Mississippi Water Resources Research Institute
Annual Technical Report
FY 2015

Introduction

Background. The Mississippi Water Resources Research Institute (MWRRI), established by the Mississippi legislature in 1984, is a quasi-state agency located at Mississippi State University (MSU) created to provide a statewide center of expertise in water resources and associated land uses that incorporates all of Mississippi's Institutions of Higher Learning in its activities. MWRRI's diverse statutory responsibilities are: 1) assist state agencies in developing and maintaining a state water management plan; 2) consult with state and local agencies, water management districts, water user associations, the Mississippi legislature, and other potential users to identify and establish water research, planning, policy, and management priorities; 3) negotiate and administer contracts with local, regional, state and federal agencies and other Mississippi universities to mitigate priority water and related problems; 4) report to the appropriate state agencies each year on research projects' progress and findings; 5) disseminate new information and facilitate transfer and application of new technologies as they are developed; 6) be a liaison between Mississippi and funding agencies as an advocate for Mississippi water research, planning, policy, and management needs; and 7) facilitate and stimulate planning and management activities that address water policy issues facing the state of Mississippi, support state water agencies' missions with research on encountered and expected problems, and provide water planning and management organizations with tools to increase their efficiency and effectiveness.

MWRRI staff work with departments and programs from Institutions of Higher Learning across Mississippi, state and federal agencies, and stakeholder organizations willing to participate in its collaborative approach in a team environment to develop approaches and projects to address the state's water resources management and research priorities.

Advisory Board. The legislation that established MWRRI also created a strong and diverse Advisory Board. The Advisory Board's role is to provide input on current and emerging priority state, regional and national water and water-related land research problems; identify opportunities to effectively collaborate with local and state governments and agencies, water user associations, other universities, federal government agencies, and the legislature in formulating MWRRI's research program; assist on the selection of research projects to be funded from USGS funds; and advise on disseminating and transferring information and technology produced by research. Designated Advisory Board members include representatives from the Mississippi Public Service Commission, Mississippi Department of Environmental Quality, Mississippi Department of Marine Resources, U.S. Army Corps of Engineers Engineering Research and Design Center, Mississippi/Alabama Sea Grant Consortium, University of Mississippi, University of Southern Mississippi, Jackson State University, Delta Council, USDA Natural Resources Conservation Service, Mississippi Soil & Water Conservation Commission, U.S. Geological Survey, USDA National Sedimentation Laboratory, and the Mississippi Water Resources Association. Five at large seats representing water stakeholders/users in private sector business and regional water management/waterway districts also serve on the Advisory Board.

Center of Excellence for Watershed Management. On April 9, 2013, MWRRI was designated by Region 4 of the U.S. Environmental Protection Agency (EPA Region 4) and the Mississippi Department of Environmental Quality (MDEQ) as a Center of Excellence for Watershed Management with the formal signing of a Memorandum of Understanding (MOU) by these parties. The MOU acknowledges that the MWRRI had demonstrated to the satisfaction of EPA and MDEQ that it has the capacity and capability to identify and address the needs of local watershed stakeholders and that it has support at the appropriate levels of MSU. It also specifies the Center of Excellence to serve as the point of contact and primary coordinating entity for colleges and universities in Mississippi. The primary purpose of the Center of Excellence is to utilize the diverse talent and expertise of colleges and universities by providing hands on practical products and services to help communities identify watershed-based problems and develop and implement locally-sustainable solutions. The MOU also guides the Center of Excellence to actively seek out watershed-based stakeholders that need assistance with project development and management, research and monitoring, education and outreach, engineering design, computer mapping, legal and policy review, and other water resource planning and implementation needs. Annual commitments of the MWRRI are also identified in the MOU.

Research Program Introduction

Background. Effective environmental planning and water resources management must first be informed and supported by scientifically-accepted research, the development of which is MWRRI's primary function. For over 30 years, MWRRI through its member Institutions of Higher Learning has worked with agencies and organizations in Mississippi and beyond to support and advance water resources research. Today, more than ever, research is vitally needed in Mississippi to advance our understanding of the science and dynamics of multiple interconnected and interdependent water-related issues and to inform our water resources planners, managers, users, and stakeholders. Since its creation and as part of its statutory responsibility, MWRRI has identified water resources research priorities through its Advisory Board and, supported by the U.S. Geological Survey through the 1984 Water Resources Research Act, has provided funding for selected research proposals that address these priorities.

Approach. MWRRI's approach to integrated water resources research seeks to explore the linkages among natural science, engineering, and the dynamics of social and economic systems that underpin water management decisions. As one of its core functions, MWRRI facilitates an annual, statewide competitive grants program to solicit research proposals for potential USGS 104b funding support. Proposals are prioritized as they relate to the research priorities established/affirmed annually by MWRRI's Advisory Board and by the ability of proposing parties to obtain letters of support and external cost share support from non-federal sources in Mississippi. The Advisory Board then evaluates and ranks all proposals, and funding recommendations are developed through consensus.

Research Priorities. During the 2015 104b funding cycle, the research priorities recommended by the Advisory Board and adopted by MWRRI are listed below:

• Climate – historic record of climatic conditions; comparison of past climate trends to variations in groundwater and surface water demands; projections of future climatic conditions. • Groundwater – innovative approaches to estimate aquifer recharge; spatial and depth variabilities of aquifer transmissivities and other characteristics. • Surface Water – performance and effectiveness of innovative and established nutrient, sediment, bacteria, and storm water management methodologies, and small community wastewater treatment technologies; linkages between N and P concentrations and ecosystem response variables; analysis of point source nutrient loading trends.

• Water Reuse and Conservation – innovative wastewater treatment technologies and reuse applications; effective irrigation efficiency and conservation methods; innovative irrigation runoff reclamation and reuse methods.

• Protection of Source Water – delineation of source water protection areas, identification of potential sources of contamination, assessment of threats, and contingency planning.

• Social Science – stakeholder perceptions and beliefs at the individual, local and regional levels related to water resources issues; social indicators to identify the potential for and evaluate the success of watershed management projects and to build effective education and outreach.

• Modeling and Tool Development – prediction of future impacts of climatologic change, water use changes, social drivers, and proposed infrastructure on water resources.

All 2015 104b proposal submittals were required to address at least one of these priorities. These priorities also guided MWRRI staff efforts to develop collaborative multi-university/agency project proposals for submission to other external funding sources.

External Review Process. MWRRI's Advisory Board consists of 20 members with water-related missions/programs – 5 state agencies, 4 federal agencies, 4 major research universities, 3 NGOs, 1 water management district, and 3 industry representatives. As mentioned previously, a major activity of this Board is to review and recommend 104b proposals for potential funding. Each year, Advisory Board members are delivered packages of all proposals submitted for potential 104b funding along with review criteria and individual proposal grading forms. After self-reviews are conducted, the full Advisory Board convenes to discuss the merits of each proposal, individual proposal grades, and then develops funding recommendations through consensus.

2015 Funded Proposals. Three projects were funded during 2015 that addressed priority water resources issues in Mississippi. These projects were:

1. Influences of wetland plant community types on water quality improvement in natural and restored wetlands of the Mississippi Delta;

2. Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary: Year 2; and

3. A preliminary investigation of surface and groundwater exchange within tailwater recovery systems of the Mississippi Delta.

Final reports for these projects are included in this document.

Additional Projects in this Report. Two research projects funded during the research cycle ending February 28, 2015 for which extensions were granted are included as final reports in this document. They are:

1. Interdisciplinary Assessment of Mercury Transport, Fate and Risk in Enid Lake (2013MS182B) and

2. Non-linear downward flux of water in response to increasing wetland water depth and its influence on groundwater recharge, soil chemistry, and wetland tree growth (2013MS183B).

Significance of Projects. Collectively, the projects contained in this document address some of the most pressing information gaps/research needs in Mississippi. These include the following:

In the Mississippi portion of the Lower Mississippi Alluvial valley (i.e., the "Delta"), some 190,000 acres have been enrolled in USDA's Wetland Reserve Program (WRP) since 1992 and over 23,000 acres are currently in Conservation Reserve Program (CRP) wetland restoration practices. The success of these wetlands in providing the desired ecological functions (e.g., wildlife habitat, water quality improvement) has been inadequately examined, but such studies are critically important for determining factors that may indicate potential success of future restoration or conservation efforts. Conservation lands in the Delta are exposed to a relatively high intensity of agricultural land use, which has the potential to negatively impact the ecological function of these lands. Comprehensive assessments of restored wetland success are needed to determine the interactive effects among land use, wetland management, and water quality improvement. Incorporation of project findings into USDA's WRP ranking tool will ensure that the most complete information is being applied to assessment and prioritization of WRP efforts within the region as well as providing new data that may affect how Delta stakeholders manage their lands.

Grand Bay National Estuarine Research Reserve (GBNERR) is located in a relatively pristine estuary in the northern Gulf of Mexico, with ambient nutrient concentrations often below detection. However, since 2005, periodic breaches in a containment levee from an adjacent fertilizer production facility have led to large fish kills throughout the Reserve and high phosphate levels (over 200 μM) while pH dropped from 7.5 to near 4.5 to GBNERR's Bangs Lake. Four essential questions needing to be answered to assess the impacts of these repeated phosphate spills on water quality in an otherwise pristine ecosystem are: 1) What is the fate of phosphorus after a spill? 2) Is there a preserved sedimentary record of past phosphorus spills? 3) Is there a biological fertilizer effect on benthic microalgae in this shallow photic system? 4) Is dry deposition of gypsum particles from the adjacent fertilizer plant a smaller but constant source of phosphorus to GBNERR? Research results are critically needed to provide information helpful for effective management of the Reserve.

Irrigation accounts for the largest use (98%) of the Mississippi River Alluvial Aquifer (MRVA), which is the primary groundwater source for agriculture in the Delta region of northwest Mississippi. Substantial withdrawals from the MRVA without equivalent recharge have resulted in a regional cone of depression in the central portion of the Delta, and depletion of the MRVA. Many agricultural producers in this region have pursued federal cost-share assistance through USDA to implement tailwater recovery systems (TWR) with and without additional on-farm storage reservoirs (OFS). A TWR is designed to capture surface runoff, reducing outflow of nutrients to receiving waters and simultaneously providing an alternative source for irrigation. This dual benefit is important because it addresses both water quality and quantity which are equally important in the region. As of August 2014, 184 TWR/OFS have been implemented in the Delta with over 50% of these systems located within the regional cone of depression. Despite their prevalence on the landscape and their popularity with producers and government agencies, minimal research has been conducted to quantify the water quality and quantity benefits of these installed practices. Accurate information of this type that quantifies the rate of ground and surface water exchange is also needed for the development of accurate water level modeling applications which are currently being developed for the region. This is critically important because studies have shown that focusing conservation efforts within the regional cone of depression lead to the greatest improvements in water storage within the MRVA. Ultimately, data such as this will assist policymakers in designing strategies and policies to effectively manage this vital resource.

Responses of water quality and wetland plant communities to multi-scale watershed attributes in the Mississippi Delta

Basic Information

Title:	Responses of water quality and wetland plant communities to multi-scale watershed attributes in the Mississippi Delta
Project Number:	2014MS190B
Start Date:	3/1/2014
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	3rd
Research Category:	Biological Sciences
Focus Category:	Wetlands, Water Quality, Management and Planning
Descriptors:	None
Principal Investigators:	Gary N. Ervin, Robert Kroger

Publications

1. Quarterly reports to MWRRI.
2. Ervin, G. N. and C. M. Shoemaker. Water quality-land use interactions in restored wetlands of the Mississippi Delta. Mississippi Water Resources Conference, Jackson, MS, April 7-8, 2015.
3. Shoemaker, C. M. and G. N. Ervin. Drivers of plant community composition in Delta wetlands. Mississippi Water Resources Conference, Jackson, MS, April 7-8, 2015.
4. Ervin, G.N. and C.M. Shoemaker., 2015. Water quality-land use interactions in restored wetlands of the Mississippi Delta. Proceedings from 2015 Mississippi Water Resources Conference, April 7-8, 2015, Jackson, MS, pg. 86, www.wrri.msstate.edu/pdf/2015_proceedings.pdf
5. Shoemaker, C.M. and G.N. Ervin, 2015. Drivers of plant community composition in Delta wetlands. Proceedings from 2015 Mississippi Water Resources Conference, April 7-8, 2015, Jackson, MS, pg. 87, www.wrri.msstate.edu/pdf/2015_proceedings.pdf
6. Ervin, G. N. and R. Kröger. Responses of water quality and wetland plant communities to multi-scale watershed attributes in the Mississippi Delta. Final Technical Report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 14 pgs.

MISSISSIPPI WATER RESOURCES RESEARCH INSTITUTE
FINAL TECHNICAL REPORT FOR GRANT # G11AP20088

Responses of water quality and wetland plant communities to multi-scale watershed attributes in the Mississippi Delta

01 March 2014 to 28 February 2016

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ABSTRACT

This project aimed to understand the influence of local and landscape factors in shaping wetland functions within the Mississippi Delta. An understanding of scale effects on function is both critical and timely for Delta wetlands. Recent efforts aimed at restoration of marginal agricultural lands to wetlands have been sponsored through government and private wetland restoration projects. Unfortunately, the outcomes of these projects in terms of conservation goals are unknown. This means that decisions to enroll lands in such programs continue to be made without a full evaluation of specific practices that may result in the greatest conservation benefits. Additionally, with little to no long term monitoring conducted on many sites, the ultimate outcome of restoration efforts is unknown. A better understanding of the influence of local and landscape factors on wetland functions in existing restorations will permit more effective targeting of limited resources towards future restorations.

This two-year study resulted in a large database relating to soil and water variables and plant species inventories of 24 Wetlands Reserve Program (WRP) restorations and six natural wetlands within the northern half of the Delta. Thus far, our analyses have indicated that WRP wetlands harbor high levels of plant species diversity and that surrounding conservation practices may be buffering these wetlands from any potential negative impacts of agricultural land use within the Delta. An experimental study of seed bank responses to flooding suggested that some of the observed differences in wetland plant diversity may be attributed to the duration of flooding in natural wetlands. Ongoing analyses are aimed at more detailed examination of how within-wetland vs. landscape factors may be shaping water quality and plant species assemblages within these wetlands.

INTRODUCTION

Considerable effort in recent years has gone into enhancing wetland habitats across the Mississippi Delta, with the objectives and benefits of improving water quality, providing flood protection, and enhancing habitat for fish and wildlife, among others (USDA NRCS 2011). In the Mississippi Delta, some 190,000 acres have been enrolled in the Wetland Reserve Program (WRP) since its inception in 1992 (Kevin Nelms, USDA NRCS unpublished data). However, the success of these wetlands in providing the desired ecological functions (e.g., wildlife habitat, water quality improvement) has been inadequately examined (Faulkner *et al.* 2011), even though such studies are critically important for determining factors that may indicate potential success of future restoration or conservation efforts.

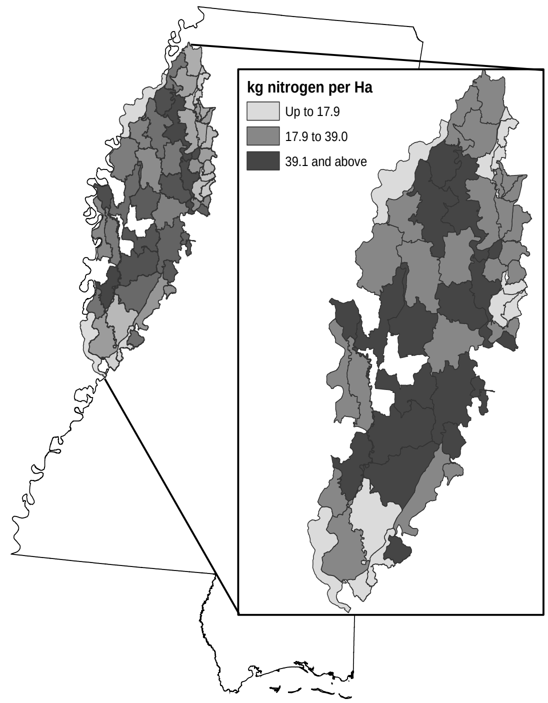

Figure 1. Watersheds within the MS delta containing WRP easements, shaded based on estimated nitrogen inputs per hectare of corn, cotton, and soybean (data from USDA NASS and USDA Economic Research Service). Boxed inset shows watersheds classified into three categories of nitrogen loading (low, medium, and high), for purposes of our proposed experimental design.

Lands enrolled in the WRP are exposed to a wide range of stressors that may limit success, in terms of restoring wetland structure and function. In the Delta region, these stressors primarily derive from agricultural land use. For example, estimates based on current agricultural data indicate that WRP lands in Mississippi experience nutrient loads in the range of 0.3 to 62 kg nitrogen per hectare and 0.3 to 45 kg phosphate per hectare within MS Delta watersheds (Figure 1). These data are based solely on average inputs of N and P fertilizers per hectare to the three major MS crops (corn, cotton, and soybeans), which themselves range from 0.5 to 78 percent of the area of individual watersheds within the Mississippi Delta (USDA National Agricultural Statistics Service [NASS] 2013).

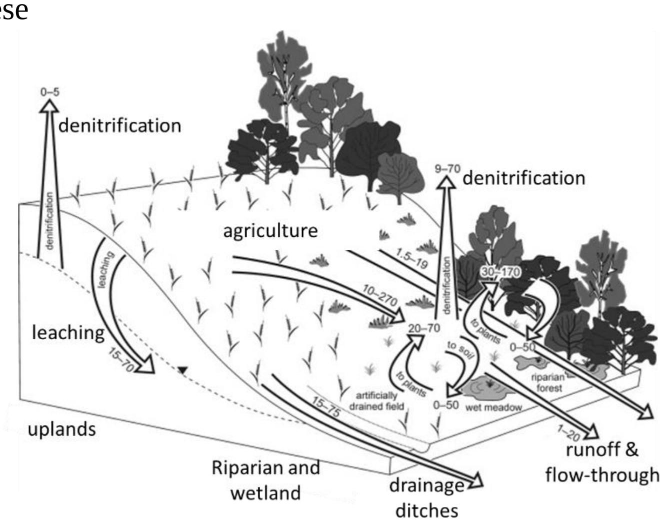

Figure 2. Fluxes of nitrogen (kg N per ha per yr) across a typical agricultural landscape at temperate latitudes. From Pärn *et al.* (2012).

To fully understand the degree to which land use impacts wetland function, it is critical to take a landscape approach to studying these ecosystems (e.g., Figure 2). Zedler and Kercher (2004) argue that wetlands are particularly susceptible to landscape-scale human activities because wetlands are "sinks" within the landscape, influenced by both terrestrial and aquatic disturbances within the surrounding watershed. Within the wetland, water quality, plant species assemblages, community types, and plant conservation values all influence water quality in different ways, but also are affected differentially by their surroundings at different spatial scales (Matthews *et al.* 2009) (Figure 3). Thus, the restoration of complex ecosystem services and functions requires an integration of local and landscape approaches (Dosskey *et al.* 2005), which is currently lacking in both restored and reference wetlands within the Mississippi Delta (Faulkner *et al.* 2011).

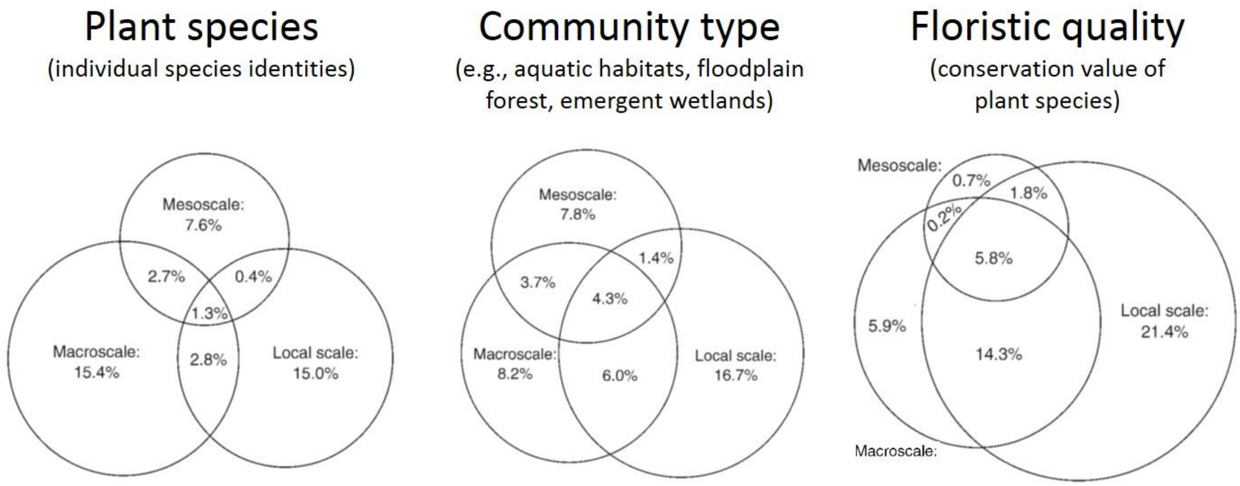

Figure 3: Environmental drivers vary across spatial scales in their relative influence on local-scale responses of wetland vegetation. Area of individual circles indicates the percent of variation in wetland plant variables explained by environmental factors at the local, meso-, and macroscales within and surrounding restored wetlands in Illinois. Modified slightly from Matthews et al. (2009).

Our specific objectives in this study were to:

1. Measure water quality and wetland plant species assemblages in restored (WRP) and naturally occurring wetlands in the Mississippi Delta, across the available gradient of estimated nutrient loadings.
2. Measure a suite of local-scale (within-wetland) factors anticipated to influence water quality and wetland plant species.
3. Assemble existing data on meso- and macroscale factors likewise thought to serve as environmental drivers of water quality and wetland plant species.
4. Quantify statistical linkages between our ecological responses (water quality and wetland plants) and potential environmental drivers at the three spatial scales of interest, as well as determine the relative importance of those environmental factors.
5. Translate these results into information that can be used to guide the placement of future wetland restoration efforts so as to optimize the likelihood of success, within the context of local and watershed-scale environmental factors and to predict the effect of future local to watershed scale changes on wetland function.

METHODS

Site selection

Twelve watersheds (HUC-12) containing WRP wetlands within the Mississippi Delta were selected for assessment (Figures 1 and 4). Fertilization and land use data from 2010-2012 were used to calculate approximate nitrogen loads (kg/ha) applied to each watershed, among the three most important crop species (Figure 1). From those data, watersheds were grouped into "high" (≥39 kg/ha), "medium" (17.9-39 kg/ha), and "low" (≤17.9 kg/ha) nitrogen fertilizer application loads (classified based on natural breaks approach in ArcMap 10.2). Those nitrogen loading groups were used to stratify study wetlands across the spectrum of nitrogen application conditions in Mississippi Delta (Figure 1). Four watersheds in each of the three nutrient load categories were selected randomly following determination of easements with landowner willingness to participate in this study. Two restored WRP wetlands in each selected watershed were monitored throughout the study, for a total of 24 restored wetlands (eight each in high, medium, and low nitrogen load watersheds). A reference (naturally occurring) wetland was identified in six of the 12 watersheds, with two in high nitrogen application watersheds, two in medium, and two low nitrogen application watersheds (Figure 2). Selection of wetland sites via landholder willingness was facilitated with the assistance of Kevin Nelms (USDA, NRCS).

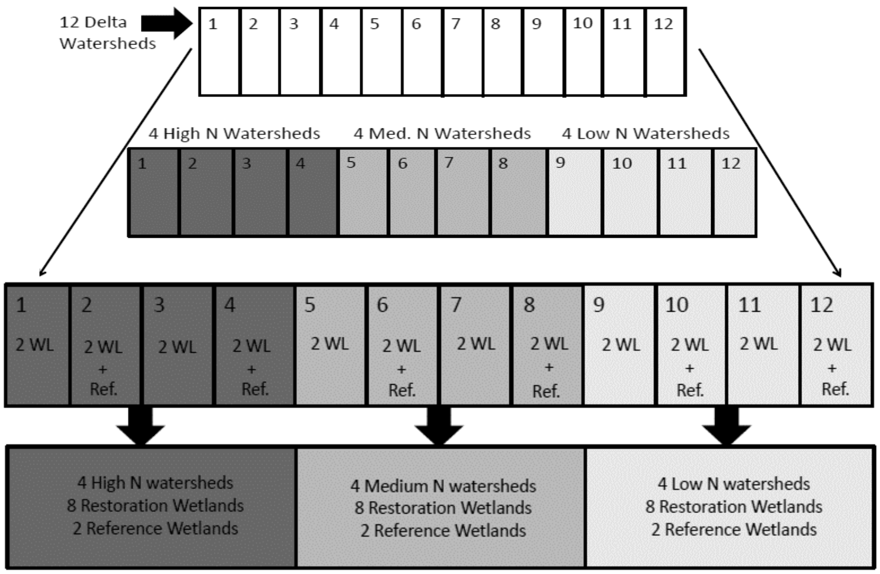

Figure4: Experimental design and wetland selection procedure. Med.=medium, WL=restored wetlands, Ref.=reference wetland. Sites will be selected with the aid of USDA personnel from candidate WRP land within the Mississippi Delta.

