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Water Operations Technical Support Program

Cyanobacteria Harmful Algal Blooms (HABs) and US Army Engineer Research and Development Center (ERDC)

Research and Services

Kaytee L. Pokrzywinski, Christopher R. Grasso, and Taylor E. Rycroft

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Environmental Laboratory

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Final report

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Abstract

This factsheet details the research and services available from the US Army Engineer Research and Development Center–Environmental Laboratory's Harmful Algal Blooms team.

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Preface

This study was conducted for the US Army Corps of Engineers New Orleans District. Financial support for this report was provided by the Water Operations Technical Support (WOTS) Program of the US Army Engineer Research and Development Center (ERDC) under Funding Account Code U4368805; AMSCO Code 008241.

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The Commander of ERDC was COL Teresa A. Schlosser and the Director was Dr. David W. Pittman.

Cyanobacteria Harmful Algal Blooms (HABs) and US Army Engineer Research and Development Center (ERDC): Research and Services

Kaytee L. Pokrzywinski, Christopher R. Grasso and Taylor E. Rycroft*

Aerial image of cyanobacteria bloom at Port Mayaca Lock and Dam in Lake Okeechobee, July 2017 (*photograph by Kaytee Pokrzywinski, US Army Engineer Research and Development Center*).

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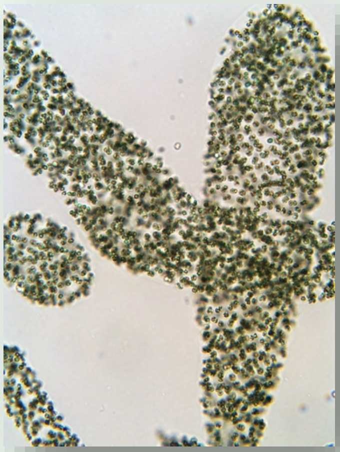
1. Harmful Algal Blooms (HABs)

Harmful algal blooms (HABs) are defined as any quantity of phytoplankton that negatively contributes to aquatic ecosystems, for example through the release of toxins or resulting hypoxia from algal cell death (Anderson et al. 2002, 705; Anderson et al. 2008, 39). Multiple lines of evidence indicate that algal blooms have increased in frequency, duration, and severity during the past several decades (Mehrubeoglu, Teng and Zimba 2014, 2), and the incidence of hypoxia has increased almost 30-fold in the United States since 1960 (National Science and Technology Council 2016, 10). In the last decade alone, major cities across the globe have suffered impaired waters because of HAB events, including cities in the United States, China, South Africa, and other parts of the world (Sitoki, Kurmayer and Rott 2012, 122; Steffen et al. 2017, 6746).

HABs affect ecosystem services in a variety of ways, through the production and release of potent neurotoxins, hepatotoxins (impacting the liver), cytotoxins, or gastrointestinal toxins (Kutser et al. 2006, 303) that negatively affect human and wildlife health. However, nontoxic HAB-forming species can also negatively affect ecosystems through shading and subsequent degradation of submerged aquatic vegetation, changes to aquatic food webs, rapid decreases in dissolved oxygen (hypoxia) that drive massive fish kills, and prolonged hypoxia, all of which are known to harm benthic macroinvertebrate communities (Paerl et al. 2001, 76; Havens 2008, 733–748).

An active cyanobacterial harmful algal bloom at Port Mayaca Lock and Dam, Lake Okeechobee, Florida, in 2018.

2. Cyanobacteria



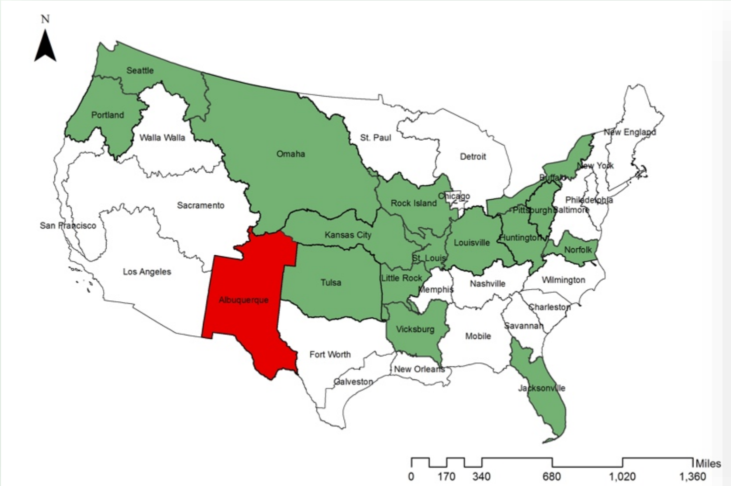
Micrograph of Microcystis wesenbergii *from Lake Okeechobee, Florida. Photo courtesy of Dail Laughinghouse, University of Florida.*

Cyanobacteria, belonging to a class of bacteria known as cyanophyceae, are the most common harmful and nuisance bloom-forming organisms in freshwater systems, often referred to as *blue-green algae* (Carmichael 2001, 1393; Ko et al. 2019, 4173). Cyanobacteria HABs (cyanoHABs) are dominated by the genera *Microcystis, Aphanizomenon, Dolichospermum,* and *Oscillatoria*, among others (Carmichael 2001, 1393; Ko et al. 2019, 4173). CyanoHABs produce potent toxins and taste or odor compounds that adversely affect aquatic ecosystems and drinking water resources (Oh et al. 2001, 1484; Suurnäkki et al. 2015, 56–7). Collectively, cyanobacteria produce more than 60 different classes of toxins, having many conformational variants within each group (Kutser et al. 2006, 303). The most widespread cyanotoxins are microcystins. Other common cyanotoxins include anatoxin-a, saxitoxins, and cylindrospermopsins (World Health Organization 2003, 1). A single species may produce multiple toxins, and multiple toxin-producing species can be present within the consortia of a single bloom event. Additionally, the toxicity of a single bloom event may vary in space and time. Furthermore, because of evolving climates and increases in human-influenced nutrient pollution, cyanoHABs in many systems are occurring more frequently, lasting longer, and expanding geographically (O'Neil et al. 2012; Huisman et al. 2018).

