Satellite-Detected Cyanobacteria in Large U.S. Lakes **on Your Android Phone**

Blake A. Schaeffer, Robyn N. Conmy, Mike Galvin, John M. Johnston, Darryl J. Keith, and Erin Urquhartn

Problem – Harmful cyanobacterial blooms and protecting public health

Safe and clean water is necessary for human and ecosystem health and economic growth. Over the last 40 years, water quality in the United States has improved, but threats to water quality remain. One issue that continues is the occurrence of cyanobacterial harmful algal blooms, or cyanoHABs. Health advisories and closure of recreational areas are often due to cyanoHAB events in our lakes and reservoirs. CyanoHABs can produce toxins but they also cause nuisance odors, and hypoxia. They are also visually noticeable by their unappealing surface scums. CyanoHABs negatively impact drinking water and can increase drinking water treatment costs for communities. They also impact the local economy, via revenue loss from recreation and businesses that rely on safe and clean water. Most cyanoHAB events are dealt with reactively, after the bloom has occurred in a response to the visual, odor, or toxin confirmation. What if we could proactively monitor and detect early development of cyanobacteria harmful algal blooms?

Solution – The power of satellite information in the hands of people

Typically, a single organization is responsible for monitoring water quality across numerous lakes covering a vast geographic area. Additionally, monitoring efforts are often constrained by limited resources including the availability of personnel. Water quality managers need access to current, inexpensive and quality data to protect water resources. To assist in the proactive management of cyanoHAB events, EPA researchers, along with researchers from NASA, NOAA, and USGS, have developed a time-efficient way to use satellite data in monitoring for cyanoHAB events to help protect recreational and drinking water sources.

The EPA developed and beta-tested the Cyanobacteria Assessment Network (CyAN) app for Android operating systems. This app uses information from the European Space Agency's Sentinel-3 satellite Ocean and Land Colour Imager to create a free, current, and immediately intuitive satellite data delivery system accessible through Android version 4.1 and above smartphones. A prototype of this mobile application was originally described in the Summer 2015 issue of *LakeLine* (35[2]:28-31). Since that time, EPA researchers have updated the app and beta tested with multiple non-government organizations, as well as state and federal agencies for managing cyanoHAB events. It is now ready for public release to support a much broader audience.

Though satellite data have been available for many years, use in decision making has been hindered by difficulties with compatibility of complicated data formats and the time burden to process and access the data. The CyAN app gives water quality managers the ability to distill and assess satellite derived cyanoHAB biomass concentrations occurring over large areas across the country. This app reduces the need for scientific expertise in satellite data processing, analysis and interpretation, and eliminates barriers to computer hardware requirements associated with the use of satellite data files. The CyAN app provides an easy to use, customizable interface to scan water bodies for changes in cyanoHAB occurrence without requiring computer programming expertise. Thus, managers can rapidly distill critical water quality information over large temporal and spatial areas. (See Figure 1.)

App functionality and satellite data have already been successfully demonstrated against 25 state health advisories, across seven states, issued in 2017. The app reported cyanoHAB increases in concentration in the same location and during the same time as an independent state issued health advisory. Over 2,000 of the largest lakes and reservoirs can be monitored across the continental U.S., with a complete list by state available in the supplemental material of Schaeffer et al. (2018).

The georeferenced data in the app allow water quality managers the ability to passively monitor a specific water body without having to filter through numerous satellite images of water bodies that aren't associated with their area of interest. Simply, users open the app once a week to receive the updated imagery. The mobile app provides monitoring data of cyanoHAB values for locations of interest for the current season, as well as on daily and weekly intervals to provide a temporal context. The app provides approximately 70 percent of the monitoring information, whereas the remaining information (such as identifying site locations of interest, setting warning thresholds) is input by the water quality manager during the setup process.

