Title Page

A. Project Title
Applying Unmanned Systems for Water Quality Monitoring

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Technical Proposal and Evaluation Criteria

A. Executive Summary

Date: October 30, 2020
Applicant Name: Oklahoma State University
City: Stillwater
County: Payne County
State: Oklahoma

Project Summary: Eutrophication, sedimentation, and harmful algal blooms (HABs) diminish the utility of reservoirs for recreation, drinking water supply, and ecosystem service provision. HAB outbreaks have increased recently and are exacerbated during drought conditions, which act to concentrate nutrients in reservoirs. The Grand Lake O' the Cherokees (Grand Lake) in Northeastern Oklahoma experienced a severe HAB outbreak during the 2011 drought that resulted in a swim ban and significant negative impacts on the local economy. Grand Lake has continued to experience HAB outbreaks in subsequent years. In addition to issues with HAB formation, severe flooding in 2015 and 2019 transported tons of sediment into Grand Lake that has led to losses in storage capacity. Forecasting HAB formation and sedimentation in reservoirs such as Grand Lake remains a formidable challenge because of the vast scale of watersheds and sources of these pollutants. There is a critical need for new monitoring methods to improve forecasts of reservoir sedimentation and HAB formation. This project will develop a monitoring system that provides high-spatial resolution datasets of nutrients, sediments, and HAB levels in Grand Lake using a variety of unmanned systems for improved decision support. The specific objectives of the project are to: (1) implement unmanned surface vessels for in-situ monitoring of bathymetry, nutrient and algal levels in surface waters, (2) implement unmanned aircraft systems for remote sensing of temperature, turbidity, and algal levels in surface waters, (3) Utilize the data from unmanned surface vessels and unmanned aircraft systems to measure the formation of HABs and sedimentation, and (4) interpret observed nutrient and sediment loadings using a watershed model. The project is a partnership between Oklahoma State University (OSU) and the Grand River Dam Authority (GRDA), who manages Grand Lake. The project is expected to assist GRDA and other stakeholders to implement best management practices for reducing non-point source runoff, issue more accurate early warnings of swim advisories due to HAB outbreaks, and provide guidance for dredging and sediment management activities at Grand Lake. Funding from Reclamation will be used for travel to and from Grand Lake to implement the monitoring system, procure electronics and water quality instruments, and provide salary for the project team members. The project is consistent with the goals of the WaterSMART Applied Science Program's objective "to develop hydrologic information and water management tools and improve modeling and forecasting capabilities." The monitoring system will increase access to information and lead to improved modeling and forecasting capabilities, which will improve the reliability of water supplies, help manage droughts, assist with endangered species requirements, and restore watershed health.

Project Duration: 24 months
Start Date: 05/01/2020
End Date: 04/30/2022
Federal facility: No

B. Technical project description and milestones

1. Introduction and Problem Statement

Runoff of soil and sediment particles from land areas diminishes surface water quality and decreases reservoir capacity. Nutrient runoff from agricultural fields, animal feeding operations, and wastewater promotes the growth of algae and cyanobacteria, which create nuisance and harmful algal blooms (HABs) in reservoirs. Sediments in runoff transport nutrients and pollutants, which affect ecosystem health and HAB formation. Eutrophication, sediment resuspension, and HAB formation diminish the utility of reservoirs for recreation and drinking water supply and negatively affect other important ecosystem services. Microcystins and other emerging contaminants are produced by HABs that create negative health impacts [1]. The decay of HABs in water bodies decreases dissolved oxygen concentrations, which causes ecological dead zones [2], [3]. HAB decay also releases compounds that cause taste and odor problems in drinking water systems that sometimes co-occur with cyanotoxins [4]. It has been suggested that HABs represent the greatest inland water quality threat to public health and ecosystem well-being [5].

HAB outbreaks in Oklahoma have increased recently, and their occurrence has negatively affected recreation and tourism in reservoirs as shown in Figure 1 [6]. The Grand Lake O' the Cherokees (Grand Lake) is a large reservoir in Northeastern Oklahoma that supplies water to cities, farms, and power plants that also serves as a popular tourist destination. Grand Lake experienced a severe outbreak of cyanobacteria during the 2011 drought that resulted in a swim ban and significant negative impacts on the local economy. Recent extreme rainfall events in 2015 and 2019 transported tons of sediment into Oklahoma water bodies, including Grand Lake. Sediments entering Grand Lake are highly polluted due to 100 years of intense mining activity in the nearby Tri-state (Kansas, Missouri, Oklahoma) area [7]. Grand Lake continues to experience diminished water quality, HAB outbreaks and sedimentation.

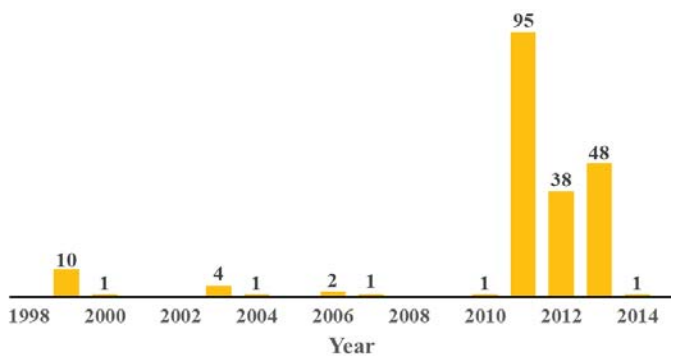

Figure 1. Number of monthly swim advisory warnings from HAB formation reports in Oklahoma reservoirs between 1998 and 2015.

Forecasting HAB formation and sedimentation in reservoirs such as Grand Lake is a complex technical challenge. HAB formation depends on the availability of carbon, nitrogen, phosphorous, sunlight, and trace nutrients. HAB growth rates are also heavily influenced by the temperature [8]. Land management practices affect sediment, nutrient and heat fluxes to water resources, thereby affecting the likelihood of HAB outbreaks. Changes in the magnitude and frequency of extreme weather events and increased agricultural production rates may exacerbate erosion and sedimentation processes and increase HAB outbreaks at locations such as Grand Lake. Because of these interrelated factors, forecasting HAB formation remains an unresolved challenge [5]. New models are needed to predict the formation of HABs and sediment transport to inform strategies for HAB mitigation and sediment management. Due to the complexity of nutrient and sediment dynamics, models are inherently limited by the availability of reliable data available for calibration.

Monitoring sediment transport, nutrient, and HAB formation in a large watershed such as Grand Lake is formidable challenge as a result of the multitude of pollution sources distributed throughout the large area. Given the growing incidence of extreme weather events and increased demand for agricultural production, there is a **critical need** for new observational methods to understand the causes of HAB formation and sediment transport to inform land and water management policies. Unmanned systems can be used to gather extensive data using both remote sensing and in-situ approaches relatively inexpensively to help improve water quality forecasts and provide enhanced decision support to water managers.

2. Project Goals and Objectives

The overall goals of this project are to develop a monitoring system for Grand Lake that provides high-spatial resolution datasets of nutrients, sediments, and HAB levels using unmanned systems and provide improved models of the behavior of these constituents. The development of these tools will assist with decision support for various water management activities at Grand Lake. Unmanned systems have potential to reduce the costs of monitoring in addition to providing extensive quantities of spatial and temporal data. The **specific objectives** of this project are to:

Objective #1: Implement unmanned surface vessels for in-situ monitoring of bathymetry, nutrient and algal levels in surface waters

Objective #2: Implement unmanned aircraft systems for remote sensing of temperature, turbidity, and algal levels in surface waters

Objective #3: Utilize the data from unmanned surface vessels and unmanned aircraft systems to measure the formation of HABs and sedimentation

Objective #4: Interpret observed nutrient and sediment loadings using a watershed model

The project will provide new monitoring tools at Grand Lake including remote sensing with unmanned aircraft systems (UAS) and in-situ sensing with unmanned surface vessels (USV). These tools will be used to assess sediment and nutrient dynamics in select parts of Grand Lake as shown in Figure 2. The long-term goal is to develop a system to identify, forecast, and respond to nutrient and sediment resuspension and HAB formation events to preserve water quality.