Data Collection

Ecological Response - *Water quality*

Water quality was assessed within each wetland four times per year: 1) March, 2) April, 3) during the first plant sampling event (May), and 4) during the second plant sampling event (August). Water samples were measured *in situ* in two locations within each wetland: 1) at the inflow, 2) at the wetland outflow, if these are clearly defined. If there are no obvious in/outflows, sampling occurred at the most likely inflow and outflow locations. Samples were measured *in situ* for nitrate-N (NO_3- -N), dissolved oxygen (DO), conductivity, oxidation-reduction potential (ORP), pH, and turbidity. During the first sampling (March) all sampling locations were marked via GPS to ensure all future measurements were taken from the same location. This sampling procedure allows for the determination of wetland function via the nitrate-N removal efficiency from inflow to outflow points. Nitrate-N is of particular importance in nutrient reduction best management practices (BMPs) within the Mississippi River Drainage Basin, as it is the leading cause behind the formation of the Gulf of Mexico hypoxic zone (Rabalais 2002).

Ecological Response - *Wetland Plant Species*

Floristic assessment inventories (e.g., Ervin et al. 2006) were conducted on plant species within the wetland sites in the spring (April-May) and in the late summer (July-August). Upon arrival, the site was visually inspected for area and site dimensions. Fifty circular plots (0.5 m^2 each) were evenly spaced along 10 transects at 20 m intervals, excluding portions of the site with standing water greater than waist deep. All plant species within the circular plots were recorded, and in the event of an unidentifiable specimen, a voucher sample was collected for eventual expert identification. Plant species were analyzed for overall species composition, the composition of species based on growth form and wetland indicator status, and their composition based on conservation value (Herman et al. 2006).

Macro- and Mesoscale Drivers - *Geospatial Data*

Land use/land use data were obtained from the United States Department of Agriculture's National Agricultural Statistics Service (http://www.nass.usda.gov). The 2014 Cropland Data Layer (CDL) was used for analyses, as it had a fine grain resolution (30 m) and included built-in classes for fallow/conservation land among a suite of anthropogenic and natural land cover classes. Future work on data collected in 2015 will use the 2015 CDL for analyses The land cover data were cursorily examined in comparison with aerial photography to ensure matches with wetland cover within the study region before this project began. These data have been verified in visual comparison with land cover in and around our study sites through the duration of this research.

Meso- and Local-Scale Drivers - *Soil Testing*

Soil sampling coincided with water quality sampling events (March, April, plant sampling 1, plant sampling 2) at each site in 2014. Three soil cores were taken from within the wetland in locations visually chosen for their heterogeneity (in an effort to represent the range of soil conditions present) and three taken within a 150 m buffer of the wetland. Within-wetland soil cores were homogenized, as were wetland buffer cores, and all were placed on ice and subsequently analyzed for total nitrogen, carbon, and phosphorus.

Local Scale Drivers - *Site Hydrology*

Twelve water level loggers were placed across nine of the twelve Delta watersheds. Within these watersheds, four loggers were placed in each nitrogen loading category. Of these four, one logger was placed in a reference wetland, while another was placed in a restored wetland within the same watershed. The remaining two were placed in two other watersheds within the same nitrogen loading category. The loggers recorded data every hour in a linear fashion over the duration of the study. This procedure captured hydrologic "fingerprints" of the wetlands and quantified site hydrology over the testing period.

RESULTS & DISCUSSION

Our initial examination of the data collected during 2014 revealed only one of the water quality parameters (conductivity, as measured during summer, Figure 5) that was strongly influenced by our *a priori* categorization of watersheds among low, medium, and high nutrient loadings (i.e., categories shown in Figure 1). Similarly, we found water quality parameters in restored wetlands as a group to not differ significantly from those in natural wetlands, except for summer conductivity measurements. Here, conductivity was highest for natural wetlands in high-agriculture-intensity watersheds; all other values were relatively similar to one another. Similarly, we found pH to be the only soil parameter correlated with the wetland and watershed categorizations. Here, soil pH was highest in the high agricultural intensity watersheds, at 5.1±0.1, followed by medium intensity (4.8±0.1) and then low intensity (4.5±0.1).

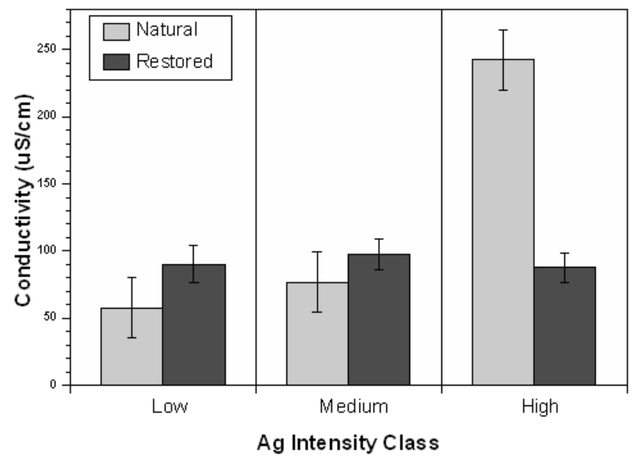

Figure 5. Conductivity, measured in our study wetlands during summer 2014, was the only water quality parameter that differed significantly among wetlands of the three agricultural use intensities or between natural and restored wetlands.

Whereas we found few differences in water quality and soil chemistry among wetlands when categorized by watershed-scale agricultural land use, we did find some interesting differences between the natural wetlands, as a group, and the restored wetlands. Soil organic matter composed a higher percentage of the soil in natural wetlands than in restored wetlands (~84% organic matter content in soil from natural wetlands, vs. ~36% in WRP soils), similar to what others have found in similar investigations (e.g., Theriot et al. 2013). There also was a greater percentage of organic matter in soils of wetlands surrounded by greater proportions of natural land cover (i.e., forests or wetlands).

The differences in the soil chemistry and landscape setting of the natural wetlands were correlated with some important differences in plant species cover between the two categories of wetlands. As noted by other investigators (e.g., Yepsen et al. 2014), natural wetlands tended to harbor more and a greater proportion of woody species (trees and shrubs) than did restored wetlands. Our preliminary examinations of the 2014 plant data showed such species as buttonbush (*Cephalanthus occidentalis*), swamp chestnut oak (*Quercus michauxii*), slippery elm (*Ulmus rubra*) and other bottomland hardwood species to occur on the six natural sites. On the restored sites, redvine (*Brunnichia ovata*) and trumpet creeper (*Campsis radicans*) frequently were recorded at 50% or more of our sample points per wetland. The proportion of those and other weedy plant species in restored wetlands also appeared to increase from low agricultural intensity watersheds to medium and high intensity watersheds, whereas they were much less abundant in natural wetlands (although the latter factor probably also is influenced by the active soil and vegetation management in many of our restored wetlands).

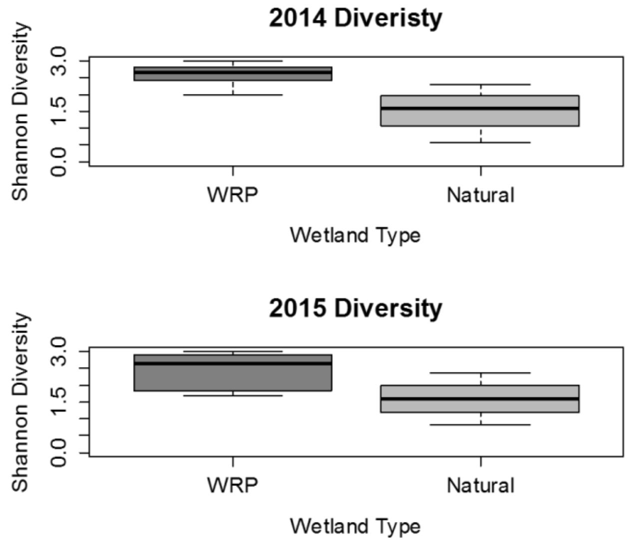

Figure 6. Plant species diversity was higher in restored wetlands in both years of the study ($P \leq 0.001$ for both comparisons).

We hypothesize that, as found by others, these differences in plant species among wetlands are influenced by differences in hydrology, soils, and/or water chemistry among wetlands. We also hypothesize that some of these differences will inform us about mechanisms that may enhance future design of wetland restorations to provide multiple benefits of restoring water quality as well as wildlife habitat in the Mississippi Delta. For example, suites of plant species found in wetlands with similar hydrological regimes (longer flooding period, earlier drawdown, etc.) may have similar influences on important water quality measures such as nutrient abatement or sediment retention, while also serving as important food or habitat for wildlife. These are questions that are being addressed by a follow-up WRRI grant to the Ervin lab (discussed in a separated Final Technical Report).

We also found that plant species diversity was significantly higher in the restored, WRP, wetlands in both years of our study (Figure 6). We attributed this in part to the management approaches applied in many of the WRP wetlands, which maintain somewhat disturbed conditions, but also to differences in hydrology between natural and restored sites. Hydrology is discussed more in the report on our other project, which was aimed more directly at the interrelationships between water quality and wetland vegetation.

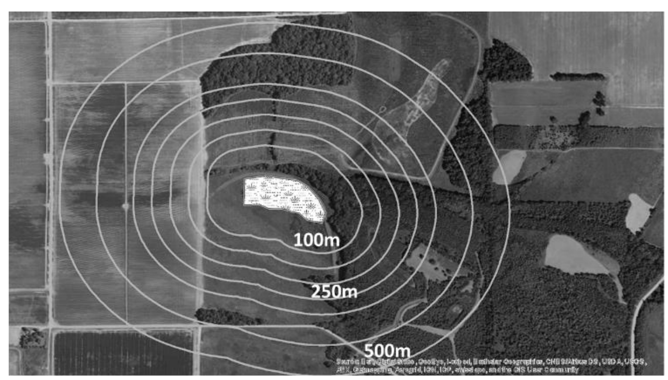

Figure 7. Land cover was examined at multiple distances from the wetland boundary, in terms of its relationship to wetland vegetation. Data from ESRI Digital Globe, a compilation of georeferenced data sources.

We found that, within 500 meters of the wetland boundaries (Figure 7), fallow land cover (usually consisting of land enrolled in conservation programs) was most strongly correlated with plant species diversity within the wetlands. We also found that the observed positive relationship between these two factors strengthened as larger areas around the wetland were included. We suspect that conservation lands in this landscape simply harbor a greater number of species adapted to the relatively diverse conditions present in the WRP wetland sites, and the close proximity has facilitated those species dispersing to our study wetlands. Other types of land cover showed general patterns in line with our expectations, but were not statistically significantly correlated with plant species diversity.

Based on a number of the patterns we observed in the above analyses, we initiated some experimental work to complement the observational studies described above and in our original proposal. We believe hydrology is a major driver of the differences in diversity that we found between the restored and natural sites. One potential mechanism for this is the influence that hydrology has on seed germination and plant establishment. To test this, we conducted an experiment examining the effects of three hydrologic regimes on seed germination. We imposed constant flooding, constant moist soil, and a fluctuating hydrology on seed banks from a subset of our natural and restored wetlands. We found similar numbers of seeds in the soil samples (~50 seeds per 70 cm^3 of soil) from both wetland types, as well as a similar proportion of seeds that germinated during our study (20-40% of seeds germinated). However, constant flooding resulted in a significantly lower proportion of seeds gemmating from the samples (Figure 8, Kruskal-Wallis P = 0.03).

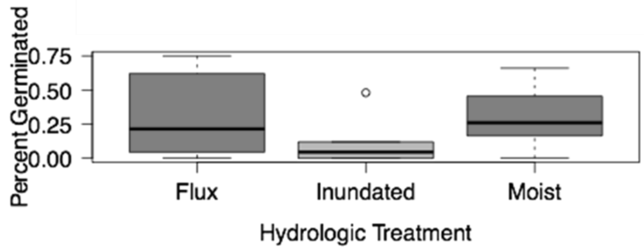

Figure 8. The constantly inundated treatment showed a significantly lower germination rate compared to that of constantly moist and fluctuating water level treatments (Kruskal-Wallis P = 0.03).

These results suggest that the year-round inundation observed in our natural wetlands may, in fact, have limited the number of species capable of establishing on those sites, consequently impacting the observed plant species diversity (Figure 6). Furthermore, it seems that, based on many of our analyses to date, within-wetland factors (habitat management, soil characteristics, hydrology) may be more important than broader-scale impacts (watershed-level nutrient loading, surrounding land use) in their effects on plant assemblages. We would caution that we are continuing our analyses of the data collected (see table below), and that subsequent information may or may not support these early observations.

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Progress related to stated objectives

1. Measure water quality and wetland plant species assemblages in restored (WRP) and naturally occurring wetlands in the Mississippi Delta, across the available gradient of estimated nutrient loadings.

This objective was completed. We have collected data from two growing seasons (2014 & 2015), including multiple water quality sampling trips during each year.

2. Measure a suite of local-scale (within-wetland) factors anticipated to influence water quality and wetland plant species.

We measured hydrology for twelve of our 30 study wetlands, sampled for soil characteristics multiple times during 2014, and collected data on water depth at each plant sampling location. Information will also be gathered from each land owner regarding specific site management activities conducted during the two years of our research.

3. Assemble existing data on meso- and macroscale factors likewise thought to serve as environmental drivers of water quality and wetland plant species.

We have assembled land use and land cover data for the entire region and have included analyses of these data in the above reported results, as well as multiple presentations given at state, regional, and international conferences.

4. Quantify statistical linkages between our ecological responses (water quality and wetland plants) and potential environmental drivers at the three spatial scales of interest, as well as determine the relative importance of those environmental factors.

These analyses were summarized above but are continuing, as part of Cory Shoemaker's dissertation research. We anticipate these analyses will form the basis for at least one peer-reviewed journal article submission.

5. Translate these results into information that can be used to guide the placement of future wetland restoration efforts so as to optimize the likelihood of success, within the context of local and watershed-scale environmental factors and to predict the effect of future local to watershed scale changes on wetland function.

This work will begin once we have assembled information on land owner management activities and have incorporated that information into our larger body of analyses of factors influencing plant and water quality in our study wetlands.

SIGNIFICANT FINDINGS

Information gained so far in this research project indicates that:

- WRP management results in a significantly altered wetland hydroperiod.
- The altered hydrology of WRP wetlands serves to enhance plant species diversity.
- WRP wetlands likely recruit plant species from adjacent or nearby conservation easements, very likely forming broad wetland "metacommunities" within the Delta's agriculture-dominated landscape.

We will build upon these findings to develop plans for future research that could use these insights to help direct future restoration/conservation efforts in the Delta.

CONTINUED RESEARCH

Although the project performance period has ended, much of the analyses of data collected remains underway. We have collaborated with Dr. Charles Bryson and Mr. John McDonald to identify the more difficult plant species from the field surveys, and plant identification is nearing completion. We currently are engaged in data analysis for one Master's student thesis that should result in at least one peer-reviewed publication, and we anticipate at least two publications to result from the doctoral dissertation that is still in progress.

Table 1. Anticipated products not yet completed from this project.

Type	Tentative title	Anticipated completion
Dissertation	*Assessing drivers of wetland plant community dynamics in the Mississippi Delta*	December 2017
Thesis	*Functions of Wetland Plant Assemblages in Water Quality Improvement in Natural Wetlands*	August 2016
Paper	Land use impact on wetland plant diversity in Mississippi Delta wetlands	Spring 2017
Paper	Responses of wetland seed banks from natural and restored wetlands to variation in flooding regime	Summer 2017
Paper	Long-term response of wetland seed banks to sediment and nutrient deposition	Spring 2018

FUTURE FUNDING POTENTIAL

Dr. Ervin made contact with Florance Bass and Doug Upton, at Mississippi DEQ, regarding future research projects that could expand on the findings resulting from this work while also contributing to wetland needs within Mississippi. Plans are to continue discussions with MS DEQ and to develop research plans that could be used to pursue potential funding opportunities that could take advantage of the information gained in this WRRI-funded project.

STUDENT TRAINING, OUTREACH, AND INFORMATION TRANSFER

Two graduate students are continuing work towards their degrees, with one planning to graduate during 2016, the other potentially as early as December 2017. These students have presented work from their projects at a number of regional conferences, resulting in one award for Best Student Presentation. The following are some of the products and future plans for results from this research.

Student Training

Name	Level	Major
Cory Shoemaker	Doctoral Student	Biological Sciences
Cory won the award for Best Student Oral presentation at the 2016 Mississippi Water Resources Conference, for a presentation on this work.		
Evelyn Windham	Master's Student	Biological Sciences
Evelyn was selected as the Department of Biological Sciences Teaching Assistant of the Year for the 2015-2016 academic year.		
McKenzie Gates	Undergraduate Student	Biological Sciences

Publications/Presentations

Ervin, G. N. and C. M. Shoemaker. 2015. Water quality-land use interactions in restored wetlands of the Mississippi Delta. Mississippi Water Resources Conference, Jackson, MS, 08 April 2015.

Gates, M., C. M. Shoemaker, E. L. Windham, and G. N. Ervin. 2016. Germination rates of Delta wetland seeds under varying conditions. MSU Department of Biological Sciences Undergraduate Research Program Symposium, April 08, 2016.

Shoemaker, C. M. 2015. Drivers of wetland plant communities in the Mississippi Delta. Department of Sciences and Mathematics, Mississippi University for Women, Columbus, MS, September 9, 2015. (Invited lecture)

Shoemaker, C. M. and G. N. Ervin. 2015. Drivers of plant community composition in Delta wetlands. Mississippi Water Resources Conference, Jackson, MS, 08 April 2015.

Shoemaker, C. M. and G. N. Ervin. 2015. Drivers of plant community composition in restored wetlands. Society of Wetland Scientists annual conference, Providence, RI, 03 June 2015.

Shoemaker, C.M. and G. N. Ervin. 2015. Drivers of wetland plant assemblages in restored and naturally occurring wetlands in Mississippi. MidSouth Aquatic Plant Management Society Conference, Mobile, AL, September 16, 2015

Shoemaker, C. M., E. L. Windham, and G. N. Ervin. Effects of land use on wetland plant diversity in Mississippi. Mississippi Water Resources Conference, Jackson, MS, 06 April 2016.

Planned web-based hosting of data and information

Final products from the project will be made available to scientists and the general public through the Ervin's membership in the Gulf Coastal Plain and Ozarks Landscape Conservation Cooperative (GCPO LCC). In particular, geospatially referenced data products resulting from this work can be made available via the GCPO LCC Conservation Planning Atlas (http://gcpolcc.databasin.org/). General information about the project and findings will be hosted through a GCPO LCC project page (gcpolccapps.org). All products made available in this manner will adhere to the data management best practices developed by the GCPO LCC.

Collaboration with Kevin Nelms of the USDA NRCS.

We have cooperated directly with the USDA NRCS in determining sites on which to conduct the research, but we also plan to maintain that collaboration to aid in information dissemination. Incorporation of our findings into the USDA NRCS WRP ranking tool will ensure that the most complete information is being applied to assessment and prioritization of WRP efforts within the region.

Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary

Basic Information

Title:	Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary
Project Number:	2014MS191B
Start Date:	3/1/2014
End Date:	7/29/2016
Funding Source:	104B
Congressional District:	4th
Research Category:	Water Quality
Focus Category:	Nutrients, Geochemical Processes, Water Quality
Descriptors:	None
Principal Investigators:	Kevin S Dillon

Publications

1. Uptake of excess phosphate by estuarine sediments in Bangs Lake (poster) Sarah Holcomb, Chris Griffin, Joshua Allen, Kevin Dillon, Kimberly Cressman, Mark Woodrey, presented at Bays and Bayous, December 2-3, 2014, Mobile, AL.
2. Sedimentary records of recurrent phosphate spills to a Gulf of Mexico estuary, (poster), Jacob Hall, Pavel Dimens, Elizabeth D. Condon, Ruth H. Carmichael, Kimberly Cressman, presented at Bays and Bayous, December 2-3, 2014, Mobile, AL.
3. Response of benthic macroalgae to phosphorus inputs in Grand Bay National Estuarine Research Reserve, (poster), Jane Caffrey, Tashana Jones, Kaleb Price, Lorenzo Modestini, Cheyene Hunt-Alderson, Kim Cressman, Mark Woodrey, presented at Bays and Bayous, December 2-3, 2014, Mobile, AL.
4. Quarterly reports to MWRRI.
5. Caffrey, J. M.; Carmichael, R. H.; Cressman, K.; Darrow, E. S.; Dillon, K. S.; Woodrey, M. S.: BRINGING TOGETHER RESEARCH AND MANAGEMENT TO EXAMINE THE CONSEQUENCES OF REPEATED PHOSPHORUS SPILLS IN A COASTAL ESTUARY. 2015 ASLO Aquatic Sciences Meeting, Feb 24, 2015. Grenada, Spain.
6. Dillon, K., K.P. Jones, G. Baine, J.G. Hall, P. Dimens, E. Hieb, K. Cressman, M. Woodrey (2015). Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary, presented at 2015 Mississippi Water Resources Conference, Jackson, MS, April 7-8, 2015.
7. Dillon, K. J. Caffrey, R. H. Carmichael, K. Cressman, M. Woodrey, 2015. Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary. Final Technical Report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 15 pgs.
8. Holcomb, S., C. Griffin, J. Allen, K. Dillon . Cressman, M. Woodrey. Uptake of excess phosphate by estuarine sediments in Bangs Lake. Pposter presented at 2014 Bays and Bayous Symposium, Mobile, AL, December 2-3, 2014.
9. Hall, J., P. Dimens, E. D. Condon, R.H. Carmichael, K. Cressman. Sedimentary records of recurrent phosphate spills to a Gulf of Mexico estuary. Poster presented at 2014 Bays and Bayous Symposium, Mobile, AL, December 2-3, 2014.

Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary

10. Caffrey, J., T. Jones, K. Price, L. Modestini, C. Hunt-Alderson, K. Cressman, M. Woodrey. Response of benthic macroalgae to phosphorus inputs in Grand Bay National Estuarine Research Reserve. Poster presented at 2014 Bays and Bayous Symposium, Mobile, AL, December 2-3, 2014.

Mississippi Water Resources Research Institute (MWRRI) / US Geological Survey Final Technical Report

September 15, 2015

Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary

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Abstract: Bangs Lake, an estuarine water body in the Grand Bay NERR, has been the site of three industrial phosphate spills from a nearby fertilizer plant since 2005. Due to restricted tidal exchange in Bangs Lake, these events have had long lasting effects on water column phosphate concentrations which may stimulate biological activity and alter the biogeochemical cycling of essential elements within the water column and the sediments. To determine the fate of excess phosphate from the industrial spills, researchers measured soluble reactive phosphate concentrations in sediment pore water and total particulate phosphate concentrations from sediment cores (0-25 cm depth) from four locations: North Bangs Lake (closest to spill locations), Bangs Lake, and two low impact reference sites (Bayou Cumbest and Bayou Heron). Researchers also conducted phosphate adsorption experiments and measured benthic chlorophyll concentrations with sediments from these sites to determine if the excess PO_4 was fertilizing benthic microalgae to determine the fate of this excess PO_4. Pore water phosphate concentrations were highest (21 uM) from 10 to 20 cm depths in North Bangs Lake cores however pore water from the surface sections of these cores had much lower phosphate concentrations (<0.5 uM). Pore water from the Bangs Lake cores consistently had elevated phosphate concentrations (2 to 5 uM) throughout the core length while pore water phosphate concentrations from one reference site were much lower (<0.7 uM), likely reflecting background levels. Phosphate adsorption experiments show that surface sediments from North Bangs Lake and Bayou Cumbest rapidly stripped phosphate from solution to final concentrations of <3 uM while surface sediments from Bangs Lake had greatly reduced phosphate adsorption capacity with much higher final concentrations (24 to 32 uM) indicating these sediments are nearing saturation. Sediment chlorophyll *a* concentrations were higher in Bangs Lake compared to the reference site. Sediment chlorophyll *a* was significantly correlated with extractable phosphate concentration in

sediments (r = 0.88). In addition, grow out experiments with amendments of phosphorus to water and sediment samples stimulated the growth of cyanobacteria capable of fixing nitrogen.

