin concentration, and environmental conditions to produce a comprehensive view of the development and demise of cyanobacteria blooms and toxicity within Lake Erie.

GLERL has also developed an airborne capability, through hyperspectral imaging, for detecting cyanobacteria HABs in situations where satellite observations are not effective, i.e. near shore near water intakes and under clouds. This work has resulted in the development of a weekly report of conditions in close proximity to drinking water intakes. NOAA is using this technology to create an airborne hyperspectral map that can be utilized by the Lake Erie's Experimental HAB Tracker, independent of satellite observations that can be obscured by clouds. Additionally, small Unmanned Air Systems (UAS) are also being applied to detecting HABs by using the same hyperspectral technology developed for airborne piloted applications with a potential transition to water intake managers. However, these UAS efforts will not occur during 2020 due to COVID-19 related delays.

Extension, Outreach, and Research

The eight NOAA-funded Sea Grant programs in the Great Lakes play a central role in supplying stakeholders with usable information and tools to further understand the causes of HABs and hypoxia issues facing the region. These programs continue to fund critical research, outreach, and educational programs on HABs and hypoxia awareness, understanding, and event preparedness and response. Examples of this work include 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. Additionally, Ohio Sea Grant has continued to host

NOAA's annual HABs Forecast event and the annual "Understanding Algal Blooms: State of the Science Conference."

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

Phosphorous Optimal Wetland Efficacy Demonstration Project

USACE, Great Lakes Restoration Initiative Partners, and the U.S.-Canada Great Lakes Water Quality Agreement Annex 4 (Nutrients) lean heavily on modeling tools to identify areas that have the highest potential impact on phosphorous reduction to Lake Erie and the Great Lakes in general. Based on these modeling efforts over many years, binational phosphorus reduction targets were adopted for the western and central basins of Lake Erie to address HABs and hypoxia. The Maumee River watershed is both the largest watershed in the Great Lakes and contributes the highest amounts of phosphorus to Lake Erie. For a landscape approach to be successful, documenting demonstration site selection, wetland design, and the Soil Phosphorus Sorption Capacity (SPSC) of the soils at the site will affect our understanding of how to manage legacy phosphorus in the system.

A demonstration project is planned for construction in the City of Defiance, Ohio, during the summer of 2020. This project will include at least 5 years of monitoring to include edge of agriculture field data collection and undated SPSC changes over time. Other demonstration projects in the Maumee basin (and potentially in other priority watersheds on the Great Lakes) may also be constructed and monitored as appropriate sites and land ownership agreements become viable. This project and possible additional sites will to add to our understanding of the potential for this landscape approach on managing nutrients (including legacy phosphorous) to achieve reduction targets in Lake Erie and on the Great Lakes.

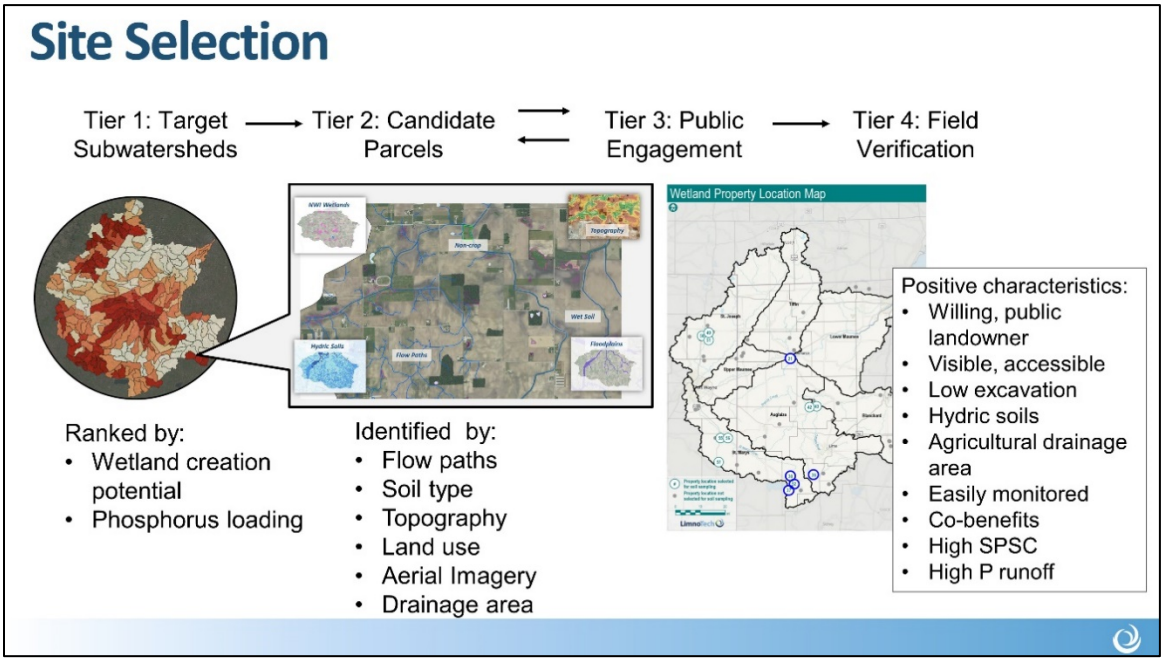


Figure 6. Considerations for site selection of demonstration projects.

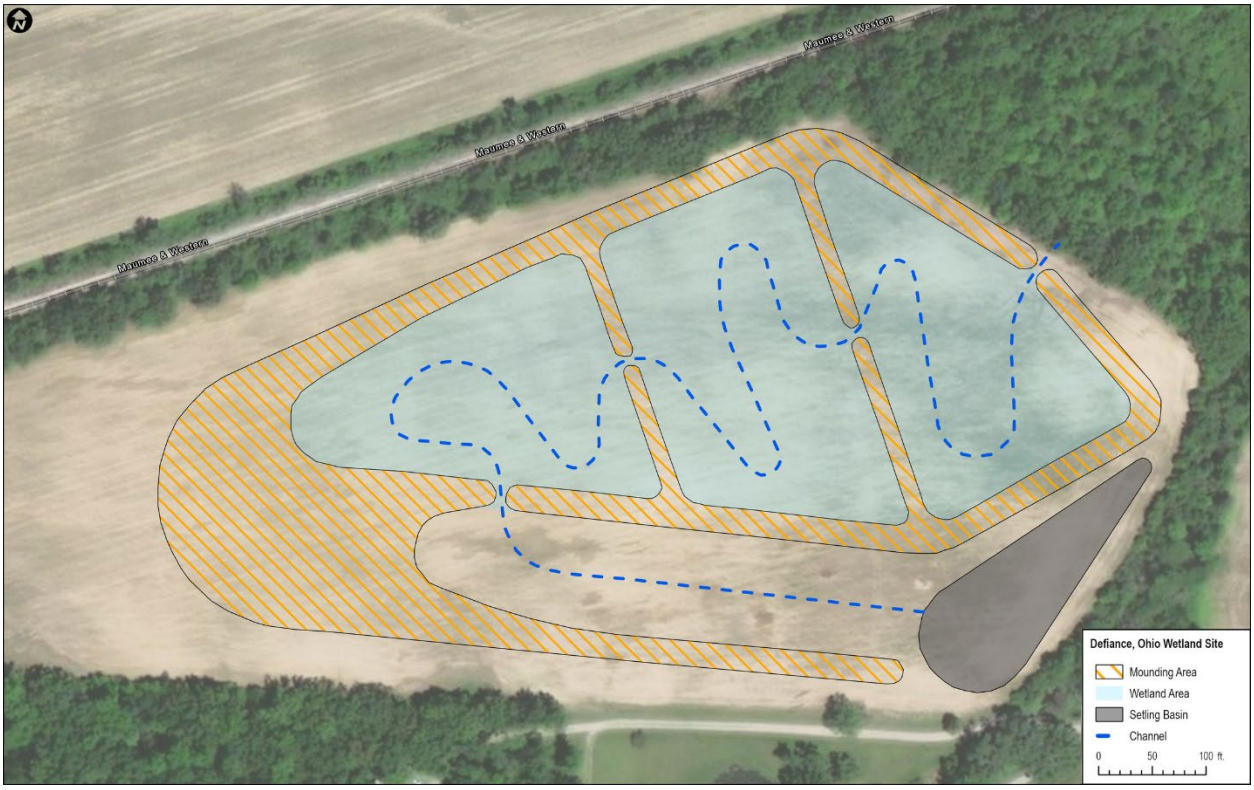


Figure 7. Conceptual plan for demonstration project in Defiance, OH (south of Maumee & Western Road).

Harmful Algae Bloom Response by USACE at USACE Managed Reservoirs

USACE water quality staff in many USACE Districts are regularly monitoring reservoir water quality at USACE managed reservoirs to document water quality is adequate to meet the many purposes for which these Civil Works Project 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 to identify driving factors of blooms, such as nutrient inputs from watershed.

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.

Operational Strategies for HAB Management in Inland Reservoirs: Energy Research and Development Center (ERDC) scientists are conducting a systematic study of the influence of USACE reservoir control options on HABs. A critical analysis of all available water quality and operations history available for inland reservoirs with records of previous HAB events is underway. The focus will be on the operational activities preceding and during the HAB event, 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.

Gene Silencing Biotechnologies for HAB Management: ERDC scientists are developing novel HAB control biotechnologies that can deliver species-specific small regulatory RNAs (srRNAs) to the cytoplasm of HAB-causing cyanobacteria to inhibit cell growth and disrupt the bloom process. The species-specific nature of this approach will minimize the ecological impacts of HAB control without adversely affecting non-target species and the environment. The srRNA gene silencing-based biotechnology can provide USACE with an environmentally benign and species-specific solution to HAB control.

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

Water quality monitoring is a fundamental component to the Civil Works mission of the USACE, and 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 data and making it difficult to characterize a whole waterbody. This in turn can diminish the ability to detect problematic water quality conditions, such as HABs. As such, remote options for routine estimation of cyanobacterial HABs are needed for effective monitoring of an ever increasing threat to water quality.

