Final Technical Report

Title: Remote Sensing of WQ and harmful algae in OK Lakes

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Principal Investigators: K.D. Hambright (University of Oklahoma); X. Xiao (University of Oklahoma); A.R. Dzialowski (Oklahoma State University)

Publications: in progress

Students and Postdocs salaried through this project

Student Status	Number	Disciplines
Undergraduate	4	2-Biology; 1-Geography; 1-Biology/Professional Writing
M.S.	1	Zoology
Ph.D.	3	2-Biology/EEB; 1-Microbiology/EEB
Post Doc	1	Remote sensing
Total	9	

Problem and Research Objectives:

The many lakes (reservoirs) of Oklahoma provide rich fisheries, abundant recreational activities, and a general, high-value aesthetic quality to the state. Larger lakes, such as Lake Texoma, Lake Eufaula, and Grand Lake, also serve as critical economic engines for surrounding communities. Agriculture and continued urban and rural development have generated excessive nutrient inputs to many of our lakes, leading to increased frequency and magnitude of harmful algal blooms (HABs), particularly of toxic cyanobacteria (blue-green algae). Blooms of cyanobacteria, which can produce a variety of harmful toxins including: hepatotoxins, neurotoxins, or dermatoxins that may be harmful or lethal to animals and humans, have been exacerbated by recent drought and heat conditions. In 2006, a pet died from cyanotoxin exposure in Lake Texoma, in 2011, Sen. James Inhofe fell gravely ill after swimming in Grand Lake during a *Microcysitis* bloom, and in 2012, two dogs died from exposure to cyanobacterial toxins in Lake Ellsworth (Lawton). Many humans have experienced sub-lethal adverse acute effects from cyanobacteria, particularly in recent years (R. Lynch, OUHSC, College of Public Health), but we have little understanding of the consequences of chronic exposures. Fortunately, no human fatalities in Oklahoma have yet been linked to cyanobacteria.

Following the 2011 HAB outbreak season, the Oklahoma Secretary of the Environment convened a committee of experts from across the state to provide recommendations for the state's HAB monitoring needs. That committee concluded that just to monitor the largest 100 lakes once monthly for a year, $3.5 million would be required (Smithee et al. 2012). A program designed to provide the necessary coverage of Oklahoma's lakes sufficient for safeguarding public health would require more frequent monitoring at higher spatial resolutions and therefore would require much more funding. More importantly, experience gained from other states faced with similar HAB problems, indicates that even the most basic (= insufficient) statewide monitoring program for HABs is not economically sustainable (K. Loftin, USGS, Lawrence, KS, pers. comm.). At present, Oklahoma does not have a sufficient monitoring program in place for protecting the health of the public who visit and swim, boat, and fish in the state's many large lakes. With little effort and monies being directed to mitigation of nutrient pollution, HAB issues are forecast to worsen with time. As such, Oklahoma is in dire need of a solution for dealing with the threat of HABs – one that is low in cost, is sustainable, and offers real-time public protection.

This project represents an initial phase of a long-term strategic plan between the Xiao, Hambright, and Dzialowski labs and other collaborating scientists, engineers, and agencies in the region (C. Armstrong and J. Wright, Oklahoma Department of Environmental Quality-DEQ; T. Clyde, US Army Corps of Engineers-USACE; J. Chambers and D. Martin, Oklahoma Water Resources Board-OWRB; D. Townsend, Grand River Dam Authority-GRDA). Our long-term goal is twofold: 1) to improve our knowledge and capacity of remote sensing of water quality and harmful algal blooms using chlorophyll-a, plus the accessory pigments phycocyanin (unique to cyanobacteria) and carotenoids (found in golden algae, another group of HAB species important in Oklahoma and the region), and 2) to develop a monitoring program for water quality and harmful algal blooms in Oklahoma lakes based on traditional approaches coupled to remote sensing and digital photography. In short, we aim to provide the State of Oklahoma a comprehensive program for monitoring surface water quality and HABs that will greatly enhance current risk management capabilities with respect to public health and the state's recreational water bodies.

This two-lake pilot study was designed to provide proof-of-concept across a range of water body types and water qualities and will provide a foundation for multiple future projects. For example, because LANDSAT images extend back to the 1970s, it may be possible to examine long-term trends in Lake Texoma (and other lakes) water quality (from LANDSAT images) as related to both land-use and climate change. Further, we are planning to expand our data collection and analyses to more lakes around the state, and because LANDSAT images have resolutions of 30 m and are available only at 16-day intervals, we have been pursuing increased collaboration with USGS and USACE to develop a near real-time, satellite-based, water quality and HAB monitoring model for all large lakes in the state using daily images from satellites such as MERIS (15 bands, 300-m resolution) and RapidEye (5 bands, 6.5-m resolution), as well as DoD satellite imagery available through the USACE. Such a monitoring tool could provide efficient, near-real time, low-cost remote monitoring for targeting limited resources for *in-situ* monitoring while allowing greater coverage of lakes for public health protection.