Introduction

Two large phosphate spills which led to large fish kills have occurred from Mississippi Phosphate Corporation (a fertilizer production facility) to the Grand Bay National Estuarine Research Reserve's (GBNERR) Bangs Lake since 2005 (Fig. 1). Following these spills, pH dropped dramatically from an average of ~7.5 to near 3.7 in Bangs Lake and phosphate concentrations following spills rose from near zero to 4.3 mg L^{-1} in 2005 and 7 mg L^{-1} in 2012 (SWMP, Darrow et al, in prep) and took six months to return to background levels of 0.01 mg L^{-1} (Fig. 2). Other nearby locations within the NERR showed smaller increases of 2.6 mg L^{-1} (Point Aux Chenes) and 0.30 mg L^{-1} (Bayou Cumbest, Darrow et al., in prep). These data demonstrate that recurrent phosphate spills can have relatively long-lasting water quality impacts across the Reserve. Further, there is some evidence of potential continuous input of phosphate to Bangs Lake from smaller ongoing spills or dry deposition. These events and the obvious biological impacts to the waters of a protected NERR warrant further investigation. While regular monitoring of water quality parameters and nutrient concentrations by the GBNERR's System Wide Monitoring Program (SWMP) provide basic information to detect these spills, the fate and persistence of the externally loaded phosphate within the system are poorly understood. For example, we know that phosphate concentrations remained elevated in surface waters for up to six months after a spill before returning to background concentrations, but we do not understand if phosphate is adsorbed and persists in sediments or flushed out of GBNERR waters by tidal action. We also do not know if there is a nutrient enrichment or 'fertilizer' effect on the ecosystem that could stimulate growth of phytoplankton, benthic microalgae, or species responsible for harmful algal blooms (Caffrey et al. 2013). In addition to acute phosphorus spills, dry deposition of phosphate-rich gypsum particles from large phosphorus stacks on the chemical plant site may be a smaller but consistent phosphate source to the GBNERR which may be responsible for frequently observed smaller phosphorus increases (Fig.2). Phosphorus is not typically measured in atmospheric monitoring programs; however, it is relatively simple and inexpensive to quantify (Williams et al., 1992).

Understanding the fate of excess phosphate inputs to Bangs Lake and nearby waters is essential to defining biological responses of the ecosystem. Phosphate can bind rapidly to sediments within the estuary and adjacent Mississippi Sound due to adsorption of phosphate to aluminum and iron rich minerals (Gomez et al., 1999, Dillon, in prep). Subsequent desorption may release phosphate back to the water column at a later time. Desorption experiments in Mississippi Sound showed increases in dissolved phosphate concentrations to 1 - 2 µM are possible (Dillon in prep.). Similar phosphorus adsorption/desorption reactions have been reported for a variety of estuarine sediments (Gomez et al., 1999, Dillon et al., 2003). Importantly, changes in sediment resuspension, pH, redox potential and ionic strength, or water column salinity that might occur during a phosphate spill or severe storm events can all alter phosphate adsorption/desorption processes (Froelich, 1988), potentially remobilizing previously stored phosphate from the sediments to the water column and affecting ecosystem processes such as nutrient cycling and food web dynamics.

In marine ecosystems, nitrogen availability often limits growth of phytoplankton and benthic microalgae. Amacker (2013) found that phosphorus additions to some sites in Grand Bay did not increase phytoplankton. Accordingly, increased water column algae growth (phytoplankton; estimated by measuring chlorophyll *a*) has not been detected in Bangs Lake following the documented phosphate spills (Caffrey et al. 2013, Cressman, unpublished data). Significantly higher benthic (bottom) microalgae growth, however, has been found closer to the fertilizer plant (Modestini and Caffrey, unpublished data) and phytoplankton concentrations have not been measured with sufficient temporal and spatial detail to dismiss possible water column effects. Because the sediments contain greater amounts of nitrogen than the water column, it is possible that phosphate spills have a greater influence on benthic algae compared to water column phytoplankton. Additionally, elevated phosphorus concentrations in freshwater dominated systems often result in blooms of toxin-producing cyanobacteria that can be harmful to animals and people (Paerl et al. 2001). Although Grand Bay is strongly influenced by freshwater inputs, no studies have tested for harmful algal blooms following the phosphate spills into Bangs Lake.

The former GBNERR Site Manager (David Ruple, now retired) and Research Coordinator (Dr. Mark Woodrey) have assembled a Phosphate Working Group (PWG) to investigate scientific questions related to these anthropogenic phosphate loadings. This working group includes members from the GBNERR, regional universities and marine labs (University of Southern Mississippi/ Gulf Coast Research Lab, University of West Florida, and Dauphin Island Sea Lab/ University of South Alabama), and the Mississippi Department of Environmental Quality (DEQ) who are currently conducting research and addressing environmental management issues within the GBNERR. This one year research project addresses four basic questions developed by the PWG to assess the water quality impacts of repeated phosphate spills on an otherwise relatively undisturbed estuarine ecosystem. (1) What is the fate of phosphorus after a spill (Where does it go)? (2) Is there a detectable preserved sedimentary record of past phosphorus spills? (3) Is there a biological 'fertilizer' effect on microalgal production? (4) Is dry deposition of gypsum particles from the fertilizer plant a source of phosphorus to the Reserve? This research project addresses the Mississippi Water Resources Research Institute's Water Quality research priority area.

This project had a large student training component: we recruited six undergraduate interns from three regional institutions to collect data to better define the fate and biological effects of recurrent phosphate spills into Bangs Lake within the GBNERR. To determine whether phosphate is adsorbed to and preserved in sediments through time, we collected sediment cores from Bangs Lake, which has been altered by direct spilling of phosphate from the Mississippi Phosphates Corporation, and 2 control sites which we believe were historically less impacted (Bayou Cumbest and Bayou Heron). We measured phosphate concentrations down-core in the sediments and are combining phosphate data with radiometric dating using Lead-210 to define dates of historical spills, including spills prior to the GBNERR's monitoring program. To define the potential for phosphate adsorption to sediments, we conducted adsorption experiments using sediments from each site. To determine if there is a biological 'fertilizer' effect on microalgal production, we measured water column and pore water nutrients and chlorophyll a concentrations in the water column (phytoplankton) and at the sediment surface (benthic microalgae) at the phosphate enriched site (Bangs Lake) and at the control site (Bayou Cumbest). We also tested the potential for dry deposition of gypsum particles to contribute phosphate to the GBNERR by measuring phosphorus dryfall and compared the results to a reference site located near the Mississippi Sandhill Crane Refuge in western Jackson County.

Sampling and Analytical Methods

Sediment cores phosphate inventory & ^{210}Pb dating - Eight sediment cores were collected from undisturbed locations in Bangs Lake and 2 cores were collected from less impacted reference sites (Bayou Cumbest and Bangs Lake) in at least 1.0 m of water using a 12.0 cm diameter x 30 cm long opaque PVC corer We sectioned the sediment cores using clean methods in 1 cm increments Each core was sectioned and processed within 24 hours of collection. To avoid cross contamination by sediments pressed along the wall of the corer, sediment sections were subsampled from the center using an acid-washed modified syringe corer. Subsamples were homogenized and divided into three portions to be analyzed for sediment phosphate concentrations, Lead-210 (^{210}Pb) activity. Phosphate was analyzed as described by Aspila et al. (1976).   Radiometric analysis and dating will be conducted by the Geotop Lab at the University of Montreal Quebec using a ^{210}Pb model.

Phosphate adsorption experiments **–** Separate sediment cores were collected from Bangs Lake and Bayou Cumbest. One 5 cm section of the surficial sediments from each core was dried and 10g of each sediment sample were placed in an acid-washed flask with 75 mls of artificial seawater with a phosphate concentration of 50uM (1.5 mg L^{-1}) then capped and placed on a shaker table. Phosphate concentrations in each flask was sampled at approximately 2, 4, 8, 15, and 30 minutes then again at 1, 2 and 4 hours. Phosphate samples were syringe filtered with a Whatman glass fiber filter and then frozen until analysis. Phosphate concentrations were determined colormetrically (Strickland and Parsons, 1972).

Benthic microalgae activity - Surface sediment samples from the top 0.5 cm layer were be collected from the marsh and subtidal sediments for analysis of chlorophyll a and the pigments associated with cyanobacteria as in Neveux et al. (2011). Samples were also collected for measurement of nitrogen fixation at the same sites as the chlorophyll analyses. We used the acetylene reduction method which has been a standard technique for measuring nitrogen fixation since the 1970s (McCarthy and Bronk 2008). During nitrogen fixation, acetylene is reduced to ethylene by the nitrogenase enzyme. Samples were incubated in an air tight flask; headspace was replaced with 10% acetylene. Headspace samples were collected at 30 minute intervals over a 3 hour time course with syringes. These gas samples were injected into a GC with an FID detector for analysis of ethylene. If necessary, the time course were lengthened if rates were low or shortened if rates were high.

Grain size analysis

Sediment samples from the phosphorus inventory cores were used for grain size analysis using the pipette method (Folk 1974). Samples (ca. 20 g) will be digested with peroxide to remove organic matter. Samples will be sieved through 64 µm screen to retain the sand. After addition of 10 mL of dispersant (Calgon), the silt and clay fractions made up to 1 L will be sampled from a graduated cylinder using fall velocity tables to determine the removal time.

Particulate phosphate dry deposition

Airborne particles for phosphate analysis were collected on 47mm glass fiber filters with a HiQ VS-Series Air Sampling Systems to estimate dry deposition to the study area. Filters were placed into the filter holder and air was pumped thru the filter for 10 to 14 days at a flow rate of 35 LPM. An additional sampler was installed and sampled for the same time interval at a reference site located 5 miles inland from Ocean Springs in west Jackson County (38 miles away). After samples were collected the filters were placed into a plastic petri dishes dried in a 60C oven and then stored in a desiccator until analyzed. For analysis, the filters were put in a glass vial with 20 mls of 1.2N hydrochloric acid and then placed in an incubator shaker (40C at 60 RPM) for 2 days to extract the phosphorus from the filters. The resultant liquid sample was then transferred to a clean vial and analyzed for phosphate colormetrically (Strickland and Parsons, 1972) after the samples with neutralized with 10N sodium hydroxide.

An automated wet/dry deposition collector was also used to collect settled airborne particles using the dry deposition side of the collector. These samplers have a rain sensor that automatically covers a dry bucket side of the collector during rain events. Buckets were cleaned with Neutrad laboratory soap, rinsed with deionized water, rinsed with 1.2N HCl, then rinsed thrice with DI water and then dried in a 40°C oven. Clean buckets were stored in plastic bags and then deployed on the dry deposition side of the collector and allowed to sit in the field for 20-28 days before being collected. Collected sample buckets were covered with aluminum foil, labeled and stored in sealed plastic bags at room temperature until analysis. For analysis, 50 to 100 mls of 1.2 N HCl was poured into the sample bucket which was then swirled carefully to wet the sides of the bucket. The acid was allowed to soak for 30 minutes then the buckets were swirled again and then the acid sample was filtered into clean vials and analyzed as described above for filter samples.

Results

Sediment cores phosphate inventory & ^{210}Pb dating

Sediment cores from Bangs Lake showed elevated particulate organic phosphorus (POP) concentrations at shallower core depths (Figure 3) with decreasing POP concentrations with increasing depth. One core from the southeast corner of Bangs Lake showed two distinct peaks at core depths of 4 and 14 cm. Based on preliminary results of the lead-210 analysis the peak at 4 cm depth corresponds to the documented 2005 spill from the Mississippi Phosphate Corporation. At this time, the lead-210 analysis has been completed however the final model results to assign dates to each core section are still being processed. Final results will be included in the Year 2 study funded by the Mississippi Water Resources Research Institute that is currently underway.

Phosphate adsorption experiments

Phosphate adsorption experiments at the Bayou Cumbest reference site showed that phosphate was rapidly adsorbed onto surficial sediments (Figure 4). Within 2 hours of exposure, the phosphate concentrations in the experimental incubations had decreased from 50uM to less than 3 uM. Concentrations continued to decrease until the last sampling at 48 hours. Pore waters from this site had low phosphate concentrations indicating that sediments had not been exposed to phosphorus from the spills. In contrast, surficial sediments from Bangs Lake had elevated pore water phosphate concentrations and sediments from this site had a reduced capacity to adsorb phosphorus out of solution (Figure 4). Phosphate concentrations in these incubations dropped from 50uM to 28uM over a 48 hour period. This shows that these sediments have been exposed to high phosphorus concentrations and are nearing their saturation point for phosphorus.

Benthic microalgae activity

Benthic chlorophyll represents microalgae living on the sediment surface. We hypothesized that fertilizer plant inputs of phosphorus would stimulate the production of benthic microalgae and potentially nitrogen fixation. Benthic chlorophyll a was measured at three locations near the fertilizer plant (Bangs Creek, Bangs North and Bangs Lake) and one location distant to the plant (Bayou Heron). Benthic chlorophyll a concentrations were highest in Bangs Lake and were higher at sites with high extractable P (Figure 5). Preliminary experiments suggested that phosphorus inputs can stimulate nitrogen fixation and growth of cyanobacteria.

Grain size analysis

Percent silt-clay was lowest at Bayou Heron west and Bangs Lake northwest and increased with increasing core depth at eastern Bangs Lake (Figure 6). Sediment cores from Bayou Heron showed evidence of previous mixing.

Particulate phosphate dry deposition

Airborne particles collected from the Grand Bay and reference site had similar baseline rates of collection (0.5 to 0.6 ug P day^{-1}) however the Grand Bay collector showed occasional increases above this baseline level to values as high as 1.2 ug P d^{-1}. The bucket collector in Grand Bay showed that rates of dry deposition at Grand Bay can range dramatically from 2 to 64 ug P day^{-1} m^{-2}. During the year 2 of this project we are developing more accurate wind rose diagrams that take wind speed and duration into account. At this time it is unclear if this dry deposited phosphorus is coming from the nearby gypsum stacks at the Mississippi Phosphates Corporation.

List of student by institution and Major that received training for this project:

Joshua Allen	MS Student USM	Coastal Sciences
Chris Griffin	senior USM	Biology
Sarah Holcomb	junior USM	Geology
Jason Hall	senior DISL	Biology
Pavel Dimens	senior DISL	Biology
Kaleb Price	junior UWF	Marine Biology
Tashane Jones	junior UWF	Biology

Relevant Findings:

This study has shown that much of the phosphate release during major industrial spills from Mississippi Phosphate Corporation is adsorbed by sediments and then sequestered in the benthos. It is still unclear however what proportions of this excess phosphorus is buried versus how much is flushed out of Bangs Lake due to tidal action. Sediment cores collected from Bangs Lake had higher particulate organic phosphorus concentrations and distinct peaks of phosphorus were found in cores collected from the southeast portion of Bangs Lake. Another major finding is that sediments in Bangs Lake had a reduced capacity to adsorb phosphorus indicating that the sediments in Bangs Lake are approaching saturation. Once saturation is reached, excess phosphorus will not be adsorbed and will only be affected by tidal advection or biological uptake. Benthic chlorophyll a concentrations were highest in Bangs Lake and were higher at sites with high extractable phosphorus. Preliminary experiments suggested that phosphorus inputs can stimulate nitrogen fixation and growth of cyanobacteria.

Future Research:

<u>In Year-2 we will refine and expand on our Year-1 research in three ways</u>, including addition of: 1) an artificial tracer (fluorescein) study to directly visualize and track water movement in Bangs Lake to define likely areas of phosphate accumulation, 2) iron and trace element analyses to spatially and temporally trace phosphate spills through detection of the chemical signature of other contaminants in spill materials, and 3) continuation of work from Year-1 at new sampling stations chosen based on outcomes of the tracer study and results of Year-1 to better define locations of effects. Ongoing work continued from Year-1 will include sampling of sediment grain size, organic carbon and nitrogen content, phytoplankton and benthic microalgae concentrations, pore water and water column nutrient analyses, which will be needed to support the newly proposed analyses and integrate the results of Year-2 with Year-1 data.

Information Transfer and Outreach:

Results from this research to date have been presented as three student posters at the Bays and Bayous Symposium 2014 (Mobile AL), a poster by PI Caffrey at ASLO's 2014 Ocean Science

Meeting (Honolulu, HI), and an oral presentation by Dillon at the 2015 Mississippi Water Resources Conference (Jackson, MS).

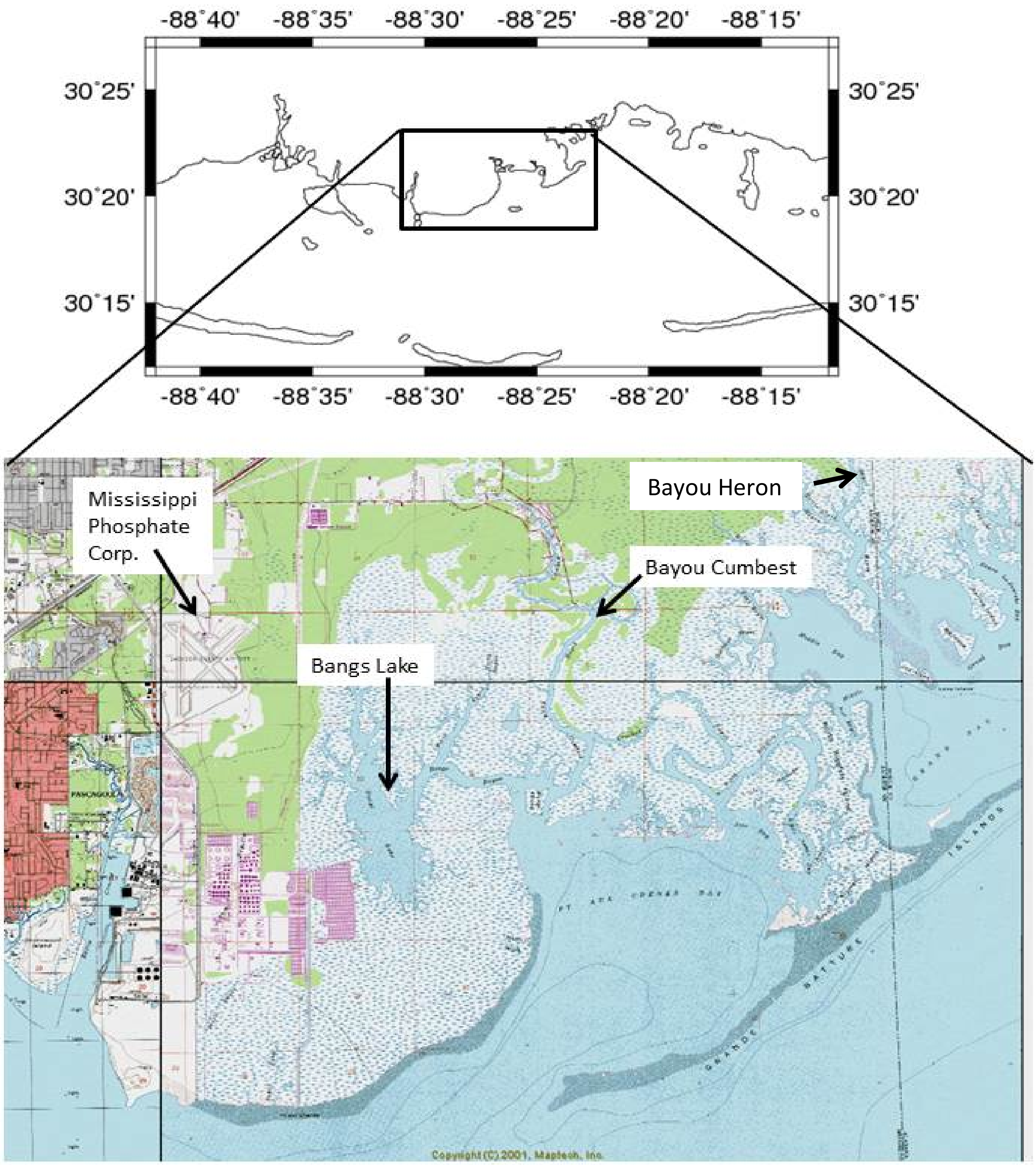

Figure 1. Map of the study sites (Bangs Lake, Bayou Cumbest, and Bayou Heron. The location of nearby gypsum stacks at Mississippi Phosphates Corporation are shown for reference.

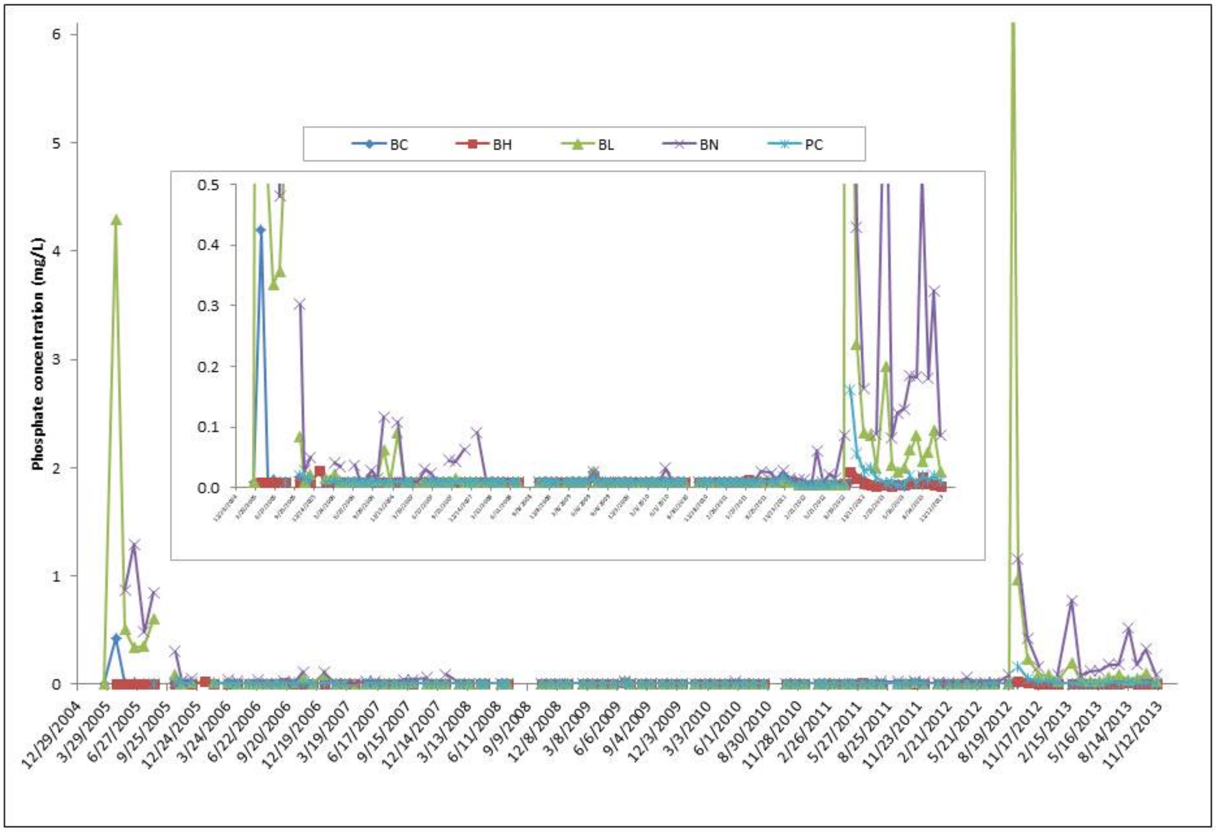

Figure 2. Water column phosphate concentration at monthly sampled stations within the GBNERR. BC = Bayou Cumbest; BH = Bayou Heron; BL = Bangs Lake; BN = Bangs Lake Nort; PC = Point aux Chenes. Inset is the same data on a smaller scale to better show smaller, more frequent changes in phosphate concentrations.

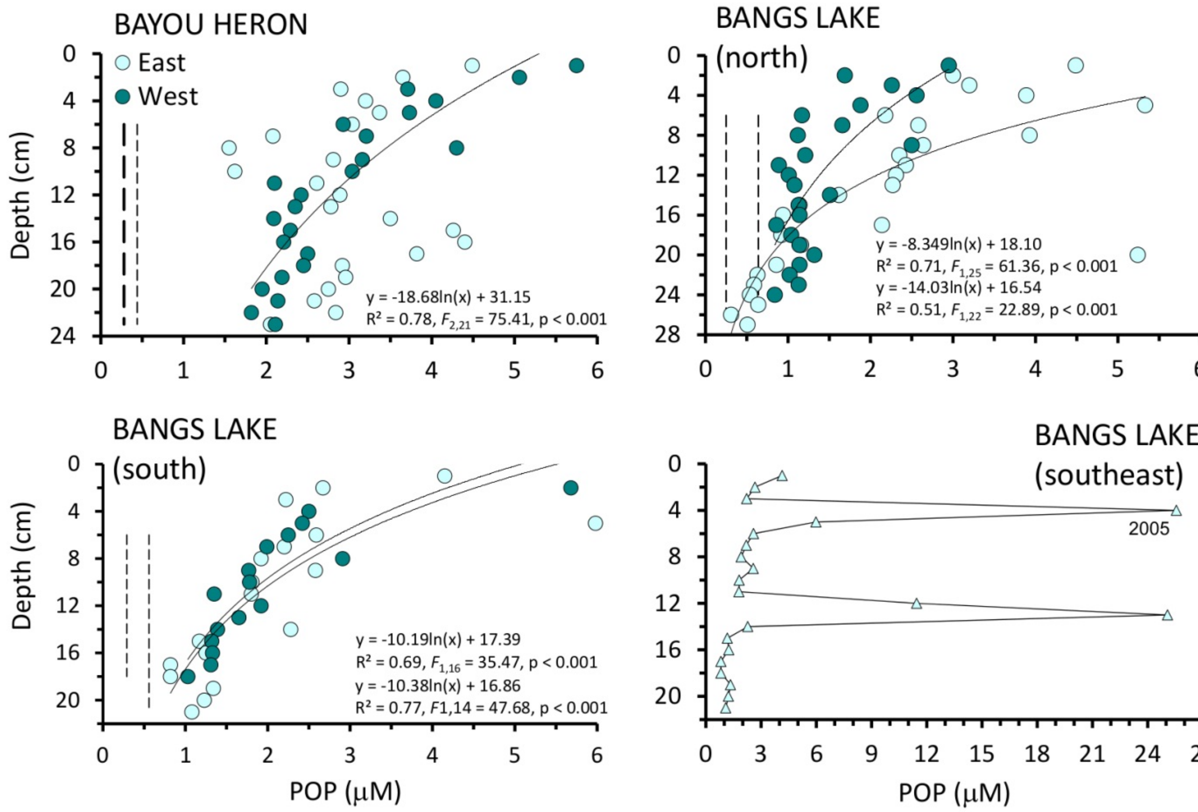

Figure 3. Particulate organic phosphorus (POP) concentrations in sediment cores from four stations in Bangs Lake. Dotted lines show background P concentrations in deeper core section.