3. HABs and the US Army Corps of Engineers

The reauthorization of the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) in 2018 acknowledged that HABs, and the need for HAB research, are a high-priority national issue. Federal policy is that HABs are one of the "most scientifically complex and economically damaging aquatic issues" posing a "significant challenge to the ability to safeguard the health of the Nation's coastal and freshwater ecosystems" (National Science and Technology Council 2016, 1). The US Army Corps of Engineers (USACE) manages over 400 freshwater waterways to provide a variety of services, including recreation, fish and wildlife management, and potable water supply. As of a 2007 National Lakes Assessment conducted by the US Geological Survey (USGS) and the US Environmental Protection Agency (USEPA) (Loftin et al. 2016), cyanobacteria and microcystins have been documented across the continental United States. Additionally, a 2014 USACE-wide survey identified cyanobacteria as the predominant bloom-forming organism in USACE-operated reservoirs. The survey also showed a recent increase in the frequency of HAB events at USACE districts. As such, the US Army Engineer Research and Development Center (ERDC) HAB technical research and service capabilities are rapidly expanding.

A map of the 2014 HAB survey by US Army Corps of Engineers districts. Districts in green reported HAB events. Districts in red reported no HAB events. Districts in white did not respond to the survey.[1]



An algal bloom at Port Mayaca Lock, Lake Okeechobee, Florida. Photo by Kaytee Pokrzywinski.

4. HABs and the US Army Engineer Research and Development Center (ERDC)

ERDC continues to advance its HAB technical capabilities, expand its research areas, and enhance its research facilities to meet the needs of USACE and the nation as freshwater HAB events increase in frequency and duration. ERDC focuses on the issues directly facing USACE and often receives input from districts. HAB research and development (R&D) efforts at ERDC primarily work towards applied methods for early detection and rapid response. Previous research efforts and reimbursable services have largely focused on four areas:

- water quality—monitoring and modeling
- detection—molecular methods to remote sensing
- control—physicochemical, biological, and chemical
- risk assessment

Each of ERDC's specific HAB technical capabilities, including reimbursable services, previous research projects, and ongoing research projects, are described in the subsequent sections. Points of contact (POCs) for each capability are included for each subsection.

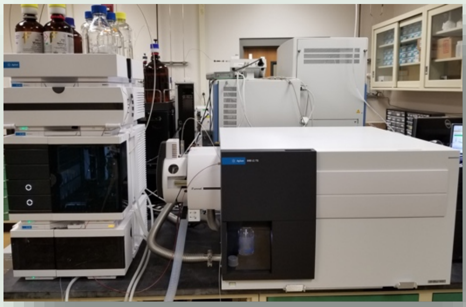
1. Figure reprinted from Brook Herman, Tony Clyde Jr., Erich Emery, Jade Young, and Kathryn Tackley, "Results of 2014 Survey on Harmful Algal Blooms Within the US Army Corps of Engineers," (unpublished manuscript, March 9, 2021), Microsoft Word file. In Review.

5. ERDC Water Quality

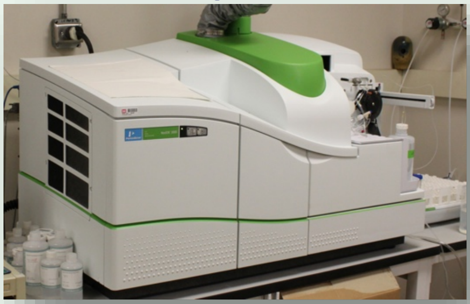
5.1 Water-Quality Monitoring and Chemical Analysis Program

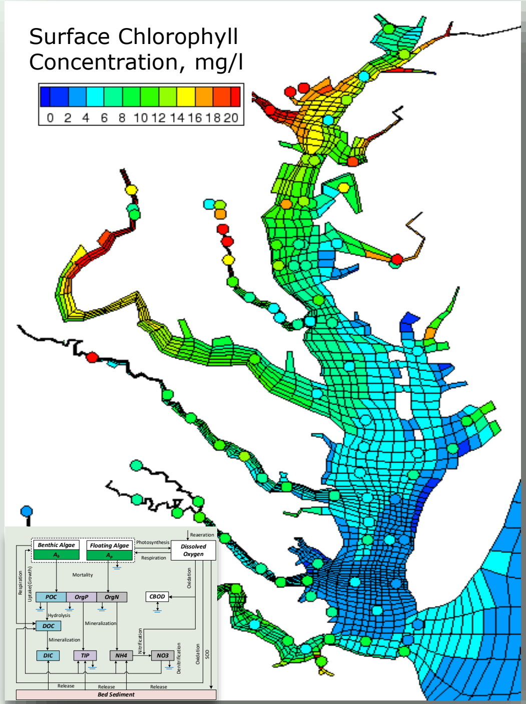
Purpose: Provide state-of-the-science chemical analysis for a full range of chemical compounds of interest in all environmental matrices (water, soil-sediment, and tissue).
Objectives and Results: Use advanced analytical instrumentation and methodologies, including interference reduction techniques, to provide lower reporting limits and higher-quality analytical data.
Benefits and Applications to USACE: In-house capabilities readily accessible to any water quality, sediment, or other environmental analysis issue facing USACE. Ultra-low detection and complex matrix experience allow generation of the highest-quality data to meet customer project needs.
Funding Source: USACE districts, including Louisville, Nashville, Pittsburgh, Vicksburg, New Orleans, Kansas City, Albuquerque, Sacramento, Los Angeles, and Tulsa.
Status: Services available for USACE districts and ERDC R&D projects.
POC: Anthony Bednar (Anthony.J.Bednar@usace.army.mil)