Methodology:

We have sampled 12 and 11 sites each in Lake Texoma and Grand Lake, respectively, based on previous monitoring programs of the PEL lab (Texoma) and the BUMP program of OWRB (Grand) (OWRB 2010). Grand Lake was visited five times; Texoma four. Many other lake visits were planned and cancelled due to overcast skies and other weather-related conditions. During lake visits, samples were collected for chlorophyll (total algae), phycocyanin (blue-green algae), golden algae, total organic carbon (TOC), colored dissolved organic matter (CDOM), and turbidity. We also measured reflectance of the water at each sample site, using ASD FieldSpec@3 and ASD Handheld-2 spectroradiometers. Ten measurements were recorded from each side of the boat, and the mean, median, and standard deviation of these twenty measurements constitute the reflectance for each site. White-surface calibration of the instrument was done every 30 minutes or more frequently if sky conditions changed. In addition to NADIR angle measurements, we carried out measurements at several viewing angles, and the resultant data will be used for radiative transfer models and the study of the effect of viewing angles on *in-situ* water reflectance. We also used a GPS-enabled digital camera (Casio Exilim EX-H20G) and an iPhone to take photos of the water at each site.

Temperature, pH, dissolved oxygen (DO), conductivity, chlorophyll a (a proxy for total algal biomass), and phycocyanin (a proxy for cyanobacterial biomass) were measured in situ with a Hydrolab DS5x sonde (Texoma) or a YSI 6600 V2-4 sonde (Grand). The sondes were deployed at 1-m intervals from the surface to the thermocline or lake bottom (depending on season and site). Light extinction was measured using a Li-Cor 2π PAR sensor deployed at 1-m intervals from the surface to 1% surface light. Secchi depth was measured using a standard 20-cm Secchi disk. Depth-integrated (upper 10 m or to 1% surface light) water samples (250 mL) were collected in sterile Nalgene bottles, stored on ice in the field, and refrigerated in the laboratory for subsequent sub-sampling for CDOM, extracted chlorophyll, and turbidity. Golden algae densities were measured using qPCR (Zamor et al. 2012). CDOM was measured by fluorometry (American Public Health Association 2012).

The spectral characteristics of water in lakes are functions of hydrological, biological and chemical characteristics of water and other interference factors (Seyhan and Dekker, 1986). We have conducted preliminary statistical data analyses of water constituents (algal pigments, turbidity, Secchi depth transparency), light penetrance and extinction, water hyperspectral reflectance from ASD spectroradiometers, and reflectance data for LANDSAT and digital camera sensors representing red, green, and blue wavelengths.

Principal Findings and Significance:

We completed five trips on Grand Lake and four on Lake Texoma for a total of 88 water samples. Due to partial cloud cover on some lake trips, we have 44 usable site-specific satellite images for Grand lake and 32 usable site-specific satellite images for Texoma.

Preliminary results are extremely promising. Both satellite- and spectroradiometer-measured reflectance were strongly related to chlorophyll, phycocyanin, and turbidity, indicating that all three water quality parameters could be accurately predicted remotely in both Lake Texoma and Grand Lake. Despite some problems with obtaining simultaneous ground and satellite data, we were able to collect water quality and reflectance data from a wide range of conditions, from low to moderate turbidities and concentrations of chlorophyll and phycocyanin. There was also a moderate degree of overlap in water quality values between the two lakes, suggesting that observed relationships may be robust across a wider range of lakes and lake types. This is particularly true for LANDSAT-based water quality estimation. However, the in-situ reflectance measures (ASD spectroradiometers, digital camera), while very accurate at estimating water quality parameters in Lake Texoma, where much less capable of such for Grand Lake. We have discussed these issues with researchers at Grand Lake and are considering options for additional measurements and parameters necessary to improve our models.

Overall, this study has provided a firm foundation for ongoing and future research aimed at developing a state-of-the-art remote sensing-based tool for providing affordable, efficient, near-real time water quality and HAB assessment, that will allow for more focused targeting of limited resources, while simultaneously allowing for greater coverage of monitored lakes across the state, particularly isolated and difficult to sample lakes, thus maximizing public health protection.

These and other results were presented at the 2014 Oklahoma Governor's Eater Conference and Oklahoma Water Resources Research Institute symposium in Oklahoma City and are currently being prepared for publication. However, because online posting of our results in this report could potentially jeopardize future publication of the student projects associated with this research, we are not presenting any details of our analyses, nor any data, in this report. Of course, we will be happy to discuss any aspect of this project in person, should anyone within the WRAB, OWRRI, USGS, or OWRB wish. Copies of all publications arising from this project will be forwarded to the OWRRI.

Literature Cited:

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