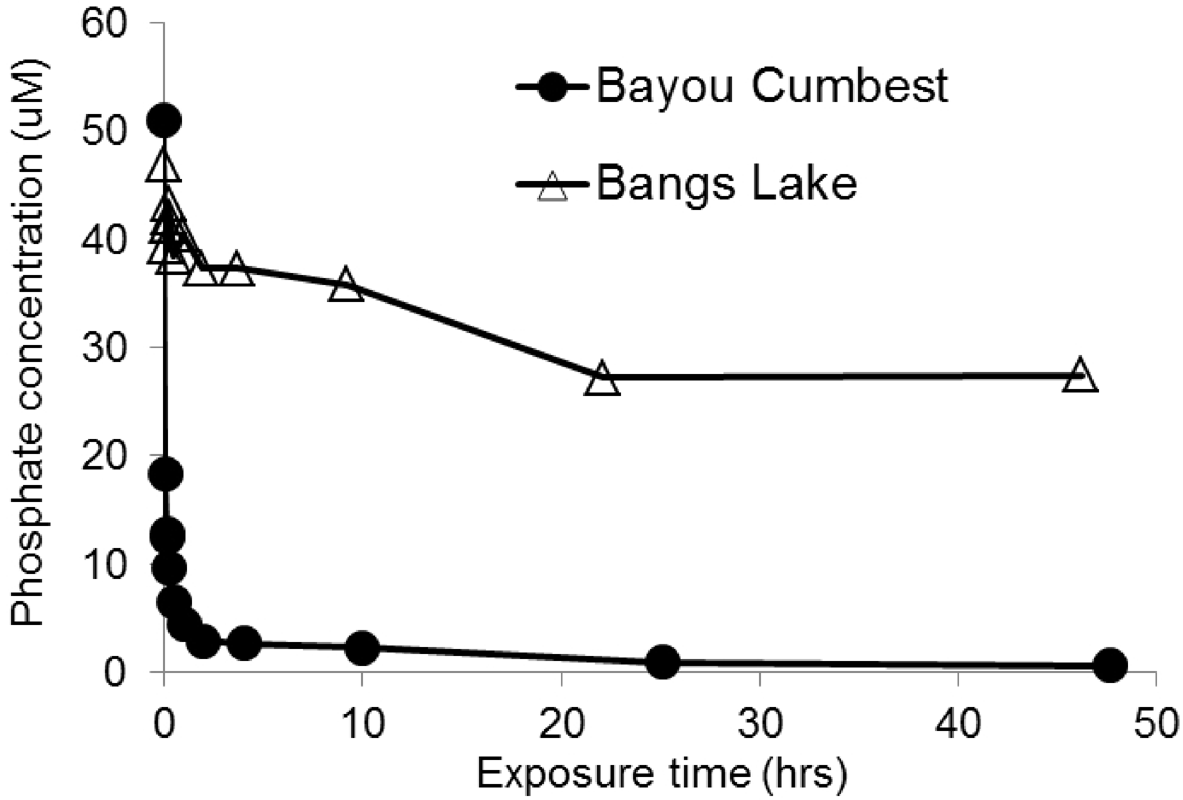

Figure 4. Results of the phosphate adsorption experiments. Phosphate concentration over 48 hours at Bangs Lake (triangle) and Bayou Cumbest (circle).

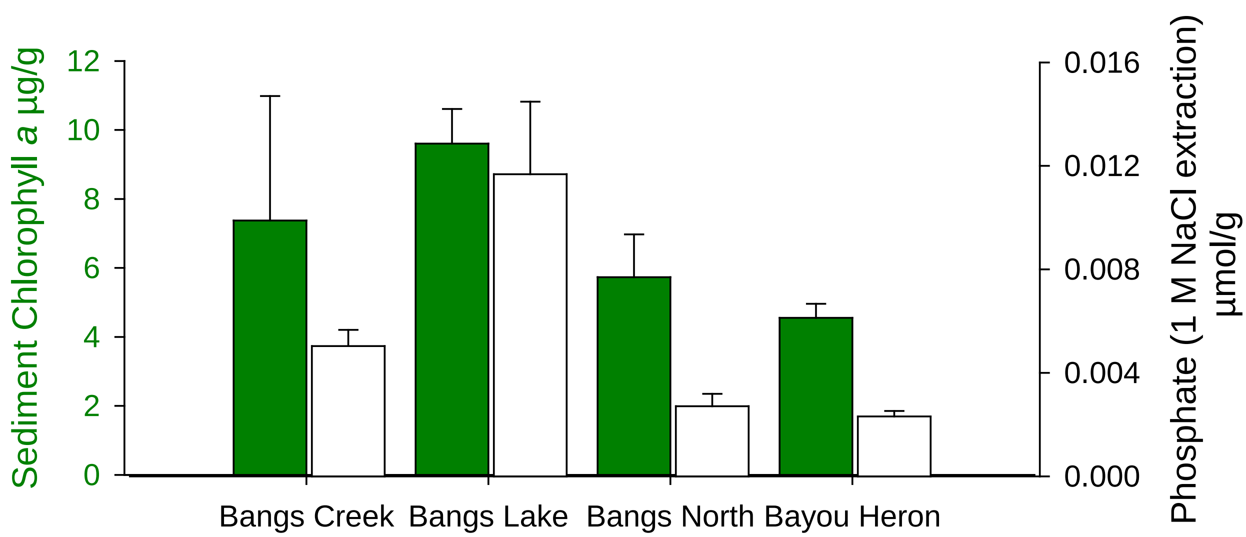

Figure 5. Sites closest to fertilizer plant had higher benthic chlorophyll a (green bars) and extractable phosphate concentrations (white bars) than site furthest away (Bayou Heron)

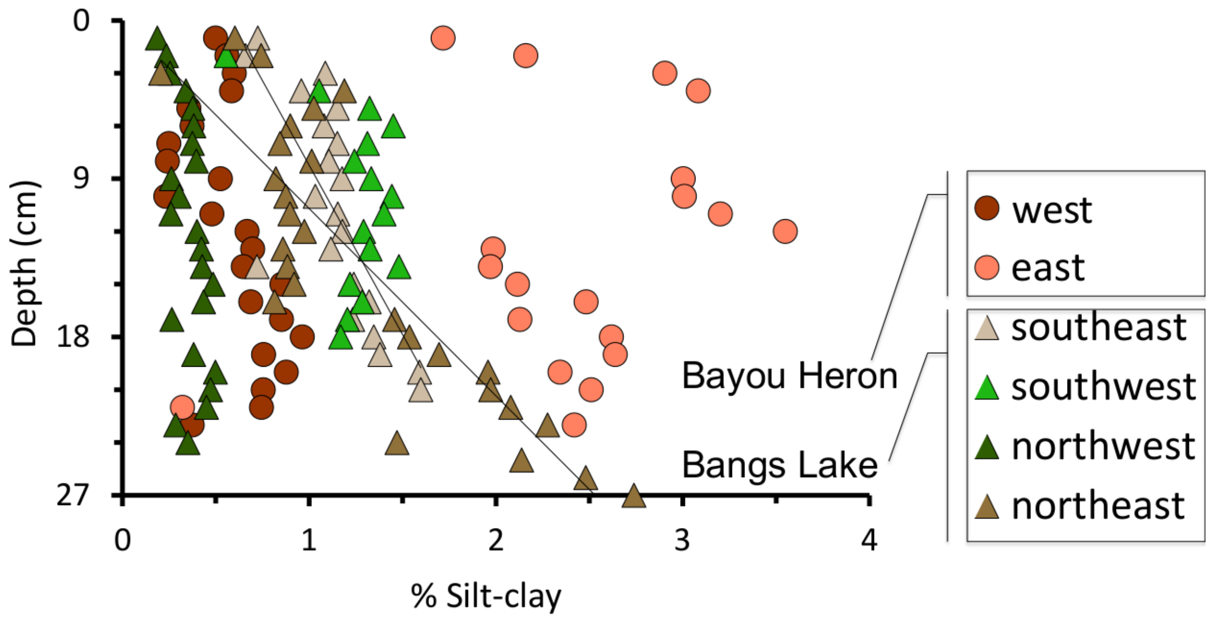

Figure 6. Results of grain size analysis for sediment samples collected in Bayou Heron and Bangs Lake.

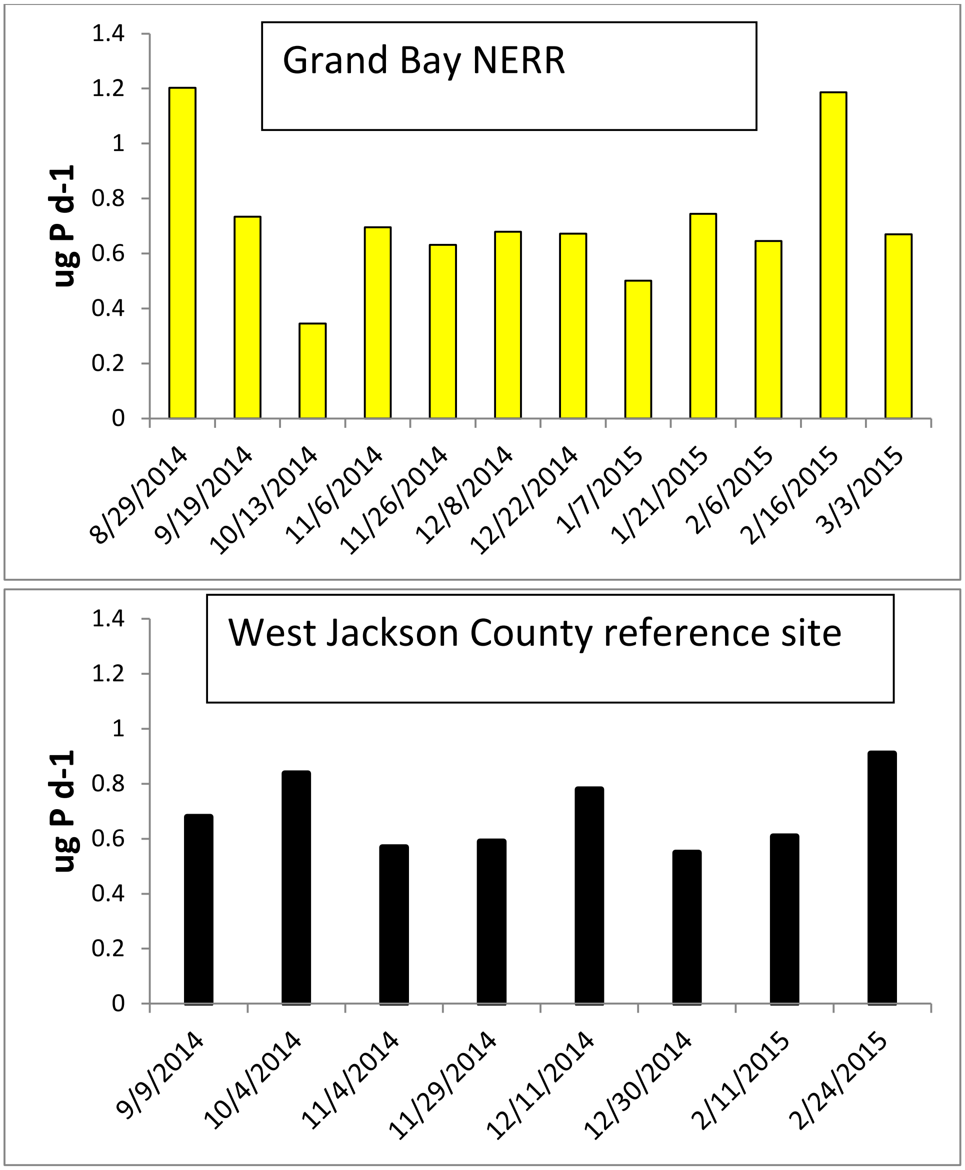

Figure 7. Average phosphate amounts collected daily on airborne particulate filters at the Grand Bay NERR and the reference site located in West Jackson County, Mississippi from August 2014 until March 2015.

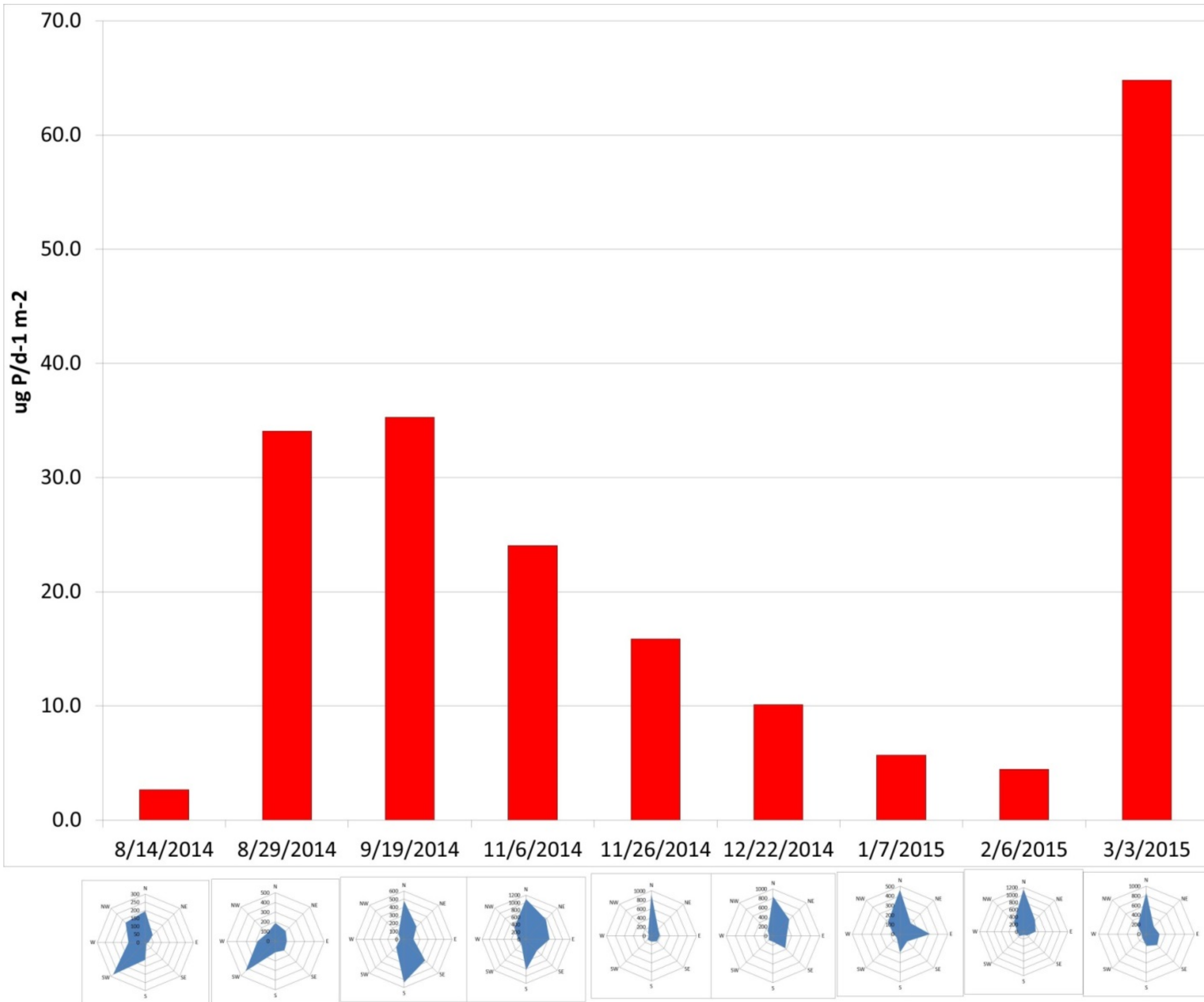

Figure 8. Settling rates of phosphorus from dry deposition collected from August 2014 to March 2015. Wind rose plots at the bottom of the graph show wind direction for the time period that the dry deposition bucket was deployed.

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Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary: Year 2

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Mississippi Water Resources Research Institute (MWRRI) / US Geological Survey Final Technical Report

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Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary: Year 2

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Abstract:
Grand Bay National Estuarine Research Reserve (GBNERR) is located in a relatively pristine estuary in the northern Gulf of Mexico, with ambient nutrient concentrations often below detection. However, since 2005, periodic breaches in a containment levee from a phospho-gypsum stack have led to high phosphate levels (over 200 µM) while pH dropped from 7.5 to near 4.5. GBNERR staff assembled a phosphate working group to investigate scientific questions related to these phosphate loadings. This working group includes members from GBNERR, regional universities, marine labs, and Mississippi Department of Environmental Quality. They identified four essential questions needed to assess the impacts of repeated phosphate spills on water quality in an otherwise pristine ecosystem. (1) What is the fate of phosphorus after a spill? (2) Is there a preserved sedimentary record of past phosphorus spills? (3) Is there a biological fertilizer effect on benthic microalgae in this shallow photic system? (4) Is dry deposition of gypsum particles from the adjacent fertilizer plant a smaller but constant source of phosphorus to GBNERR? Research results will provide information critical for management of the Reserve.

Introduction
Two large phosphate spills have occurred from Mississippi Phosphate Corporation (a fertilizer production facility) to the Grand Bay National Estuarine Research Reserve's (GBNERR) Bangs Lake (Fig. 1) since 2005 Following these spills, phosphate concentrations in Bangs Lake surface waters rose from near zero to extremely high concentrations (as high as 7mg L^{-1} or 225 µM) and pH dropped dramatically from an average of ~7.5 to 3.7. Less dramatic changes in phosphate concentrations and pH were measured at other regularly sampled stations nearby, and large fish kills also occurred throughout the Reserve. In addition to delivery of phosphorus itself to coastal waters, other contaminants including trace elements and heavy metals that are hazardous to local

biota are conveyed in spill material (Salomons 1989). Further, there is some evidence of potential continuous input of phosphate to Bangs Lake from smaller sources (i.e. ongoing spills, dry deposition, and/or groundwater seepage). These events and the obvious biological impacts to the waters of a protected NERR warranted further investigation. While regular monitoring of water quality parameters and nutrient concentrations by the GBNERR's System Wide Monitoring Program (SWMP) provides basic information to detect these spills, the fate and persistence of the externally loaded phosphate within the system are poorly understood. For example, we know that phosphate concentrations remained elevated in surface waters for up to six months after a spill before returning to background concentrations, but we do not understand if phosphate is adsorbed and persists in sediments, flushed out of NERR waters by tidal action, or some combination of these two fates. We also do not know if there is a nutrient enrichment or 'fertilizer' effect on the ecosystem that could stimulate growth of phytoplankton, benthic microalgae, or species responsible for harmful algal blooms (Caffrey et al. 2013). In addition to acute phosphorus spills, dry deposition of phosphate-rich gypsum particles from large phosphorus stacks on the chemical plant site may be a smaller but consistent phosphate source to the GBNERR which may be responsible for frequently observed smaller phosphorus increases. Phosphorus is not typically measured in atmospheric monitoring programs, however, it is relatively simple and inexpensive to quantify (Williams et al., 1992).

The GBNERR assembled a Phosphate Working Group (PWG) to investigate scientific questions related to these anthropogenic phosphate loadings. This working group includes members from the GBNERR, regional universities and marine labs (University of Southern Mississippi/ Gulf Coast Research Lab, University of West Florida, and Dauphin Island Sea Lab/ University of South Alabama), and the Mississippi Department of Environmental Quality (DEQ) who are currently conducting MWRRI funded research that addresses the following scientific questions developed by the PWG to assess the water quality impacts of repeated phosphate spills on an otherwise relatively undisturbed estuarine ecosystem. In year 1, we conducted experiments to characterize phosphate adsorption by sediments in Bangs Lake and less impacted reference sites within the GBNERR (Bayou Cumbest, Bayou Heron). We found that sediments from Bangs Lake had a reduced capacity for phosphate adsorption due to previous phosphate exposure while sediments from the less impacted site had a much higher capacity for phosphate adsorption. Sediment core results also showed spikes in particulate phosphorus concentrations at depth consistent with historical phosphate spills preserved within the sedimentary record. We also observed increased benthic chlorophyll concentrations at the Bangs Lake site relative to nearby Bangs Creek and Bayou Heron, suggesting that benthic microalgae production in Bangs Lake is stimulated by periodic phosphorous spills and/or chronic atmospheric deposition of phosphorus. This was a consistent pattern throughout the summer months.

In Year 2 we completed radiometric dating analysis for sediment cores from Year 1 and expanded on our research in three ways, including addition of: 1) an artificial tracer (fluorescein) study to simulate a phosphorus spill which will allow direct visualization of a contaminated plume and will allow us to track water movement in Bangs Lake to define likely areas of phosphate accumulation, 2) Iron and trace element analyses to spatially and temporally trace phosphate spills through detection of the chemical signature of other contaminants in spill materials, and 3) continuation of work from Year-1 at new sampling stations chosen based on outcomes of the tracer study and results of Year-1 to better define locations of effects. More than 99% of trace metals are bound to and retained in sediments, serving as an archive of historical changes in environmental conditions including contaminant exposure (Salomons 1998). Phosphate mineral fertilizers and the by-products from their production have distinct and traceable element profiles that can function like a fingerprint to indicate the types of pollution or contaminant entering a system. Ongoing work continued from Year-1 included sampling of sediment grain size, organic carbon and nitrogen content, phytoplankton and benthic microalgae concentrations, porewater and water column nutrient analyses, and airborne particulate phosphorous conentrations which will all be needed to support the newly proposed analyses and integrate the results of Year-2 with Year-1 data.

Sampling and Analytical Methods

Fluorescent dye tracer experiment to track water movement from spill area –
A fluorescent dye (fluorescein) was used as a surface water tracer to characterize movement of a parcel of tracer-laden fresh water that was released in north Bangs Lake. 1.5 kg of dye was added to a large tank filled with 750L fresh water and transported to the release site with MS DMR's oil skimmer pontoon boat. After release, surface water samples were collected at selected sites from small boats, canoes and kayaks into plastic sample bottles. We followed the colored water mass to collect samples based on visual observation of the dye after release. The position (latitude and longitude) of each sample location was determined with GPS units on each boat. In addition, ISCO automated water samplers were deployed to collect surface water samples at 15-60 minute intervals at two SWMP sampling locations (North Bangs Lake and Bangs Lake). Water samples were analyzed for fluorescein concentrations with a Turner field fluorometer that was calibrated with known fluorescein concentrations.

Grain size analysis
Sediment samples from the phosphorus inventory cores were used for grain size analysis using the pipette method (Folk 1974). Samples (ca. 20 g) were digested with peroxide to remove organic matter. Samples were sieved through 64 µm screen to retain the sand. After addition of 10 mL of dispersant (Calgon), the silt and clay fractions made up to 1 L was sampled from a graduated cylinder using fall velocity tables to determine the removal time.

Sediment cores phosphate inventory & ^{210}Pb dating - Eight sediment cores were collected from undisturbed locations in Bangs Lake and 2 cores were collected from less impacted reference sites (Bayou Cumbest and Bangs Lake) in at least 1.0 m of water using a 12.0 cm diameter x 30 cm long opaque PVC corer We sectioned the sediment cores using clean methods in 1 cm increments Each core was sectioned and processed within 24 hours of collection. To avoid cross contamination by sediments pressed along the wall of the corer, sediment sections were subsampled from the center using an acid-washed modified syringe corer. Subsamples were homogenized and divided into three portions to be analyzed for sediment phosphate concentrations, Lead-210 (^{210}Pb) activity, Cesium-137 (^{137}Cs) activity and Thorium-228:Thorium-232 ratios ($^{228}Th/^{232}Th$). Phosphate was analyzed as described by Aspila et al. (1976). Radiometric analysis and dating was conducted by the Geotop Lab at the University of Montreal Quebec using CRCS and CRS ^{210}Pb models.