The purpose of this research is to expand the development of remote sensing software tools to estimate potential HAB indicators: 1) chlorophyll-a; 2) phycocyanin, a proxy for cyanobacterial or blue-green algal biomass; and 3) turbidity, focusing on small, inland waterbodies in support of USACE water quality monitoring needs. The work builds on foundational research conducted by the USACE Engineer Research and Development Center and partners and is supported by the USACE Great Lakes & Ohio River Division to evaluate remote sensing algorithms and imagery for the estimation of the three water quality parameters mentioned above. The primary goal is to transition remote sensing research findings to detect HAB indictors, presented in a series of peer-reviewed publications (Beck et al., 2016, 2017, and 2019), into software tools and approaches that districts can implement in their water quality monitoring operational activities.

As part of the software tool development, partners at the University of Cincinnati developed an R software package, *waterquality*, containing an evolving list of satellite-derived algorithms for the detection and quantification of the three primary water quality proxies (Johansen et al., 2020).

The tool is under on-going development and has been tested on airborne and satellite imagery to estimate potential HAB indicators, including the 2019 summer outbreak along the Mississippi Gulf Coast. In addition to its currently demonstrated utility in the northern Gulf of Mexico, this technique can be applied toward detecting HAB indicators in the Great Lakes.

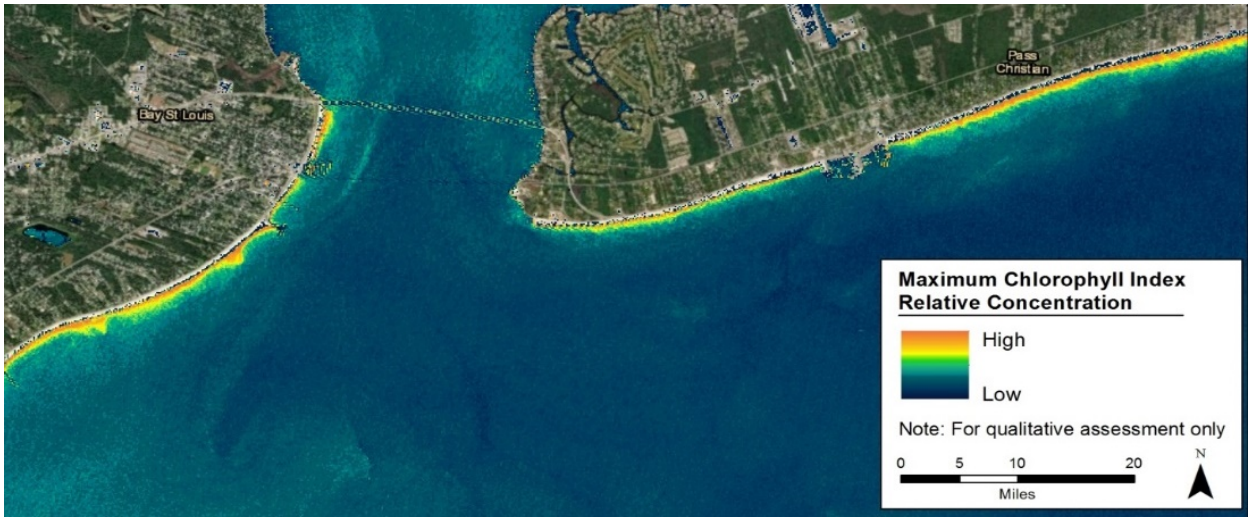


Figure 8. Zoomed in area of high-resolution imagery near Bay St. Louis, MS, July 17 2019 (post-hurricane Barry), showing elevated chlorophyll concentrations along the shoreline that can go undetected with coarse spatial resolution imagery.

D. Department of the Interior – National Park Service

In 2018, HABs were identified as a nationwide priority issue in 88 ocean, coastal, and Great Lakes parks by Regional Natural Resource Chiefs. In response, the National Park Service (NPS) developed a three-year targeted action plan to provide guidance on monitoring, testing, reporting, and managing HABs in national parks. This is an ongoing effort to improve HABs coordination among parks and develop additional education and outreach resources on HABs. In addition to this nationwide effort, there are several ongoing monitoring and research projects in Great Lakes parks aimed at helping NPS better manage HABs.

- Sleeping Bear Dunes National Lakeshore: NPS, in cooperation with UW-Milwaukee School of Freshwater Science and other partners, is conducting nuisance algal monitoring and research. This is a long-term project, and NPS is currently synthesizing multiple years of data. In addition, experimental work to

reduce invasive mussel densities and related benthic algal production is also underway.

- 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, cyanopigments, and other parameters. Concurrently, NPS worked with the State of Wisconsin to develop outreach materials, including a flyer and wallet cards, to help visitors identify HABs and protect themselves and their pets. Apostle Islands National Lakeshore has also purchased the informational HABs signage developed by the state for use during blooms. Overall, NPS participates in the Lake Superior Partnership Working Group's Algal Bloom Subgroup and works with other agencies to improve algal bloom detection and response in western Lake Superior.

E. Department of the Interior – United States Geological Survey

Phosphorus and Nitrogen Transport from the Binational Great Lakes Basin Estimated Using SPARROW Watershed Models

As part of a binational effort between the U.S. and Canada, Midcontinent SPARROW (SPAtially Referenced Regression On Watershed attributes) models were developed and used to estimate phosphorus (P) and nitrogen (N) loading throughout the entire Great Lakes Basin based on nutrient inputs similar to 2002 (Robertson et al., 2019). Previous SPARROW models only estimated U.S. nutrient loading (Robertson and Saad, 2011). The new models have a higher resolution (~2-km^2 catchments) than the earlier models (~480- km^2 catchments), enabling improved descriptions of where nutrients originate.

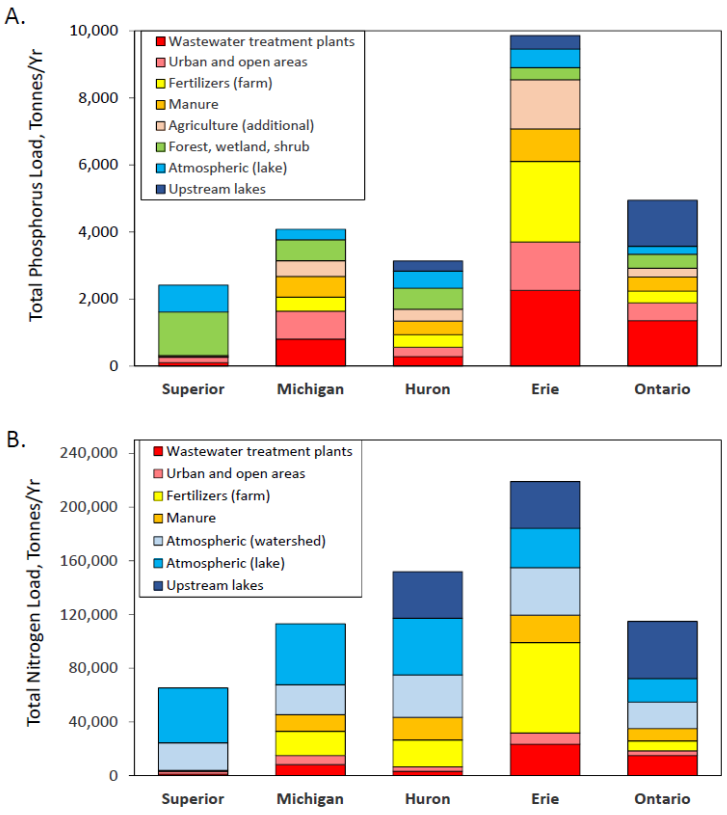


Figure 9. U.S. Geological Survey SPARROW model estimates of delivered incremental (a) total phosphorus and (b) nitrogen loads, in metric tonnes per year, to each of the Great Lakes subdivided by the source of the nutrient (includes watershed loading, atmospheric deposition, and transport from upstream adjacent lakes; after Robertson et al. 2019).

Interactive online mappers allow users to explore P and N loads and yields, and the importance of the different nutrient sources in a specific river basin.

Total P loading from the watershed ranged from 1,610 metric tonnes per year (Tonnes/yr) into Lake Superior to 8,900 Tonnes/yr into Lake Erie. Contributions of P from the United States ranged from 53-54 percent for Lakes Superior, Huron, and Ontario, to 77 percent for Lake Erie and 100 percent for Lake Michigan. The largest general watershed source of P was forest sources for Lake Superior, urban sources (wastewater treatment plants and urban runoff) for Lakes Michigan and Ontario, and agricultural sources (fertilizers, manure, and other agricultural sources) for Lakes Huron and Erie. In addition to watershed loading, sources of nutrients include atmospheric deposition and transport from upstream adjacent lakes (collectively shown in the figure). Over 30 percent of the P loading to Lake Superior was from direct atmospheric deposition, and over 27 percent of the P entering Lake Ontario was from Lake Erie.

Total N loading from the watershed ranged from 24,500 Tonnes/yr into Lake Superior to 155,000 tonnes/yr into Lake Erie. Contributions of nitrogen from the United States ranged from 37-44 percent for Lakes Superior and Huron, to 60-69 percent for Lakes Erie and Ontario, to 100 percent for Lake Michigan. Agricultural sources (fertilizers and manure) were the dominant general watershed source for nitrogen for Lakes Michigan, Huron, and Erie, atmospheric deposition on the land was the dominant source for Lake Superior, and there was no dominant general watershed source for Lake Ontario. Direct atmospheric deposition on the lake surface represented between 13-15 percent (Lakes Erie and Ontario) and 62.5 percent (Lake Superior) of total N loading. Over 35 percent of the N entering Lake Ontario was from Lake Erie.