LC-QqQ-MS for organic analyses



ICP-MS with Reaction Cell interference reduction technology for metals analyses





CE-QUAL-ICM model employs high fidelity hydrodynamics, and advanced nutrient cycles and algae kinetics to model 36 water quality constituents in Chesapeake Bay

5.2 Surface Water-Quality Modeling

Purpose: Provide computational tools to identify relationships between hydrometeorological and biogeochemical (nutrient) drivers, human activities, and water quality.
Objectives and Results: Develop and apply state-of-the-art water-quality models for a variety of scales and domains. In-house modeling capabilities have been validated and applied to thousands of sites from upland watersheds to inland lakes, river systems, estuaries, and coastlines. Models include CE-QUAL-ICM (3D), ICM-Lite (3D), CE-QUAL-W2 (2D), AdH-NSM (2D/3D), HEC-RAS 1D/2D, and HEC Res-Sim.
Benefits and Applications to USACE: Modeling allows better prediction of dynamic responses to natural and human activities in and around USACE projects to inform HAB and ecological assessment, mitigation, and restoration.
Funding Source: Multiple ongoing reimbursable and R&D projects and collaborators.
Status: Services available for USACE Districts and ERDC R&D projects.
POC: Jodi Ryder (Jodi.L.Ryder@usace.army.mil)

5.3 Historic Data Analysis

Purpose: To analyze historical water quality and operations data from multi-use reservoirs and other projects in various USACE districts to identify potential cyanoHAB drivers and changes in inland lake cyanoHAB occurrence.

Objectives and Results: Identify chemical and biological water-quality parameters as predictive indicators for cyanoHAB events. These indicators inform models and aid in the ability of USACE to manage and maintain waterways. Develop conceptual models describing the likely drivers of HABs in USACE reservoirs and potential impacts of reservoir operations on HAB occurrences. Broader studies are needed to generalize cyanoHAB drivers across regions.

Benefits and Applications to USACE: Provides a better understanding of the impacts of nutrient loading on cyanoHAB susceptibility in USACE reservoirs and other water-body types affected by USACE projects that experience frequent HAB events affecting regional stakeholders. These projects lay the groundwork for the prediction and restoration of healthy conditions in susceptible or affected waterways. By focusing on identifying key parameters necessary to model and predict cyanoHAB occurrence in managed waterbodies, this work can provide recommendations for additional information and data collection needed to model the influence of operations on cyanoHABs for each reservoir.

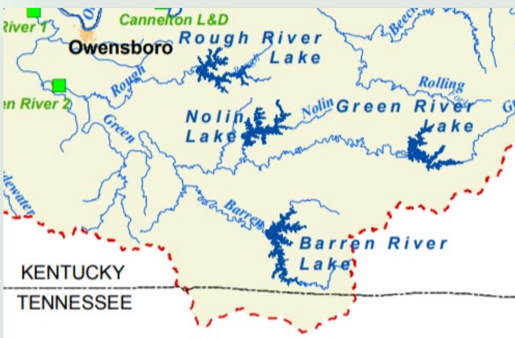
Publications: Kaytee Pokrzywinski, Jed Eberly, Christina Saltus, Scott Bourne, Jade Young, Jennifer Thomason, and Carina Jung, "Evaluation of Historic Water Quality Data and Recent CyanoHAB Events: A Case Study in Adjacent Watersheds," (unpublished manuscript, March 9, 2021), Microsoft Word file. In Review.

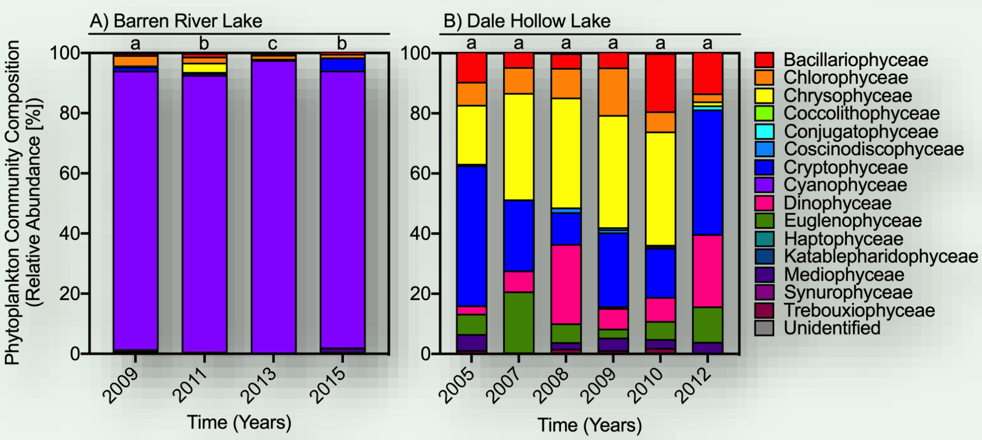
Funding Source: Aquatic Plant Control Research Program (APCRP) and LRL.