Biological response to inputs from phospho-gypsum stack

Four sampling stations (BCr, BCr2013, BN, and BL; Figure 3) were selected to assess spatial variability associated with benthic microalgae and sediment characteristics near the phosphogypsum spill and contrast that with a control site far from the spill (BH). Two sites at an intermediate distance (BC and PC) were also sampled periodically. We collected sediment samples in summer and early fall from June through September in 2014 and June through October 2015. These results from 2014 and 2015 are compared with prior sampling from December 2012 and June 2013. Sediment nutrient bioassay experiments were conducted in June and August 2015 from Bangs Lake. In May 2015, Gary Baine began collecting monthly water samples from Bangs Lake to evaluate the response of phytoplankton to nutrient additions and the role of microzooplankton grazing on phytoplankton growth. This study provides a point of comparison to an earlier study on phytoplankton response to nutrient additions conducted in 2011 (Amacker 2013) before the inputs from the phosphogypsum stack began entering the Reserve.

Surface water samples were collected and later filtered through GF/F filters for chlorophyll a, nitrate+nitrite, ammonium and dissolved inorganic phosphate (DIP). Water quality parameters measured included temperature, salinity, dissolved oxygen concentration and pH. We calculated light attenuation using Beers Law from light profiles with a Licor 4 Pi sensor.

Sediment cores were collected using a push corer. Analyses were made in triplicate unless otherwise noted. Approximately 0.5 g from the top 0.5 cm layer was collected for analysis of chlorophyll a. The remaining top 0-1 cm surface layer was split into analyses for water content, sediment phosphorus and extractable P and NH4+ concentrations. For extractable nutrients, approximately 10 g of sediment was extracted with 10 mL of 1M NaCl for 15 minutes. Extracts were filtered through GF/F filters and later analyzed for DIP and NH_4^+. Water content was determined by weight after drying at 60 ℃ for a week. In 2014, dry sediments were ashed at 500 ℃ for 1 hour to determine organic content. Water column and sediment chlorophyll samples were extracted in 6 mL of 90% acetone, sonicated and read after 24 h on a Turner Designs™ fluorometer (Welshmeyer 1994). Ammonium concentration was measured fluorometrically using an o-phthaldialdehyde and borate buffer reagent (Holmes et al. 1999). Nitrate + nitrite concentrations were measured using cadmium reduction to nitrite with subsequent addition of sulfanilamide and N-1 naphthyl ethylenediamine dihyrochloride (Jones 1984). Phosphate was measured as in Parsons et al. (1984). Sediment phosphorus was measured as in Aspilla et al. (1976) where inorganic P is measured in dry sediments, total P was in ashed sediments and organic P was calculated as the difference.

Two types of nutrient bioassay experiments were conducted in 2015 from Bangs Lake, one with water to examine the phytoplankton community response to nutrient additions and the other with sediments to examine the response of benthic microalgae to nutrient additions. Starting in May 2015, we collected 10 L of water, filtered it through 80 µm mesh to remove large grazers and dispensed into 21 acid-washed, 250 ml polycarbonate bottles. Triplicate bottles of each treatment of the bioassay experiment were: (1) no nutrient addition (control), (2) nitrate only (15 µM N), (3) ammonium only (15 µM N), (4) phosphorus only (1 µM P as PO_4^{3-}), (5) silicate only (15 µM Si), (6) all nutrients, nitrogen, phosphorus and silicate (15 µM N, 1 µM P, 15 µM Si) and (7) a 10% diluted treatment with all nutrients to examine the effect of microzooplankton grazing. Bottles were incubated for 48 hours in a temperature controlled room under fluorescent lights with PAR levels of approximately 250 µmol photons m-2 s-1. In vivo chlorophyll fluorescence was measured initially and daily thereafter. After 48 hours, 60 ml samples were filtered onto GF/F filters to analysis of extracted chlorophyll. We performed similar bioassays using surface sediments. The top 1 cm was slurried and dispensed into 20 mL vials along with 10 mL of GF/F filtered sample water. The treatments were (1) a no nutrient addition control, (2) ammonium only (60 µM NH_4^+) , (3) phosphate only (4 µM P) or (4) both ammonium and phosphate. After 24 and 48 hrs in the controlled temperature and light incubator, approximately 1 g of sediment was removed for chlorophyll a analysis. Phytoplankton production alone was estimated using the Cole and Cloern (1987) BZI method, which uses chlorophyll concentrations, secchi disk depth and daily light data, all values currently collected by the Reserve.

Potential nitrification and nitrogen fixation experiments were also conducted using sediments. Nitrification is the microbial oxidation of ammonium to nitrate. It was measured in aerobic sediment slurries where approximately 1 g of surficial sediment was dispensed into 50 mL centrifuge tubes along with 50 mL of filtered site water (Henriksen et al. 1981). Tubes were amended to a final concentration of 500 µM NH_4^+. Initial and final (24 hr) samples were collected for analysis of nitrite and nitrate + nitrite. These are considered potential measurements because the required substrates, NH_4^+ and oxygen are added in excess. Experiments were conducted in July and September 2014 from Bangs Lake, Bayou Heron and Bangs Creek and in September and October 2015 from Bangs Lake and Bayou Heron. Nitrogen fixation is the reduction of dinitrogen gas to ammonium. In freshwater, phosphorus inputs often stimulate nitrogen fixation by cyanobacteria, while in marine systems, nitrogen fixation rates are generally low. Nitrogen fixation was measured using the acetylene reduction method which has been a standard technique since the 1970s (McCarthy and Bronk 2008). If nitrogen fixation is occurring, acetylene will be reduced to ethylene by the nitrogenase enzyme. In 2014, the top 1 cm of sediment was incubated under aerobic conditions while in 2015, the top 10 cm were incubated under anaerobic conditions. Samples were incubated in an air tight flask and the headspace was replaced with 10% acetyelene. Headspace samples were collected at 30 minute intervals over a 3 hour time course in syringes and analyzed in a GC with an FID detector for analysis of ethylene. Preliminary nitrogen fixation experiments were conducted in June and July 2014. Additional experiments were conducted in September and October 2015.

Particulate phosphate dry deposition

An automated wet/dry deposition collector was also used to collect settled airborne particles using the dry deposition side of the collector. These samplers have a rain sensor that automatically covers a dry bucket side of the collector during rain events. Buckets were cleaned with Neutrad laboratory soap, rinsed with deionized water, rinsed with 1.2N HCl, then rinsed thrice with DI water and then dried in a 40°C oven. Clean buckets were stored in plastic bags and then deployed on the dry deposition side of the collector and allowed to sit in the field for 20-40 days before being collected. Collected sample buckets were covered with aluminum foil, labeled and stored in sealed plastic bags at room temperature until analysis. For analysis, 50 to 100 mls of 1.2 N HCl was poured into the sample bucket which was then swirled carefully to wet the sides of the bucket. The acid was allowed to soak for 30 minutes then the buckets were swirled again and then the acid sample was filtered into clean vials and analyzed as described above for filter samples.

Airborne particles for phosphate analysis were collected on 47mm glass fiber filters with HiQ VS-Series Air Sampling Systems to estimate dry deposition to the study area. Filters were placed into the filter holder and air was pumped thru the filter for 10 to 14 days at a flow rate of 20 to 35 LPM. Flow rates were recorded when each filter was deployed and retrived. An additional sampler was installed and sampled for the same time interval at a reference site located 5 miles inland from Ocean Springs in west Jackson County (38 miles away). After samples were collected the filters were placed into a plastic petri dishes dried in a 60C oven and then stored in a desiccator until analysis. For analysis, the filters were put in a glass vial with 20 mls of 1.2N hydrochloric acid and then placed in an incubator shaker (40C at 75 RPM) for 3-4 days to begin to extract the phosphorus from the filters. Sequential extractions with 20 mls of 1.2 N HCl for 3-4 days were conducted until all phosphorus had been recovered. The resultant liquid samples for each extraction was transferred to clean vials, neutralized with 10N sodium hydroxide and analyzed for phosphate colormetrically (Strickland and Parsons, 1972). Sodium phosphate standards were made with 1.2 N HCl, neutralized with 10N NaOH and analyzed in the same manner as the samples.

RESULTS

Fluorescent dye tracer experiment to track water movement from spill area –

The tracer experiment was conducted on June 30, 2015 during a falling tide. We were able to track the fluorescein plume for approximately 4 hours. The tracer slug was advected south from the release site and flowed along the marsh edge in the northeast portion of Bang Lake before being transported into the Bangs Bayou channel by the falling tide. Sample fluorescein concentrations are shown for hours 1 to 4 in Figures 4 - 7. Once in this deeper channel fluorescein concentrations dropped below detection quickly due to vertical mixing processes that diluted the tracer (Figure 7).

Grain size analysis

Percent silt-clay was lowest at the Bangs 2 site and highest the Bangs 1 and Bayou Heron sites (Figure 8). Percent silt-clay increased with depth at the western Bangs Lake sites (Bangs 2 and 3). The northeastern Bangs site (Bangs 1) showed little variability in texture with depth while Bangs 4 and Bayou Heron cores showed a general increase in silt-clay content to 12.5 cm depth and then decreased deeper in the cores.

Sediment cores phosphate inventory, ^{210}Pb dating and Porewater Analysis

Particulate organic phosphorus in all sediments cores increased toward the surface (Figure 9). Particulate organic phosphorus concentrations in Bayou Heron sediment core sites differed between 2014 and 2015 are shown separately in Figure 9A. Core phosphate concentrations from western Bangs Lake (Bangs 2 and 3) showed little variation between the two years hence the values presented as means for both years. West sites in Bangs Lake (nearer MS Phosphates) were similar to control (Bayou Heron), while east sites further from the source site had similar patterns but higher values, with distinct peaks near 13 cm and 4 cm depth in the Bangs 1 core, ~ corresponding to the years in the 1980s and mid to late 2000s, respectively (Figure 9B; Tables 1-4). When these high values are removed (Figure 10), the remaining data more clearly show that phosphorus values were higher at depths above 7 cm at these sites on the east side of Bangs Lake, suggesting continuously higher phosphorus inputs in recent years (~corresponding to years since 2010 at all sites; Tables 1-4).

During 2015, sites on the eastern side of Bangs Lake (sites 1 and 4; Figure 11) had significantly higher phosphate concentrations in sediment porewater than the control site (Bayou Heron). TDN concentrations were higher than Heron Bayou only at the northeast site (site 4; Figure 10).

Biological response to inputs from phospho-gypsum stack

Hydrographic conditions

Summer temperatures ranged from 28 to 30 ℃ and was similar in both years at the Bangs Lake SWMP station (Fig 12). Salinity is normally at a minimum in the spring and increases throughout the summer and into the fall. In 2014, the minimum summer salinity was 6.2 and the maximum was 28.7, while in 2015, minimum salinity was 10.1 and maximum was 29.9 (Fig 12).

Sediment characteristics

Except for Bangs Creek and mid Bayou Cumbest, sediments were predominantly fine sand, with a relatively low water content. The highest sediment phosphorus values, both inorganic and organic were at the two Bangs Creek stations. Bangs North also had high inorganic phosphorus concentrations. Surprisingly, there was little difference between sediment phosphorus concentrations either inorganic or organic in Bangs Lake and sites further away (Table 1, Figure 13). There were declines in the inorganic P at Bangs Creek and Bangs North between 2013 and 2015, although variability between replicates was high. In contrast extractable P in surficial sediments was significantly higher at Bangs Lake than Bayou Heron (Table 1, Figure 14, t-test $p = 0.04$). A vertical profile of extractable P and NH_4^+ from September 2015 revealed that P concentrations in the top 0-4 cm was higher at Bangs Lake than Bayou Heron ($p=0.002$) while the concentrations in the 4-6 cm layer was similar (Figure 15). In contrast, while extractable NH_4^+ in surficial sediments was generally higher at sites near the phosphogypsum stacks (Table 1), there was variability over time (Figure 16) and surficial sediments from Bangs Lake were not significantly different from Bayou Heron (t-test $p = 0.71$). However, vertical profiles of extractable NH4+ from Bangs Lake in September 2015 were significantly higher than at Bayou Heron (Figure 16, $p<0.001$).

Primary Producers

The highest concentrations of benthic microalgae occurred at Bangs Creek 2013 in June 2013 prior to sampling funded by MWRRI (Figure 17). Benthic chlorophyll was often higher at Bangs Lake compared to other locations (Figure 17). It was significantly greater at Bangs Lake than Bayou Heron (t-test $p = 0.004$). Benthic microalgae showed little response to additions of NH_4^+, P addition or both nutrients (Figure 18). There was no significant difference ($p>0.05$) between nutrient treatments and control samples in either June or August (Figure 18). On average, light levels on the bottom were above 5% of surface irradiance and often above 20% (Figure 19), levels potentially high enough to saturate photosynthesis by benthic microalgae (Gattuso et al. 2006)

Phytoplankton biomass as measured by water column chlorophyll a concentrations were generally highest in the summer (Figure 20). Concentrations across the NERR were higher in 2015 than 2014 (Figure 20, K. Cressman, pers. Comm.). Nutrient bioassays revealed that the greatest response to nutrient additions during late fall and winter (Figure 21). Positive growth rates only occurred in nitrogen addition treatments and there were no consistent differences between ammonium and nitrate. Phosphate or silicate did not stimulate phytoplankton growth, although nitrate plus silicate did (Figure 21). These results are similar to Amacker (2013) which found that phytoplankton growth was only stimulated by N additions and never by P additions. The diluted + nutrient treatment (all diluted) had significantly higher growth rates than the corresponding whole water + nutrient treatment (all) (Figure 22). This suggests that grazing by microzooplankton can affect phytoplankton growth rates and is likely responsible for the negative growth rates observed in the control, P and Si treatments during summer months. Phytoplankton production based on the Cole and Cloern (1987) BZI model was highest during the summer months when chlorophyll a concentrations were high and longer daylight occurred.

Productivity was generally higher at Bayou Cumbest and Point aux Chenes compared to Bangs Lake or Bangs North (Figure 23).

A principal component analysis was conducted with the June data from 2013-2015. The first three components could explain 71.5 % of the variance in the data (Table 2). The first principal component was dominated by water column chlorophyll, water column chlorophyll, sediment chlorophyll and extractable P with stations closer to the phosphogypsum stacks separating from the stations further away (Figure 24). The second principal component was dominated by salinity, temperature, percent surface irradiance and water column ammonium concentrations which led to the stations grouping by year (Figure 24). There was much less difference among the stations in 2015 than in 2013 (Figure 24).

Sediment nitrogen transformations

Potential nitrification rates were highest in July 2014 at Bangs Creek (Figure 25). Rates from Bangs Lake and Bayou Heron were similar to one another and during all three sampling periods (Figure 25). There was little difference between 2014 and 2015 sampling dates. Because nitrogen fixation measurements in 2014 only included the top 1 cm of sediment and were incubated aerobically, rates were much lower and not directly comparable to rates measured in 2015. In 2014, nitrogen fixation was correlated to concentrations of extractable P (Figure 26), with rates near the gypsum stacks being somewhat higher than rates at Bayou Heron. In September 2015, nitrogen fixation was significantly higher at Bayou Heron than Bangs Lake which was slightly negative (Figure 27). However by October, rates at Bayou Heron had declined and were similar to those at Bangs Lake (Figure 27).

Particulate phosphate dry deposition

Phosphate dry deposition rates ranged from 2.4 to 64.8 ug P $m^{-2}d^{-1}$ and was highest on March 2, 2015 (Figure 28) while deposition rates at the West Jackson County reference site ranged from 3.8 to 28.0 ug P $m^{-2}d^{-1}$. The amount of bucket deposition samples collected from the reference site are more sparse than the Grand Bay site due to mechanical problems with the rain/dust collector and frequent contamination from birds utilizing the sides of the bucket. It appears that the Grand Bay site typically had higher rates of phosphate deposition than the background site however the smaller number of samples collected from the reference site does make direct statistical comparisons impossible. The average dry deposition rate for the Grand Bay site was 23.3 ± 16.1 ug P $m^{-2}d^{-1}$ while the average deposition rate for the reference site was 15.0 ± 10.4 ug P $m^{-2}d^{-1}$

Relevant Findings:

This study has shown that much of the phosphate release during major industrial spills from Mississippi Phosphate Corporation is adsorbed by sediments and then sequestered in the benthos. It is still unclear however what proportions of this excess phosphorus is buried versus how much is flushed out of Bangs Lake sue to tidal action. Sediment cores collected from Bangs Lake had higher particulate organic phosphorus concentrations and distinct peaks of phosphorus were found in cores collected from the southeast portion of Bangs Lake. Benthic chlorophyll a concentrations were highest in Bangs Lake and were higher at sites with high extractable phosphorus. Preliminary experiments suggested that phosphorus inputs can stimulate nitrogen fixation and growth of cyanobacteria.

List of student by institution and Major that received training for this project:

Name	Level	Major
Sarah Holcomb (USM)	Junior	Geology
Tiffany Berry (USM)	Junior	Geology
Jenna Sleek (UWF)	Senior	Biology
Rachel Capps (UWF)	Junior	Biology
Yishen Li (DISL)	Junior	Biology
Joshua Millwood (DISL)	Junior	Biology

Table 1 – Characteristics of sediments in Grand Bay. Average concentrations of water content, inorganic and organic sediment phosphorus, extractable phosphorus and ammonium.

Station	Sand content	Silt content	Clay content	Water content	Inorganic P	Organic P	Extract P	Extract NH4
	%	%	%	%	µmol/gdw	µmol/gdw	nmol/cm^3	nmol/cm^3
Bangs Creek 2014	nd	nd	nd	50%	722	633	2.25	33.2
Bangs Creek 2013	15%	52%	33%	44%	1311	1304	2.79	51.8
Bangs North	76%	23%	1%	49%	1212	232	1.46	33.0
Bangs Lake	95%	3%	1%	50%	330	303	6.52	21.1
Bangs Bayou	96%	2%	2%	26%	nd	nd	2.34	34.2
mid Bayou Cumbest	38%	40%	22%	nd	nd	nd	0.37	79.3
Point aux Chenes	74%	22%	4%	42%	267	361	2.76	13.3
Bayou Cumbest	86%	10%	4%	55%	nd	nd	1.32	46.1
Bayou Heron	85%	10%	5%	47%	495	231	0.98	17.2

Table 2 – First three Eigenvectors from principal component analysis using data from June in 2013, 2014, 2015.

Variable	PC1	PC2	PC3
% variation	35.9	23.2	12.4
Salinity	0.184	**-0.427**	0.182
Temp	0.091	**-0.51**	-0.195
DO	0.281	-0.136	-0.316
Percent Surface Irradiance	0.188	**0.494**	0.071
Water Column chlorophyll	**-0.44**	0.129	0.037
Water Column NH_4^+	0.152	**0.324**	-0.244
Water Column DIP	**-0.442**	-0.01	-0.257
Percent Water	-0.062	0.151	-0.72
Sediment Chlorophyll	**-0.365**	-0.101	-0.217
Extractable P	-0.276	0.25	0.344
Extractable NH_4^+	**-0.379**	-0.127	-0.007
Distance from stacks	0.273	0.247	-0.115

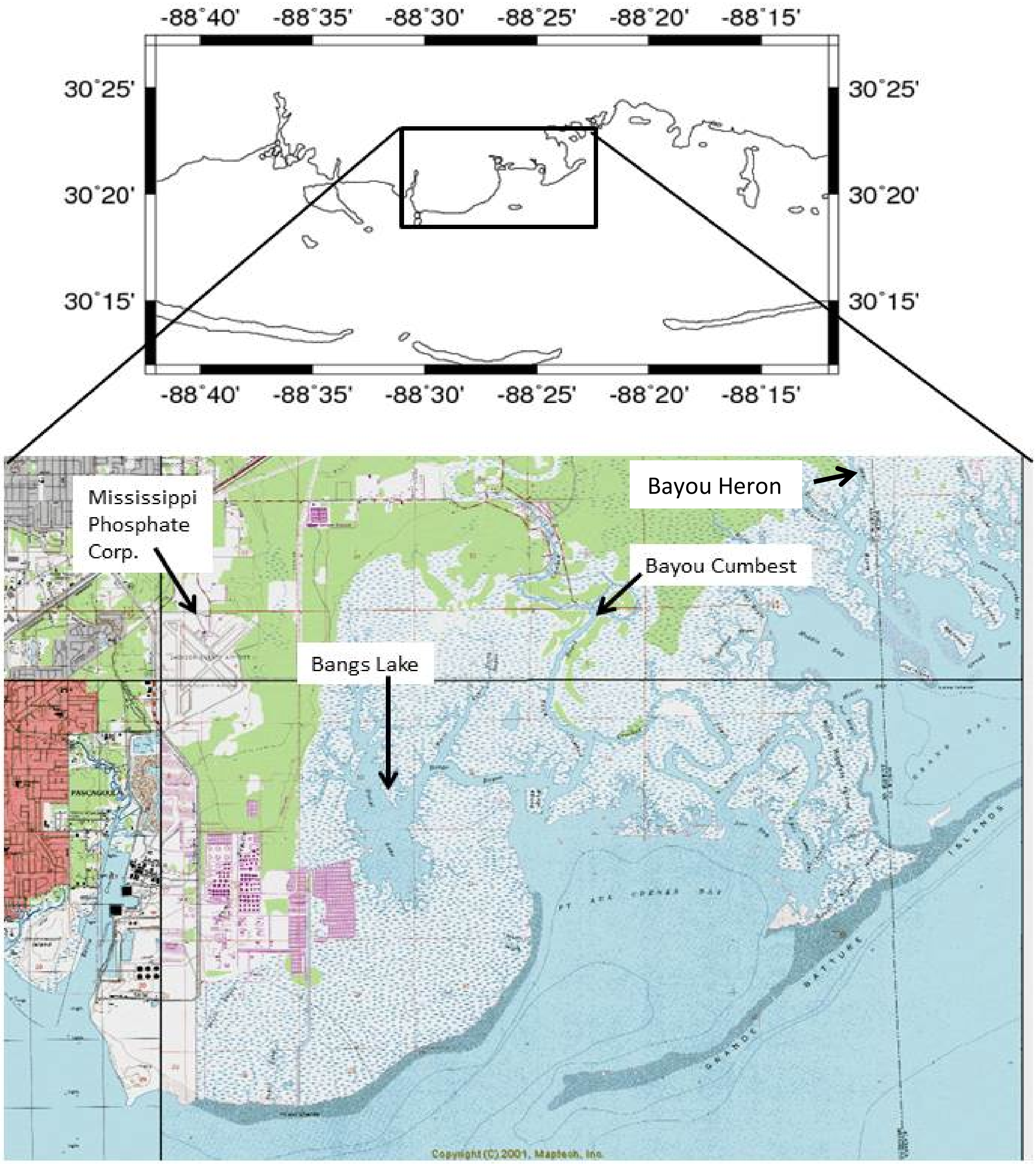

Figure 1. Map of the study sites (Bangs Lake, Bayou Cumbest, and Bayou Heron. The location of nearby gypsum stacks at Mississippi Phosphates Corporation are shown for reference.

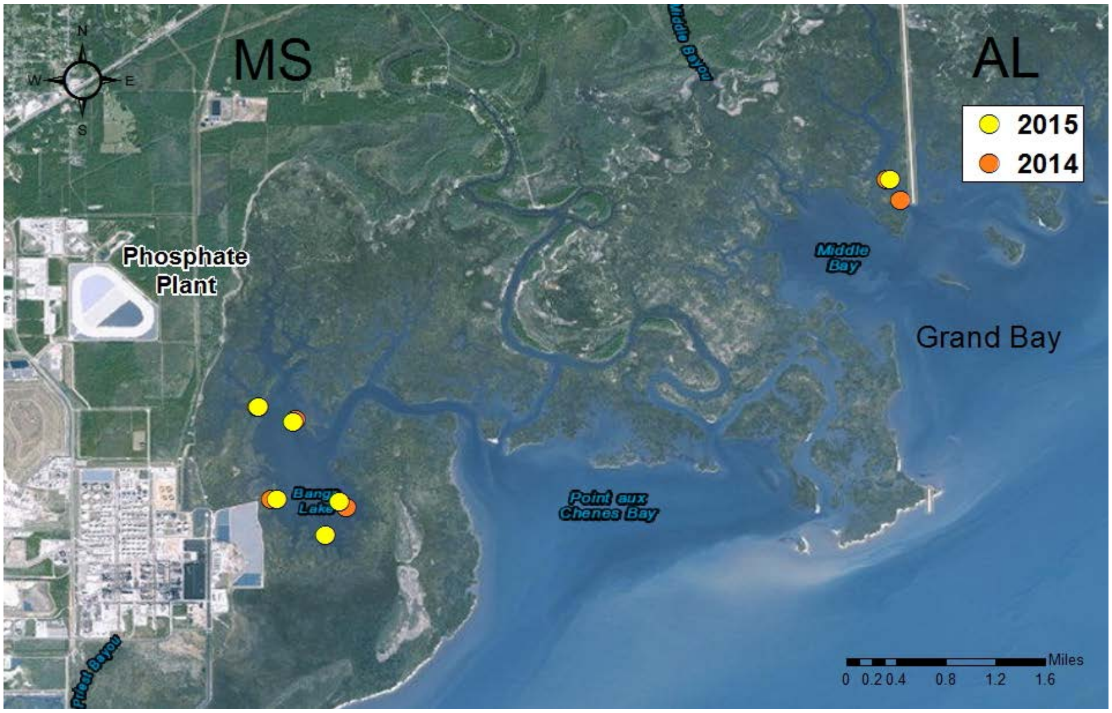

Figure 2. Map of Bangs Lake Bangs Lake sampling sites of sediment cores used for phosphate inventory and radiometric dating. Numbers denote core site numbers: 1 = Southeast (SE) 2 = Southwest (SW) 3 = Northwest (NW) 4 = Northeast (NE)

Figure 3. Location of benthic algae and sediment sampling stations in 2013-2015. BB and mid BC were only sampled in 2013.