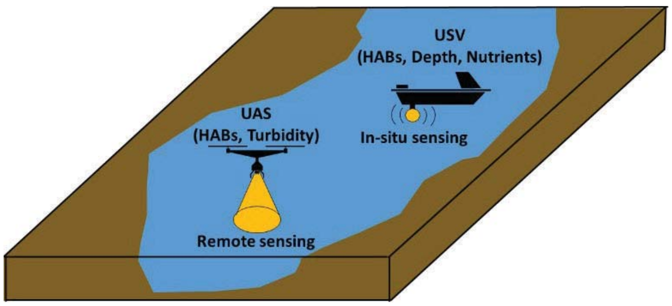

Figure 2. Proposed UAS and USV-based monitoring system for nutrient and sediment dynamics.

Rationale. The focus of the study will be on Horse Creek cove, which is a high nutrient arm of Grand Lake that has a relatively small watershed. By assessing a small catchment where there are fewer sediment and nutrient sources, it will be possible to gain insight into the relationships between HABs, climatic conditions, sediments, and nutrient precursors. HABs often commence in shallow waters when they are fed by tributaries with high nutrient loadings, since sunlight can penetrate the majority of the water column and water temperatures are higher. Shallow coves are difficult to monitor with satellite imagery due to turbidity and nearby land interference. According to reports, HAB outbreaks often begin where Horse Creek enters the reservoir. We hypothesize that by analyzing the coves with warm water that receiving high nutrient loadings, we will be able to understand the importance of nutrient releases in shallow sediments relative to influxes during summer storms. This pilot study will build on research by the project team using a USV equipped with in-situ water quality probes and UAS outfitted with multispectral image capturing tools. A water quality model will be developed to interpret the behavior of nutrients and sediments in Horse Creek cove. The project is expected to assist stakeholders at Grand Lake to implement best management practices (BMPs) for reducing non-point source runoff, issue early warnings of swim advisories due to HAB outbreaks, and provide guidance for sediment management at Grand Lake.

Project Participants. The project is a partnership between Oklahoma State University (OSU) and the Grand River Dam Authority (GRDA), who manages Grand Lake. The project manager for the project is Dr. David Lampert, Assistant Professor of Civil & Environmental Engineering at OSU. Dr. Lampert's expertise lies in water quality and contaminant transport modeling, water pollution monitoring, and environmental software development [9]–[13]. The co-project manager is Dr. Jamey Jacob, Professor of Mechanical and Aerospace Engineering at OSU. Dr. Jacob is the Director of OSU's Unmanned Systems Research Institute (USRI) [14]–[16]. The USRI will leverage the project activities by providing engineering support, hardware, and materials to maximize project's chances for success. Dr. Lampert and Dr. Jacob have been collaborating on the development of unmanned systems for surface water monitoring for the past two years with support from the OSU Vice President for Research.

GRDA Project Partnership. Dr. Darrell Townsend and Dr. William Mausbach of GRDA will coordinate with the OSU team to implement and test the unmanned water quality monitoring system at Grand Lake (see attached letter of participation). Dr. Townsend is an expert in watershed management and water quality who oversees GRDA's water quality laboratory. GRDA staff and summer interns will assist the OSU team with sample collection, analysis, and quality assurance. GRDA is interested in collaborating with the OSU team because of the challenges associated with managing Grand Lake and because of their interest in the new unmanned systems technology. GRDA staff want to use this technology to improve the reliability of water supplies, manage droughts, meet endangered species requirements, and restore watershed health.

Project Category. This is a University application that falls under **Category B** in the solicitation.

3. Benefits to Water Supply Reliability

The project will specifically improve the following issues listed in the solicitation: (a) water supply reliability, (d) drought management activities, (g) ability to meet endangered species requirements, and (h) watershed health.

(a) ***Water supply reliability***. Loadings of sediments, additions of nutrients, and outbreaks of HABs diminish the reliability of water supplies. Water bodies experiencing outbreaks of HABs cannot be used for recreational purposes due to human and animal health risks. HAB presence in drinking water supplies requires advanced treatment to remove toxic substances and taste and odor compounds. Sedimentation decreases the available volume of reservoirs used for supply. Many water intakes from Grand Lake are located nearshore, where they are susceptible to silting. This project will provide improved information on all of these issues that affect the water supplied by Grand Lake. The improved information and modeling will help to reduce these effects and thereby improve water supply reliability.

(d) ***Drought management activities***. In addition to decreased volumes of water, droughts act to concentrate pollutants and other inputs in water supplies. Higher levels of nutrients during droughts, combined with warmer water and abundant sunshine lead to HAB proliferation. This project will create tools that can be used to identify HAB outbreaks early and monitor their progression throughout drought periods. Such a tool will be particularly important to GRDA in drought scenarios when either an in-situ or ex-situ treatment process is needed to ensure the quality is suitable for drinking water supply. The watershed model will also be useful for estimating the effects of climate change on HAB formation at Grand Lake in the future.

(g) ***Ability to meet endangered species requirements***. Grand Lake is home to the threatened Neosho Madtom, which is a small North American freshwater catfish. Dams and reservoirs have inundated much of the Madtom's habitat, destroying the gravel riffles and the swift currents the fish needs lives. High levels of turbidity, sedimentation of gravel areas, changes in water temperature, and pollution from feedlots affect the Madtom's habitat. This project will provide improved information on each of these water quality issues that could lead to restored habitats for the Madtom in and around Grand Lake.

(h) ***Watershed health***. The levels of nutrients, sediments, and dissolved oxygen are key indicators of the health of an aquatic ecosystem such as Grand Lake. The proposed unmanned systems and water quality monitoring tools will provide high resolution indicators of the presence of nutrients and suspended particles that can be used to understand the effects of BMP implementation at Grand Lake. HAB outbreaks can produce toxins and reduce dissolved oxygen levels, which reduce the health of the watershed. The monitoring system developed in this project will help identify and respond to HABs more quickly to reduce these effects.

Relationships to ongoing work at Grand Lake. The project activities will complement ongoing water quality monitoring that is performed by GRDA to assess issues including sedimentation and HAB formation. GRDA's staff have a variety of tools for monitoring, including sondes and HAB toxicity assays. There are no ongoing monitoring projects with unmanned systems or watershed models for Horse Creek cove. GRDA has been investigating the usage of satellite-based systems for remote sensing of HABs. The unmanned systems should provide higher spatial and temporal resolution data than the satellite approach and the laboratory testing. The system will also potentially save costs on water quality lab assessments in the reservoir by reducing labor time.

4. Need for Project and Applicability of Project Results

The project will provide a new monitoring system for nutrients, sediments, and HABs at Grand Lake. Given the growing incidence and impacts of HABs and sedimentation on surface waters, the results will have long-term benefits for watershed and water quality management in the area.

Interested parties. The need for enhanced water quality monitoring has been expressed repeatedly by GRDA and other stakeholders in the region. The Grand Lake Watershed Plan provides an overall strategy for nutrient management within the multistate area [17]. Each of the three major rivers (Neosho, Spring, and Elk) that feed the reservoir has nutrient impairment issues. GRDA has identified watershed-wide sediment and nutrient modeling and stream bank stability studies as a priority initiative to help restore the lake [17]. Stakeholders throughout the watershed including the Oklahoma Conservation Commission (OCC) and the Oklahoma Water Resources Board (OWRB) are attempting to improve implementation of BMPs for nutrient management that would benefit from these improved observation tools [18].

Information to be obtained. The results of this project will be immediately valuable, since HAB outbreaks often commence in Horse Creek. By developing an unmanned systems approach now, it will be possible to extend this project from this one small part of the watershed to encompass a much larger area to identify and respond to sources of impairment in the future. The tools will be used to inform swim advisories and provide warning to drinking water providers dependent on the water. The results will also provide insight into the levels of sedimentation that occurred during the recent flooding, since the last bathymetric survey was performed in 2009. The results are expected to be highly transferable to other users in Oklahoma. The OWRB has expressed interest in unmanned systems for a variety of monitoring activities.

Stakeholder participation. GRDA has agreed to work with the OSU team to access the locations in Grand Lake to study water quality as outlined in the attached letter of participation. GRDA will provide feedback to the OSU team on the utility of the unmanned systems monitoring program to ensure that it provides maximum value for water management. GRDA staff provide guidance to the OSU team on how this program can be implemented to assist GRDA improve the reliability of water supplies, help manage droughts, assist in meeting endangered species requirements, and restore watershed health. The OSU team will also meet with OWRB, OCC, and other state agencies and water managers to gather input on the application of this technology at other sites in Oklahoma and feedback on how to make the system more useful.