Examples of feedback provided from CyAN mobile app beta testers:

Aaron Borisenko, State of Oregon Department of Environmental Quality: *"Moving ahead we want to spread the word about the application and get more eyes on the situation. It is important to identify where blooms are typically occurring using CyAN app as an early warning system."*

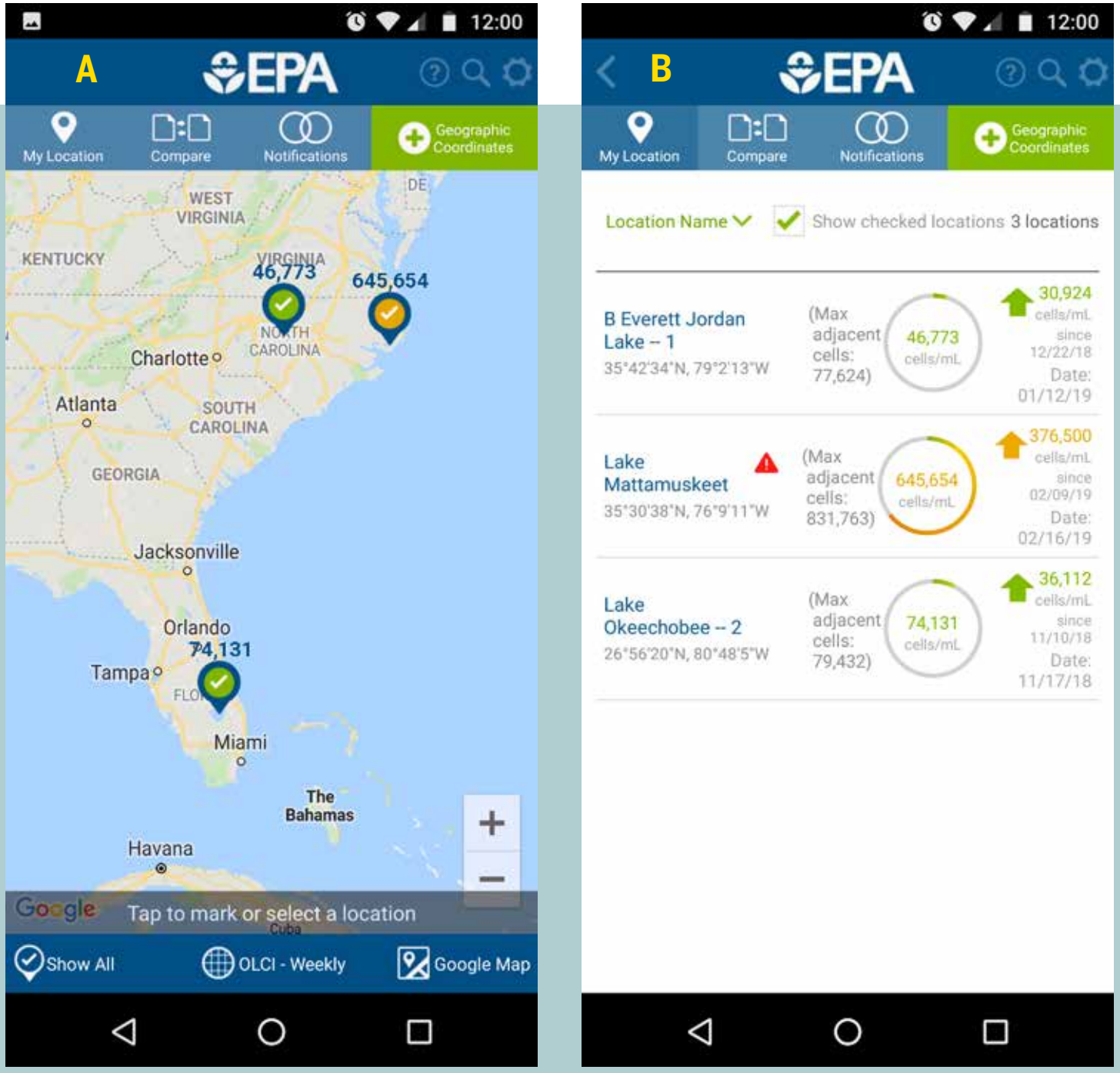
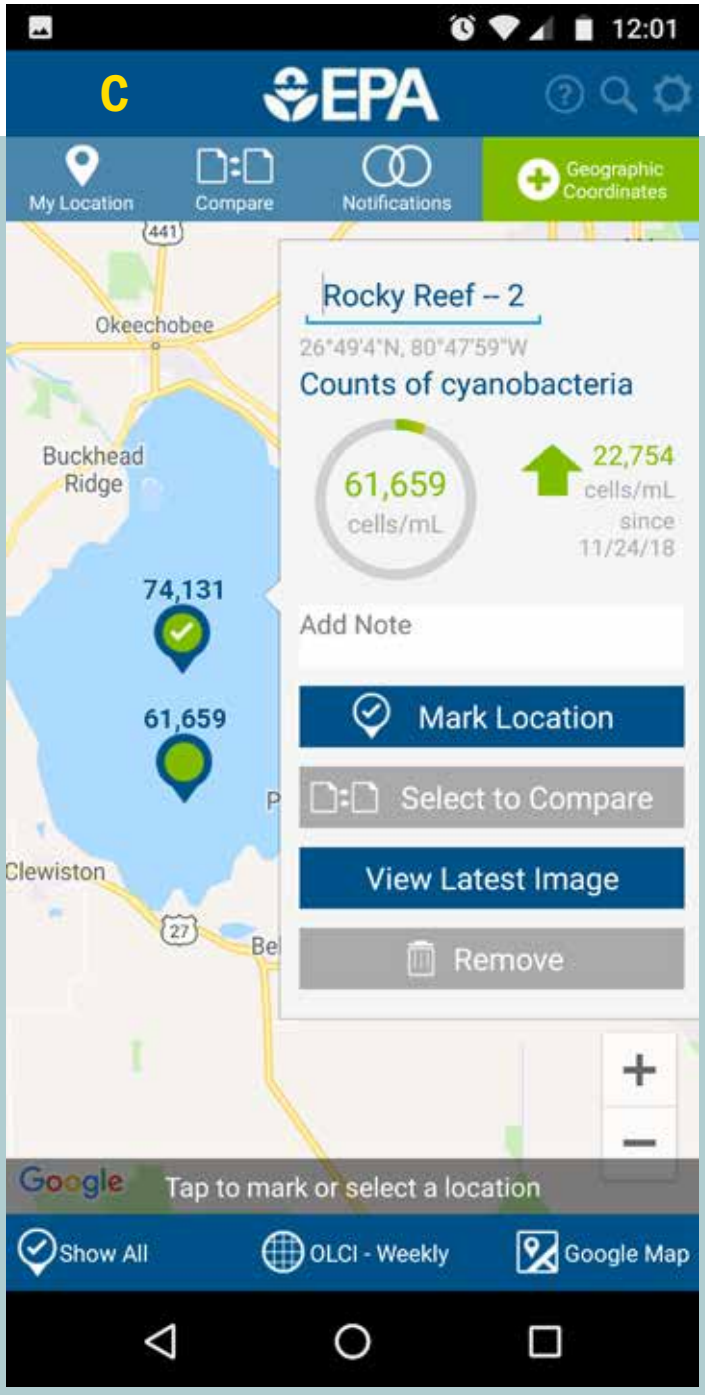
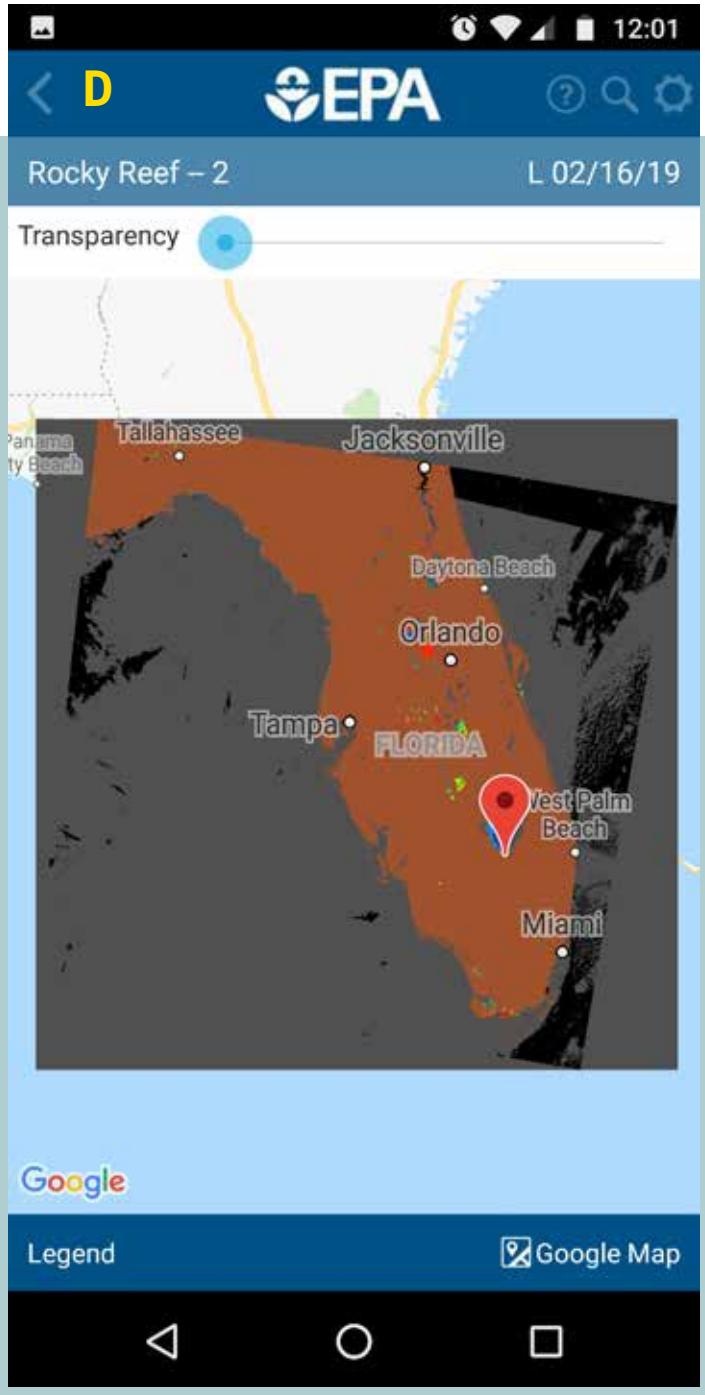