Great Lake Restoration Initiative Edge-of-Field Monitoring

The Great Lakes Restoration Initiative Edge-of-Field Monitoring project focuses on identifying and reducing agricultural sources of excess nutrients, which can threaten the health of the Great Lakes. USGS supports these efforts by utilizing edge-of-field monitoring to assess the quantity and quality of agricultural runoff and evaluate the effectiveness of conservation practices that aim to reduce sediment and nutrient loss. The USGS approach uses a nested-basin design that includes individual

Figure 10. Edge-of-field site demonstration to educate producers, agency personnel, and policy makers about GLRI conservation efforts and monitoring to evaluate the water-quality benefits of conservation practices.

field runoff and larger sub-basin streams. By monitoring at multiple scales, the immediate effect of conservation practices at the field scale and the cumulative effect on the larger watershed can be evaluated. Projects with this multi-scale approach typically take 5-10 years to achieve quantitative results.

Agricultural conservation practices were selected and designed through the collaboration between private producers and USDA-NRCS. Selected conservation practices and locations were identified by the USDA-NRCS because of their frequency of use and information needs. Four watersheds (Lower Fox, Saginaw, Blanchard, and Genesee Rivers) were targeted because of the high density of agricultural land use and ecosystem impairments. Currently there are 6 sub-basin stream sites, 14 edge-of-field surface sites, and 10 edge-of-field subsurface tile sites located in 5 States in the Great Lakes Basin.

One of the strengths of the GLRI monitoring project is the direct interaction between producers, conservationists, and science agency personnel. The commitment to collaboration extends beyond the final assessment of conservation practice effectiveness and can provide valuable information for use in adaptive implementation and farmer-to-farmer communication. It also provides an avenue for feedback from the agriculture industry that can help with promotion and implementation of the conservation practices. Results from these studies will help inform the benefit of the targeted approach of agricultural conservation practices to improve water quality from these agricultural settings.

Real-Time Assessments of Water Quality – A Nowcast for *Escherichia coli* and Cyanotoxins

Water-borne contamination from disease-causing (pathogenic) organisms and cyanobacterial toxins (cyanotoxins) in water resources is a major water-quality concern. Tools for timely and accurate estimates of fecal-indicator bacteria (FIB: used to indicate when pathogens may be present) and cyanotoxin concentrations are needed to identify when levels pose a threat to recreational and drinking-water resources. Nowcasts are one such tool that can be used to aid in management decisions – they use mathematical models to provide estimates of FIB and cyanotoxin concentrations in near-real-time using surrogate explanatory variables.

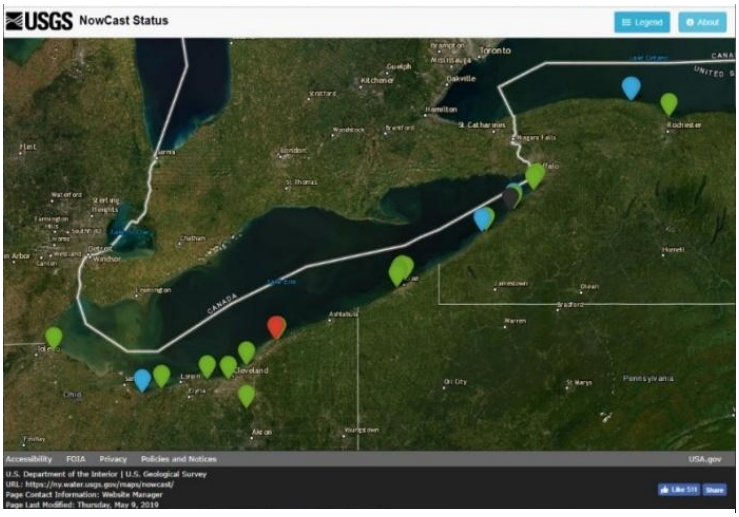


Figure 11. The Great Lakes NowCast is a public notification system and a data management system for beach managers.

The USGS is collaborating with State and local partners to develop nowcasts for *E. coli* (a FIB) and microcystin at inland and Great Lakes beaches and drinking-water intakes. During 2019, the Great Lakes NowCast provided nowcasts for 25 beaches and 1 recreational river site in Ohio, Pennsylvania, and New York. Models are currently available for *E. coli* concentration estimates, where beach advisories or closings based on model results are available to the public using signage at the site or through a public website. The USGS is continuing to work with partnering agencies to refine existing models, expand the Great Lakes NowCast, and implement the use of microcystin models. Nowcasts benefit the public by providing water-quality information in near-real-time. Nowcasts benefit water-resource managers by automating data management; standardizing methods among agencies; providing data to make well-informed, timely management decisions; and for drinking-water plant managers, providing data to help optimize treatment or intake options for current conditions.

F. National Science Foundation

The National Science Foundation (NSF) funded research projects related to HABs and hypoxia. In FY18 and FY19, NSF supported seven projects (totaling ~$4M) specifically related to HABs/hypoxia in the Great Lakes region. NSF supports projects on the fundamental biological and ecological mechanisms of toxin production and bloom formation, as well as projects leading to new technologies and approaches for bloom monitoring and mitigation. For example, Geoscience directorate (GEO), in collaboration with the National Institute of Environmental Health Sciences (NIEHS), supported the Lake Erie Center for Fresh Waters and Human Health for $5.2M ($3.6M from NSF), for a five-year period beginning in August 2018 (OCE-1840715). The National Institute of Environmental Health Sciences (NIEHS) contributes $1.6M on this collaboration effort. This multi-institutional center with its Core-based infrastructure investigates the environmental factors that determine growth and toxicity of cyanobacterial HABs in Lake Erie. Partnering institutions include 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. A Facility Core of the Lake Erie Center provides metadata for the research projects and a database available to all Great Lakes scientists. Broader impacts of the Center include providing a Community Engagement Core conducting outreach activities to inform the public on the effects of HABs. Other outreach activities include a community-engaged scholarship training for scientists, practitioners or community members associated with the Center, and an assessment for Great Lakes and environmental health literacy of stakeholders to inform general outreach efforts. Also, the Center also engages charter boat captains as community stakeholders in a citizen science program to obtain near real-time data on HAB severity in Lake Erie.

The Engineering Directorate (ENG) funded an award in the Faculty Early Development (CAREER) program called “Leveraging Hydro-climatic Processes to Advance Season-ahead Cyanobacteria Prediction and Beach Management.” The goal of this project is to develop prediction models of HABs and eutrophication conditioned on hydrodynamic

variables in order to inform lake management in the Great Lakes region (CBET – 1845783). The Mathematics & Physical Sciences (MPS) Directorate supported a project on mathematical modeling of HABS population dynamics called "Dynamics of Phytoplankton in Water Columns: Persistence, Competition, and Evolution" (DMS-1853561). In this project, researchers from Ohio State University are using modeling to help understand how mixing affects competition between toxic algae and non-toxic diatoms, to enable more effective hydrologic control strategies.

Regarding monitoring, NSF supported the National Ecological Observatory Network (NEON), which includes aquatic remote sensing and measurement infrastructure for the scientific community, geographically distributed across the United States. The ENG funds pre-competitive engineering research for novel sensors or sensor systems to detect harmful algal toxins arising from HABs. For example, in a project called "Multiplexing Detection of Extracellular and Intracellular Toxins in Water by gallium nitride (GaN) Field Effect Transistors" (ECCS-1809570), researchers from Ohio State University are developing sensor systems for on-site real-time multiplexed monitoring of the biotic and abiotic water components. GaN field-effect transistor-based immunologic biosensors will enable monitoring at higher spatial and temporal scales than is currently feasible. This sensor system will be field tested in Lake Erie. NSF also funded research instrumentation for characterizing microbial communities associated with HABs. For example, instrumentation for next generation nucleic acid sequencing was funded with a Major Research Instrumentation grant (MRI- 1828451) at Grand Valley State University's Annis Water Resources Institute (AWRI), whose mission is to integrate research, education, and outreach to enhance and preserve freshwater resources in the Great Lakes region.

As an example of NSF's support of research to help mitigate impacts of HABs in the Great Lakes region, the Geosciences Directorate funded a project from the University of Michigan called "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.

G. 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, 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 face the Nation and its citizens; *extension* to take knowledge gained through research and education and extends it to people who need it and can use it; and *education* to strengthen schools and universities in their efforts to train the next generation of scientists, educators, agricultural 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.

Additionally, 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 recently released "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.

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

Farm Bill Conservation Practice Standards Review

Section 2502 of the 2018 Farm Bill (P.L. 115-334) required expedited review of all 169 conservation practice standards (CPS) by 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. NCRS 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.

A Federal Register Notice (45 days) was published on March 11, 2019, soliciting input from state technical committees, partners, and other interested parties to review each CPS and provide comments, identify innovations, and scientific and technology advancements with respect to CPS revisions. Literature reviews for 87 CPS were commissioned through three task orders with contractors to support the review of CPS. Information from the literature reviews and Federal Register comments will be incorporated into CPS revisions.

The 2018 Farm Bill review of all 169 CPS, including a public review, was completed as of August 8, 2019.

USDA NRCS Great Lakes Restoration Initiative (GLRI)

Through the GLRI, NRCS can provide additional assistance beyond Farm Bill Programs to farmers and landowners to combat invasive species, protect watersheds and shorelines from non-point source pollution, and restore wetlands and other wildlife habitat areas. Since 2010, NRCS has funded more than 2,700 conservation contracts, with over $114.8 million in GLRI financial assistance, to help farmers implement conservation practices on over 613,000 acres within the Great Lakes Basin priority watersheds. Through implementing conservation practices in the Great Lakes Region, efforts to target phosphorus delivery have reduced over 1.1 million pounds of phosphorus in GLRI targeted areas. NRCS GLRI efforts also target wildlife habitat and invasive species control. Over 7,900 acres of wildlife habitat has been protected, restored and/or enhanced by GLRI through implementing 84 contracts totaling $284,500. Over 2,600 acres of aquatic/terrestrial invasive species were controlled by GLRI funded projects in 69 sites, totaling $539,200.

NRCS continues to work with the U.S. Geological Survey (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 NRCS, the USGS, University of Wisconsin-Green Bay, and Purdue University are assessing in-field soil health benefits of conservation practices as well as sediment and nutrient export in surface water and tile runoff from select farm fields in four Great Lakes priority watersheds. 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 over 117 projects in the Great Lakes Basin.