5. Background

Project Study Location. Grand Lake has a watershed of more than 10,000 square miles of natural and agricultural land extending into four states (Oklahoma, Arkansas, Kansas, and Missouri) as shown in Figure 3. Grand Lake supplies water to cities, farms, and power plants. It is also a popular tourist destination. The reservoir regularly experiences HAB outbreaks in the summer months that affect the provision of these services. Grand Lake is managed by GRDA, who performs extensive monitoring for HABs. The combination of existing monitoring efforts, regular outbreaks, mixed agricultural and natural land use make Grand Lake an ideal location to investigate the dynamics of sediments, HAB formation and nutrient management.

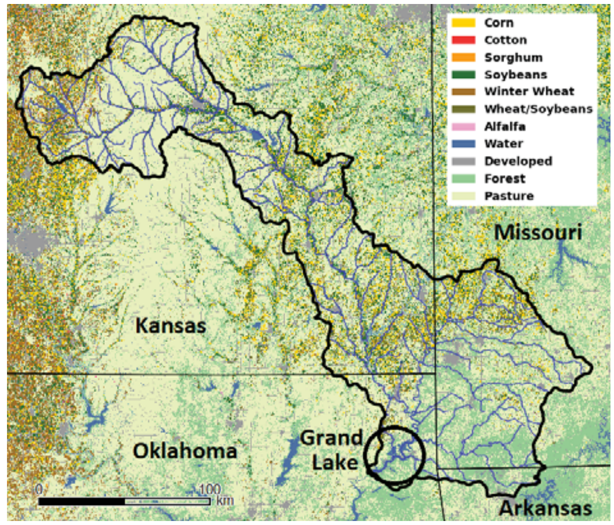

Figure 3. Grand Lake Watershed.

Grand Lake was formed by the construction of the Pensacola Dam on the Neosho (Grand) River shown in Figure 4. The Spring and Elk Rivers are additional primary contributors, but water is also supplied by many smaller tributaries as shown in Figure 4. Different land management practices in these watersheds create areas of varying trophic status through the lake. The Horse Creek Watershed contains many acres of row crops including corn, wheat, and soybeans, while the Honey Creek Watershed contains extensive pastureland. Additional sources of nutrients include septic systems, wastewater treatment plants, and animal feeding operations. The lack of controls on nutrient runoff has diminished the water quality in these coves. Assessments by GRDA and OCC have determined that the Sycamore Creek and Drowning Creek watersheds are relatively undisturbed and possess comparatively high water quality. GRDA has partnered with other state agencies and stakeholders to implement nutrient reduction practices for Honey Creek [18], [19]. The variable trophic status of these coves of Grand Lake provides an opportunity to compare the nutrient dynamics of impaired and pristine sub-watersheds.

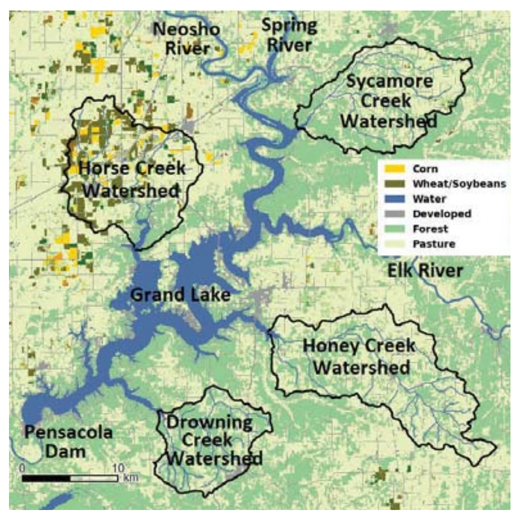

Figure 4. Grand Lake Tributaries.

Recent HAB Outbreaks and Droughts at Grand Lake. The Horse Creek cove was the site of extreme HAB outbreaks in 2011 [20] and again recently [21]. The Southern Plains often experiences hydrologic extremes, including recent periods of drought (2010-2013) and flooding (2015, 2019). The probability of HAB formation increases during droughts when stream flows decrease, causing nutrient levels and water temperatures to increase. The Palmer Hydrologic Drought Index (PHDI) is often used to characterize drought severity, with values less than 2 representing extreme droughts [22]. The monthly PHDI between 2010 and 2017 for Northeastern

Oklahoma shown Figure 5 illustrates the drought conditions during recent HAB outbreaks. Future changes in climate could exacerbate these events. The project team at OSU has been working with GRDA to apply remote sensing algorithms to the reservoir [23], using satellite data from the Landsat missions and open source software to monitor HABs on the basis of chlorophyll-a (Chl-a) and cyanobacterial levels. Figure 6 shows remotely-sensed observations in Horse Creek cove in recent summers. The HAB outbreak appears prominently during the 2011 drought.

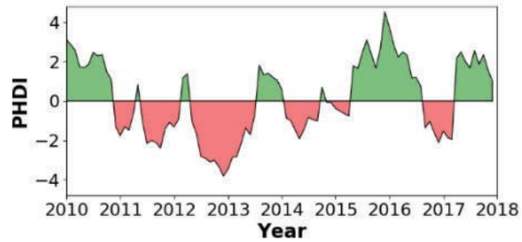

Figure 5. Recent droughts in Oklahoma.

***HAB Background*.** Nutrient pollution has raised global algal biomass rates by approximately 60% relative to background conditions, which is the driver behind HAB proliferation [24]. The limiting nutrient for HAB growth is often either nitrogen or phosphorous [25], although other critical nutrients have been connected to HAB growth rates [26]. In inland freshwater systems, phosphorous is more frequently the limiting nutrient [27]. Other recent research has indicated that phosphorous limits HAB growth in the warmer summer months, whereas nitrogen limits growth in the spring [28]. Dual control strategies for nitrogen and phosphorous reduction have thus been suggested [29]. A previous study at Grand Lake found that release of phosphorous from the sediments created nitrogen limiting conditions following thermocline erosion [30]. The monitoring system proposed in this project should provide better insight into HAB formation and control strategies at Grand Lake that are transferable to other locations. HABs are sometimes initiated from resting cysts present in bottom sediments [31], so re-suspension events may be important. Internal processes within coves can release nutrients to sustain and shift blooms to harmful levels with toxin releases. Thus it is important to understand nutrient sources and the internal dynamics in coves that might become hydrologically isolated during the growing season.

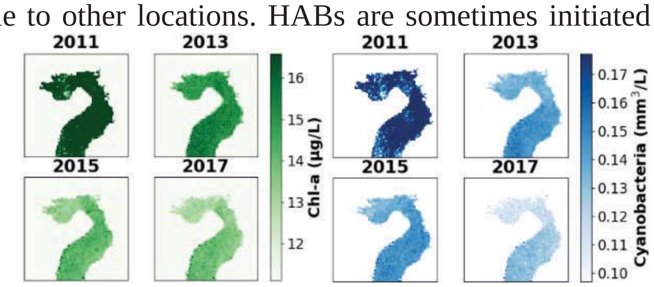

Figure 6. Chl-a (left) and Cyanobacteria (right) in Horse Creek cove in recent summers.

Sediment Background. Increased levels of suspended solids have major impacts on navigation, water supplies, water quality and ecology. Sediments that are transported into reservoirs are eventually deposited, which results in losses of reservoir capacity [32]. Sedimentation reduces the navigational capacity of waterways, which eventually requires dredging to restore channel depths [33]. The costs of diminished navigation can reach $5 per ton of eroded soil in areas of significant shipping. The presence of suspended particles in water supplies also increases costs for drinking water treatment plants [34]. Fish habitats are negatively affected by high levels of suspended solids, which decrease water clarity [35]. Heavy metals are often strongly associated with sediments, so re-suspension of contaminated sediments can substantially increase their levels in water systems and lead to bioaccumulation [36]. Metal pollution in sediments is particularly troublesome at Grand Lake due to the legacy of 100 years of mining at the Tar Creek Superfund site upstream in the watershed [7]. Toxic hydrophobic organic compounds also accumulate in sediments near their sources, where they can be released to create environmental risks [37]. Since phosphorous levels in water are often a limiting nutrient for the growth of HABs, reducing sediment re-suspension is one of the primary approaches available to water managers for preventing HAB formation [38]. For all these reasons, it is critically important to develop approaches to understand sediment transport and resuspension within reservoirs such as Grand Lake.

