

The future of water quality is here:

Forecasting cyanobacterial harmful algal blooms

Blake Schaeffer, Michael Paul, Donald Benkendorf, Gregg Serenbetz, Deron Smith, & John M. Johnston

Lakes and reservoirs across the United States offer a reliable source of drinking water, recreation, and natural beauty. For a lot of people, summertime means swimming, fishing, and boating, while for water managers it means working quietly behind the scenes to keep those experiences safe.

Harmful algal blooms

Each summer, some lakes can turn a blueish-green color due to the growth of cyanobacteria, also called blue-green algae. When cyanobacteria grow to excess, they can potentially produce toxins, and are then called cyanobacterial harmful algal blooms, or cyanohABs. The toxins can cause serious health effects including respiratory issues, and skin irritation and illness in humans and animals. In addition to being a threat to public health, cyanohABs can cause taste and odor issues, impact aquatic life, and negatively impact the economy. CyanohABs have become a persistent, nationwide health concern, and public health advisories are sometimes needed to protect people and their pets from exposure. Water utilities also need to be on alert to treat water that is sourced from rivers and lakes or reservoirs to remove these toxins.

Forecasting blooms

Managing cyanohABs requires early detection, quick response, and ideally the ability to anticipate cyanohABs before they worsen. Until recently, consistent forecasting of cyanohAB levels wasn't possible at a national scale. That gap in capability reached a turning point when Congress authorized the Harmful Algal Bloom and Hypoxia Research and Control Act, funding federal agencies to research, monitor, and forecast these events. The U.S. Environmental Protection Agency was ready for the challenge. What followed was a scientific effort to answer the difficult question: can we forecast cyanobacterial

harmful algal blooms like we forecast the weather?

The task was complex because cyanohABs don't behave the same way in every lake. Blooms can develop during the spring through late fall. Some persist for weeks, while others may rapidly form and fade within a few days. Each event is shaped by local environmental conditions, including water-body size and depth, nutrient concentrations, rainfall, watershed characteristics, and temperature. In addition, existing cyanohAB models typically focused on a few well-studied lakes that require continuous and intensive field sampling. Therefore, scaling from a single lake to the entire nation was difficult.

Modeling and testing

To tackle this, Environmental Protection Agency (EPA) scientists turned to a new modeling framework and leveraged satellite data. The Cyanobacteria Assessment Network (CyAN; www.epa.gov/cyanoproject) – a multi-agency collaboration including EPA, National Aeronautics and Space Administration (NASA), National Oceanic Atmospheric Administration (NOAA), and United States Geological Survey (USGS) focused on identifying cyanobacteria blooms across the largest 2,192 U.S. lakes using data from the European Space Agency's Sentinel-3 Ocean and Land Colour Instrument (OLCI). The OLCI measures light reflected by water on the Earth's surface. The presence of cyanobacteria creates a unique signature in the light reflected from surface waters, which can be detected by the Sentinel-3 OLCI. Scientists developed an algorithm to convert the detected wavelengths of reflected surface light into an estimated abundance of cyanobacteria dominated chlorophyll-a. From this process, the CyAN team quickly amassed a huge dataset of cyanohAB observations for all of the targeted lakes. By combining the satellite observations with predictors like water temperature,

precipitation, lake size and depth, the EPA team built a national forecasting model that can be updated weekly without the need for constant field observations at every lake (Schaeffer et al. 2024). We can now monitor real-time cyanohAB conditions with satellites and forecast the probability that a cyanohAB event will occur the following week.

The team tested the model across all 2,192 lakes from 2021-2023. Each week we compared the predicted bloom probabilities with the satellite observations for every lake. The results were promising; the model correctly identified cyanohAB conditions with 90 percent accuracy. It also worked across a diverse range of locations, from Florida to Utah. This approach filled the critical gap in the capability of forecasting cyanohAB occurrence.