Status: Ongoing HAB Research Project (FY20–25) and available services for USACE districts.

POC: Jodi Ryder (Jodi.L.Ryder@usace.army.mil)

__Left:__ Reservoirs in the Green River Basin, Kentucky. __Right:__ HABs near the intake structure at Barren River Lake, Kentucky.



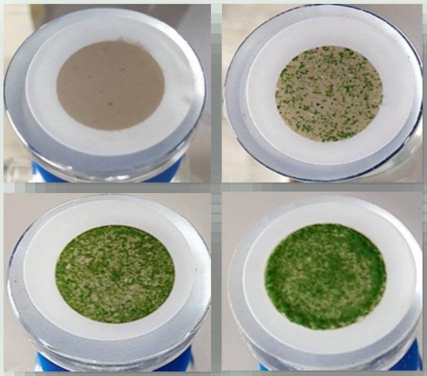


Phytoplankton community composition data from Barren River Lake, Kentucky, and Dale Hollow Lake, Tennessee, between 2005 and 2015, showing greater than 90% cyanophyceae in the Barren River Lake's phytoplankton community.

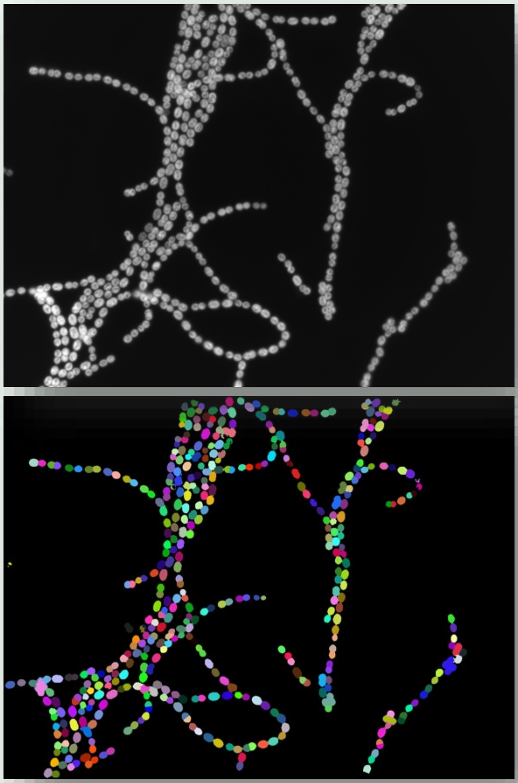
6. ERDC HAB Detection

6.1 Biomass Assessments

Purpose: To assess bulk cyanobacterial biomass in field samples for resource managers and research projects.
Objectives and Results: Visible wavelength spectrophotometry can determine the concentration of chlorophylls and phycocyanin (unique cyanobacteria pigment) in algal extracts from grab samples, a common practice for routine monitoring programs. ERDC uses USEPA method 446 (Arar et al. 1997).
Benefits and Applications to USACE: Assistance with routine HAB monitoring programs for early detection of HAB events.
Funding Source: APCRP, Aquatic Nuisance Species Research Program (ANSRP), MVN, and US Army Garrison Fort Buchanan.
Status: Available services for USACE districts and ERDC R&D projects.
POC: Karl Indest (Karl.J.Indest@usace.army.mil)



Filtration of various field samples for pigment extractions from Port Mayaca, Lake Okeechobee, Florida, July 2017.



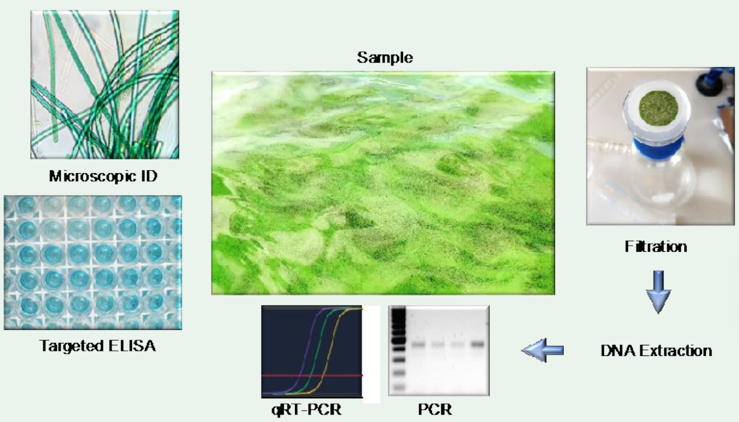
Microscopic imaging of Dolichospermum *sp. The top panel shows the original chlorophyll fluorescence in black and white, and the bottom panel is a map of positively identified cells from the R-program. Unique adjacent colors indicate individual cells counted by the program.*