Additional Water Quality Monitoring Approaches. Satellite-based remote sensing provides one approach to gather more data on HAB and sediment levels in reservoirs. The CyAN project is focused on developing an early warning system for HABs using satellite imagery [39]. CyAN is a joint effort of the U.S. Geological Survey (USGS), Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). While this approach shows great promise, the unmanned systems-based methodology developed in this research should provide advantages during periods of cloud and aerosol coverage, increasing the spatial and temporal frequency of observations, detecting near-shore blooms, and facilitating collection of physical samples for toxin analysis.

6. Project Implementation

The complexity of sediment, nutrient and HAB dynamics appears to be ripe for innovation from the ongoing data revolution, provided reliable sources of information are provided. This project will create an observatory for water quality at Grand Lake that will provide a foundation for improved modeling and decision support. The **specific objectives** of the project are to: (1) implement unmanned surface vessels for in-situ monitoring of bathymetry, nutrient and algal levels in surface waters, (2) implement unmanned aircraft systems for remote sensing of temperature, turbidity, and algal levels in surface waters, (3) utilize the data from unmanned surface vessels and unmanned aircraft systems to measure the formation of HABs and sedimentation, and (4) interpret observed nutrient and sediment loadings using a watershed model.

***Objective #1: Implement unmanned surface vessels for in-situ monitoring of bathymetry, nutrient and algal levels in surface waters*.** The project team has developed a customized USV for bathymetric surveying and temperature measurement that can also monitor additional water quality parameters including nitrates, ammonia, turbidity, conductivity, chlorophyll-a, pH, and phycocyanin. Data processing algorithms have also been developed to turn the raw data into gridded products. The existing technology will be used to implement a monitoring program at Grand Lake to analyze nutrient, sediment, and HAB formation dynamics.

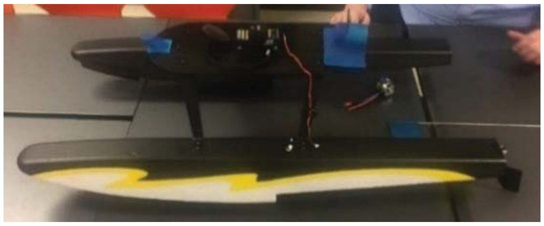

Figure 7. USV prototype: OSU Autoboat.

Current experimentation is being done with a manually controlled remote control (RC) boat with an attached embedded system to gather and fuse global positioning system (GPS) and temperature data shown in Figure 7 named the "OSU autoboat." The OSU autoboat is a pontoon based fan boat system that is powered by a RC fixed wing motor and propeller combo, but features a rudder instead of vectored thrust. The automation system is a Pixhawk 2.1 flight controller in rover mode with GPS and telemetry feedback, which enables fully autonomous missions for high accuracy and repeatable data collection. The prototype is designed to be compact and water resistant so that data can be collected and stored to a micro SD card for post processing. The logging system hardware consists of a Teensy 3.6 USB development board with integrated SD card reader, a Venus GPS module with an ANT-555 GPS antenna, and a waterproof DS18B20 temperature sensor. The software for the Teensy 3.6 is written with the Arduino and the Teensyduino libraries. Each time the system is powered on, the software creates a unique file on the SD card, sends a request for data to the DS18B20, gathers GPS and sensor data, and stores the data into a file. Adjustable data logging rates provide a balance between volume and accuracy.

The OSU autoboat can explore a body of water randomly or by following a set GPS path. This plan includes the use of a Pixhawk autopilot, programmed to control the boat's rudder from one of the numerous PWM outputs. The Pixhawk has internal GPS and a compass for guiding the USV to particular waypoints as well as logging the coordinates of the USV data. A microcontroller gathers data from the Pixhawk and measurement readings from onboard sensors. A radio transceiver is used between the USV and a ground station computer. The computer can be used to set a geofence for random guidance within a specified area or set waypoints for the USV to follow. This ground station runs Mission Planner software to make a user interface. The logging software gathers GPS data using publicly available MAVLink libraries.

Additional communications are being set up between sensors onboard the USV. The capabilities are being expanded to monitor nitrates, ammonia, turbidity, conductivity, chlorophyll-a, pH, and phycocyanin using an EXO3 sonde shown in Figure 8 from YSI, Inc. An interface for communication is being developed between the sonde and the USV currently, but it should be ready prior to the start of the project. The EXO3 is a 5-port multiparameter sonde with a built-in antifouling system capable of wireless communication at low power consumption. Communication channels make use of an RS-485 port.

Figure 8. YSI EXO3 Sonde.

The capabilities of the USV are being tested by surveying Boomer Lake and other reservoirs near the OSU campus. While the USV course can be either directly controlled or follow a predetermined pattern on the lake, machine learning capabilities are being developed to perform exploration, avoid objects, respond in real time to sensor data, and incorporate human input. These capabilities will allow the USV to map an area while searching for key environmental conditions along gradients to find hot spots or determine optimum sampling conditions to maximize coverage in a limited amount of time, with the system navigating autonomously according to sensor input.

Following a survey with the USV, the observations can be used to create a map as shown in Figure 9 using data from a 2015 hydrographic survey of Boomer Lake and software the OSU team has developed that interpolates individual observations to generate a gridded data product. Following successful demonstration of mapping reservoir characteristics, this approach will be used for water quality and bathymetric mappings at the Horse Creek Cove at Grand Lake. Chlorophyll, turbidity, and phycocyanin observations will be checked against lab measurements to verify efficacy. We will compare results with remotely-sensed observations of these parameters from satellite imagery. A preliminary test run at Boomer Lake was able to closely match the water depths from the 2015 survey as shown in Figure 10. The differences are likely due to variable lake levels and other sources of measurement error such as bobbing that will be eliminated in the next few months.

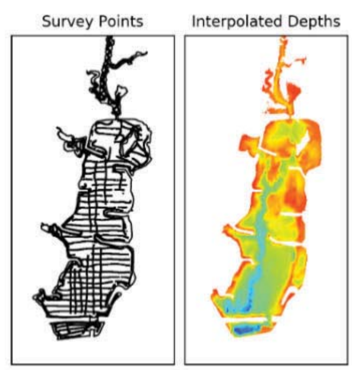

Figure 9. Interpolation algorithm example.

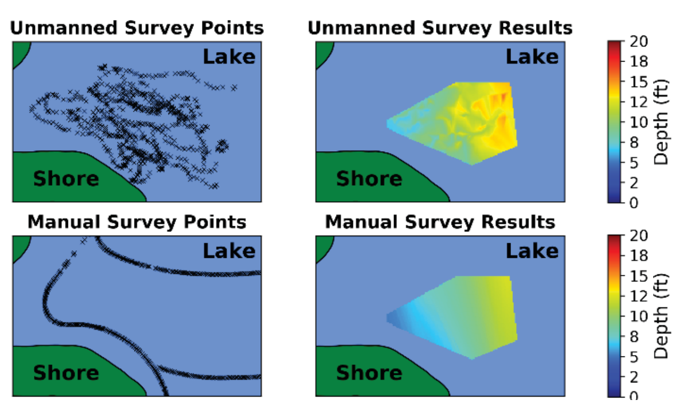

Figure 10. Unmanned bathymetric survey versus results from a 2015 manual survey at Boomer Lake.

The USV will be used to generate an extensive dataset of water quality parameters routinely at Grand Lake over the course of the project. The first summer will focus on implementation of the monitoring system at Horse Creek. A graduate student will continue to travel monthly to Grand Lake throughout the project period to gather high resolution data at Horse Creek Cove. The student will spend approximately one month mapping nutrient and HAB data in various coves in July and August each year of the project, since this is the typical HAB formation period. The primary focus will be on the cove receiving inflow from Horse Creek, so the USV will be deployed in this reach on repeated trips weekly in the morning and afternoon. We expect to develop a rich dataset that can be used to map water quality.