Figure 1. Main page (A) of the CyAN app allows for pin placement in locations of interest, where the user can see an alphabetical list of locations (B) with coordinates, biomass concentrations and changes from previous detections. Viewing a specific pin location (C) and selecting "View Latest Image" allows the user to (D) view the satellite area to identify if another location may be of interest.

Benjamin Holcomb, Utah Department of Water Quality: *"The images we've been receiving through the CyAN project have been tremendously helpful to the Utah Division of Water Quality (UDWQ), providing the foundation for a wide range of useful outputs. It allows UDWQ to better target field sampling and more efficiently use our limited resources to protect public health. Finally, images are easily shared with response agencies as a useful visual communication aid."*

Daniela Gurlin, Wisconsin Department of Natural Resources: *"The CyAN app provides our water resources specialists a tool to access near real-time satellite data products for detecting and quantifying algal blooms in hundreds of lakes across Wisconsin. Simple map navigation and minimal steps required to mark locations and view the latest images make this app a useful tool for responding to questions related to the potential presence of harmful algal blooms in specific lakes. Time series images and blooming charts provide*





additional insights into the temporal dynamics and intensities of algal blooms at a particular location."

Angela Shambaugh, Vermont Department of Environmental Conservation: *"Large lakes like Lake Champlain have an extremely patchy distribution of cyanobacteria due to varying environmental conditions and lake shape. The CyAN app helps viewers visualize that patchiness and provides additional context for our [cyanobacteria] Tracker Map which shares data gathered by our cyanobacteria monitoring program."*

Bart Johnsen-Harris, Environment America: *"From Florida to the Great Lakes to California, we are seeing widespread outbreaks of toxic algae in our waterways. As I work on these issues and advocate for clean water policy, CyAN has proved to be a uniquely helpful tool. I expect that scientists, lawmakers, and concerned citizens alike will benefit from these maps."*

Lenard Long, Lake Cascade Citizen Scientist Monitoring Group: *"Our goal is to enhance the community's ability to rapidly respond to and manage the growing threat posed by toxic algae by reducing human controlled nutrient pollution; the CyAN app helps us do that . . . the CyAN app has been extremely useful. . . ."*

Into the details – Translating satellite data for decisions

Within the Geographic Coordinates tab on the app, the user can add specific location information such as latitude and longitude for monitoring stations, recreational locations, and public drinking water surface intakes. Adding and removing locations is also a simple process. Locations are stored in list-form for a quick and easy way to visualize the current data and recent changes in thresholds. It is important to know that a pin location only provides data that is a cyanoHAB detect in that specific pixel location. If that specific pixel location does not have any detectable measures of cyanoHAB, or is covered with clouds during the season, no data are returned to the end user to conserve data transfer