Accessing the forecasts

Water managers can now access the forecasts through the EPA HABs forecast website (www.epa.gov/habs/hab-forecasts), which displays a national map of cyanohAB probability with weekly updates. Users can also view maps by week (Figure 1), explore trends in individual lakes (Figure 2), and download data. The EPA HABs forecast website is available to everyone – including local health departments and state environmental agencies.

Where once, decisions had to be reactive – made after cyanohABs formed and toxins were possibly present – this new forecasting service makes it possible to act earlier. Now, public health advisories, drinking water protection, and additional field monitoring can be more targeted based on what is likely to happen, not just what has already occurred.

Continued challenges

The challenges of addressing cyanohABs are not over. For example, the current

model can forecast the presence of cyanobacteria blooms, but it cannot determine whether the bloom is toxic or exactly where it will occur in the waterbody. Future improvements include higher resolution imagery to provide forecasts for smaller lakes and waterbodies. But thanks to the combined effort of satellite remote sensing experts, field scientists, modelers, GIS scientists, and web design staff, a major piece of the cyanoHAB puzzle has fallen into place for public health protection. The EPA team continues to provide reliable forecasts while the next generation of improved forecasting models are developed.

Just like weather forecasts change how we plan our summer days, this new forecasting ability can change the work that water managers do behind the scenes to keep us safe. When combined with real-time satellite monitoring and field observations, this approach can help identify large lakes in a state or region at risk of exceeding thresholds for cyanoHABs. Local and state water quality managers can use the forecast to make faster and better-informed management decisions regarding recreational and drinking water safety. Innovative prediction tools like this empower decision-makers to protect people before problems reach the shoreline. The future of water quality isn't just about detecting what has already happened – it's about seeing what is coming next. And now, we can.

Reference

Schaeffer, B.A., N. Reynolds, H. Ferriby, W. Salls, D. Smith, J. Johnston, and M. Myer. 2024. Forecasting freshwater cyanobacterial harmful algal blooms for Sentinel-3 satellite resolved U.S. lakes and reservoirs. *Journal of Environmental Management*. 349: 119518.

Dr. Blake Schaeffer is an EPA research scientist in Durham, N.C. His research focus is on the use of satellite remote sensing technology to monitor water quality in coasts, estuaries, and lakes. His interests generally include integrating remote sensing technologies into water quality management frameworks. You can contact Blake at schaeffer.blake@epa.gov.