6.2 Microscopy

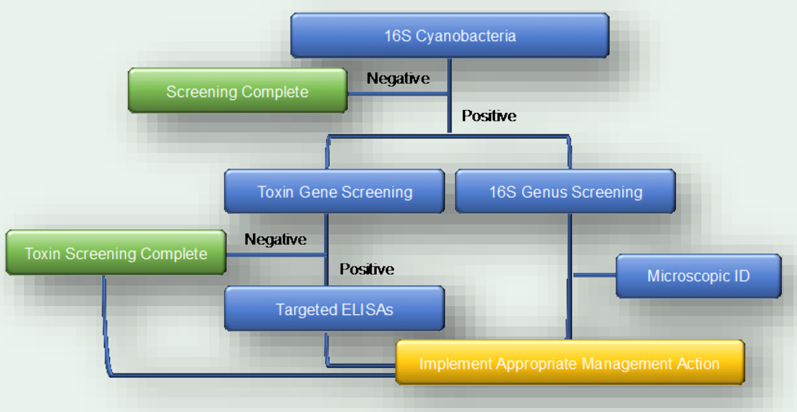
Purpose: To establish an efficient and reliable method of identifying and counting algae and cyanobacteria in environmental samples and to validate other detection strategies limited by the challenges presented by cyanobacterial filaments and colonies.
Objectives and Results: R-programming automates the counting of cells from fluorescence microscope imagery, including filaments and colonies, eliminating the tedious and time-consuming method of manually counting cells. This method allows rapid quantification for molecular studies.
Benefits and Applications to USACE: ERDC's automated, high-throughput image-processing method can enumerate cells and particles in minutes rather than hours. This quantification of cells delineates bloom and nonbloom conditions in USACE reservoirs and other water bodies and can inform planning and execution of downstream analyses.
Publications: Pokrzywinski, Boyd, and Smith (2019)
Funding Source: APCRP
Status: Available services for USACE districts and ERDC R&D projects.
POC: Karl Indest (Karl.J.Indest@usace.army.mil)

6.3 Molecular Tools

Purpose: To develop a time- and cost-effective tiered monitoring approach to rapidly (<2 days) screen for cyanobacteria and associated toxins.
Objectives and Results: Samples are screened for the presence of molecular markers specific to cyanobacteria using PCR/qPCR (Phytoxigene) methods (target sequences specific to 16S rRNA total cyanobacteria and *Microcystis* spp.). Positive samples are then screened for the presence of toxin-specific molecular markers to further characterize the community (toxin genes: microcystin and nodularin, cylindrospermopsin, saxitoxin and anatoxin). Toxin quantification (enzyme-linked immunosorbent assays [ELISAs]) are then performed on any samples that tested positive for a particular cyanotoxin gene.
Benefits and Applications to USACE: ERDC's tiered approach enables rapid identification of cyanobacteria at the genus level and provides an indication of potentially toxic blooms, enabling early detection and rapid response programs.
Publications: Christopher Grasso, Brianna Peloquin, David Berthold, H. Dail Laughinghouse IV, and Kaytee Pokrzywinski, "A Rapid Molecular Screening Approach for Routine Cyanobacterial Monitoring," (unpublished manuscript, March 9, 2021), Microsoft Word file.
Funding Source: APCRP
Status: Available services for USACE districts and ERDC R&D projects.
POC: Karl Indest (Karl.J.Indest@usace.army.mil)



Workflow schematic of molecular approaches and lab methods. Microscopic image credit: Dail Laughinghouse, University of Florida.



Tiered molecular-based monitoring approach.

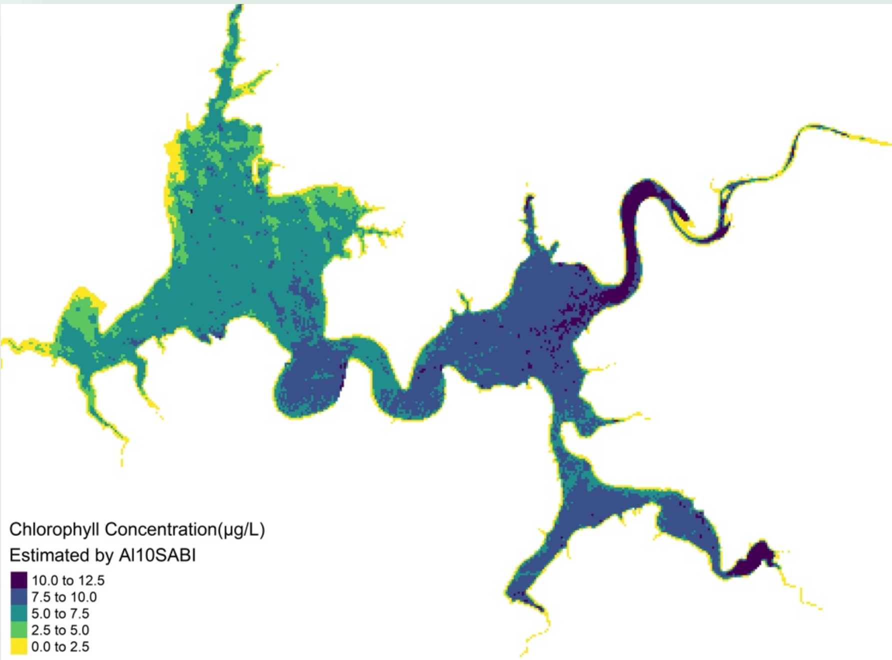
6.4 Cyanotoxins

Purpose: To determine the presence or absence of toxins in environmental samples via ELISAs.
Objectives and Results: ERDC uses ELISAs to determine the concentration of HAB-associated toxins microcystin, cylindrospermopsin, anatoxin, and saxitoxin using USEPA method 546 (Zaffiro, Rosenblum, and Wendelken 2016).
Benefits and Applications to USACE: Assist with routine HAB-monitoring programs for informed decision support by providing rapid (<1 week) toxin information.
Funding Source: APCRP, ANSRP, and MVN.
Status: Available services for USACE districts and ERDC R&D projects.
POC: Karl Indest (Karl.J.Indest@usace.army.mil)

6.5 Sensing-Based Software Tool Development

Purpose: To develop remote sensing software tools for estimating HAB water-quality indicators at USACE-managed inland lakes and reservoirs, ultimately supporting proactive monitoring and management strategies.
Objectives and Results: A beta version of a hands-on R software package is available for developing image-based abundance maps of HAB indicators, such as phycocyanin and chlorophyll *a*. Additional tools will include an ArcGIS workflow toolbox, representing a more streamlined approach with pre-set options for HAB indicator estimation as well as a web-based viewer for limited but easy access to HAB indicator estimations, using constrained image types and algorithms.