NRCS National Water Quality Initiative (NWQI)

In July 2018, NRCS committed to extend the National Water Quality Initiative (NWQI) through FY23. NWQI is a partnership program with USDA, USEPA, 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 $9 million to treat 30,000 acres within the Great Lakes basin to help improve water quality.

Figure 12. Example of a USDA edge-of-field water quality monitoring station in Ohio.

Conservation Effects Assessment Project (CEAP)

Conservation Effects Assessment Project (CEAP) assessments help to determine current impact, remaining conservation needs, and strategies for increasing effectiveness to achieve benefits from additional conservation. A new CEAP Watershed Assessment Study to document measurable effects of conservation practices on water quality at edge-of-field and small watershed scales was established in 2018 as a paired watershed study in the Blanchard River Watershed in Ohio, which drains into the Maumee River Basin. Findings on practice effectiveness and effective conservation strategies will be communicated via the Blanchard River Demonstration Farm Network and various science forums in the region. This information will be used to inform adaptive management strategies of agricultural

producers, USDA, GLRI, and the Annex 4 of the Great Lakes Water Quality Agreement (GLWQA).

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 on-going within the Western Lake Erie Basin (WLEB). Edge-of-field research at 46 sites by USDA and small watershed assessments of existing as well as innovative conservation practice standards are also on-going. In addition, a new assessment of legacy phosphorous was initiated in 2020 in the WLEB. Other activities include a new assessment for quantifying lag time in watersheds that was initiated by USDA in 2018 in the Maumee River Basin and in other locations around the nation. Furthermore, the CEAP Cropland 2.0 producer survey, administered by the USDA National Agricultural Statistics Service (NASS) was completed and data analysis for cultivated cropland is on-going. Results are expected to begin being released in 2021.

I. United States Environmental Protection Agency

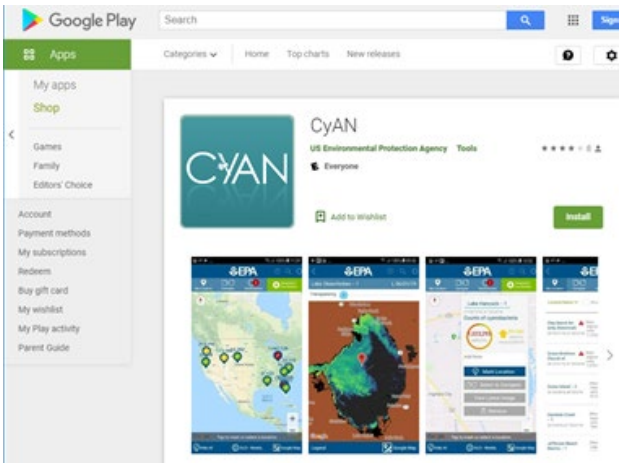


Figure 13. Screenshot of Google Play CyAN mobile application made publicly available in July 2019. The mobile application includes data for the Great Lakes.

The Cyanobacteria Assessment Network (CyAN) is a multi-agency project among USEPA, 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. This research supports Federal, state, and local partners in their monitoring efforts to assess water quality to protect aquatic and human health. CyAN provided daily, weekly, and true color satellite data using the European Commission's Copernicus Program Sentinel-3A Ocean and Land Color Instrument (OLCI) images that were made accessible to 32 state departments of health or environment with webinar trainings and technical assistance as requested in 2019. Methods for quantifying the cyanobacterial HAB annual magnitude, frequency, extent, and occurrence have been developed and published.

The CyAN Android mobile application was made publicly available July 2019 on Google Play (Figure 1). The mobile application uses the Sentinel-3A cyanoHAB data for the continental United States, including the Great Lakes. USEPA is currently developing a prototype of a device-agnostic responsive web application mimicking the Android app for access on desktop computers, iPhones and various other devices. Within 6 months Google Play reported 1,000+ downloads with 4.0 star rating. A 2-minute overview training video is available for the public and a full detailed training video is also available. There have been newspaper reports and State emails indicating the app helped with health advisories, such as "USACE uses CyAN app for health advisory in Allegheny Reservoir in the reach of the Seneca Nation of Indians territory." A

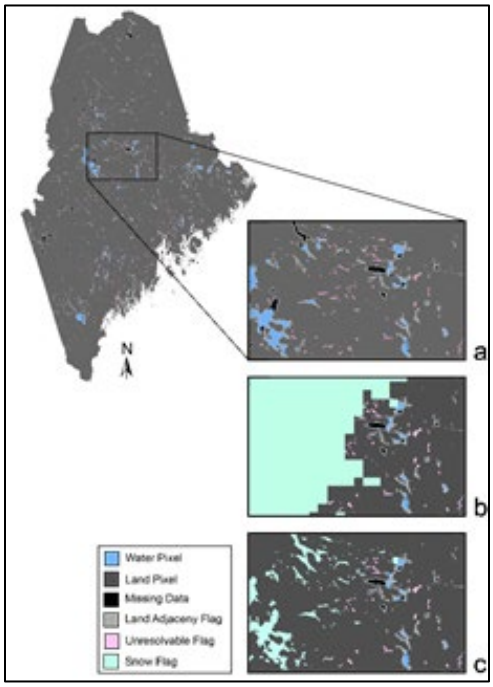


Figure 14. Example of all quality flags applied to a Sentinel-3 Ocean and Land Colour Instrument (OLCI) file. A satellite water quality data file will already have cloud and cloud shadow (a) QA flags applied in black pixels. The additional QA flags of unresolvable waterbodies (pink) and land adjacent pixels (grey) are added in (a). A snow/ice Spatial Polygon mask (green) is overlaid onto the satellite data file (b) and any remaining water pixels are flagged (c).

Lake Line article (Schaeffer et al., 2019) summarized feedback on the CyAN app, such as: Aaron Borisenko from State of Oregon Department of Environmental Quality "… using CyAN app as an early warning system" and Daniela Gurlin from Wisconsin Department of Natural Resources: "… near real-time satellite data products for detecting and quantifying algal blooms in hundreds of lakes across Wisconsin."

Satellite Lake Water Quality Flags

Monitoring the freshwater spatial extent, temporal frequency, magnitude, and occurrence of cyanobacteria in lakes and reservoirs is a challenge. Satellite remote sensing offers a technology for continuous information in data-poor regions throughout the United States. Quality assurance flags were developed to remove errors in the presence of snow and ice, land-water adjacent pixels, and small unresolvable waterbodies (Figure 10) for satellite imagery from Envisat Medium Resolution Imaging Spectrometer and Sentinel-3 OLCI across the continental United States. In addition, an updated and more accurate Shuttle Radar Topography Mission (SRTM) Waterbody Data layer, that contains valid waterbody and coastal ocean delineations, was produced through these efforts. The quality flag dataset is used to remove errors during the quantification of the spatial extent, temporal frequency, magnitude, and occurrence of cyanobacterial HABs across the US. The quality assurance flag datasets can benefit the scientific community in processing lake water quality by addressing errors from snow/ice, land adjacency, and land masking in the satellite data processing methodology. This work has been recently published by Urquhart and Schaeffer (2020) in *Data in Brief*.

Quantifying Cyanobacterial Occurrence

Researchers at USEPA conducted a study to provide a national overview on the percentage of lakes experiencing a cyanobacterial HAB on a weekly basis. A total of 2,321 lakes across the contiguous United States were included in the analysis. USEPA examined four spatial area thresholds (1 pixel, 10, 20, and 30 percent) to define when a waterbody is classified as experiencing a bloom. Across these four thresholds, USEPA explored variability in bloom percentage with changes in seasonality and lake size. As a validation of algorithm performance, USEPA analyzed the agreement between satellite observations and previously established ecological patterns, although data availability in the wintertime limited these comparisons on a year-round basis. Changes in cyanobacterial bloom percentage at the national scale followed the well-known temporal

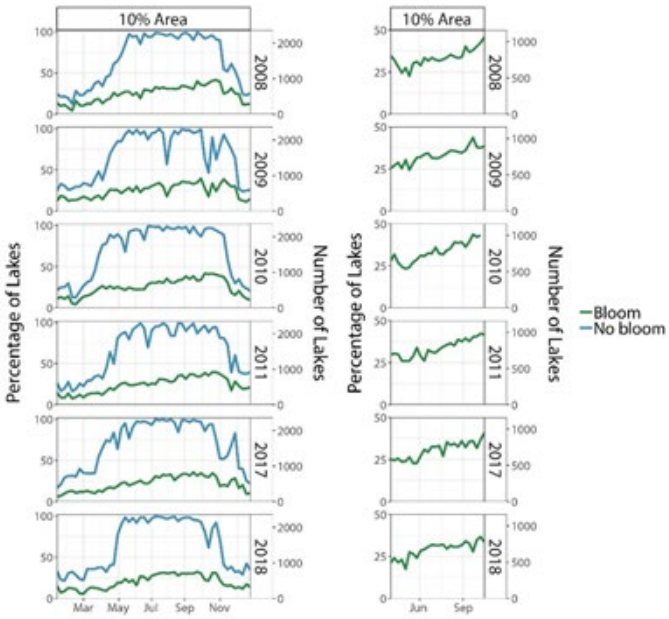


Figure 15. Time series indicating the national percentage (left axis) and number (right axis) of lakes experiencing a cyanobacterial bloom on a weekly basis for the years 2008 through 2011, 2017 and 2018 based on a spatial area threshold of 10 percent. The left hand figure shows a stacked (cumulative) time series indicating lakes experiencing a bloom (green) and not experiencing a bloom (blue). The right hand figure shows a time series of just the months of May through October, during which snow and ice extent are limited increasing spatial coverage across CONUS. In this time series, the denominator reflects the number of observable lakes each week rather than using a constant denominator that reflects all valid lakes across CONUS.

pattern of freshwater blooms. The percentage of lakes experiencing a bloom increased throughout the year, reached a maximum in fall, and decreased through the winter. Wintertime data, particularly in northern regions, was consistently limited due to snow and ice cover. With the exception of the Southeast and South, regional patterns mimicked patterns found at the national scale. The Southeast and South exhibited an unexpected pattern as cyanobacterial bloom percentage reached a maximum in the winter rather than the summer. Lake Jesup in Florida was used as a case study to validate this observed pattern against field observations of chlorophyll a. Results from this research establish a baseline of annual occurrence of cyanobacterial blooms in inland lakes across the United States (Figure 3). In addition, methods presented in this study can be tailored to fit the specific requirements of an individual system or region. This method has been recently published by Coffer et al. (2020) in *Ecological Indicators*.