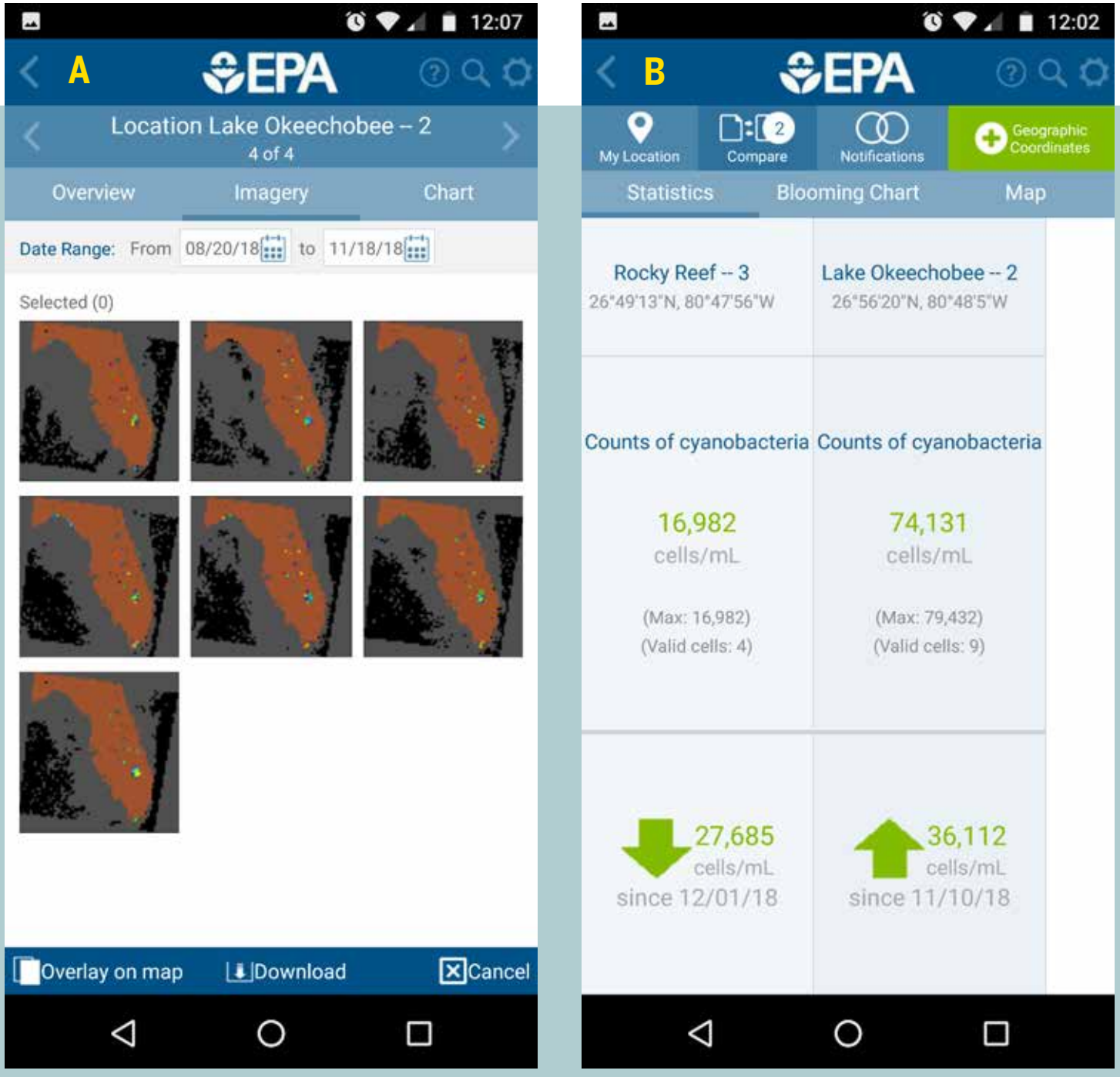