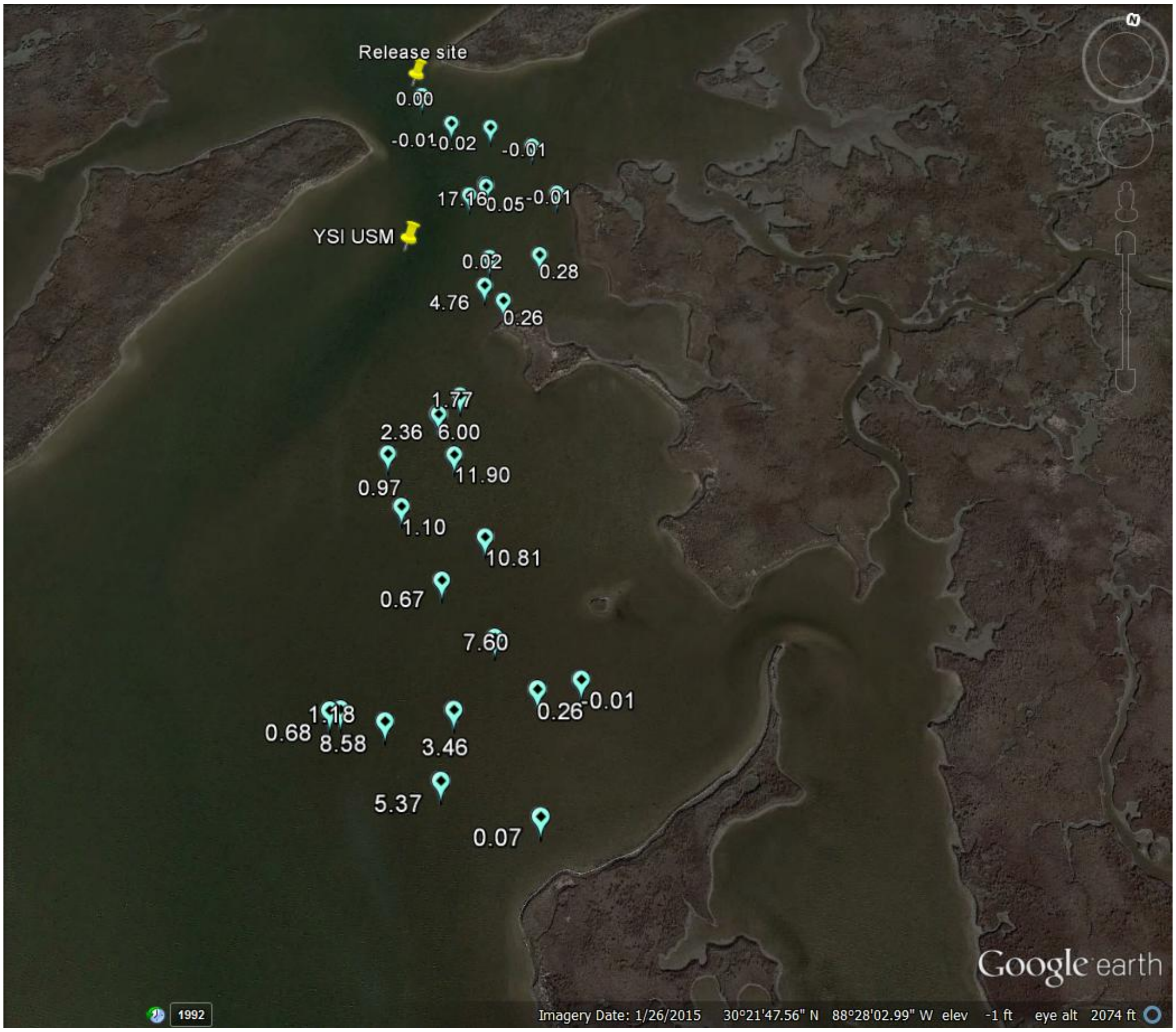

Figure 4. Fluorescein concentrations (ppm) collected in hour 1 of the tracer experiment.

Figure 5. Fluorescein concentrations (ppm) collected in hour 2 of the tracer experiment.

Figure 6. Fluorescein concentrations (ppm) collected in hour 3 of the tracer experiment.

Figure 7. Fluorescein concentrations (ppm) collected in hour 4 of the tracer experiment.

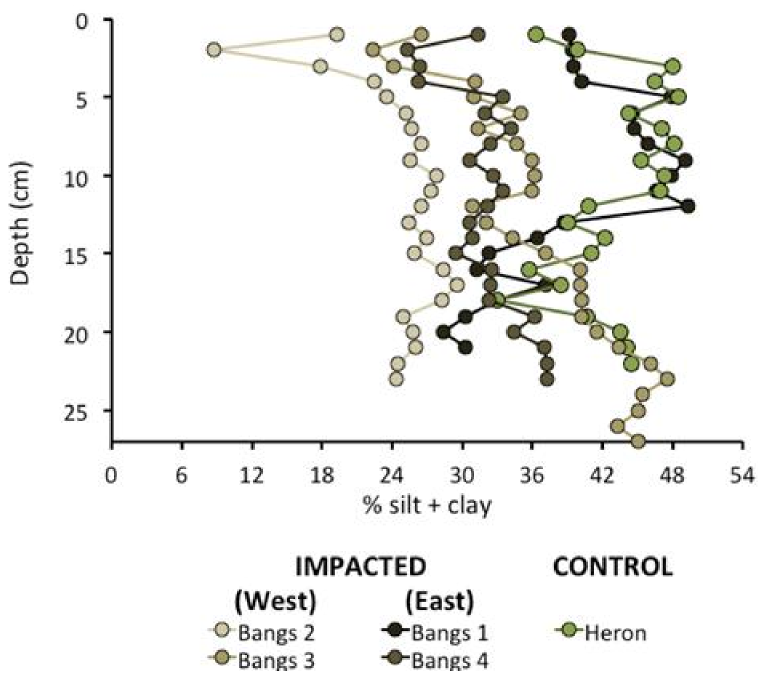

Figure 8. Results of grain size analysis for sediment samples collected in Bayou Heron and Bangs Lake.

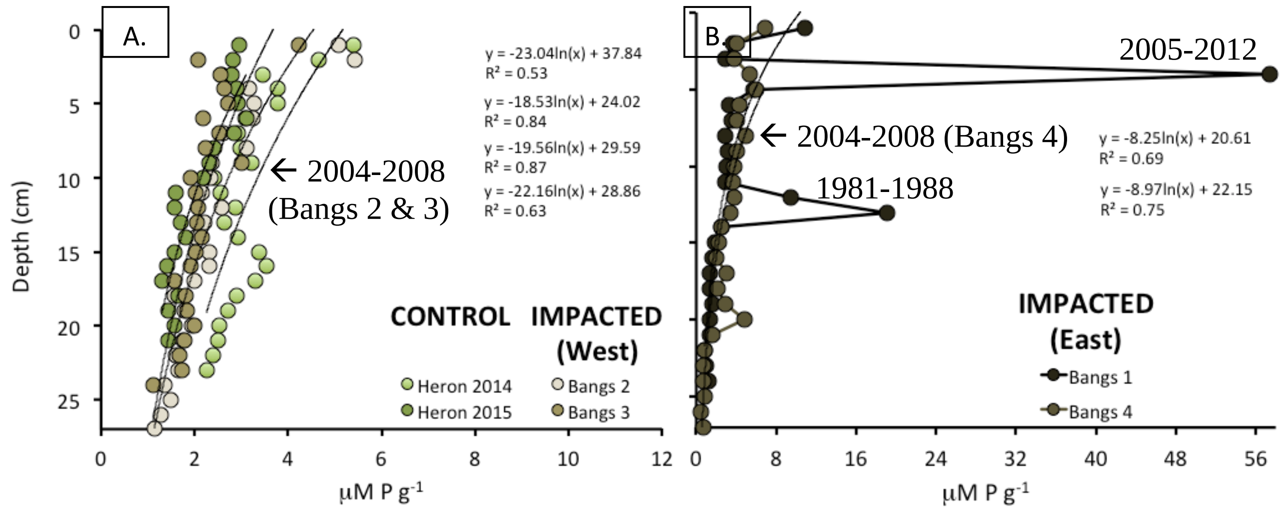

Figure 9. Concentrations of particulate organic phosphorus in sediments from Bayou Heron and 4 sites in Bangs Lake sampled during 2014 and 2015.

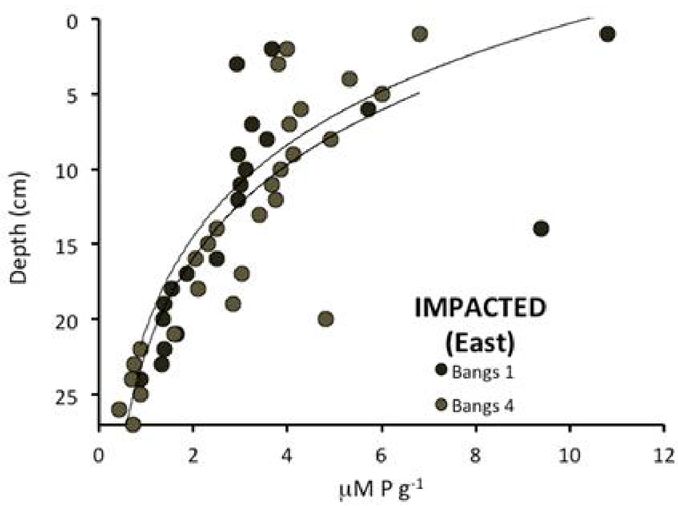

Figure 10. Concentrations of particulate organic phosphorus in sediments from Figure 9B with high concentrations removed from trendline.

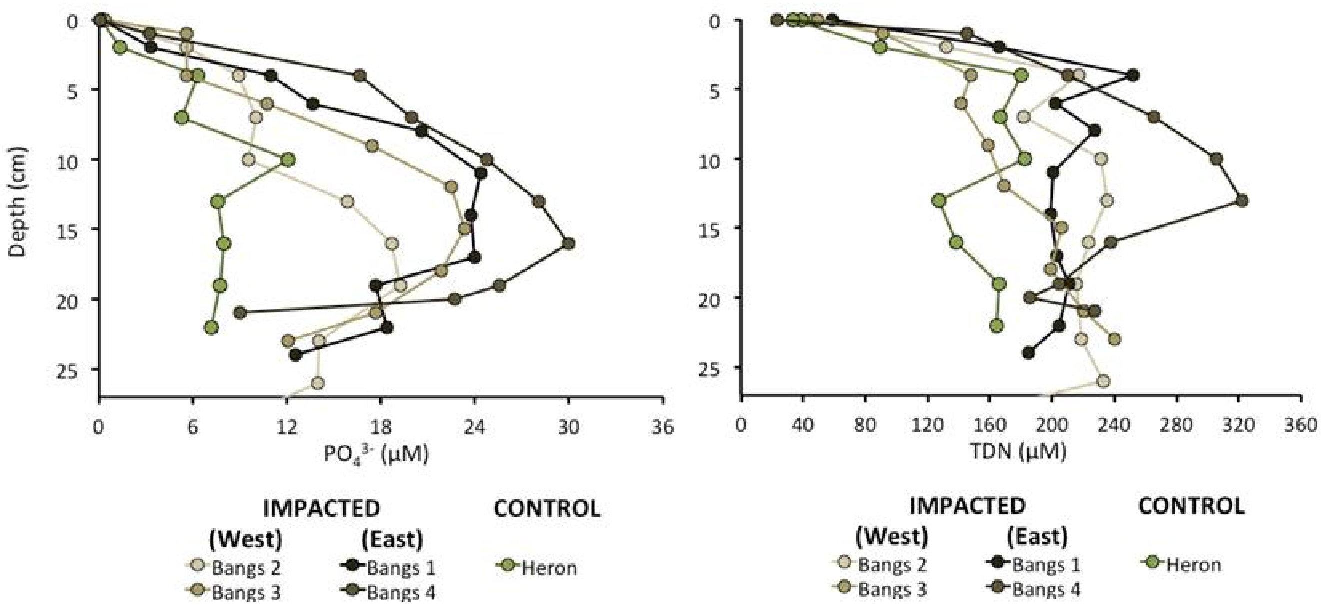

Figure 11. Porewater phosphate (left panel) and total dissolved nitrogen (right panel) concentrations from Bangs Lake and Bayou Heron coring sites.

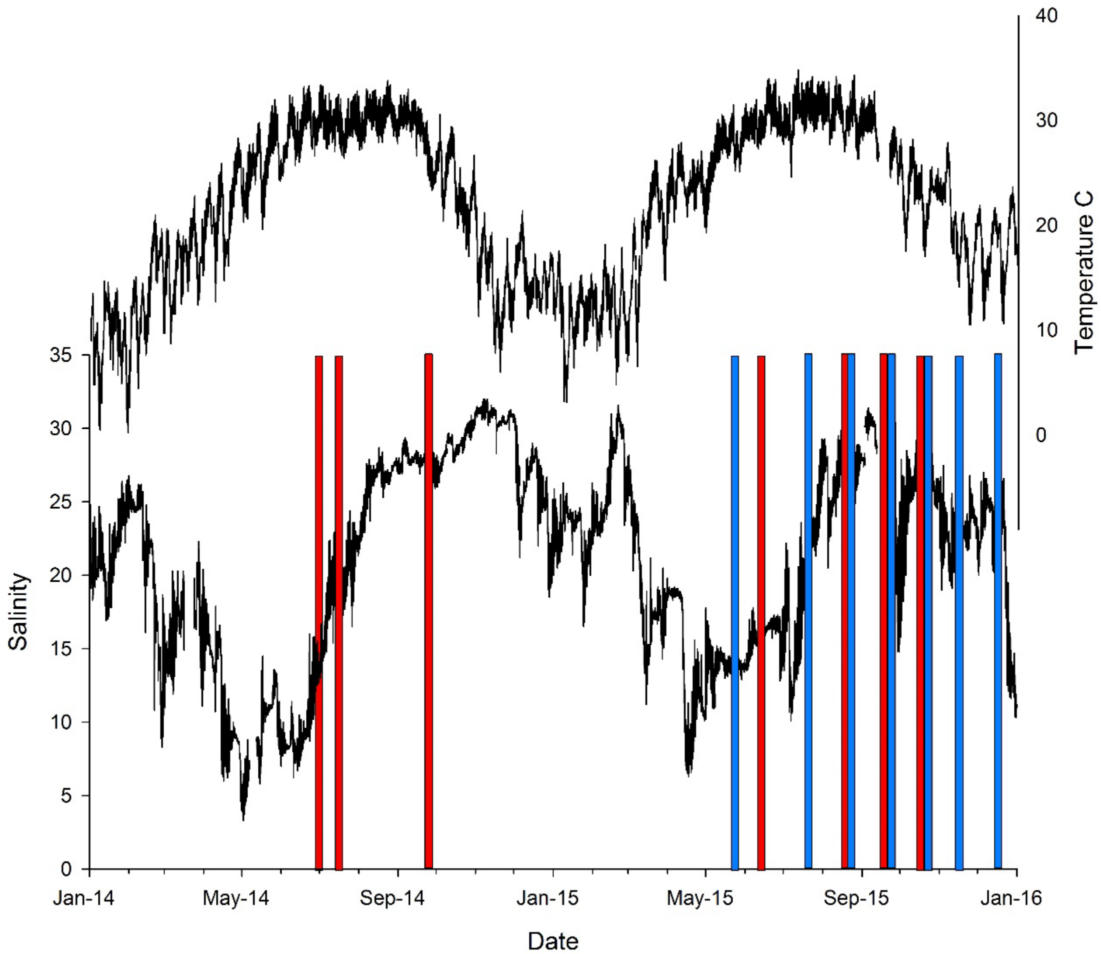

Figure 12. Temperature (°C) and Salinity between January 2014 and December 2015 from SWMP datasonde at Bangs Lake. Red bars represent sediment sampling dates. Blue bars represent water sampling for phytoplankton nutrient bioassays.

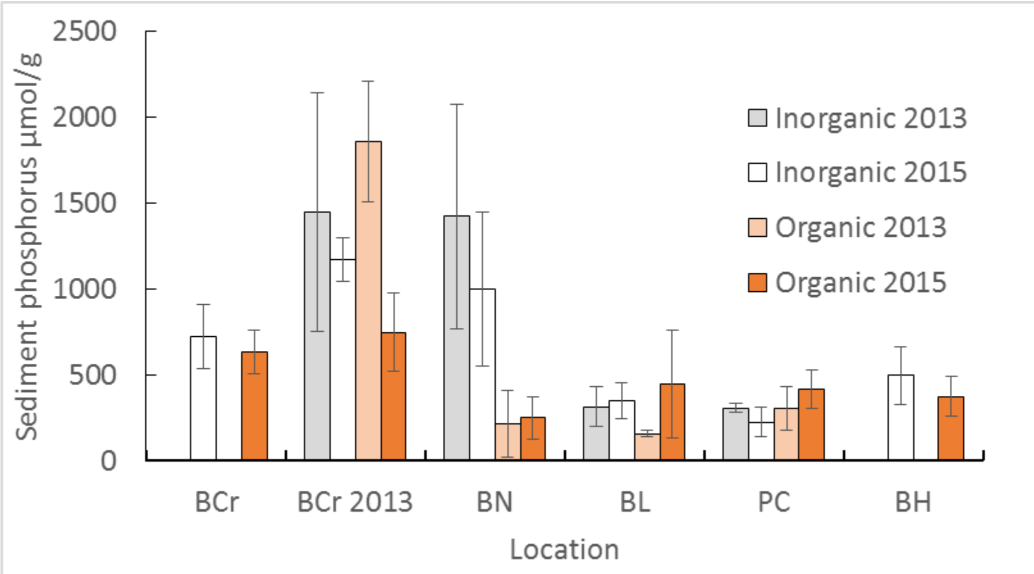

Figure 13. Surficial sediment phosphorus concentrations µmol/g from June 2015 and June 2013 samples in Grand Bay. Mean + S.E.

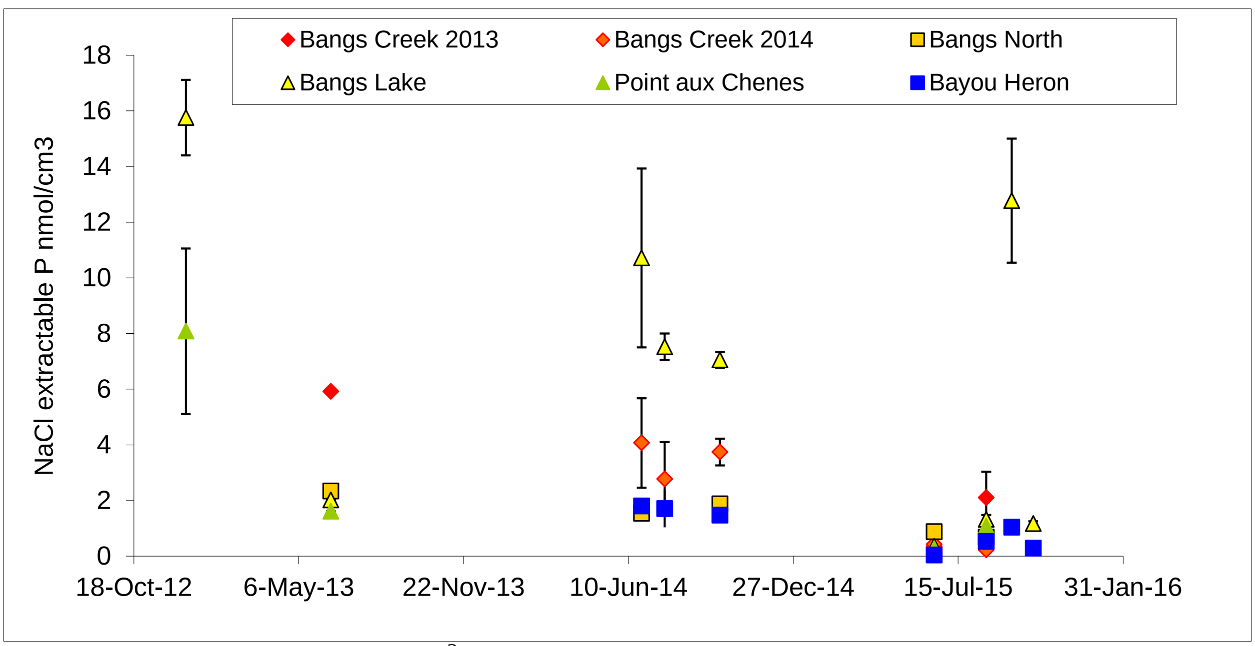

Figure 14. Extractable P (nmol/cm^3) in surficial sediments in Grand Bay. Mean + S.E.

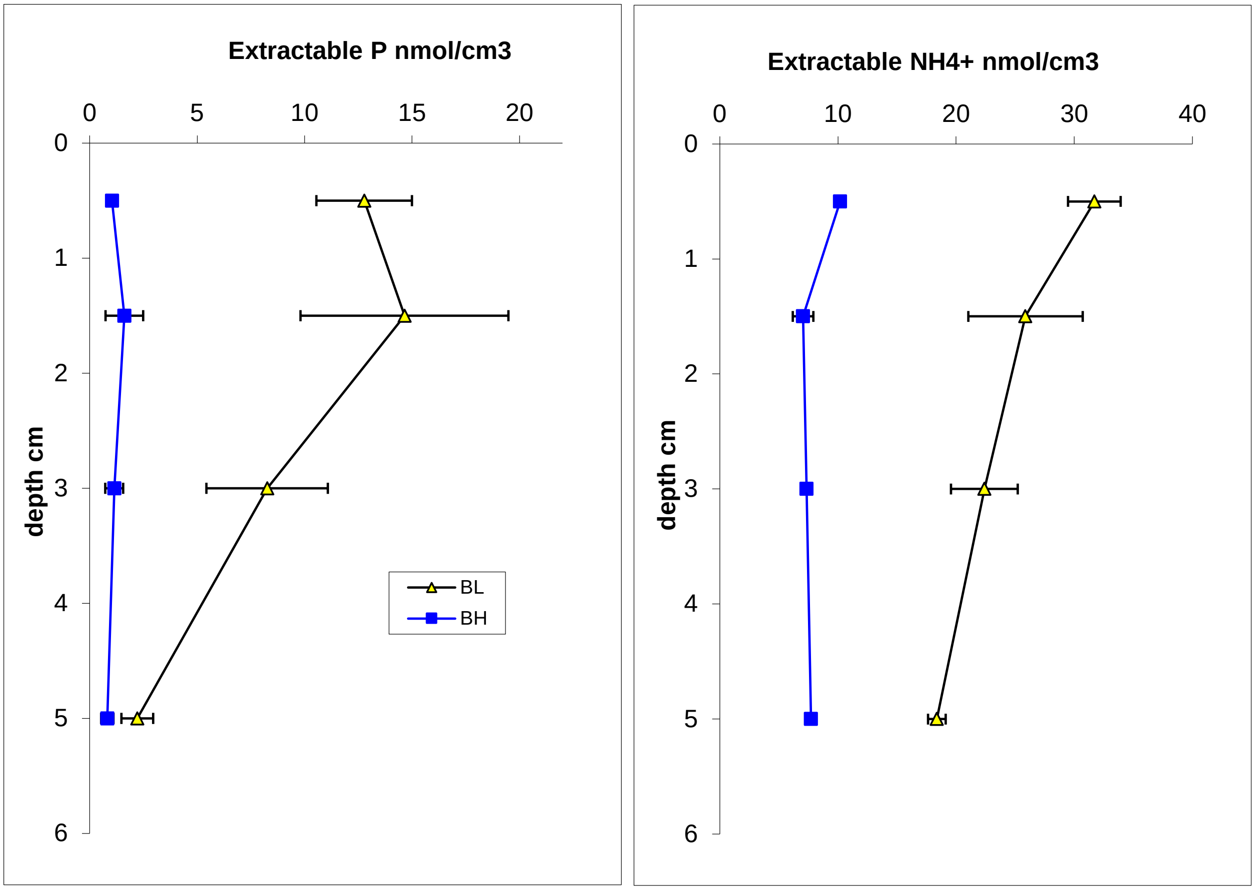

Figure 15. Vertical profile of extractable P (left panel) and NH4+ (right panel) in Bangs Lake and Bayou Heron from September 2015. Mean ± S.E.