In addition to these research activities, USEPA has taken several actions to protect public health from HABs, including the development of Recommended Recreational Ambient Water Quality Criteria or Swimming Advisories for two cyanotoxins, microcystins and Cylindrospermopsin, for the protection of human health while swimming or participating in other recreational activities in and on the water. For further information on these and other activities, please refer to Appendix A.

IV. Conclusion

A great deal of 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 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* as well as included new activities in Appendix B. Some important advancements include:

- HAB forecasts becoming operational.
- Advancements to better detect HABs and toxins.
- Coordination with stakeholders through citizen science efforts.
- Enhancement of models allowing drinking water managers the ability to prepare for when HABs or hypoxia are in the vicinity of water intakes.
- Numerous publications determining the fate and transport of nutrients that may support HABs or hypoxia.

The programs, policies, and other activities highlighted in this progress report 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 agencies involved have also been working since the publication of the aforementioned report 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 will 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.

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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*. The table below follows the format of Appendix 3 in the 2017 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, On-Going, 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.	On-going	CDC continues to conduct health surveillance through NORS and OHHABS. CDC provides publicly accessible NORS data through a website (https://wwwn.cdc.gov/norsdashboard/). CDC is reviewing OHHABS data in order to summarize and release the inaugural surveillance data report.
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, Ohio, and Wisconsin. The activity is supported by the Great Lakes Restoration Initiative. Fellows focus on waterborne disease detection,	On-going	CDC continues to engage with Great Lakes states on waterborne disease detection, investigation, response and reporting. In 2019, the funding support mechanism transitioned to a CDC grant. This Great Lakes activity continues to be supported by the Great Lakes Restoration Initiative. CDC also facilitates a recurring series of calls with interested State and Federal partners to discuss health surveillance for

				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.		HABs.
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, USEPA, 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).	On-going	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.
Multiple	CDC, USEPA, 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	On-going	The Certified Reference Material (CRM) workgroup was an IWG subgroup on CRMs/Analytical Methods, which was dissolved in May 2019. Here are the accomplishments. The workgroup put forward an active information and outreach campaign to achieve level understanding among the subgroup members. The workgroup held a call with an expert from NRC Canada to discuss high technical level instruction on reference materials; developed a CRM one pager designed to accurately inform potential users; and organized a special CRM session at the US National HAB Symposium to engage the HAB

				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.		community. Several products were initiated but not finalized, including: a world-wide compendium of HAB reference materials; a compendium of HAB analytical methods in use by different Federal agencies; and development of a process using established criteria, to determine priority, demand, and feasibility for interagency cooperation to develop CRMs.
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.	On-going	CDC has added microcystins to the suite of toxins the laboratory can detect in clinical specimens.
DHHS	FDA	HABs		Method development, refinement, and validation for detecting HAB toxins. Improving understanding of HAB toxin sources and vectors that impact seafood and dietary supplement safety.	On-going	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).
DOC	NOAA	HABs	National Phytoplankton Monitoring	The PMN was established to monitor phytoplankton and HABs and promote environmental stewardship through the	Ongoing	NOAAs Phytoplankton Monitoring Network (PMN) was established in 2001 to monitor potentially harmful phytoplankton and HABs. In

			Network	use of citizen volunteers. The NOAA PMN, in partnership with USEPA 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 currently 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. Currently, 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.		2015, PMN entered into an interagency agreement with USEPA Office of Water to establish a freshwater cyanobacterial monitoring program in the Great Lakes, and it rapidly expanded from there. In 2019, there were 47 total active sites in 14 states monitoring freshwater sites. Of these, there were 6 active sites in the Great Lakes in Ohio and Michigan. These 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 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	Ongoing	The Lake Erie HAB Bulletin has been transitioned to operations and NCCOS will continue to improve and develop similar products for HAB impacted regions of the Great Lakes. The HAB Severity (Seasonal forecast) is produced annually by the NCCOS HAB Forecast branch. NOAA NCCOS also began automated daily satellite imagery of cyanobacterial blooms for western Lake Erie, Saginaw Bay, and Green Bay in 2019 and estimates of bloom area in western Lake Erie as appropriate. NOAA NCCOS will

				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.		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.
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	In 2019, the Lake Erie Experimental HAB Tracker was re-coded for operations, and was run concurrently by NOAA GLERL and NOAA CO-OPs to evaluate the operational version. In 2020, CO-OPs plans to run the operational model. GLERL developed and assessed an experimental Saginaw Bay HAB Tracker, and conducted stakeholder meetings. An approach was developed to extend the Lake Erie HAB Tracker to predict probability of exceeding the microcystin public health advisor level, and a manuscript was submitted. The Lake Erie Experimental HAB Tracker will continue to be improved at GLERL with the addition of biological parameters.
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-	On-going	The eight NOAA Sea Grant programs in the Great Lakes region continue to fund critical research, outreach, and educational programs to understand the causes of HABs and hypoxia and raise associated awareness, event preparedness, and response. Examples of this work include development of publications, websites, collaborations with municipalities on outreach materials, citizen science monitoring programs with charter boat captains, and advancing HABs early warning systems. Sea Grant supported research also explores the

				makers and the public on HAB topics of relevance to their lives.		socioeconomic impacts of HABs, such as potential effects on Lake Erie's sportfishing industry and how the value of beaches for local economies is affected when water quality issues like HABs occur. More recently, Sea Grant has extended its engagement in research on HABs to areas beyond Lake Erie, such as Lake Champlain and other parts of the Great Lakes that are affected, like Green Bay in Lake Michigan and Saginaw Bay in Lake Huron. Sea Grant programs have also partnered with NOAA to develop tools that engage stakeholders in better understanding 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. 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, and are conducting community engagement trainings for HABs scientists and are trying to determine their outreach, engagement, and science communication needs, as part of the Great Lakes Center for Freshwater and Human Health.
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 US regions, including the Great Lakes.	On-going	ECOHAB continues to support ongoing research in the Great Lakes. In 2018, ECOHAB funded two projects: 1. Develop a predictive understanding of *Microcystis* blooms and toxin production ($1M total funding for 2018-2020)

						2. Link models and field experiments to forecast the potential toxicity of *Microcystis* cyanobacterial blooms in Lake Erie ($655K total funding for 2018-2020)
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.	On-going	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 ($877K total funding for 2019-2022).
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.	On-going	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.
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.	On-going	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. Although no event has been funded in the Great Lakes since the Toledo water crisis.
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,	On-going	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

				NOAA hopes to develop a hypoxia warning 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.		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 ($1.54M total funding for FY16-FY21).
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.	On-going	Sea Grant programs in the Great Lakes 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 HAB and hypoxia across the region. Examples include the Sea Grant Watershed Game and the Tipping Point Planner. Additionally, Ohio Sea Grant continues to facilitate forums for information sharing 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."
DOC	NOAA	HABs	NOAA's Great Lakes HAB monitoring and experiment	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	On-going	Research has expanded to focus on multidisciplinary research and includes both experimental and monitoring initiatives to further understand the drivers of cyanobacteria bloom growth and toxin production within the

			program	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 measure 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 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). Further, NOAA GLERL, in collaboration with NOAA NCCOS 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		Great Lakes. This includes a focus on not only physicochemical factors, such as eutrophication, but biotic factors, such as phytoplankton succession, predator interactions, role of carbon, cyanobacteria secondary metabolites, and interaction with other bacteria and viruses. 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). Weekly sampling occurs at eight established sites in the western basin of Lake Erie and biweekly sampling occurs at five sites in Saginaw Bay spanning a gradient of nutrient concentrations as well as drinking water intake locations (e.g., Toledo, OH and Monroe, MI). Sampling occurs from May through October. Real-time data is still collected at four of the sites. NOAA GLERL supplies critical data, including toxicity, 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 has developed a second generation Environmental Sample Processors (2G ESPs) network in Lake Erie. From 2017 - 2019 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. In 2020, NOAA GLERL will establish the first 2G ESP network within a freshwater ecosystem. The 2G ESP network will provide autonomous, high-frequency bloom toxicity monitoring for stakeholders. The 2G ESPs will be deployed at two locations

				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.		within the western basin of Lake Erie near the Toledo Water Intake and near Monroe, MI. Experimental work includes seston communities from both Lake Erie and Lake Huron. Experiments include measurements of cyanobacteria buoyancy to quantify the relationship between colony size and vertical velocity, data collected from these experiments has been used in the three-dimensional lagrangian particle transport model to effectively predict HAB advection (details provide under the HAB tracker project). Nutrient bioassays experiments have been conducted to quantify the effects of inorganic nutrient concentrations and light on cyanobacteria growth and cyanobacteria toxin profiles. This work is currently being prepared for publication. Additional experiments focused on the role of carbon in bloom formation, role of dressined mussels on the development of cyanobacteria blooms, and influence of secondary metabolites produced by cyanobacteria influence phytoplankton succession. 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 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	On-going	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 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