Benefits and Applications to USACE: The software tools will provide a near real-time mesoscale characterization of lake and reservoir status, providing critical and timely information for determining appropriate and effective HAB assessment and management strategies. It also guides point sampling efforts to prioritize collection locations. Lastly, it provides an early warning system for resource managers.
Publications: Johansen et al. (2018 and 2019); Xu et al. (2019).
Funding Source: ANSRP
Status: Ongoing research project (FY19–21).
POC: Molly Reif (Molly.K.Reif@usace.army.mil)



Remote sensing technology provides a synoptic view of water-quality conditions across a waterbody, such as in this example at Harsha (East Fork) Lake, Ohio. These data help water resource managers react to events, such as HABs, in a timely manner.

6.6 Unmanned Aircraft System (UAS)–Based HAB Detection and Monitoring

Purpose: To develop new lab- and field-based capabilities using hyperspectral imagery for the early detection and routine monitoring of cyanoHABs. When mounted on an unmanned aircraft system (UAS), this technology guides point-sampling efforts to streamline sampling resources and analytical costs.
Objectives and Results: Merges hyperspectral and UAS technologies to obtain unique hyperspectral signatures from cyanobacteria and allow researchers to rapidly identify blooms in target water bodies without the drawbacks of traditional sampling. Spectral variations within species can be associated with changes in nutrient and toxin status that could determine the physiological state of a bloom event.
Benefits and Applications to USACE: On-site cyanoHAB sample collection often requires boat transportation and relies on a point-sampling approach, in which full water-body characterization is both cost and time intensive. Remote sensing–based guidance for point-sampling efforts can reduce the amount of grab samples required and help direct where sampling should occur. Mesoscale linkage of spectra to toxin status can allow assessment of bloom extent and associated risks.

6.6 Unmanned Aircraft System (UAS)–Based HAB Detection and Monitoring – Cont.

Publications: Kaytee Pokrzywinski, Richard Johansen, Molly Reif, Scott Bourne, Shea Hammond, and Kenneth Matheson, "A Spatiotemporal Assessment of an Unmanned Aircraft System Equipped with Hyperspectral Imaging for Cyanobacterial Bloom Monitoring," (unpublished manuscript, March 9, 2021), Microsoft Word file. Submitted; Kaytee Pokrzywinski, Christopher Grasso, Kenneth Matheson, Molly Reif, and Brianna Fernando, "Hyperspectral Analysis of Cyanobacteria Laboratory Cultures: Determining Spectral Variability and Predictability of *Microcystis aeruginosa* and *Dolichospermum* sp.," (unpublished manuscript, March 9, 2021), Microsoft Word file.
Funding Source: APCRP
Status: Ongoing research project (FY16–21)
POC: Molly Reif (Molly.K.Reif@usace.army.mil)

Laboratory hyperspectral imager and associated images (left) along with unmanned aircraft system (UAS)–based hyperspectral sensor (top right) and associated imagery from Port Mayaca, Lake Okeechobee, Florida.

6.7 In Situ Platforms

Purpose: To develop rapid assessment tools to evaluate HAB extent and density throughout the water column.
Objectives and Results: Various sensors, including chlorophyll + blue-green algae phycocyanin and phycoerythryin, additional chlorophyll and blue-green algae probes, and autonomous vehicles such as I3XO ecomapper and BlueROV2 (right) for use in routine monitoring of cyanobacteria density and distribution.
Benefits and Applications to USACE: Rapid in situ screening tools can be used to understand bloom extent and severity. These technologies can also correlate satellite imagery to ground measurements for forecasting and prediction efforts.
Funding Source: ANSRP
Status: Services available for USACE districts and ERDC R&D projects.
POC: Alan Katzenmeyer (Alan.W.Katzenmeyer@usace.army.mil)

I3XO Ecomapper

BlueROV2

6.8 Microcystin Aptamer Sensor

Purpose: To develop an integrated DNA aptamer-based impedance biosensor platform (IAIB) for rapid detection of freshwater cyanotoxins in USACE waterways.
Objectives and Results: The ERDC Environmental Microbiology Team has a demonstrated expertise in aptamer development and was recently awarded a patent for developing aptamers able to bind to explosives. In this effort, we are applying our expertise to optimize DNA aptamers specific for microcystins and other emerging toxins, for example, anatoxin and cylindrospermopsin, by assessing the sensitivity and specificity of these elements in an increasingly complex aqueous milieu using an impedance-based mini-electrode.
Benefits and Applications to USACE: A key tool in the effective management of and response to HABs and their toxins is the ability to rapidly determine the presence and concentration of toxins in USACE waterways. Currently, methods rely on complex procedures, require time-consuming sample preparation, and laboratory instrumentation, which results in delays in critical management and mitigation strategies. There is a lack of rapid, field-portable, user-friendly analytical tests for assaying the presence of cyanotoxins in waterways.
Publications: Eberly, Crocker, and Indest (2017), Eberly et al. (2019).
Funding Source: ChemCraB Congressional interest item.
Status: Ongoing HAB research project (FY18–20).
POC: Karl Indest (Karl.J.Indest@usace.army.mil)