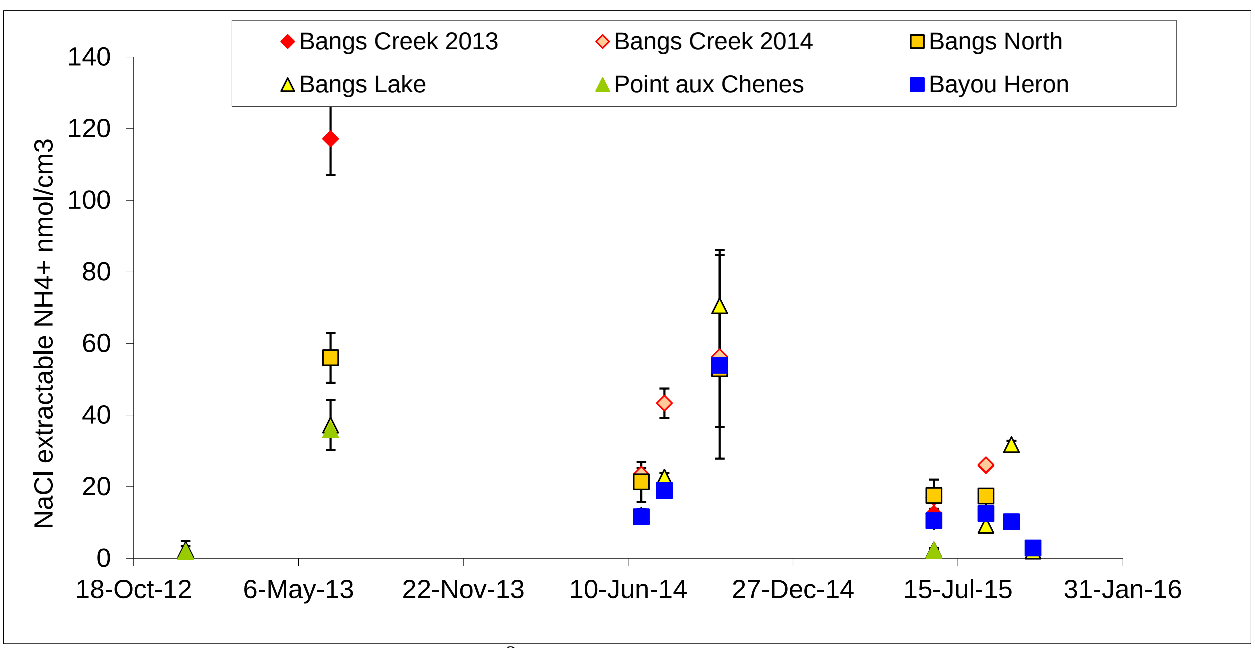

Figure 16. Extractable NH_4^+ ($nmol/cm^3$) in surficial sediments in Grand Bay. Mean ± S.E.

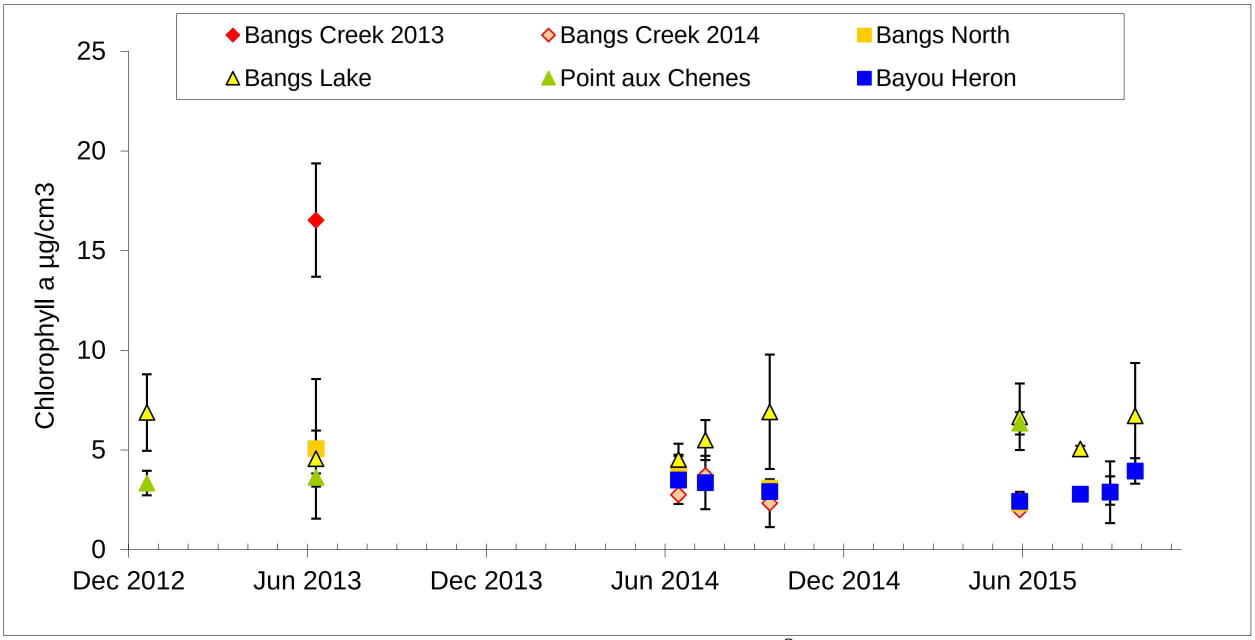

Figure 17. Sediment chlorophyll concentrations (µg chla/cm^3) in surficial sediments from Grand Bay. Mean $\pm$ S.E.

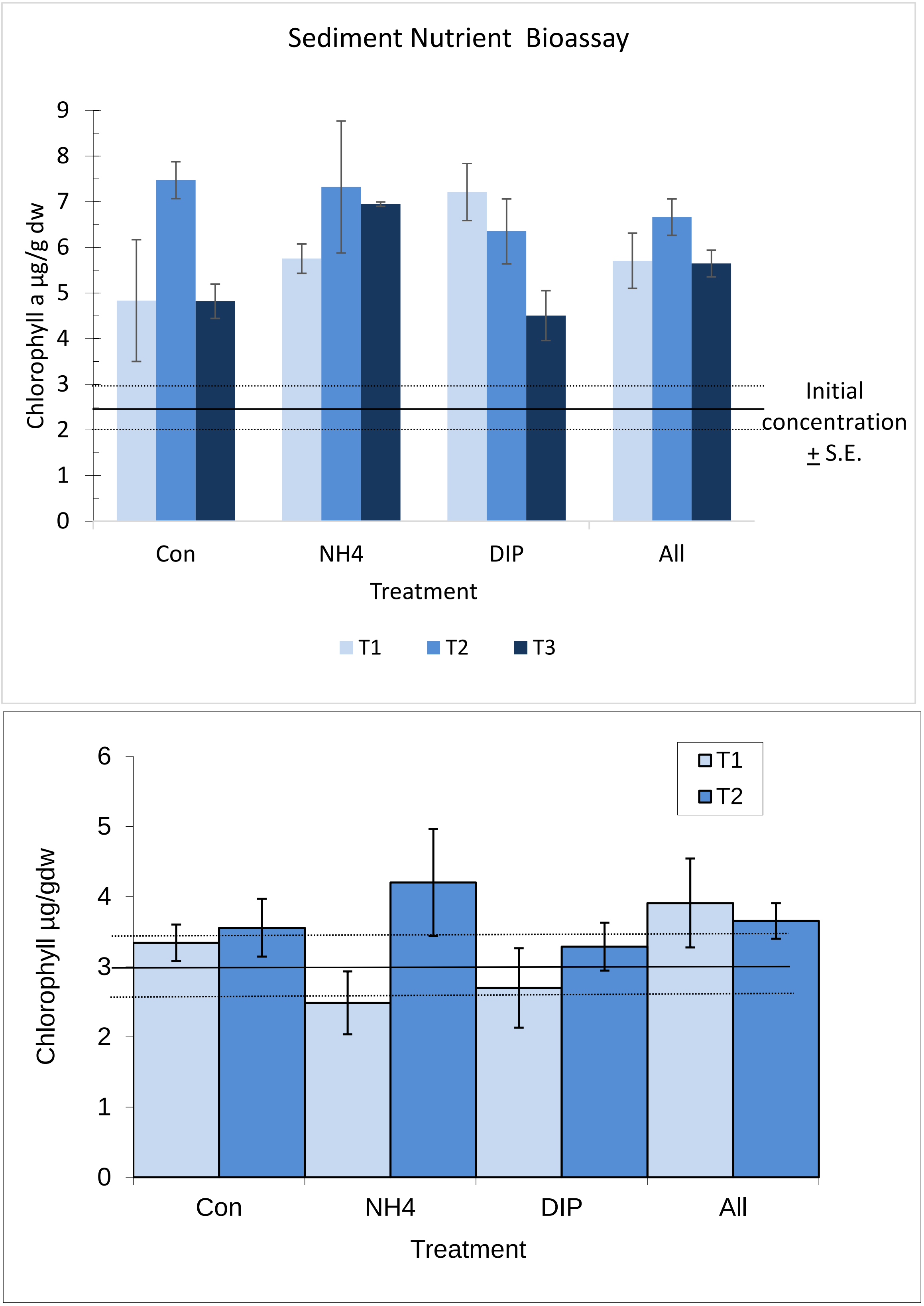

Figure 18. Nutrient bioassay experiment for benthic microalgae from Bangs Lake in June and August 2015. Solid line indicates initial concentration. Control treatments Mean + S.E.

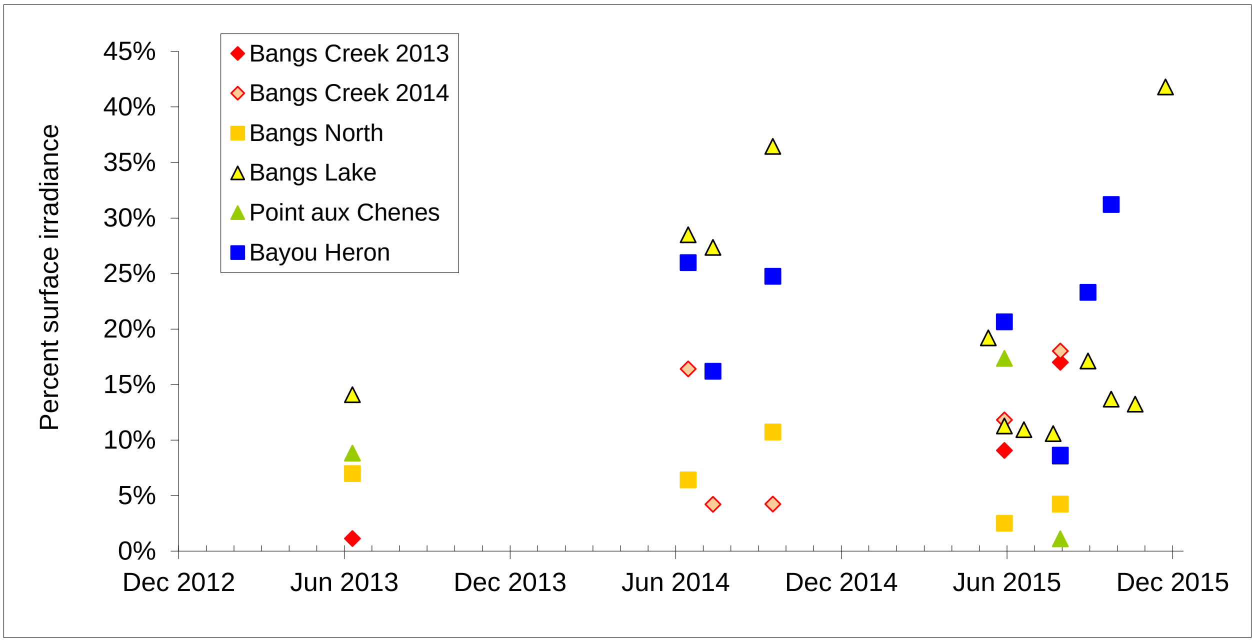

Figure 19. Percent of surface irradiance on bottom in Grand Bay. Values calculated based on k_d and water depth

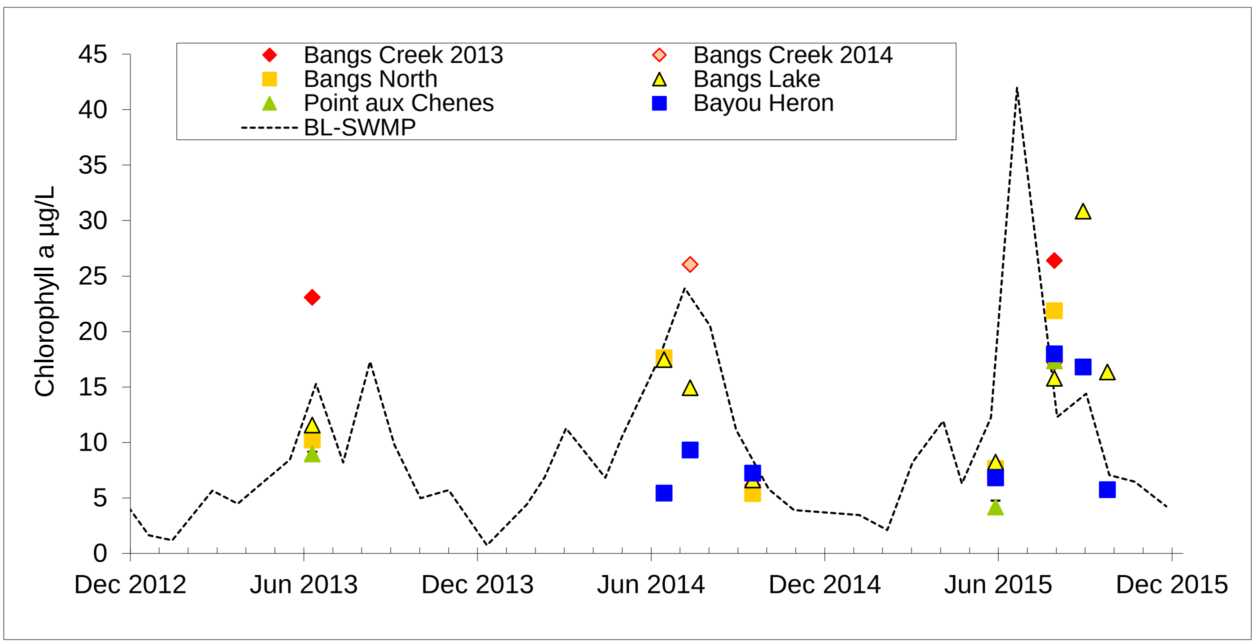

Figure 20. Water column chlorophyll a (µg chla/L) from Grand Bay. Dotted line represents monthly SWMP monitoring data from Bangs Lake (K. Cressman, pers. Comm.).

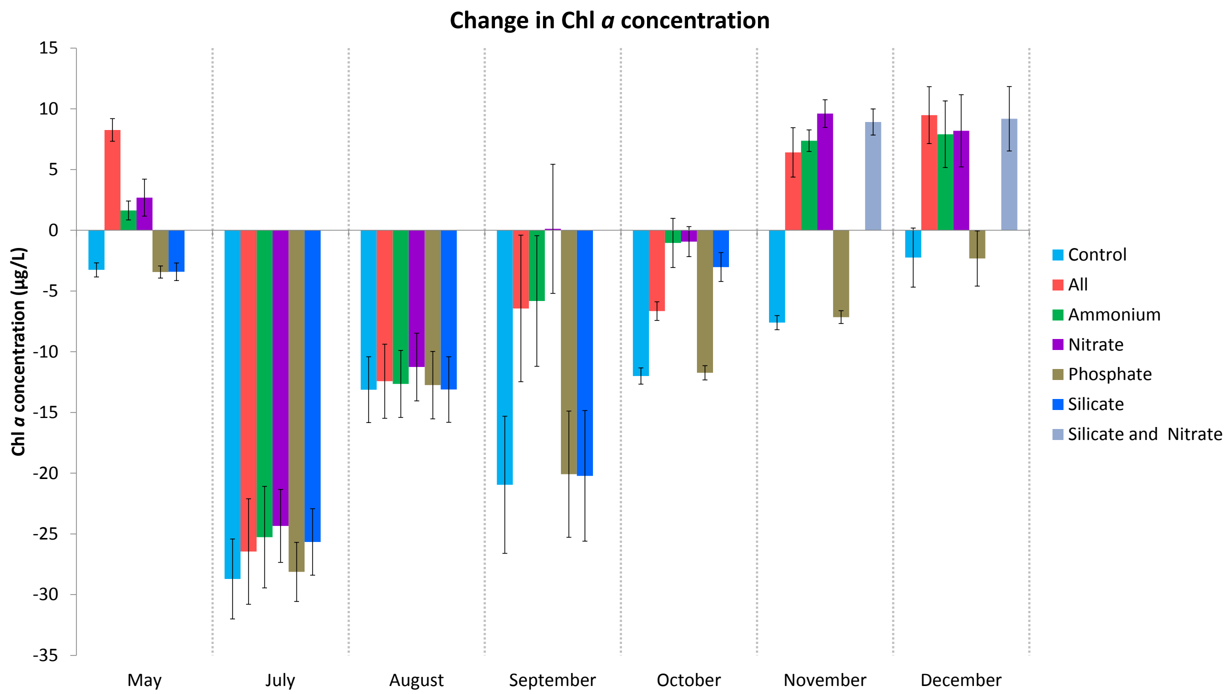

Figure 21. Phytoplankton nutrient bioassays from Bangs Lake between May 2015 and December 2015. Change in chlorophyll a concentration after 48 hrs relative to initial concentrations. Bars represent the change in chlorophyll a over 48 hours. Mean ± SD.

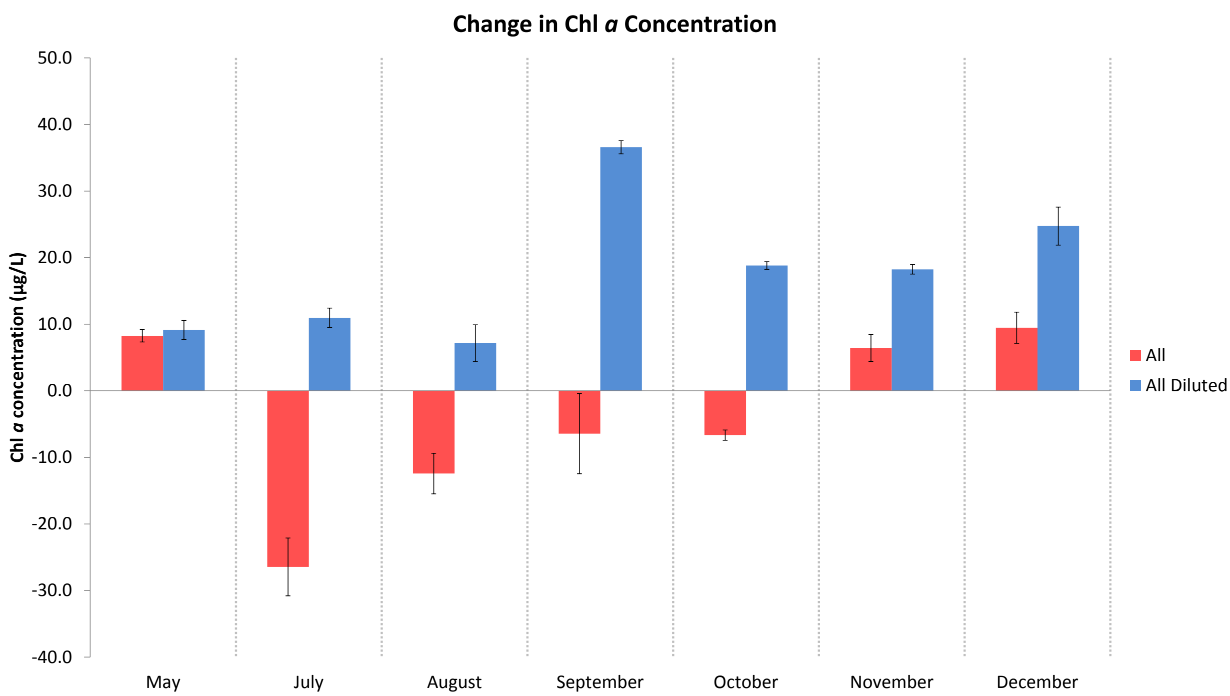

Figure 22. Effect of microzooplankton grazing on phytoplankton growth in Bangs Lake between May 2015 and December 2015. Change in chlorophyll a concentration after 48 hrs relative to initial concentrations. Whole water (all) or diluted (10% whole water & 90% GF/F filtered water) amended with nutrients (NH_4^+, NO_3^-, DIP, Si). Mean ± SD.

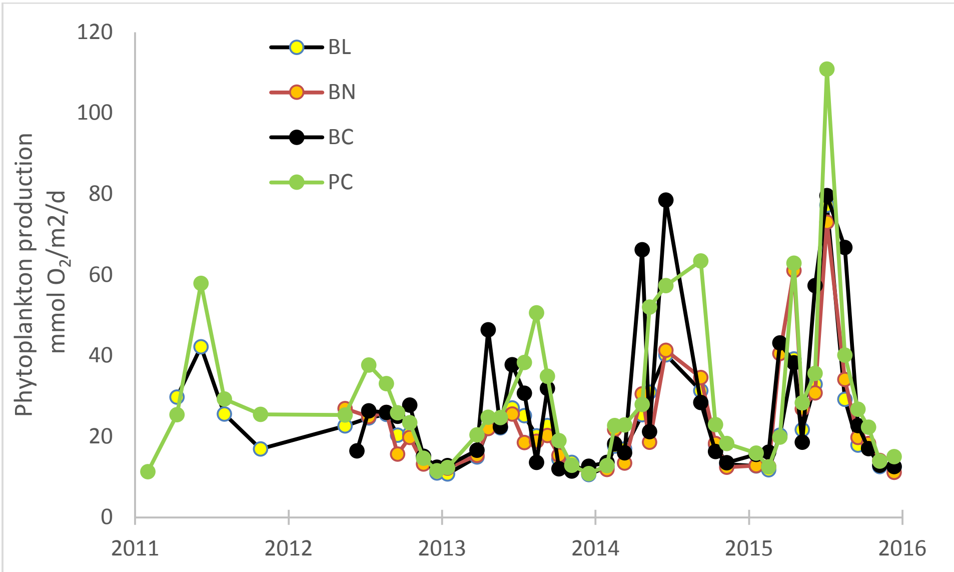

Figure 23. Phytoplankton production (mmol/m2/d) estimated using the Cole and Cloern (1984) BZI model using data from NERR SWMP monitoring program and this study.