				phosphorus will contribute to the GLRI's goal of reducing algal bloom growth through reductions in phosphorus.		growth through reductions in phosphorus. Additional details are provided in NOAA's Great Lakes HAB monitoring and experiment program.
DOC	NOAA	Both	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.	On-going	Thanks to a grant through the Federal Ocean Technology Transition project, GLOS is partnering 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 aims to combine existing data streams from in-water sensors and incorporate new technology into a system that will allow water managers and the public to anticipate HABs and react effectively. See https://www.glos.us/projects/habs/ and https://www.frontiersin.org/articles/10.3389/fmars.2019.00731/full for more details. 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 currently 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 https://www.glos.us/smartgreatlakes/ 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 (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.	On-going	No updates
DOD	USACE	HABs and Hypoxia		USACE is currently involved in modeling two of the three GLRI priority watersheds (Saginaw and Maumee). The goals of the modeling and forecasting efforts include identifying the highest impact locations for wetland creation and phosphorous absorption; and facilitating interagency and stakeholder partnerships to implement phosphorous optimal wetland creation when possible.	On-going	Modeling efforts are complete for both watersheds. A Pilot wetland demonstration sight was selected in the Maumee River watershed. Currently the wetland is being designed and construction is expected to be complete in October 2020.
DOD	USACE	HABs		The USACE Energy Research and Development Center (ERDC) provides support for the Great Lakes & Ohio River Division's water quality monitoring program. Assess hyperspectral and other imagery to identify water quality indicators	On-going	The Pilot demonstration to develop image-based water quality estimation algorithms at Harsha Lake (series of publications in 2016-2019) is now complete. Current research is focused on building software tools making use of the algorithms

				of HABs.		from the Pilot demonstration project mentioned above. The software tool development is in early stages and a beta R software package is available, https://github.com/RAJohansen/waterquality
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 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 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.	On-going	In 2018, NPS Regional Natural Resource Chiefs identified HABs as one of seven priority issues in the 88 ocean, coastal, and Great Lakes parks. A targeted 3-year 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.
DOI	USGS	HABs and hypoxia	National Water Quality Program/National Water Quality Assessment 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 and estuaries are monitored at several sites and locations throughout the	On-going	Several nutrient studies that have direct relevance or transferability to the Great Lakes have been completed, including: Tracking changes in nutrient delivery to western Lake Erie (Choquette et al, 2019)

				Great Lakes watersheds. Annual updates from 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. USGS is pioneering new field sensor methods and systems for monitoring and delivering real-time nutrient data in collaboration with the Nutrient Sensor Challenge.		Recent trends in nutrient and sediment loading to coastal areas of the conterminous US (Oelsener and Stets, 2019) Variable impacts of contemporary versus legacy agricultural phosphorus on US river water quality (Stackpoole et al., 2019) Catchment-level estimates of nitrogen and phosphorus agricultural use from commercial fertilizer sales (Stewart et al, 2018) Annual updates on streamflow, nutrient and sediment concentrations and loads, and pesticide concentrations from river and stream sites are made available to the public. Data collected prior to 2018 are available through an online web tool that visualizes changes over time and allows for downloading data. Data through 2018 are available through ScienceBase.
DOI	USGS	HABs and hypoxia	National Water Quality Program/National Water Quality Assessment	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.	On-going	The first large-scale studies demonstrating the occurrence of cyanotoxins in wadeable streams and large rivers were completed. These studies have transferability to the Great Lakes and included: Spatial and temporal variation in microcystin occurrence in wadeable streams in the southeastern United States (Loftin et al, 2016a) Cyanotoxin occurrence in large rivers of the United States (Graham et al., 2020)
DOI	USGS	HABs	National Water Quality	HAB research is conducted in at least 20 USGS Water Science Centers, working	On-going	The feasibility of using on-site sensors in

			Program/ Cooperative Matching Funds	closely with State, local, and Federal partners. Studies include both short- and long-term projects focused on quantifying blooms and associated toxins and taste-and-odor compounds, and understanding causal factors. Many studies employ new and developing sensor technology to detect algal pigments. For example, in a study in Ohio, scientists are developing real-time and comprehensive models to estimate microcystin concentrations at 7 drinking-water intakes and 4 recreational sites.		nowcast and forecast models to estimate microcystin levels was demonstrated for recreational sites in western Lake Erie and Ohio (Francy et al, 2016). A follow-up study identifying factors significantly related to observed microcystin concentrations was completed at 2 recreational and 5 drinking-water plant intake sites in Ohio; 18 site-specific models were developed to estimate exceedance of pertinent microcystin action levels. Hyperspectral microscopy is being used to develop a library of the optical character of cyanobacterial genera (Paine et al, 2018; Slonecker et al, 2020); potential for scaling up to remote sensing applications is being studied.
DOI	USGS	Hypoxia	National Water Quality Program/National Water Quality Assessment	The USGS SPARROW model quantifies nutrient and sediment sources and loads to the Great Lakes. USGS is modeling groundwater/surface water interactions at the hydrologic unit code (HUC) 8 scale throughout the US part of the Great Lakes Basin, which will provide key information on travel times for recharging water to flow to a receiving surface water.	On-going	The binational SPARROW model, including an online mapper, for the entire Great Lakes watershed was completed (Robertson et al, 2019). In addition to the SPARROW models for the binational Great Lakes watershed, the USGS has developed flow and suspended sediment models and updated the phosphorus and nitrogen SPARROW models of the US part of the Great Lakes basin (Robertson and Saad, 2019). The base year for the new model predictions has been updated from 2002 to 2012. The new models represent nutrient inputs and management practices similar to 2002, but used a finer resolution, improved estimates of wastewater treatment plant contributions, and more accurate loads for calibration. Interactive mappers are available for these models as well as four other regions

						covering the rest of the CONUS.
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 NRCS, monitoring at edge-of-field (22 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 allow for adaptive management processes to occur. Additional monitoring near the mouths of 24 tributaries 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. Finally, USGS works collaboratively with NOAA, USEPA, 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.	On-going	The results from the first set of edge-of-field sites are being analyzed. Reports quantifying the amount of nutrient and sediment reductions as a result of GLRI projects will be released in 2020 and 2021. In 2018, the USGS published a surrogate regression approach to estimate continuous tributary loading at these sites and provided loads from 2011-13 (Robertson et al, 2018). The USGS is now developing ways to use these techniques to estimate more real-time loads at each of these sites from 2014-present. This information will be used to better quantify nutrient load reductions to the Great Lakes. Two additional major tributary monitoring sites were added in Ohio to allow for better tracking of nutrient and sediment inputs to Lake Erie. There are now 26 monitoring locations near the mouths of major tributaries spread across all five Great Lakes.
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	On-going	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 (GeoHEALTH-USGS, December 2018). The team is advancing methods for algal toxin detection in a variety of matrices (water, sediment, tissue, and

				being pioneered including toxin-specific 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. Pioneer new field monitoring methods (sensors), assessment techniques, and laboratory methods needed to address HAB issues in freshwaters. New methods		aerosols). 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), Clark et al., 2017; Seegers et al., 2018; Mishra et al., 2019), and toxin chemistry of potentially toxic cyanobacteria cultures collected from algal blooms in waterbodies across the country (Francy et al., 2016; Loftin et al., 2016a, b; Fuller et al., 2017; Larson et al. 2017, 2018; Romanok et al., 2018; Christen et al., 2019). The team is also 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 nearing completion of a historical review of cyanotoxin and other algal toxin occurrence on Reserved Federal Lands and effects on DOI Trust species. The combination of national-scale and local studies with advanced methods development aids in understanding drivers of toxin production and movement, populations exposed to algal toxins, and supports the design of economically and scientifically sound prevention and mitigation strategies

				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.	On-going	This research has led to information products showing effects of HABs on mollusks and other herbivorous animals (Larson et al, 2018), that benthic animal distributions can be used to map hypoxic extent (Karatayev et al, 2018), and that fish behavioral response to hypoxia can make fish easier to catch (Kraus et al, 2015).
DOI	USGS	HABs and hypoxia	GLRI	Edge of field monitoring stations: 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 will gather weather data and sample runoff water during storm events. The water samples will be analyzed for their phosphorus, nitrogen, and sediment content. USDA-Natural Resources Conservation Service (NRCS) staff will assist the cooperating farmer with installing conservation practices in the field above the stations. This analysis will help quantify the value of conservation practices in reducing sediment and nutrient delivery from these fields, under these conditions, in order to improve water quality.	On-going	The results from the first set of edge-of-field sites are being analyzed. Reports quantifying the amount of nutrient and sediment reductions as a result of GLRI projects will be released in 2020 and 2021. In addition, new sites have been added to evaluate the effectiveness of bioreactors for improving water quality.
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	On-going	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 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.		reducing nutrient loads into the Great Lakes. During FY 2018, Federal agencies and their partners funded nutrient and sediment reduction projects on over 115,000 acres of targeted watershed in the Great Lakes Basin using GLRI funding which are projected to prevent over 1 million pounds of phosphorus from entering the Great Lakes annually. During FY 2018, Federal agencies and their partners also funded urban runoff projects that are anticipated to capture an average annual volume of more than 250 million gallons of untreated urban runoff per year. These efforts have also facilitated the development of a GLRI-funded, NOAA developed Nutrient Risk Runoff Decision Support Tool.
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, silage leachate containment areas, a waste storage structure, and nutrient management on conservation demonstration farms in the Fox River basin. The farms are open for annual tours 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.	On-going	USGS Update: USGS performs some monitoring on some of these Demonstration Farms, but NRCS does most of the coordination. USDA NRCS update: The addition of 4 more demo networks in Wisconsin, for a total of 25 more farms (plus NY/PA and OH) since 2017. Demo farms have led to very robust GLRI Nearshore EQIP (conservation program) sign-ups in Wisconsin and observable increases in living winter cover and crop residue, evidenced with satellite imagery. They are leading the way on conservation innovation, particularly on soil health in the heavy clay soils of this dairy-focused region of Wisconsin and sharing their knowledge and success with farms in their neighborhood and across the state and 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 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.	On-going	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 reported to water intake managers from 30 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 by 2022. 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 2017 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.
Multiple agencies	Multiple agencies and partners, including but not limited to USEPA, 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 USEPA 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.	On-going	USEPA plans to continue including cyanotoxins data as data is available. To explore the data go here: https://www.waterqualitydata.us/portal/ USACE WQ data is available through Access to Water (A2W), the public mirror to our Corps Water Management System (CWMS). USGS- In 2019, just over 25 million results were added to the Water Quality Portal.
Multiple agencies	Multiple agencies and partners , including but not limited to USDA ARS, NOAA, NPS, NSF, USEPA, USFS, USGS	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.	On-going	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 US, many in the Great Lakes Region. NADP partners have been collaborating with Utah State University to develop improved sample collection methods to capture atmospheric dry deposition of phosphorus. NADP developed total atmospheric nitrogen deposition maps for the United States. Science needs for continued development of total atmospheric nitrogen deposition budgets in the United States were identified (Walker et