Objective #2: Implement unmanned aircraft systems for remote sensing of temperature, turbidity, and algal levels in surface waters. A monitoring system to estimate the concentrations of suspended particles, HABs, and water temperature will be implemented using remote sensing with multispectral imagery from UAS. This approach provides many advantages over the USV, although not all water quality parameters can be sensed remotely (e.g., depth, nitrates). The USV and UAS data are thus complementary, and the co-generation of UAS and USV data provide opportunities to assess the performance of remote sensing methods. Previous studies in the literature provide the data needed to quickly implement this UAS-based water quality monitoring approach. UAS-based multispectral imagery technology has been used to assess concentrations of suspended solids levels in reservoirs and streams [40], [41] and surface water temperatures [42]. The concentrations of HABs in water are related to the abundance of the green pigment chlorophyll-a and the blue-green pigment phycocyanin. Algorithms have been developed to estimate the levels of these pigments based on the absorption and reflectance from spectroradiometers [43]. We will use these existing approaches to monitor chlorophyll-a and phycocyanin levels at Grand Lake in this project. The values of the specific absorption coefficients from the literature will be updated using the in-situ observations from both the USV and other measurements by GRDA staff. The resulting tool will enable the observations of the formation of the HABs throughout the summer bloom period.

The project team has extensive experience in the development of small UAS technology for environmental applications, including atmospheric boundary layer sensing and water monitoring. The OSU USRI has designed UAS with autopilot capabilities, ground control and telemetry for repeated flights over designated test areas including GPS data for post-processing of longitude, latitude, altitude and speed. Other onboard sensors can be included as needed for additional atmospheric and environmental measurements. Figure 11 shows a quad copter UAS developed at OSU similar to the model that will be deployed at Grand Lake for gathering multispectral imagery data for estimating water quality parameters. The OSU USRI team has been using UAS imaging to estimate Normalized Difference Vegetation Index (NDVI) for agricultural based on previously established methods [44]. We will build on these existing capabilities and other research, which has demonstrated the ability for UAS to map water quality parameters at ~0.2 m pixel resolution [45]. Following integration of the various UAS components, the system will be tested for efficacy and then used for an intensive deployment Grand Lake. The data will be compared to in-situ measures with assistance from GRDA staff to validate the approach.

Figure 11. OSU UAS.

As demonstration of aerial surveillance capabilities, Lake Carl Blackwell was surveyed to examine an infestation of Floating Yellow Heart, an invasive lily that can be seen on the water surface, allowing it to be monitored from an aerial perspective. The infestation was monitored over a manner of months using both RGB and multispectral imagery. The platforms and sensors flown are from the OSU USRI fleet including a DJI Phantom 4 Pro platform that was flown throughout the time period and the standard RGB camera was used to collect the imagery. These images were processed using Agisoft Metashape, a Structure from Motion software, to render orthomosaics and develop 3D point clouds. In addition, a Micasense Red Edge was integrated on a DJI Matrice 100 and flown over specific coves to get multispectral orthomosaic data. The flights were flown at an altitude of 300 ft and approximate flight speed of 20, yielding a spatial resolution of 2.5cm/pixel for the datasets. The flights took approximately two hours to complete each day and 6 coves were covered. The UAS flew in a lawnmower pattern at 80% front and sidelap as shown in Figure 12. The defoliant SePRO procellaCOR was administered in the area of the infestation and the results were recorded and processed using these methodologies over a manner of months. The orthomosaics were processed using GIS tools and the change in area was quantified. Evaluation of the infestation area showed a rapid decrease in coverage, as shown in the left side of Figure A, demonstrating the differences between the months of May, June, and August.

Figure 12. Image survey process to monitor infested cove.

Objective #3: Utilize the data from unmanned surface vessels and unmanned aircraft systems to measure the formation of HABs and sedimentation. Remote sensing and machine learning have been applied to identify algal blooms, although most of this work has been conducted in coastal waters using data from satellites [46]. The data generated in Objective #1 and #2 will provide a unique opportunity to implement machine learning for HAB monitoring and potentially, for forecasting HAB evolution. The UAS-based estimates of chlorophyll and phycocyanin will be compared with observations from the USV. The in-situ monitoring of Chl-a and phycocyanin with the USV and the spectral imagery from the UAS will be used to generate algorithms to identify the concentrations of HABs. These algorithms will then enable the UAS-based monitored data to be translated into digital representations of HAB concentrations. These data would be particularly valuable when considering swim advisories and understanding HAB evolution each year.

A hydrographic survey with the USV will be used to estimate sediment accumulation in reservoirs. Grand Lake was surveyed in each summer of the project for bathymetry in 2009 [47]. The data collected by the USV will be interpolated as illustrated in Figure 9 to create a gridded data product. The data from 2009 can then be used to estimate the degree of sedimentation over the past decade. This information will provide an important calibration parameter for the watershed models that will be developed in Objective #4. It will also be useful for understanding the degree of sediment transport into the reservoir during the recent flooding events in 2015 and 2019. An additional survey will be performed in the second year to estimate sedimentation across the project period.

Machine learning will be explored to forecast HAB evolution based on the other water quality parameters. These forecasting tools will be helpful to assess strategies for in-situ HAB treatment approaches either by removing precursors or the algal biomass. Data from the USGS Landsat Mission will be compiled and used to compare the observations from Objective #1 and to assist in the machine learning efforts. Satellite-derived remote sensing observations of water quality maps will be compared with the Chl-a and phycocyanin, from the USV to assess compared these methods. The previous research with remote sensing data in saltwater systems will provide a foundation for this work focused on fresh water systems [46]. A machine learning model will be trained to use the temperature, dissolved oxygen, nitrate, turbidity data to predict Chl-a and phycocyanin levels. Depth and climatic conditions (wind, solar radiation, etc.) will also be included as training variables. We will examine a number of different algorithms to train the models from the datasets for this task, including feed-forward neural networks, back propagation, genetic programming, and support vector machine applications [48], [49]. The machine learning will be performed in the Python Programming Language using the Scikit-learn libraries [50].

Fluvial classification examples are shown as a demonstration, which uses aerial surveys combining both visual and IR images to determine the mixture of alluvial and sedimentary portions of the South Canadian River to develop connectivity metrics on a temporal scale and at varying flowrates. To characterize river connectivity, imagery was recorded and run through Agisoft Metashape, a Structure from Motion software, yielding orthomosaic data as well as shallow bathymetric data. An example of the flight path overlaid on a point cloud rendered from the data collected is shown in Figure 13. The data were collected at different flowrates throughout the year and the datasets are being evaluated for connectivity based on a ratio of sand bars and islands within the riverbanks to the overall river surface. Examples of this classification are shown in Figure 14, moving from an automated color classification, to riverbank identification, to connectivity classification.

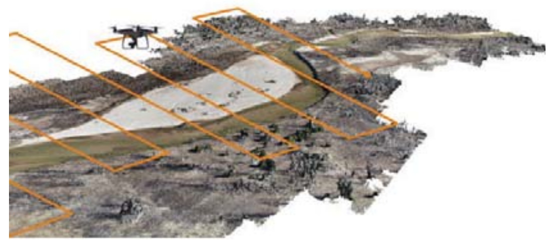

Figure 13. UAS survey pattern.

Figure 14. Image processing sequence for river classification.

The imagery used was gathered using a Phantom 4 Pro platform with the onboard RGB camera. A FLIR thermal camera was added to the phantom to include thermal data collection during the photogrammetric flights. The connectivity metric is being automated through different methodologies and compared to thermal imagery for error validation. The thermal imagery is currently being stitched together by hand and options for automating the process using RGB imagery are being explored. These methodologies include using Python, MATLAB, and GIS tools to classify images utilizing object recognition algorithms.

Objective #4: Interpret observed nutrient and sediment loadings using a watershed model. The proposed monitoring systems developed in Objective #1 and #2 will provide information that can be translated into new and enhanced simulation tools. The work in this objective will focus on estimating nutrient fluxes into the Horse Creek cove from upstream in the watershed, given that this area is a known source of nutrients that shows persistent HAB formation. A monitoring station will be installed to provide estimates of the discharge needed to calibrate the model. The watershed has no streamflow monitoring stations currently, so an unmanned system will be installed to monitor discharge and nutrient fluxes. We will use a MeterGroup CTD combined sensor that provides water depth (stage), conductivity, and temperature output that can then be used to monitor stage continuously. We will use an Arduino mayfly datalogger board to capture the output from water level sensor. Open source libraries are available to connect the datalogger to internet-compatible devices [51]. An acoustic Doppler instrument will then be used to measure discharge during a few high flow events to develop the rating curve. A solar-powered Teledyne Isco autosampler will be used to collect samples into a refrigerated holding container. The autosampler will be programmed to collect samples infrequently during flow water level conditions, but at high resolution during storms when water level rises. The turbidity observations will be cross-correlated with total suspended solids measurements to provide an algorithm to estimate solids concentrations. The team has all of this equipment available to begin using for this project immediately. Physical samples will be retrieved periodically and analyzed for suspended solids, ammonia, nitrates, dissolved and total phosphorous to estimate nutrient loadings into the cove and to form the basis for watershed modeling efforts. GRDA staff will assist with sample collection and analysis.