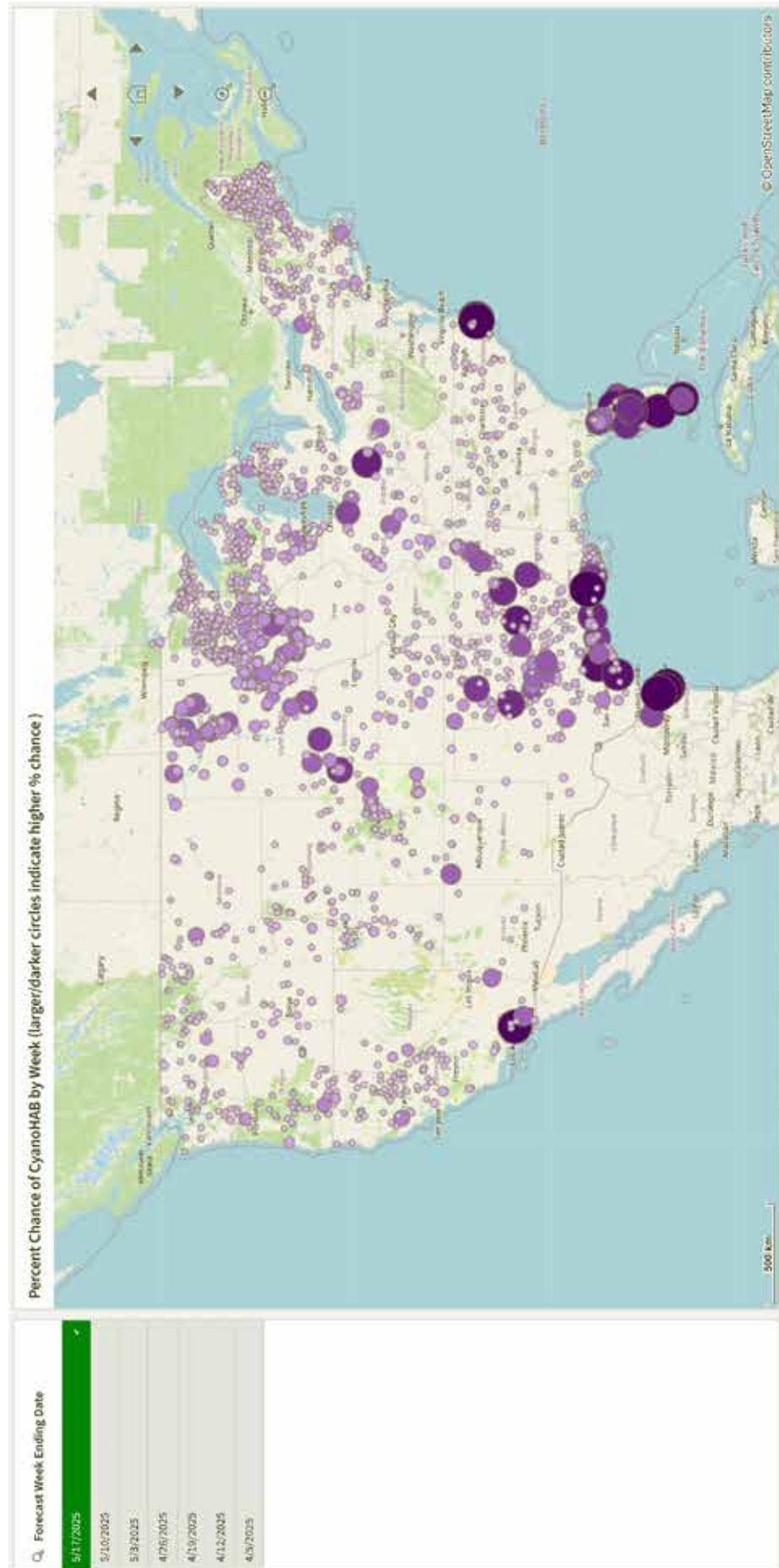
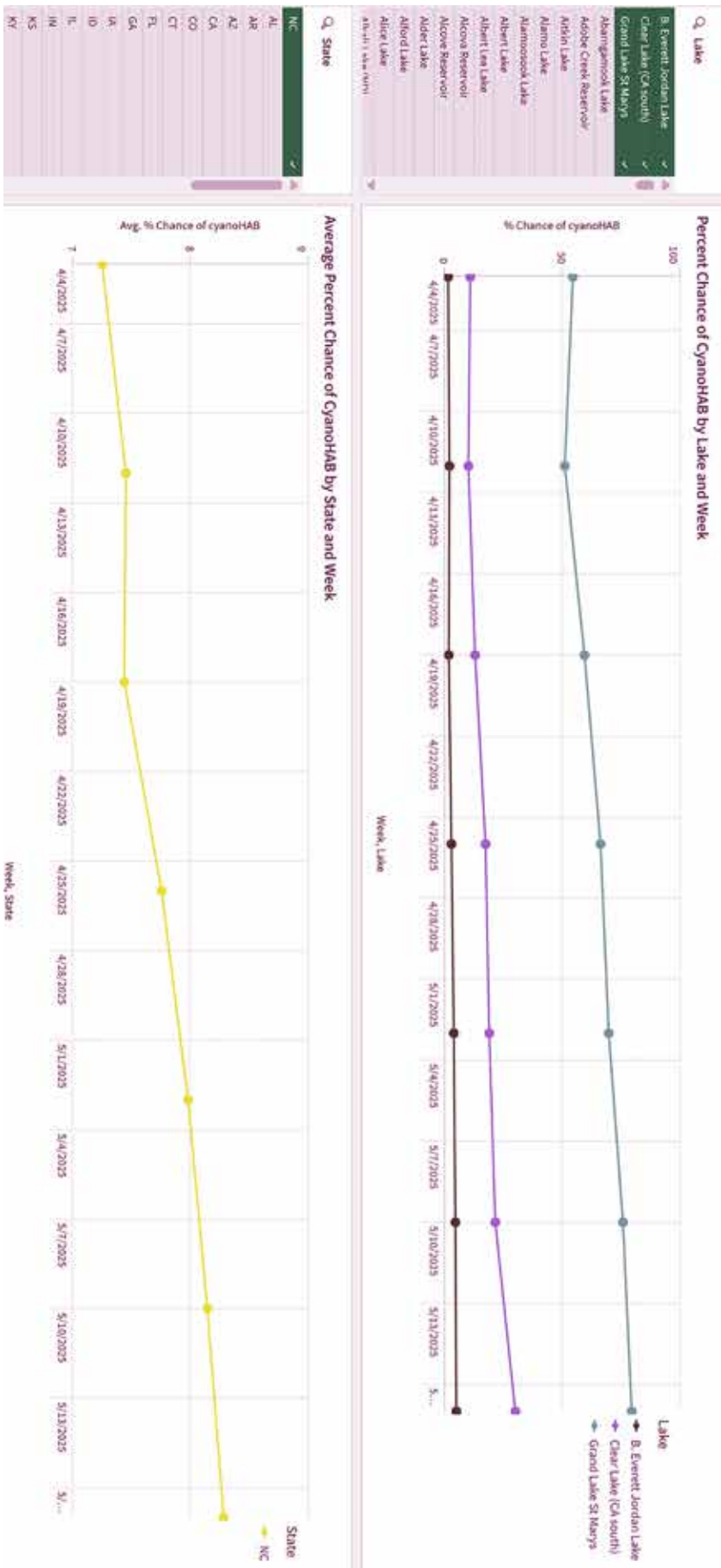