						al., 2019).
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	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.
Multiple agencies	Multiple Agencies, USEPA 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 USEPA. 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 USEPA Region 8 with plans to expand to Lakes Michigan, Superior, Huron, and Grand Lake St. Mary in 2016.	On-going	NOAA's Phytoplankton Monitoring Network (PMN) was established in 2001 to monitor phytoplankton that could potentially cause HABs along America's coastlines. In 2015, NOAA entered into an interagency agreement with USEPA's Office of Water to expand the PMN into freshwater sites and employ a citizen-science public participation model for freshwater cyanobacterial monitoring in the Great Lakes. In 2019, there were 24 citizen-science groups with 47 sites in 14 states actively monitoring HABs in their communities. The PMN is active in 2 of the 8 U.S. states bordering the Great Lakes; Michigan and Ohio border 3 of the lakes (Erie, Huron and Michigan).
NASA	NASA	HABs	The Ocean Biology and Biogeochemistry Program	Basic HABs research resulting in publications and new retrieval algorithms.	On-going	
NASA	NASA	HABs	Health and Air Quality Applications	Monitoring and surveillance of cyanobacterial HABs in drinking and recreational water supplies. Satellite derived products that were developed for	On-going	Monitoring and surveillance of cyanobacterial HABs in drinking and recreational water supplies. Satellite derived products were developed for western Lake Erie, and are part

			Program	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.		of NOAA's operational Lake Erie HAB Forecast. 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.
NSF	Joint initiative between NSF and NIEHS	HABs	Ocean and Human Health Initiative, a collaboration between NSF's Division of Ocean Sciences, and the National Institute for Environmental Health Sciences	Studies of the effects of HAB toxins on human and mammalian physiology, development of biomarkers for chronic toxin exposure, and the design and testing of novel technologies for *in situ* detection of algal toxins in fresh- and salt-water environments. For example, a number of ongoing studies are supported that analyze the effects of domoic acid on neurotoxicity as well as cognitive impacts in human cohorts, non-human primates and rodent models. Also accepting unsolicited applications for support and use of time sensitive mechanism to allow research support for unanticipated bloom events.	On-going	
NSF	NSF	HABs	Division of Ocean Sciences (OCE), NSF Ocean Observatories Initiative	Observational capabilities for research in marine systems.	On-going	
NSF	NSF	HABs	Directorate for Geosciences, Prediction and Resilience Against Extreme Events (PREEVENTS)	Focused interdisciplinary research projects.	On-going	

NSF	NSF	HABs	Division of Biological Infrastructure, National Ecological Observatory Network (NEON)	Observational capabilities for ecological research.	On-going	
NSF	NSF	HABs	Division of Ocean Sciences	Research Support, unsolicited proposal in marine ecology.	On-going	
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, Environmental, and Transport Systems	Research grants in Environmental Engineering & Sustainability cluster on HABs/hypoxia - prediction, detection, mitigation, and environmental impacts.	On-going	
USDA	USDA/Multiple agencies, led by USDA NRCS, Partner with ARS, NIFA, FSA, and NASS. Also includes USGS, NOAA, FWS, USEPA, BLM, NASA, USDA Economic Research	HABs and hypoxia	CEAP-1, Analyses of Agricultural Practices in 2003-06	The Conservation Effects Assessment Project (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. USGS will	On-going	USGS update: USGS uses available conservation data in analyses to show direct effects on water quality; however, conservation data is often not available because of privacy concerns. USDA update: 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

	Service and US Forest Service			incorporate conservation data collected by CEAP into their surface water quality monitoring. The National Cropland Assessment combines information from NASS producer surveys and conservation practice data as inputs into two models [Agricultural Policy EXtender field-scale model and Hydrologic Unit Model for the United States/Soil and Water Assessment Tool (HUMUS/SWAT) watershed model] to estimate the environmental benefits of conservation practices and conservation treatment needs within major drainage basins of America. These include sub-basins of the Mississippi River Basin, Chesapeake Bay and Great Lakes. In addition, the Watershed Assessment Component of CEAP conducts small watershed scale studies 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.		Agricultural Research Service, with USGS as a partner. New national assessment of watershed lag time initiated in 2018 in over 20 watersheds 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 on-going within the WLEB. Edge-of-field assessment of existing and innovative conservation practice standards is on-going. Watershed assessment of cumulative effects of conservation is also on-going. The CEAP Cropland 2.0 producer survey, administered by the USDA National Agricultural Statistics Service (NASS), was completed and data analysis is on-going.
USDA	Multiple agencies, led by USDA NRCS. Partner with ARS, NASS and FSA	HABs and hypoxia	CEAP	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	Completed	SWAT model report released in October 2017. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/ceap/pub/?cid=nrcseprd1355818

				trends and progress in conservation as well as evaluate additional treatment 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 NIFA and NRCS	Hypoxia	CEAP	As part of the CEAP Watershed Assessment Studies, USDA's NIFA and NRCS jointly funded 13 projects to evaluate the effects of cropland and pastureland conservation practices on spatial and temporal trends in water quality at the watershed scale. In some projects, participants also investigated social and economic factors that influence implementation and maintenance of practices. The NIFA-CEAP projects were conducted from 2004 to 2011. They were mainly retrospective, in that they focused on conservation practices and water quality monitoring efforts that had been implemented before the NIFA-CEAP projects began.	Completed	
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. This will be the first portable kit to be certified by USEPA and will be used by the USGS.	On-going	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. Objective 2 was accomplished by 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 is automatically baseline corrected and area under curve is integrated to calculate charge Q. Based on Standard calibration for Nitrate content of the sample, result of the nitrate analysis is displayed on 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 the 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 nitrogen (N) and phosphorus (P) and innovative agro-ecosystem management	On-going	The BNRE Program – Water for Agriculture awarded funding to 14 projects that address the program priorities for a total of $5,683,967.00

				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, it continuous 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 Sustainable Corn Project	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: 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	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. 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.

				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).		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 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.	On-going	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 Improve Water Quality (NCERA-217); ● Enhancing Nitrogen Utilization in Corn-Based Cropping systems	On-going	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. SERA-46 has provided expertise and impacts toward 1) strengthening networks, 2) conservation systems research and outreach, and 3) monitoring, calibration, and validation. Specific SERA-46 impacts related to the priority areas,

				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).		as mentioned earlier, include the execution of a semantic and qualitative analysis of the 12 state nutrient management strategies within the context of USEPA's guidance contained in the 2009 Stoner memo. SERA-46 members conducted and published a comprehensive analysis of three complete science assessments developed by Iowa, Illinois, and Minnesota as a component of their state nutrient management strategies with the support of a grant from the Walton Family Foundation ($344,954). To help states in the development of standardized tracking of non-point source metrics, SERA-46 partnered with the HTF, pilot states, and the Walton Family Foundation ($314,308) to support the development of NPS metrics and a common measurement framework. Members of SERA-46 partnered with NCERA-217 to deliver and make available to HTF members an Extension publication called "Ten Ways to Reduce Nitrogen Loads from Drained Cropland in the Midwest (University of Illinois Extension, 2016)". SERA-46 members secured a two-year grant (totaling $151,440) from USEPA and a second award ($13,500) from the Gulf of Mexico Alliance (GOMA) to develop and implement consistent, correlatable measures to track progress in the human dimension of reducing nutrient pollution within the basin and across the northern Gulf. SERA-46 also received a grant from USEPA ($247,895) in support of a project called "Building capacity for watershed leadership," to develop needs assessment in watershed leadership and training, host a Great Lakes to Gulf Watershed Leadership Summit for farmers, farm advisors, Federal, state, and local agencies, and NGOs. It engaged two pilot watersheds – one in Ohio and one in Arkansas – to help begin building

						out the network on local watersheds. The group also received complementary funding from the Environmental Defense Fund and Walton Family Foundation ($60,000) to explore and share best practices for "getting to scale," and secured a grant from USDA-SARE ($78,268) to implement a train-the-trainer model to train county extension agents in conservation planning and delivery. In 2019, a group of SERA-46 members also secured approximately $1.1 million in funding from USEPA to expand farmer-led conservation activities and watershed leadership in the MARB. Collectively, SERA-46 members have secured approximately $2.3 million in support of the shared priorities developed in collaboration with the HTF. For more information about the committee and its accomplishments, go to: https://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. This committee, chartered for the 5-year period of 10/01/2018 to 09/30/2023, and is focused on these objectives: Develop an interdisciplinary approach to identify watersheds and source areas within watersheds contributing to P loss risks impacting P sensitive water bodies; expanding and improving upon risk and site assessment tools Develop a science-based foundation for best

						management practices (BMPs) to reduce field landscape nutrient losses to surface waters by erosion and runoff (surface and subsurface). Develop and disseminate a manure management strategy based on both P and N Provide nutrient management and loss information to agencies (USEPA, NRCS) to help them better prevent nonpoint source degradation of surface waters by nutrients, while maintaining agricultural productivity. Coordinate responses to inform ever-changing policy needs as Government, Land Grants, and NGOs develop, plan and implement strategies to bring about long-term, lasting reductions in nutrient loss potential from agricultural production activities. Develop state-of-the-science white papers on strategic or targeted topics related to the measurement, analysis, prediction, and policy of nutrient management, fate and transport of nutrients in water, water quality impairment, and remediation <u>Drainage Design and Management Practices to Improve Water Quality (NCERA-217)</u> - 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. This committee has accomplished the following: The current project has developed several new and effective drainage design and management options, all of which reduce nutrient delivery to

						the Nation's waters, while maintaining strong crop productivity. The committee studied the effectiveness of edge-of-field structures across the Midwest, NY, NC, and Canada and worked with USDA-NRCS to establish design standards for these practices (e.g., Conservation Practice Standard #554 "Drainage Water Management," CPS #604 "Saturated Buffer," and CPS #605 "Denitrifying Bioreactor"). The existence of these standards means farmers can apply for cost-sharing of these practices, dramatically increasing producer interest. In terms of work outputs, the committee, in the past four years, has generated at least: 122 peer-reviewed publications; 78 Extension and non-refereed publications; 262 presentations to farm, research, and state/Federal agency audiences; and two national ASABE extension excellence awards for regional publications. Committee members led development and planning of the 10th International Drainage Symposium with 250 attendees representing the U.S., Denmark, Canada, Ireland, Finland, Norway, Sweden, Latvia, Lithuania, and the Netherlands (134 presentations/abstracts which resulted in publication of 14 papers in special issues of the Transactions of the ASABE and Applied Engineering in Agriculture). Collaborative efforts among committee members resulted in multi-institutional and cross-disciplinary projects totaling more than $30M, including funding by the USDA-NRCS-CIG program, USDA-NIFA-AFRI, and the Foundation for Food and Agriculture Research. The committee was recently awarded the 2018 Experiment Station Section Award for Excellence in Multistate Research. <u>Enhancing Nitrogen Utilization in Corn-Based</u>