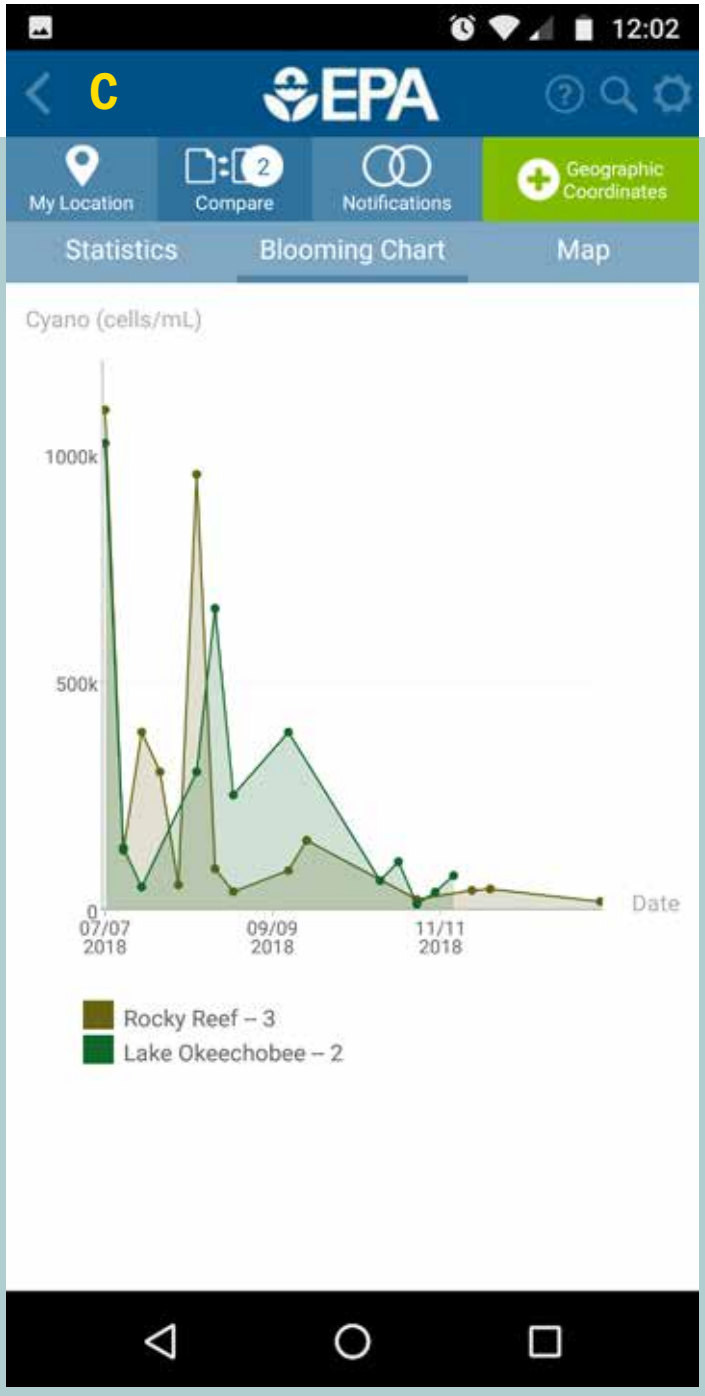