The influence of climatology and nutrient sources in the Horse Creek watershed shown in Figure 15 will require a model to simulate runoff and land management practices. The Hydrological Simulation Program in Fortran (HSPF) will be the basis for this tool. The OSU project team has extensive experience in watershed model development that will facilitate its creation. The project director has a specialized set of tools for data processing and calibration that will simplify this task [9], [13]. Model development should be straightforward, since there are no reservoirs and significant hydraulic structures in the area. The model will be used to simulate runoff from nutrient sources in the watershed including septic systems, in-stream recreation, livestock, and wastewater treatment plants into the lake.

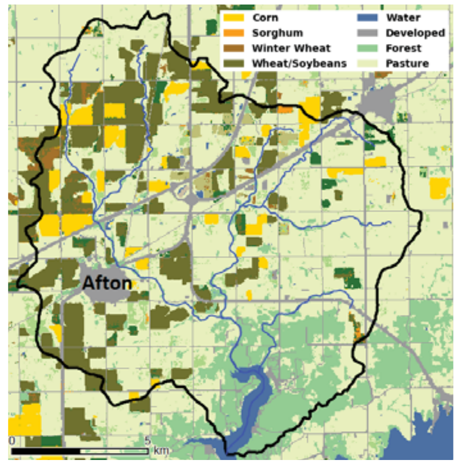

Figure 15. Horse Creek Watershed.

Key inputs to the model include climate, land use, hydrography, and nutrient applications. Typical values for nutrient sources including feedlots and septic systems will be used to inform these models. Daily climate data, including precipitation and minimum and maximum air temperature will be obtained from nearby climate stations. Soil properties will be derived from the Soil Survey Geographic database. Land-cover types will be determined using a 16-class land cover classification scheme at a 30-meter spatial resolution. Data generated by the monitoring station will be used to calibrate the model. The model will be able to forecast nutrient loadings in the watershed. The development of this tool for watershed management, combined with machine learning for HAB formation rates in the reservoir, should enable forecasting under various climate scenarios in future research efforts. The results are expected to provide improved information on behavior of non-point sources pollutants to regulatory agencies and stakeholders of Grand Lake. This information can improve decisions regarding BMPs for reducing non-point source runoff, early warnings of swim advisories due to HABs, and appropriate locations for dredging activities.

Work plan. The project will take place across a 2-year period beginning in late spring of 2020. The project is divided into eight separate tasks to meet the four objectives. The first three months of the project will be focused on installing the in-stream monitoring system at Horse Creek, coordinating sampling with GRDA, implementing the UAS-based remote sensing platform, and performing initial testing at Grand Lake (Task 1). At the end of the summer in Year 1, an intense sampling will take place to attempt to capture the dynamics of the HAB formation at Horse Creek and to perform a complete bathymetric survey of Horse Creek cove (Task 2). After the intense sampling period at the end of the first summer, the OSU graduate student will continue to return to Grand Lake monthly to perform monitoring with both the UAS and USV, collect samples from the monitoring station, and communicate with GRDA throughout the remainder of the project (Task 3). The emphasis of the project will shift during the fall and winter months to data and analysis and modeling, since HAB and nutrient dynamics are primarily a summer phenomenon.

During the first month after the summer sampling period in Year 1, data from the bathymetric survey will be used to estimate reservoir sedimentation since 2009 (Task 4). Analysis of the data from the summer HAB sampling trip will then become the primary focus. The USV in-situ observations will be used to assess the efficacy of the remote-sensing approach and develop machine learning tools to provide gridded estimates of HAB levels in Horse Creek (Task 5). By the start of Year 2, the watershed modeling will begin with assistance from data from the in-stream monitoring station. The first three and last three months in Year 2 will be focused on model development and calibration (Task 6). During the summer of Year 2, another intense monitoring of HAB dynamics will take place, guiding by observations from GRDA. The machine learning-based forecasting of HAB formation rates will take place for six months in the latter half of Year 2 (Task 7). The team will prepare a final report on the project during the final month of the project (Task 8). The project timeline is shown in the Gantt chart in Figure 16.

Task	Year 1												Year 2											
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Task 1	■	■	■																					
Task 2				■												■								
Task 3					●	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	
Task 4					■																			
Task 5						■	■	■	■	■	■	■												
Task 6													■	■	■						■	■	■	
Task 7																	■	■	■	■	■	■		
Task 8																								■

Figure 16. Project timeline.

Relevant existing data and models. This project will generate a variety of new products, but many relevant existing software tools and data on land usage, climatology, and hydrology are available that will also be used. The HSPF source code developed by USGS and EPA will be used to create the watershed model for Horse Creek cove. The project team has developed open-source tools (PyHSPF) for automatically scraping web data for integration into HSPF models [13]. This Python interface will be very useful for exploring future climate and land use scenarios for the watershed. Land usage data will be taken from the Cropland Data Layer, which is produced annually. High resolution climate data (5-minute) used in the models for the area are available from the Oklahoma Mesonet [52]. For the unmanned systems data, software has been developed in Python for interpolating observations to form gridded data products. We will make these available, including derived products. The estimation of reservoir sedimentation since 2009 will make use of the existing bathymetric survey.

Qualifications of project team. The project manager is Dr. David Lampert, Assistant Professor of Civil & Environmental Engineering at OSU. Dr. Lampert is an expert in water quality and contaminant transport modeling, water pollution monitoring, and environmental software development [9]–[13]. Dr. Lampert has a PhD in Civil Engineering from the University of Texas at Austin and is a registered Professional Engineer in Oklahoma and Texas. He has been awarded grants and contracts exceeding $800,000 from sponsors including the U.S. Environmental Protection Agency, Department of Energy, Department of Agriculture, and Department of the Interior. He has published 15 peer-reviewed journal papers on a variety of environmental topics and has develop an extensive software package for hydrologic modeling. Dr. Lampert will oversee the overall project management, data collection, and water quality analysis. A graduate student in environmental engineering will perform the majority of the unmanned systems monitoring implementation and data analysis under the supervision of Dr. Lampert. The student will be selected that has experience in environmental modeling and water system monitoring.

The co-project manager for the project is Dr. Jamey Jacob, Professor of Mechanical and Aerospace Engineering at OSU. Dr. Jacob is an expert in unmanned systems [14]–[16] and serves as the John Hendrix Chair and Professor in the School Mechanical and Aerospace Engineering at OSU. Dr. Jacob received his PhD from the University of California at Berkeley and is the author of over 100 papers and technical reports in the areas of unmanned systems, aerodynamics, and flow control. He serves on the Governor's Aerospace and Autonomous Systems Council and as president of the Unmanned Systems Alliance of Oklahoma and was the lead investigator on the $6 million National Science Foundation Grant "RII Track-2 FEC: Unmanned Aircraft System for Atmospheric Physics." Dr. Jacob will supervise the development and deployment of the USV and UAS at Grand Lake. The USRI will leverage the project activities by providing engineering support, hardware, and materials to maximize project's chances for success. Support from Reclamation will be used for a research engineer from USRI to assist with the unmanned systems implementation.

Project start date. The team will be ready to begin immediately upon notice to proceed.