7. ERDC Physical Control Methods for HABs

7.1 HAB Interception Treatment and Transformation System (HABITATS)

Purpose: Develop a scalable capability to remove algae, algae-entrained nutrients, and potential algal toxins from large water bodies and develop resource-recovery methods that enable efficient management of the resulting biomass while destroying any potential toxins.
Objectives and Results: The FY19 pilot-scale on-shore demonstration showed that HABITATS removes >90% of algal cells and entrained nutrients, reducing total nitrogen and total phosphorus in the treated water by 65% and 95%, respectively. The collected biomass was transformed into biocrude fuel at bench scale using hydrothermal liquefaction. FY20 research studies are focused on scaling up the hydrothermal liquefaction process and system integration optimization at pilot scale. A shipboard mobile HABITATS capability is also under development.
Benefits and Applications to USACE: HABITATS provides a new capability for efficiently managing the potentially toxic biomass resulting from algae cleanup operations.
Publications: Page et al. (2020)
Funding Source: ANSRP
Status: Ongoing HAB research project (FY19–22)
POC: Martin Page (Martin.A.Page@usace.army.mil)

HABITATS employs efficient technologies for algae interception (left), water clarification and algae concentration (middle), and transformation into biofuels (right).

7.2 Operational Controls

Purpose: To develop predictive models to better understand the impact of operational decisions on the dynamics of HABs and provide guidance on operational management techniques and procedures.
Objectives and Results: ERDC is conducting a systematic historical study of the influence of reservoir control options on HABs and developing two modeling tools and protocols to allow reservoir managers to test the projected effects of operational changes (for example, withholding or releasing water and using targeted flow strategies such as horizontal flushing or hypolimnetic withdrawals). The first model uses nutrient and water-quality data as drivers and then predicts HAB prevalence using those factors. The second model ties operational functions into the first model to predict spatial HAB patterns.
Benefits and Applications to USACE: Provides an understanding of the effects of previous attempts to operationally manage HABs and their rates of success in reducing bloom extent, duration, and expression of toxins. The end product of this work will be a dashboard incorporating both models to allow water resource managers to test the impacts of certain operational decisions on HABs.
Funding Source: ANSRP
Status: Ongoing HAB research project (FY20–24).
POC: Jodi Ryder (Jodi.L.Ryder@usace.army.mil)

8. ERDC Chemical Control Approaches for HABs

Microcystis was cultured in tanks (top) and treated with a specialized nozzle (middle) for two hours. A significant decrease in both chlorophyll a and microcystin were observed within two hours of treatments (bottom).

8.1 Hydrodynamic Cavitation

Purpose: To assess the effectiveness of hydrodynamic cavitation in removing cyanobacteria cells and toxins from water through the generation of microbubbles in contaminated water.
Objectives and Results: Experimental studies showed that hydroxyl radicals were generated when microbubbles imploded and, after two hours of cavitation, *Microcystis* sp. and microcystins were reduced by 48% and 68%, respectively.
Benefits and Applications to USACE: Hydrodynamic cavitation can effectively treat cyanobacteria in a minimally invasive, energy-efficient, cost-effective way. This technology could be used in problematic areas and small coves for spot-treating harmful algae.
Publications: Medina, Griggs, and Thomas (2016), Thomas et al. (2019).
Funding Source: APCRP
Status: Previous HAB research project (FY18–19).
POC: Victor Medina (Victor.F.Medina@usace.army.mil)

In situ mesocosms at Pahokee Marina, Lake Okeechobee, Florida, used to evaluate a peroxide-based algaecide (Pak27, SePro Corp) on a natural bloom event in a confined setting.

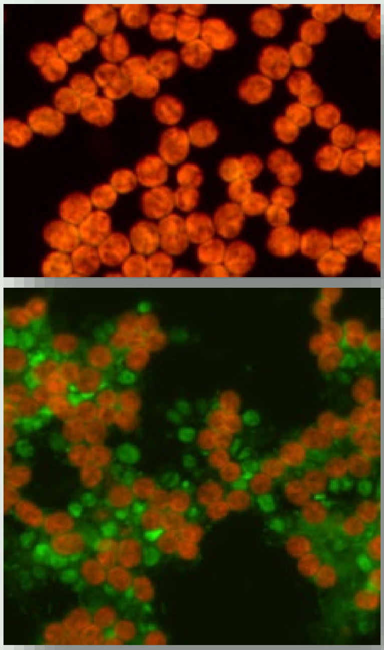
8.2 Scalable Algicide Treatments

Purpose: To identify scalable, peroxide-based algicides active against a suite of cyanobacteria and to identify potential chemical-based treatments for broad-scale cyanoHAB control in freshwater systems.
Objectives and Results: A 2019 mesocosm study (left) demonstrated more than 80% reduction in chlorophyll a concentrations as early as six hours after treatment. The greatest efficacy was observed in mesocosms that received a second peroxide dose, corresponding with sustained suppression of chlorophyll a (74%) for the entire study (72 hours). This rapid, scalable strategy provides short-term relief from cyanoHAB events during the early stages of blooms.
Benefits and Applications to USACE: Effective chemical control strategies can assist resource managers with effective, rapid-response plans to mitigate cyanoHAB events.
Publications: Kaytee Pokrzywinski, West Bishop, Christopher Grasso, Erika Van Goethem, Benjamin Sperry, Brianna Peloquin, and Kurt Getsinger, “Assessing a Peroxide-Based Management Approach for Cyanobacteria in Lake Okeechobee: A Mesocosm Study,” (unpublished manuscript, March 9, 2021), Microsoft Word file. Submitted.
Funding Source: ANSRP
Status: Ongoing HAB Research Project (FY19–21).
POC: Kurt Getsinger (Kurtis.D.Getsinger@usace.army.mil)