						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%. Committee Outcomes or Projected Impacts 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.
USDA	NRCS	Hypoxia	AFRI Water for Agriculture Challenge Area	● Regional Conservation Partnership Program (RCPP): This NRCS-funded program promotes coordination between NRCS and its partners to deliver conservation assistance to producers and landowners. RCPP combines the authorities of four former conservation programs – the Agricultural Water Enhancement Program, the Chesapeake Bay Watershed Program, the Cooperative Conservation Partnership Initiative and the Great Lakes Basin Program. Around $14.6 million USD has been invested in programs along the Mississippi River Basin. ● 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	On-going	

				individuals.		
USDA	ARS	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 minimize the water quality impacts of agricultural management.	On-going	Updates provided in bullets under CEAP entry above
USDA	ARS and NRCS	HABs	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	On-going	Updates provided in bullets under CEAP entry above
USDA	NIFA and ARS	HABs		Support of extramural and intramural research on the effects of HABs and HAB toxins on food safety, aquaculture, and livestock.	On-going	
USDA	ARS	HABs and hypoxia		Research on nutrient management, nutrient contribution to hypoxia, and aquaculture. Long-Term Agro-Ecosystem Research (LTAR) and Watershed Research Centers.	On-going	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

						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.	On-going	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 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 on-going 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 published in 2016.
USDA		HABs and hypoxia	Nonpoint Education for Municipal Officials (NEMO)	The National NEMO Network is a collection of outreach programs across the U.S. that educate local (town/city/county) land use decision makers about protecting water quality as communities grow. There are currently NEMO program in 30 states, most led by either University-based Extension (USDA.gov) and/or Sea Grant programs.	On-going with other funding sources.	The National NEMO program, housed at the University of Connecticut Extension, no longer 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.

USEPA	USEPA	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 creating disinfection by-products (DBPs) precursors.	On-going	This work has produced a series of webinars, oral presentations at National meetings and conferences, and peer reviewed journal submissions During the 2018 bloom season, USEPA partnered with 5 public water systems to collected samples at five drinking water utilities under different source water conditions and management scenarios for a variety of factors, including microcystins, total trihalomethanes and haloacetic acids in finished water. After evaluation of the collected data, USEPA will publish the findings.
USEPA	USEPA	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. USEPA 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, USEPA is developing Human Health Water Quality Criteria (HHWQC) for cyanotoxins in recreational waters.	On-going	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, as part of the Unregulated Contaminant Monitoring Rule 4, public water systems are monitoring ten (10) cyanotoxin-related analytes at the entry point to the distribution system of surface water systems and systems using ground water under the direct influence of surface water. All large systems are monitoring and a subset of small systems are monitoring as part of UCMR 4. Systems are monitoring twice a month for 4 consecutive months, once during the 2018-2020 monitoring period. USEPA will be releasing the data quarterly as it is reported by the public water

						systems. In May 2019, USEPA 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. Final HHWQC can be found here: https://www.epa.gov/wqc/recreational-water-quality-criteria-and-methods.
USEPA	USEPA	HABs	Monitoring and Analytical Methods Development	A collaborative effort of USEPA, 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 U.S. It will include assessing risk to human health from satellite multispectral data to assess biological conditions and risk to human health in lakes and reservoirs in the United States.	On-going	This work has produced peer reviewed journal articles, a series of webinars, a database and software, assessment models, training methodology, satellite data, and an US Patent.

				USEPA also provides nationally consistent and scientifically defensible assessments of aquatic resources through the National Aquatic Resource Surveys (NARS), including indicators associated with cyanotoxin exposure. USEPA and its regions are also working on monitoring efforts including the Great Lakes Restoration Initiative projects and Phosphorus Reduction Strategy. USEPA 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. USEPA 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.		
USEPA	USEPA	HABs	Drinking Water Treatment	USEPA is working collaboratively with regional offices to assess the presence of HABs-related organisms and toxins in drinking water treatment plant intakes 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 SDWA finished water quality standards	On-going	This work has produced a series of webinars, oral presentations and peer reviewed journal submissions.
USEPA	USEPA	HABs	Outreach	USEPA conducts webinars and provides online resources to promote public	On-going	As part of this work, the EPA has conducted

				awareness and information sharing.		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 (CyAN app website with outreach material , CyAN app overview video, CyAN app Training video, CyAN Project, Fact Sheets), and webinars and workshops (Water Research Webinars, USEPA Annual Drinking Water Workshop). More specifically, in May 2019, USEPA updated and reorganized our online information about cyanobacterial HABs in water bodies, creating a new website dedicated to scientific information, USEPA tools, and collaborative work on cyanoHABs in U.S. waters. USEPA also published new infographics that State and local governments can use to communicate basic information about HABs to the public. Downloadable and printable versions of the infographics are available at https://www.epa.gov/cyanohabs/infographics-help-educate-public-habs-basics. USEPA continues conducting national webinars and publishing the monthly HABs newsletters. For example, in 2019, USEPA conducted three national webinars to prepare States and Tribes for the HABs Season focusing on HABs in drinking water, coastal waters, and in Recreational Waters. These resources could be found here: https://www.epa.gov/cyanohabs/epa-newsletter-and-collaboration-and-outreach-habs.

USEPA	USEPA	Hypoxia	Monitoring	USEPA 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.	On-going	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. During 2020, GLNPO will continue the DO logger deployment. The USGS Great Lakes Science Center collaborates with GLNPO by conducting additional Lake Erie DO monitoring surveys.

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 2017 *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, On-Going, Postponed, Terminated)
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.	On-going
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.	On-going
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.	On-going

DOC	NOAA	HABs		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 Okeechobee's Port Mayaca Lock, Lake Newport Ohio and Constitutional Gardens in 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.	On-going
DOC	NOAA	HABs		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 blooms, to operations at NOAA CO-OPS by 2020 and incorporate it into the Lake Erie Harmful Algal Bloom bulletins as an upgrade.	On-going
DOC	NOAA	HABs	HABs	The NOAA National Centers for Coastal Ocean Science (NCCOS) will continue improving satellite products, seasonal	On-going

				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 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	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 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	On-going

				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.	
DOC	NOAA	HABs	Third generation Environmental Sample Processor (3G ESP) long-range autonomous underwater vehicle (LRAUV)	A major advance in HAB monitoring technology is currently underway 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 archived for post-deployment recovery and laboratory-based 'omics analyses.	On-going
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 Enviornmental Protection Agency, Michigan DNR, and Ohio and Michigan municipal drinking water managers.	On-going
DOC	NOAA	HABs	Upgrading and Planning for the Transition of the Lake	GLOS with partners from NOAA (GLERL), LimnoTech, The Ohio State University, Cleveland Water Alliance,	On-going

			Erie HABs Early Warning System to a sustainable Operational Form	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 currently being incorporated into the HABs portal and Early Warning System (EWS). In years 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.	
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. USEPA assists with field data collections on Lake Ontario and the NPS assists with logistical support on Lakes Michigan and Huron.	On-going
DOI	USGS	HABs and Hypoxia	GLRI	USGS is investigating the status of legacy nutrients (phosphorus and nitrogen) in the Fox River Basin (WI) and the Maumee River Basin (OH, IN, MI) to better inform the impacts of legacy nutrients in relation to agricultural Best Management Practices (BMPs) and other nutrient reduction activities. Data analyses and reporting are ongoing for the Fox River Basin and data collection is ongoing in the Maumee River Basin. Efforts in the Maumee River Basin are also being coordinated with NRCS to complement similar ongoing projects.	On-going

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, including data directly related to assessing HABs, in more affordable and rapid ways than previously possible, and in more locations (Eberts et al., 2019).	On-going
DOI	USGS	HABs	National Water Quality Program/ Directed Cooperative Matching Funds	Eleven new HAB Directed Cooperative Matching Funds Projects with direct relevance or transferability to the Great Lakes were started in 2019. These projects advance real-time monitoring, remote sensing, and use of molecular techniques to identify and predict the occurrence of HABs and the toxins they produce.	On-going
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. For example, a pilot algal assessment in the Delaware River basin will evaluate new ways to assess and model algal communities and use this information, along with models of water quality, to forecast the likelihood of HABs within four New Jersey watersheds.	On-going

DOI	USGS	HABs	Environmental Health: Toxic Substance Hydrology and Contaminant Biology Programs	Toxin Exposure and Effects: The USGS's Toxins and HABs Science Team is identifying environmental drivers of 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. The team is also continuing to provide information on algal toxins in drinking water at business and residential taps, and in fish tissue to inform human exposure. The team's approach using a combination of analyses of existing data at varying spatial scales, laboratory methods development for algal toxins, remotely sensed data and tools, field studies, and laboratory exposures supports the development of decision tools to protect health of wildlife and the public from algal toxin exposures.	On-going
NSF	NSF	Both	Divisions of Mathematical Sciences (DMS) and Chemical, Bioengineering, Environmental & Transport Systems (CBET)	Modeling to predict and understand HABs/Hypoxia dynamics	On-going