Products resulting from project. The results of this study are expected to provide a new approach for high-resolution water quality and bathymetric mapping system at Grand Lake, new tools to monitor HAB outbreaks, and enhanced assessment of the interconnections between sedimentation, nutrient runoff and HAB formation. The specific products resulting from this project include:

- An unmanned surface vessel-based monitoring system that provides high-resolution gridded estimates of water depth, temperature, turbidity, chlorophyll-a, phycocyanin, and nitrates
- An unmanned aircraft system that provides gridded estimates of water temperature, turbidity, chlorophyll-a and phycocyanin
- Twenty gridded data products for Horse Creek cove with estimates of water temperature, turbidity, chlorophyll-a, phycocyanin, and nitrate concentrations
- Daily gridded data products of water temperature, turbidity, chlorophyll-a, phycocyanin, and nitrates for Horse Creek cove across two month-long periods during HAB outbreaks
- Hourly time series of turbidity and discharge from Horse Creek across the project period
- A time series of nutrient observations from physical samples taken from Horse Creek
- A gridded dataset of the water depth throughout Horse Creek cove in each year of the projet
- An estimate of the total amount of sedimentation since 2009 in Horse Creek cove
- An HSPF watershed model for Horse Creek that forecasts the discharge, sediment and nutrient loading into Grand Lake as a function of land usage, climate, and water management
- Open source software product that forecasts HAB growth based on estimates of water temperature, turbidity, nitrates, and climate data
- A journal publication comparing satellite, UAS, and USV for water quality monitoring
- A journal publication on the applications of machine learning techniques to study HABs
- A journal publication on modeling relationships between nutrients and HAB formation
- A final report for Reclamation summarizing the project results and conclusions

7. Dissemination of results

GRDA and other Oklahoma government agency meetings. The project team will hold meetings monthly with GRDA to provide updates on project status. These will take place in person frequently, although some may also be performed remotely. Key results and conclusions will also be communicated in meetings regularly held with other stakeholders including agricultural communities, the OCC, local conservancy districts, OWRB, and the Army Corps of Engineers.

Journal publications. Journal publications will be developed to disseminate results to the scientific community and water managers. Three articles are expected as described previously.

Conference presentations. The project team will present results annually at the Oklahoma Governor's Water Conference, the Oklahoma Clean Lakes and Watersheds Conference, and the Oklahoma Water Appreciation Day to educate local water resource stakeholders on the results.

Academic educational curriculum. Dr. Lampert will incorporate the results into a series of lectures and one-two class assignments on applications of nutrient modeling and big data into his graduate course on environmental modeling to educate future water scientists and engineers.

GRDA outreach. The GRDA Ecosystems and Educational Center will incorporate results into their educational programs on conservation and watershed management. GRDA is currently implementing a "Guard the Grand" (GTG) program that includes workshops aimed at helping residents and businesses implement best management practices. GTG is designed to heighten environmental stewardship in residents of the Grand Lake watershed. The program provides education to 4^{th} grade students to improve environmental problem-solving skills and educates business and residents in the watershed on BMPs to reduce pollutant loadings to the reservoir.

Unmanned Systems Research Institute outreach. The USRI will offer outreach educational workshops for the environmental community on applications of unmanned systems. The team is working to improve public perceptions of robotic technologies and provide the public with real-world examples of how this technology can benefit society. Workshops will be scaled to K-12 educational activities to promote interest in science and teach primary school students how multiple fields (engineering, agriculture, etc.) work together to overcome real-world challenges. Workshop formats will include in-class and hands-on, plus on-line courses and summits. A companion website will be used to inform the broader community about the program.

Reclamation-sponsored webinar. The project team will disseminate deliverables and discuss application to management questions in a webinar through Reclamations web platform.

8. Relationships to Department of the Interior Priorities

The project is consistent with the goals of the Department of the Interior and the WaterSMART Applied Science Program. This project specifically addresses the following Department of the Interior Priorities:

- ***Creating a conservation stewardship legacy second only to Teddy Roosevelt***. This project will utilize new science of water quality monitoring and unmanned systems to identify best practices to manage land and water resources in the Grand Lake watershed and help stakeholders adapt to changes in the environment.
- ***Restoring trust with local communities.*** This project will expand lines of communication between GRDA, communities in the Grand Lake watershed, OWRB and OCC.

This project directly supports the WaterSMART objective "to develop hydrologic information and water management tools and improve modeling and forecasting capabilities." The monitoring system will increase access to information and lead to improved modeling and forecasting capabilities, which will improve the reliability of water supplies, help manage droughts, assist with endangered species requirements, and restore watershed health.

C. Project location

This project will take place at the Grand Lake O' the Cherokees in Northeastern Oklahoma. Grand Lake has a watershed that extends into four states (Oklahoma, Arkansas, Kansas, and Missouri). The location of Grand Lake on a U.S. Map is shown in Figure 17. The map was created using a shapefile of all the U.S. states and a shapefile of the outline of the reservoir from a bathymetric survey by the Oklahoma Water Resources Board available on their website [47].

D. Data management practices

All data products generated by the proposed research will be made available to the public. Data collected during this study will be archived in accordance with the Department of Interior and Geodata.gov criteria. Observations will be made of nutrients, algal levels, toxins, and other water quality parameters. Input files used to generate models and results that are published will be placed online to provide access to the information. Data sets and model simulation input files will be placed on Science Commons repositories. Software created as part of the research will be made open source and distributed through channels such as GitHub. Important datasets will be given digital object identifiers to enable persistence online.

Figure 17. Location of Grand Lake on U.S. Map.

***Standards, Data Organization, Documentation and Metadata*.** The associated data types will be disseminated using open formats. General metadata related to the project will be created for each data product. The metadata will be use open standard formats such as text (TXT) files. Vector-based data products will use open formats such as the ESRI shapefile (SHP). Images and other gridded raster products will be generated in Tag Image Bitmap File (TIF). Proprietary formats requiring commercial software will not be used. A README.txt text file summarizing metadata related to the study will be disseminated with raw data files to enhance discovery and facilitate validation of results.

***Policies for Data Access, Sharing and Reuse*.** Project data will be made publicly available through the Science Commons and ShareOK repositories by the end of the fiscal year of publication or the project finish date. Results will be made available for a minimum of five years past the end of the project. There will be no additional restrictions or permissions required for accessing the data, other thank acknowledgement of the role of the sponsor and authors.

***Data Preservation and Archiving*.** Public data will be disseminated through supplemental data files online and the Science Commons repository using standard file formats. The long-term strategy for the maintenance, curation and archiving of the data will be implemented when the data are migrated to the Science Commons and OSU Library repositories for archiving. Preservation, review and long-term management of data collected during this study will be archived for a period of at least five years after the project completion date. The data will be stored in a specific virtual archive and made publicly available through the Science Commons repository.

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Project Budget

A. Funding plan

This project will utilize unmanned systems to monitor water quality at Grand Lake in Northeastern Oklahoma. The total project costs are $300,000, including $150,000 from Reclamation and $150,000 from OSU. The funding from Reclamation will support the OSU project team's salaries, travel to Grand Lake, and materials and supplies for the monitoring system as outlined subsequently in the budget details. The $150,000 non-federal cost share comes from OSU and consists of in-kind support for the project from Dr. Lampert's and Dr. Jacob's academic year salaries across the 2-year project. A letter of commitment from the OSU Vice President for Research is included indicating support for the project. The funds will be made available on the project start date, which is proposed as May 1, 2020. There are no time constraints on these funds.

B. Budget proposal

Table 1. – Total Project Cost Table

SOURCE	AMOUNT
Costs to be reimbursed with the requested Federal funding	$150,000
Costs to be paid by the applicant	$150,000
Value of third-party contributions	$0
TOTAL PROJECT COST	**$300,000**

Table 2. – Total Budget Proposal

BUDGET ITEM DESCRIPTION	COMPUTATION		Quantity Type	TOTAL COST
	$/Unit	Quantity		
Salaries and Wages				
David J. Lampert, Asst. Professor	$9,189	7.46	Months	$68,644
Jamey D. Jacob, Professor	$21,630	0.9	Months	$19,467
TBN, Research Engineer	$4,205	2.4	Months	$10,243
TBN, Graduate Research Assoc.	$4,400	9	Months	$40,194
Fringe Benefits				
Faculty (34.78%)				$30,716
Staff (39.78%)				$4,136
Graduate Student (7.43%)				$3,032
Equipment				
N/A				
Travel				
Stillwater, OK to Grand Lake, OK	$4,000	2	Trips	$8,000
Stillwater, OK to Grand Lake, OK	$100	20	Trips	$2,000
Supplies and Materials				
Water quality sensors	$100	20		$2,000
Electronic/mechanical parts	$100	20		$2,000
Containers	$21	10		$211
Contractual/Construction				
N/A				
Third-Party In-Kind Contributions				
N/A				
Other				
Compliance costs (Reclamation)				$5,000
Tuition (GRA support)				$7,316
TOTAL DIRECT COSTS				**$202,959**
Indirect Costs				
Modified Total Direct Costs (MTDC)	49.6%			**$97,041**
TOTAL ESTIMATED PROJECT COSTS				**$300,000**

C. Budget narrative

Salaries and Wages—
SENIOR PERSONNEL
Support is requested for one summer month at 50% time effort for Dr. David Lampert, Principal Investigator ($9,189 monthly salary) in each year of the project. Dr. Lampert will oversee field sampling and development of a water quality monitoring program based on unmanned systems for Grand Lake and oversee all project management. Dr. Lampert will also provide 37.80% in Year 1 and 33.93% in Year 2 of his nine-month academic salary as cost share for the project.