9. ERDC Biological Control Strategies for HABs

9.1 Gene Silencing for CyanoHAB Control

Purpose: To develop an RNA interference (RNAi)-based and species-specific novel biotechnology for efficient HAB control.
Objectives and Results: ERDC is screening RNAi-based gene silencing agents (GSAs) to suppress cyanobacterial growth by inhibiting such key biological processes as photosynthesis and nitrogen assimilation. This project is identifying the most effective vehicle for delivering GSAs via cell-penetrating peptides.
Benefits and Applications to USACE: The technique will provide an environmentally benign cyanoHAB mitigation approach with limited effects on nontarget organisms and without secondary chemical contamination.
Funding Source: APCRP
Status: Ongoing HAB research project (FY17–22).
POC: Ping Gong (*Ping.Gong@usace.army.mil*)



Epifluorescence micrographs of Microcystis aeruginosa. *The top panel shows chlorophyll autofluorescence (red) in the absence of a gene-silencing agent (GSA). The bottom panel shows chlorophyll autofluorescence in addition to green fluorescent protein (GFP) labeled GSA (green) for visualization of cellular attachment.*

9.2 Cyanophages

Purpose: To identify and isolate naturally occurring cyanophages as a novel technology for the control and mitigation of freshwater cyanoHABs.
Objectives and Results: Cyanophages are a group of viruses that specifically infect cyanobacteria and are integral to the natural regulation of cyanobacterial populations. ERDC has partnered with the US Bureau of Reclamation to identify and characterize various cyanophages, with high specificity for high-priority cyanobacteria, namely *Microcystis* spp. Cyanophages with high abundance and genetic diversity have been isolated from lakes and ponds, which can infect cultures of known bloom-forming freshwater cyanobacteria.
Benefits and Applications to USACE: Using cyanophages to treat cyanoHABs is a promising technology, with the potential to mitigate blooms without chemicals or energy-intensive methods, like physically filtering out the algae, and other treatment processes.
Funding Source: ANSRP
Status: Ongoing HAB research project (FY 20–22).
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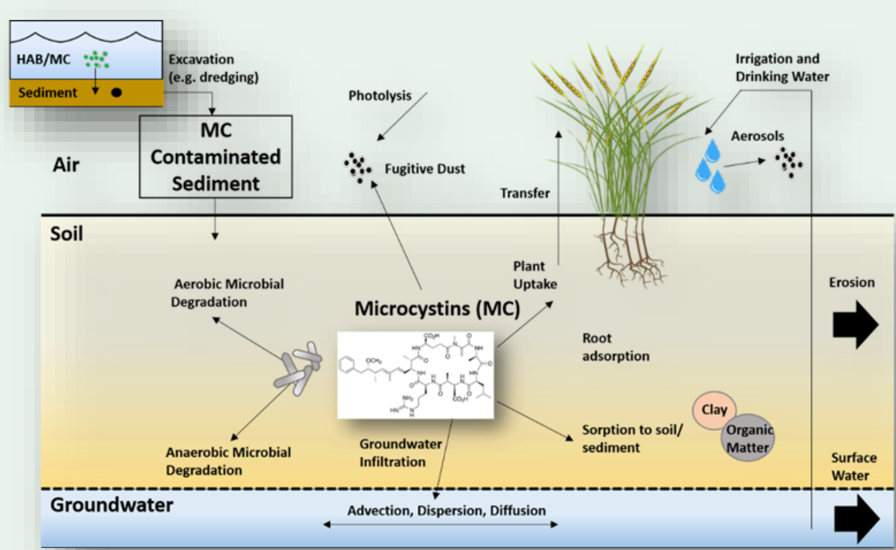
10. ERDC Risk Assessment for HABs

10.1 Site-Specific Risk Framework

Purpose: To apply a site-specific HAB risk framework, assess the treatment efficacies and ecological risks of chemical algaecides, and evaluate ecological and human health risks from algal toxins.
Objectives and Results: ERDC can identify potential HAB treatment solutions, determine treatment efficacy, and provide site-specific algal response data. ERDC also performs ecological risk assessment and toxicity testing to define risks to fish and invertebrates and determine the margin of safety for nontarget organisms. Lastly, ERDC provides technical support for ecological and human health risk assessment from exposures to algal toxins.

Benefits and Applications to USACE: ERDC assists with risk communication, an important step in translating and conveying risk assessment findings to a broad set of stakeholders, including the general public.
Publications: McQueen et al. (2020)
Funding Source: USACE–Buffalo District
Status: Available service for USACE districts and ERDC R&D projects.
POC: Andrew McQueen (Andrew.D.Mcqueen@usace.army.mil)



Microcystin transfer and transformation pathways in nearshore environments (McQueen et al. 2020).

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