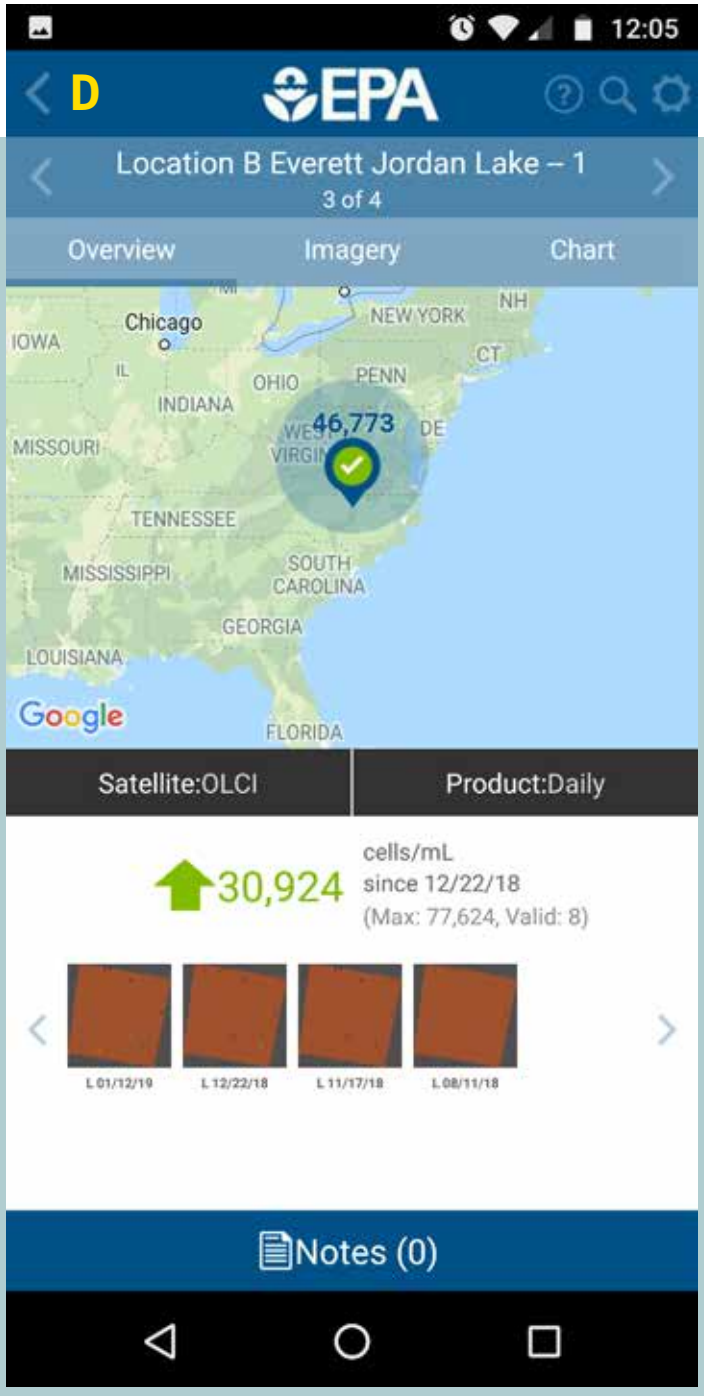
Figure 2. Users can (A) browse through a time series of images for their areas of interest, compare (B) concentrations and changes at specific locations, (C) visualize time series, and (D) switch between locations to see available satellite images.