Support is requested for one summer month at 10% time effort for Dr. Jamey Jacob, co-Principal Investigator ($21,630 monthly salary) in each year of the project. Dr. Jacob will work with Dr. Lampert to supervise the implementation of unmanned systems for water quality monitoring. Dr. Jacob will also provide an in-kind donation of 4.08% in Year 1 and 3.66% in Year 2 of his nine-month academic year salary as cost share for the project.

OTHER PERSONNEL
Support is requested for a research engineer ($4,205 monthly salary) from the Unmanned Systems Research Institute at 10% in each year of the project to assist with technical implementation of the water quality monitoring system.

Support is requested for one graduate research associate (PhD) ($4,400 monthly salary) for nine months at 50% time effort for each year of this project. The graduate research associate will be responsible for travel to Grand Lake to install the water quality monitoring system and assessment of the effectiveness of the new program.

Fringe Benefits—
Fringe benefits are for health care and other benefits for the employees, faculty and students. Fringe benefit rates are negotiated annually with the Office of Naval Research and will be adjusted accordingly. The FY20 benefit rate for faculty members is 34.78%, the staff benefit rate is 39.78%, and the graduate student benefit rate is 7.43%.

As per Oklahoma State University practice, **there is an annual increase of 3-percent** included for estimation of subsequent years for each employee’s salary, benefits and tuition. The University will document employees’ time based on percent of time effort. The salaries shown are the same as would be paid for performing University functions.

Travel—
Funds are requested for the graduate research associate to travel to Grand Lake to utilize the unmanned systems to monitor the water quality. $4,000 are required for ground transport ($1,000), lodging ($2,000), meals and other incidental expenses ($1,000) for an extended month-long stay at Grand Lake for the graduate research assistant in Year 1 and 2 of the project to install equipment to sample water quality and closely monitor water quality during the summer algal bloom period. Additional funds of $1,000 in Year 1 and 2 are requested for trips by the PIs and research engineers to travel to Grand Lake to implement monitoring systems. A total of 20 trips are planned at a cost of $100 each for ground transport (172.5 miles round trip at $0.58/mile). Travel expenses will be reimbursed at rates consistent with Oklahoma State University’s approved policies and will not exceed the greater of approved State or Federal rates.

Equipment—
None requested.

Materials and Supplies—
Materials and supplies are budgeted to $4,211.00 for the project. The costs for supplies include water quality sensors ($2,000), electronic and mechanical parts for the monitoring system ($2,000), containers needed for water quality analysis ($211).

Contractual—
None requested.

Third-Party In-Kind Contributions—
None.

Environmental and Regulatory Compliance Costs—
Funds are requested in the amount of $5,000 to pay for costs of environmental and regulatory compliance. These costs will cover Reclamation's assessment of to determine the level of environmental compliance required for the project.

Other Expenses—
TUITION
One graduate student will work on this project. The tuition remission for the graduate research students is requested and is calculated at a rate of 18.2% of GRA salary.

Indirect Costs (Facility & Administrative Costs)—
The allowable Facility & Administrative Cost rate for on-campus research is 49.6-percent of Modified Total Direct Costs (MTDC) until further amended. This is the predetermined rate negotiated with Oklahoma State University by the Department of the Navy, Office of Naval Research, 800 North Quincy Street, Arlington, VA, 22217-5660, for the Federal Government. Facility & Administrative Costs are calculated on total direct costs less items of equipment, capital expenditures, charges for patient care and tuition remission, rental costs, scholarships, and fellowships as well as the portion of each subgrant and subcontract in excess of $25,000. Fringe benefits applicable to direct salaries and wages are treated as direct costs.

Environmental and cultural resources compliance

Will the proposed project impact the surrounding environment (e.g., soil [dust], air, water [quality and quantity], animal habitat)? Please briefly describe all earth-disturbing work and any work that will affect the air, water, or animal habitat in the project area. Please also explain the impacts of such work on the surrounding environment and any steps that could be taken to minimize the impacts.

The project does not have any land-based component that would disturb soils or land habitats. The USV will be used to monitor water systems. Since Grand Lake is a recreational area with heavy boat traffic, the impacts of the USV on the water expected to be negligible. The UAS will be used only for remote sensing at low aerial velocities that do not affect birds or emit air pollutants, so there are no expected environmental impacts from the UAS.

Are you aware of any species listed or proposed to be listed as a Federal threatened or endangered species, or designated critical habitat in the project area? If so, would they be affected by any activities associated with the proposed project?

Based on results from a search with the U.S. Fish and Wildlife Service's mapping tool (https://ecos.fws.gov/ipac/), the project study area includes ten threatened or endangered species, including four mammals: the Gray Bat (endangered), the Indiana Bat (endangered), the Northern Long-eared Bat (threatened), and the Ozark Big-eared Bat (endangered); three birds: the Least Tern (Endangered), the Piping Plover (threatened), and the Red Knot (threatened); one fish: the Neosho Madtom (threatened); one clam: the Neosho Mucket (endangered); and one insect: the American Burying Beetle (endangered). There are no critical habitats in the project area. The project consists purely of monitoring activities, so it is not expected to disrupt any species or habitats.

Are there wetlands or other surface waters inside the project boundaries that potentially fall under CWA jurisdiction as "Waters of the United States?" If so, please describe and estimate any impacts the proposed project may have.

Yes. The project will focus on Grand Lake and the Horse Creek tributary, and it includes wetlands near the lakeshore. There are no proposed construction activities, implementation of hydraulic structures, or diversions of flow that are expected to generate pollution or disturb the areas. The project is therefore not expected to have any impacts on the Waters of the United States.

When was the water delivery system constructed?

Grand Lake was formed by the damming of the Neosho River. Construction of the Pensacola Dam began in 1938 as a Works Progress Administration project. The dam was completed in March 1940, creating the lake behind it.

Will the proposed project result in any modification of or effects to, individual features of an irrigation system (e.g., headgates, canals, or flumes)? If so, state when those features were constructed and describe the nature and timing of any extensive alterations or modifications to those features completed previously.

No. The project consists purely of monitoring activities, so it is not expected to disrupt any irrigation systems.

Are any buildings, structures, or features in the irrigation district listed or eligible for listing on the National Register of Historic Places? A cultural resources specialist at your local Reclamation office or the State Historic Preservation Office can assist in answering this question.

No.

Are there any known archeological sites in the proposed project area?

No.

Will the proposed project have a disproportionately high and adverse effect on low income or minority populations?

The project is focused only on monitoring, so there are no expected effects on minority or low income populations.

Will the proposed project limit access to and ceremonial use of Indian sacred sites or result in other impacts on tribal lands?

The project is not expect to affect any tribal lands.

Will the proposed project contribute to the introduction, continued existence, or spread of noxious weeds or non-native invasive species known to occur in the area?

The project is not expected to affect weeds or invasive species.

Required permits or approvals

Not applicable.

Vice President for Research
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Bureau of Reclamation
Financial Assistance Support Section
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30 October, 2019

RE: Oklahoma State University CEAT Proposal Number **EN-20-RS-142**

Oklahoma State University is pleased to submit the Department of Interior, Bureau of Reclamation proposal entitled "Applying Unmanned Systems for Water Quality Monitoring" in response to BOR-DO-19-F012. David J. Lampert, Assistant Professor, School of Civil & Environmental Engineering, will be the project director on behalf of our institution.

The University has reviewed and approved the cost share in the amount of $150,000. In the event that an award is forthcoming, OSU will enter into an agreement for performance of those project activities for which the PI is responsible.

Our college and university are firmly committed to supporting the research activities for this project. Our college provides continuing salary support, laboratory facilities, secretarial and other infrastructure support, and will continue to do so for the proposed project.

Sincerely,

Kenneth W. Sewell
Vice President for Research