Figure 1. Public website example forecast map for the week ending on May 17, 2025. Larger and darker circles indicate a higher probability of a bloom.

Figure 2. Public website time series of weekly lake (top) and state (bottom) averaged probabilities for April 5 through May 17, 2025.



Dr. Michael Paul is the EPA National Harmful Algal Bloom Program Lead, responsible for coordinating all HAB related activities across the agency. He also supports the nutrient and biological criteria development programs in the Office of Water. Mike has more than 30 years of experience in the research and management of aquatic ecosystems, including 20+ years in water quality criteria development across the nation. He can be reached at paul.michael@epa.gov.



Dr. Donald Benkendorf is an EPA physical scientist in Washington, DC. He works on the National Aquatic Resource Surveys team and has broad research interests in the areas of monitoring and assessment of aquatic resources. You can contact Donald at benkendorf.donald@epa.gov.



Gregg Serenbetz is an EPA Environmental Protection Specialist in Washington, DC. He works on the National Aquatic Resource Surveys team with a focus on wetland monitoring and analysis. He can be reached at serenbetz.gregg@epa.gov.



Deron Smith is an EPA Information Technology Specialist in Athens, GA. His work has focused on applied scientific software applications, cloud computing architectures, and machine learning models. He can be reached at smith.deron@epa.gov.



Dr. John M. Johnston is an EPA supervisory ecologist in Athens, GA. His research focus is on water quality monitoring and modeling to forecast ecosystem services and their influence on human health. His interests include life cycle impact assessment, remote sensing, spatial modeling, and sustainability analysis. Current projects include forecasting lake cyanobacterial bloom probability and urban storm water management and reuse. He can be reached at johnston.johnm@epa.gov.