rates. Based on user feedback, there is now an option for tapping a pin on the main page and viewing the entire satellite area that contains their locations of interest, so the entire geographic location can be quickly viewed and determine if a different location should be selected. The satellite images may also be downloaded to the mobile device as a PNG file for record-keeping or exported for quick use in a presentation. Data used in the app are considered provisional and will contain errors, such as potential false positive detections near shore and during snow and ice events. Data were validated to stage 2 of 4 on NASA's data maturity level ranking. This is defined as "data product accuracy is estimated using a significant set (although not full US) of independent measurements obtained from selected locations and time periods and field program efforts. There have been some peer-reviewed publications on the accuracy, but for limited spatial areas."

Summary

The CyAN app provides easy access to satellite data and some basic analyses, delivering a proactive ability to monitor spatial and temporal information on





cyanoHAB events across more than 2,000 of the largest U.S. lakes and reservoirs. This intuitive tool reduces the barriers to accessing satellite water quality data for monitoring and improves the use of limited resources in responding to events. More detailed technical information on the CyAN mobile application is found in Schaeffer et al. (2018). The mobile application is available to the public this year and will soon be on the Google Play store and at https://www.epa.gov/water-research/cyanobacteria-assessment-network-mobile-application-cyan-app.

Reference

Schaeffer et al. 2018. Mobile device application for monitoring cyanobacteria harmful algal blooms using Sentinel-3 Ocean and Land Colour Instruments. *Environmental Modelling and Software* 109: 93-103.

Acknowledgements

The work was supported by the USEPA and the NASA Ocean Biology and Biogeochemistry Program/ Applied Sciences Program proposal 14-SMDUNSOL14-0001. Hosting costs were supported by the U.S. EPA Office of Science Information Management. This article has been reviewed by the National Exposure Research Laboratory and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government. The views expressed in this article are those of the authors and do not necessarily reflect the views or policies of the USEPA.

Blake A. Schaeffer is a physical scientist at the Environmental Protection Agency in Durham, NC. 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.

Robyn N. Conmy is a research ecologist at the Environmental Protection Agency in Cincinnati, OH. Her research is dedicated to characterizing optical properties of organic matter in water bodies and discerning their impact to water quality conditions. Her research interests include carbon biogeochemical cycling, optical tracking tools (in-situ and satellite remote sensing), landscape-watershed interactions, crude oil fate and transport, light attenuation in water and surface-groundwater interactions. You can contact Robyn at conmy.robyn@epa.gov.

Mike Galvin is a computer scientist at the Environmental Protection Agency in Athens, GA. He supports environmental and ecological research efforts building models, databases and software components furthering Agency projects. His interests include technologies and infrastructures supporting the development of software tools aiding the characterization and assessment of ecosystem issues. You can reach Mike at galvin.mike@epa.gov.

John M. Johnston is a supervisory research ecologist at the Environmental Protection Agency 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. You can contact John at johnston.johnm@epa.gov.

Darryl J. Keith is a research oceanographer at the Environmental Protection Agency in Narragansett, RI. His research focus is on the use of remote sensing technology to monitor water quality in coasts, estuaries, and lakes using aircraft and satellites. His interests generally include image processing, algorithm development, and integrating remote sensing technologies into water quality monitoring programs. You can contact Darryl at keith.darryl@epa.gov.

Erin Urquhart is an ORISE research fellow at the Environmental Protection Agency in Durham, NC. Her research focus is on the use of satellite remote sensing technology to monitor water quality in coasts, estuaries, and lakes. Her research interests lie at the intersection of applied water resource science and end-user and public health applications. You can contact Erin at urquhart.erin@epa.gov.

UPCOMING IN *LAKELINE* –

LakeLine Fall 2019:

The fall issue of *LakeLine* will cover topics related to Source Water Protection. Articles will cover a range of management, protection, and planning maasures utilized in keeping our drinking water supplies safe and available.