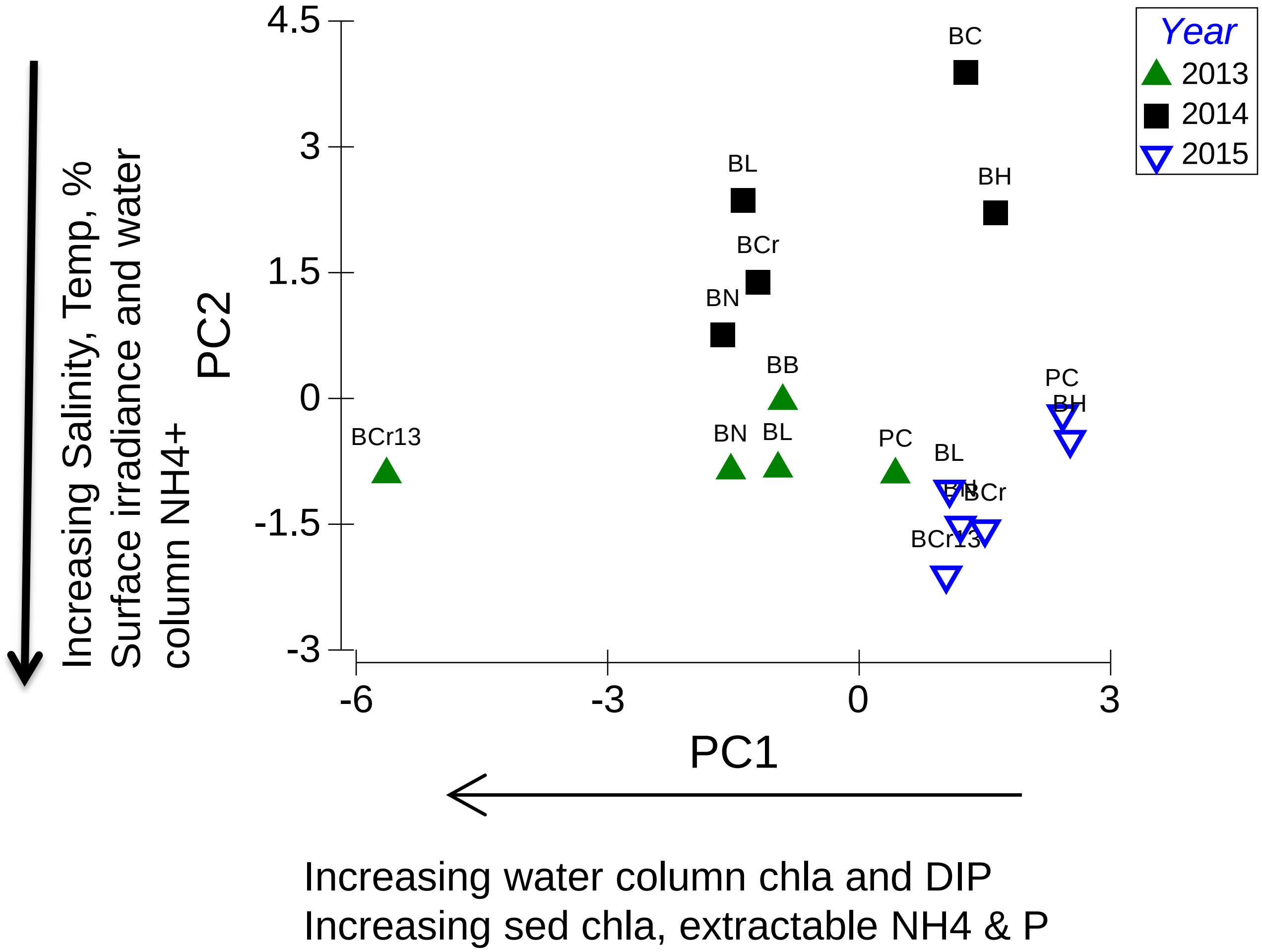

Figure 24. Principal component analysis of water column and sediment characteristics during June

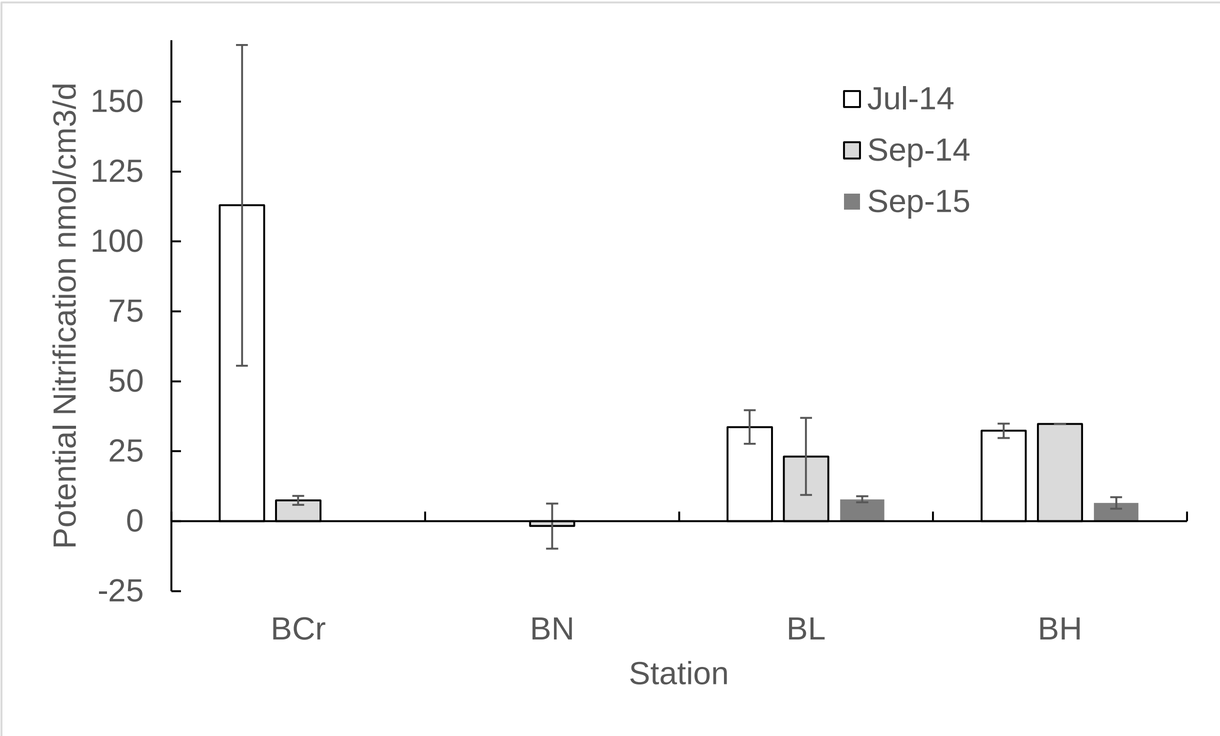

Figure 25. Potential nitrification rates (nmol/cm3/d) in Grand Bay on July 2014, September 2014, and September 2015. Mean ± S.E.

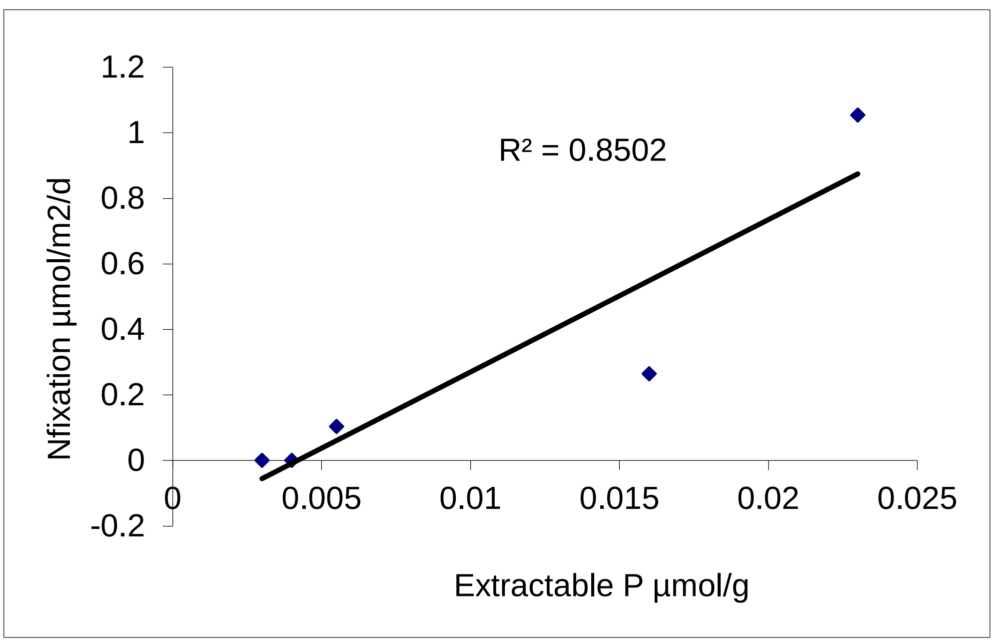

Figure 26. Nitrogen fixation (µmol/m2/d) versus extractable P concentrations (µmol/g)

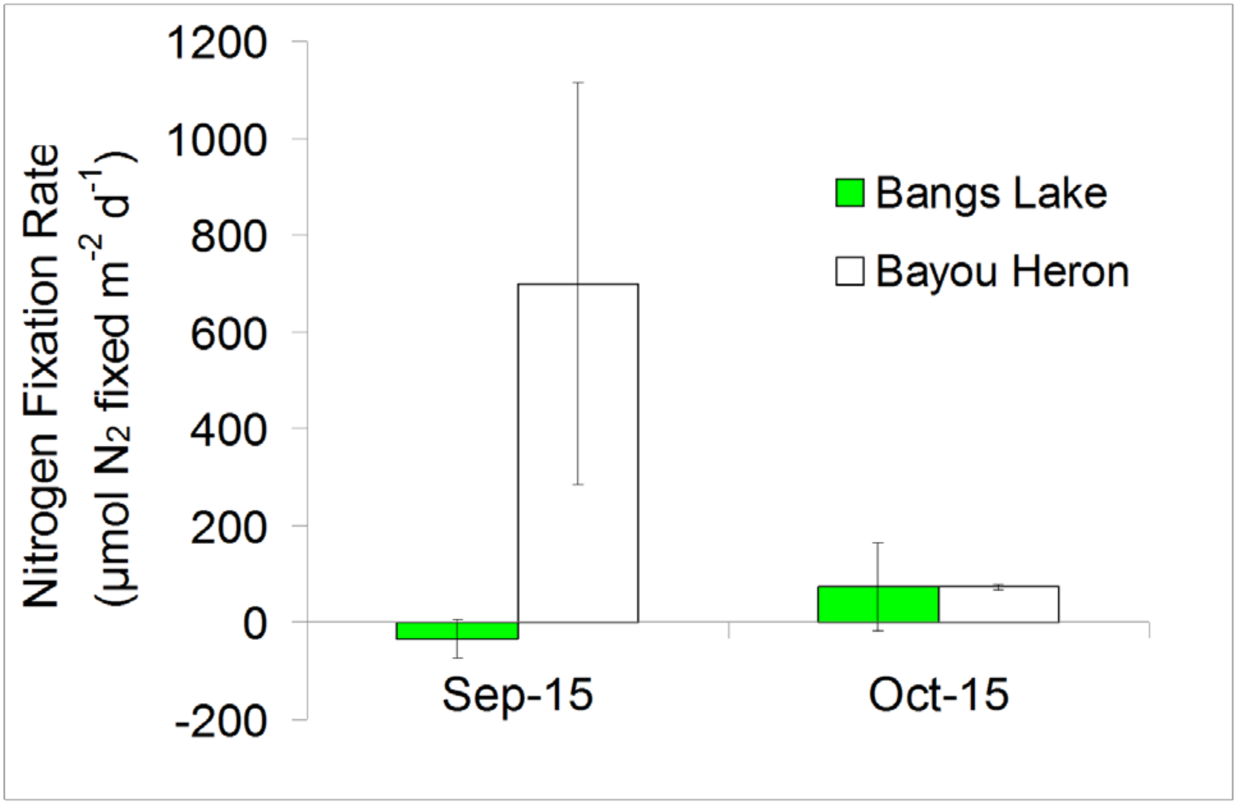

Figure 27. Nitrogen fixation rate (μmol/m2/d) in September and October 2015 at Bangs Lake and Bayou Heron

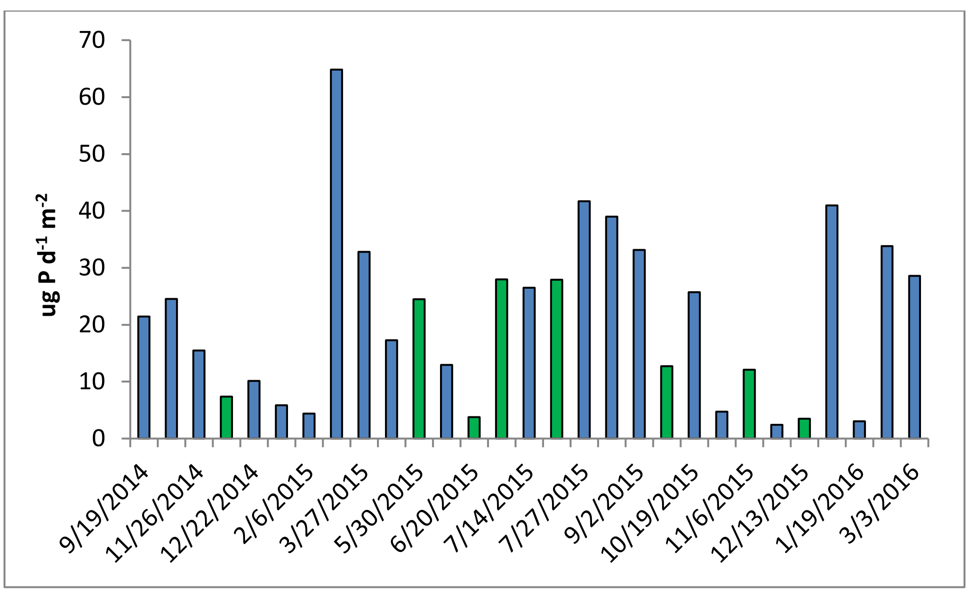

Figure 28. Phosphate dry deposition rates from dry bucket collectors. Blue bars denote GBNERR samples and green bars represent deposition rates from the reference site.

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Influence of wetland plant community types on water quality improvement in natural and restored wetlands of the Mississippi Delta

Basic Information

Title:	Influence of wetland plant community types on water quality improvement in natural and restored wetlands of the Mississippi Delta
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End Date:	2/28/2016
Funding Source:	104B
Congressional District:	3rd
Research Category:	Biological Sciences
Focus Category:	Wetlands, Water Quality, Management and Planning
Descriptors:	None
Principal Investigators:	Gary N. Ervin

Publications

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3. Windham, E.L., C.M. Shoemaker, G.N. Ervin, 2016. Functions of wetland plant assemblages in water quality improvement. Oral presentation at 2016 Mississippi Water Resources Conference, Jackson, MS, April 5-6, 2016.
4. Ervin, G.N., 2016. Influence of wetland plant community types on water quality improvement in natural and restored wetlands of the Mississippi Delta. Final technical report, presented to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 12 pages.

MISSISSIPPI WATER RESOURCES RESEARCH INSTITUTE
FINAL TECHNICAL REPORT

Influence of wetland plant community types on water quality improvement in natural and restored wetlands of the Mississippi Delta

01 March 2015 to 28 February 2016

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ABSTRACT

In an effort to quantify the specific linkages between wetland plants and water quality in Mississippi Delta wetlands, we assessed vegetation and water quality in 30 wetlands, including 24 Wetland Reserve Program (WRP) restorations and six naturally occurring wetlands. Our goal was to examine interactions among water quality parameters and plant species to determine which plant species assemblages appear to most strongly influence nutrient and sediment concentrations in these wetlands. We found substantial differences in the hydrology of restored, versus naturally occurring wetlands, and these differences were correlated with differences in plant species diversity among wetlands. We did not see significant correlations between specific plant species and water quality parameters, but we did find that some plant growth forms were consistently correlated with such water quality parameters as pH, conductivity and nitrate concentrations. We will be working with the USDA NRCS in an effort to translate results of this work into information useful for the design of future restorations, such that they can yield the greatest improvements in water quality while also providing other benefits, such as wildlife habitat, for the Mississippi Delta.

INTRODUCTION

In the Mississippi portion of the Lower Mississippi Alluvial valley (i.e., the "Delta"), some 190,000 acres have been enrolled in the Wetland Reserve Program (WRP) since 1992 and over 23,000 acres are currently in CRP wetland restoration practices (Kevin Nelms, USDA NRCS unpublished data). The success of these wetlands in providing the desired ecological functions (e.g., wildlife habitat, water quality improvement) has been inadequately examined, but such studies are critically important for determining factors that may indicate potential success of future restoration or conservation efforts.

Conservation lands in the Delta are exposed to a relatively high intensity of agricultural land use, which has the potential to negatively impact the ecological function of these lands. For example, estimates based on current agricultural data indicate that watersheds in Mississippi experience nutrient loads in the range of 0.3 to 62 kg nitrogen per hectare and 0.3 to 45 kg phosphate per hectare within the Delta (Figure 1). These data are based solely on average inputs of N and P fertilizers per hectare of the three major MS crops (corn, cotton, and soybeans), which themselves range from 0.5 to 78 percent of the area of individual watersheds within the Mississippi Delta (USDA National Agricultural Statistics Service).

Figure 1. Wetlands examined during our research, plotted against USDA National Agricultural Statistics Service and USDA Economic Research Service data on estimated agricultural fertilizer inputs to corn, cotton, and soybeans. Boxed inset on left is shown in greater detail on the right, to indicate the distribution of our study wetlands across three categories of nitrogen loading, for purposes of our

Comprehensive assessments of restored wetland success are needed to determine the interactive effects among land use, wetland management, and water quality improvement. With this in mind, we set out to evaluate the linkages between water quality and wetland plant assemblages within the Delta. This work was part of an overall research program investigating the impacts of land use on water quality and wetland plant assemblages in natural and restored Delta wetlands.

Our specific objectives in this study were to:

1. Measure water quality parameters (changes in nutrient and sediment loads) and wetland plant species assemblages in restored and naturally occurring wetlands in the Mississippi Delta, across the available gradient of estimated nutrient loadings.
2. Quantify statistical linkages among nutrients, sediment, and wetland plant species, with the objective of determining which suites of species are most closely correlated with greater reductions in nutrient and sediment loads.
3. Translate these results into information that could be used to guide the design of future wetland restorations so as to optimize the likelihood of establishing wetland plant assemblages most likely to contribute to water quality improvements.

METHODS

Site selection

Twelve watersheds (HUC-12) containing WRP wetlands within the Mississippi Delta were selected for assessment (Figure 1). Fertilization and land use data from 2010-2012 were used to calculate approximate nitrogen loads (kg/ha) applied to each watershed, among the three most important crop species. From those data, watersheds were grouped into “high” (≥39 kg/ha), “medium” (17.9-39 kg/ha), and “low” (≤17.9 kg/ha) nitrogen fertilizer application loads (classified based on natural breaks approach in ArcMap 10.2). Those nitrogen loading groups were used to stratify study wetlands across the spectrum of nitrogen application conditions in Mississippi Delta (Figure 1).

Four watersheds in each of the three nutrient load categories were selected randomly following determination of easements with landowner willingness to participate in this study. Two restored WRP wetlands in each selected watershed were monitored throughout the study, for a total of 24 restored wetlands (eight each in high, medium, and low nitrogen load watersheds). A reference (naturally occurring) wetland was identified in six of the 12 watersheds, with two in high nitrogen application watersheds, two in medium, and two low nitrogen application watersheds (Figure 2). Selection of wetland sites via landholder willingness was facilitated with the assistance of Kevin Nelms (USDA, NRCS).

Data Collection

Water sample collection in each wetland took place along the “shoreline” of the wetland and within the wetland interior, with the number of samples collected depending on the size of inundated portion of the wetland on each sampling date. We collected four water samples from sites where the largest inundated area was less than 50m on its longest dimension (two shore and two interior samples) and six samples when the inundated area was larger than this (three shore, three interior samples).

Where obvious inflow points were present, the shore samples were collected from two or three of those locations, depending on wetland size. When obvious inflows were absent (which was most often the case), sample points were spaced at intervals of: approximately one-third the longest dimension (wetlands < 50m), one-fourth the longest dimension (wetlands ≥ 50m), or evenly distributed when the largest inundated area had an approximate diameter of 20m or less. We also sampled from wetland outflows when water levels were sufficient to generate flow through the outflow structures of restored wetlands (and from the major natural outflow for natural wetlands).

Sampling along the shore and within the wetland interior was expected to permit a wetland-scale evaluation of changes in nutrient and sediment concentrations as surface water passes through the vegetated zone of each wetland. Inclusion of samples from outflows, when present, was expected to permit an estimation of nutrient and sediment reductions for each wetland, relative to "inflow" loads and plant assemblages in each wetland.

Water chemistry

Water samples were analyzed for nitrate-N, ammonia-N, phosphate-P, dissolved oxygen (DO), conductivity, pH, and turbidity. We used in-situ data collection sondes (Hach Hydrolab DS5 sonde) to measure water temperature, conductivity, pH, DO, and turbidity. Concentrations of nitrogen and phosphorus were determined through analysis at the Mississippi State University Water Quality Laboratory.

All water samples were handled, collected, and transported according to EPA quality assurance/quality control guidelines (USEPA 2002). Water samples were transported (in coolers, on ice at ~4°C) from field sampling locations to the Mississippi State University Water Quality Laboratory for analysis. Unfiltered samples were analyzed for total inorganic phosphorus (TIP) using TNT 843 analysis kits (HACH, Loveland, CO, USA) according to methods described in APHA et al. (1998). All samples also were filtered through 0.45μm cellulose membrane filters to be analyzed for ammonia (NH_3), nitrate (NO_3^-), and nitrite (NO_2^-) using a Lachat Flow Injection Analysis (FIA) 8500 (Lachat Instruments, Loveland, CO, USA). Lachat FIA standard methods of automated cadmium reduction allow for analysis of NO_x^- and NO_2^- (APHA 1998), where NO_3^- values are calculated as the difference between NO_x^- and NO_2^-. Ammonia, NO_3^-, and NO_2^- were added together to calculate total inorganic nitrogen (TIN).

Sediment retention

Total suspended solids (TSS, a measure indicative of both inorganic sediment load and transport of organic particulates within and from the wetland) were measured by filtering water samples through pre-combusted (500°C), pre-weighed 0.7 μm glass fiber filters. The filters, along with the non-dissolved particulate matter from water samples, were dried at 105°C and re-weighed after drying to determine TSS concentration (APHA et al., 1998).

Wetland Plant Species

Floristic inventories (e.g., Ervin et al. 2006a) were conducted on plant species within the wetland sites in the spring (late May) and in the summer (early August). Fifty circular plots (0.5 m^2 each) were evenly spaced (~25m apart) along transects systematically covering each site, excluding portions of the site with standing water greater than waist deep. All plant species within the circular plots were recorded, and in the event of an unidentifiable specimen, voucher samples were collected and transported to the Mississippi State University Herbarium for expert identification.

Plant species are being analyzed for overall species composition, the composition of species based on growth form, and wetland indicator status. In this way, sites can be represented by dominant plant species, as well as by detailed species presence data, for analysis against water quality parameters.

Site Hydrology

Twelve water level loggers (Rugged Troll 100, In Situ Inc., Ft. Collins CO) were placed across nine of the twelve Delta watersheds. Within these watersheds, four loggers were placed in each nitrogen loading category. Of these four, one logger was placed in a reference wetland, while another was placed in a restored wetland within the same watershed. The remaining two were placed in two other watersheds within the same nitrogen loading category. The loggers recorded data every hour in a linear fashion over the duration of the study. This procedure captured hydrologic "fingerprints" of the wetlands and quantified site hydrology over the testing period.

RESULTS & DISCUSSION

Hydrology differed markedly between the natural and WRP wetland sites (Figures 2 and 3). Natural sites maintained standing water on-site throughout a substantial portion of the year, but WRP wetlands exhibited shallower water overall, as well as a significant period of exposed sediments during each year. As discussed in a separate report, data suggested that this difference in hydrology may have resulted in a significantly higher plant species diversity in the WRP wetlands (Ervin & Kröger, 2016).

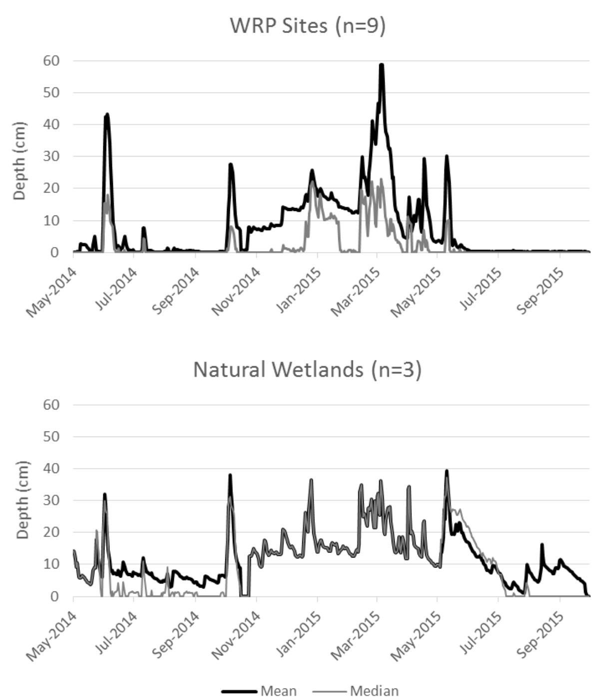

Figure 2. Hydrographs for sites on which water level loggers were installed. The data covered two research seasons for work funded by MS WRRI.

The management approaches used in WRP wetlands include annual drawdowns of water levels to stimulate spring and summer growth of desirable waterfowl forage plants. This is a major cause for differences observed in hydrology between wetland types. Local precipitation patterns also resulted in not only some differences among wetlands, but also periods of very dry conditions across all study sites (Figure 4, Table 1). This hampered our ability to examine plant-water quality interactions during portions of the year.

Despite the problems with water availability in August and October 2015, we were able to collect and process 177 water samples in March and 142 samples in May.

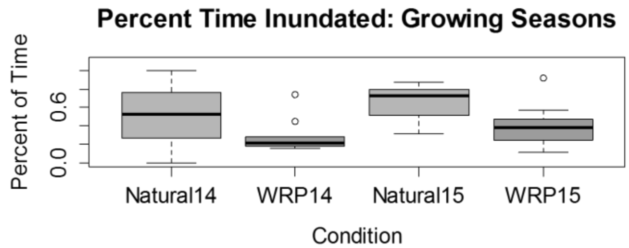

Figure 3. We found a general tendency (not statistically significant) for natural wetlands to remain flooded for a longer proportion of the growing season than did WRP wetlands.

One complicating issue with determining dominant plant species at water quality sampling locations in March was that sampling occurred before the majority of plants had emerged for the 2015 growing season. To facilitate a correlation of water quality sampling with dominant stands of vegetation within each wetland, we used plant survey data from August 2014 to determine water sampling locations. Maps of probable plant assemblages were interpolated using Thiessien polygons (in ArcMap GIS version 10.2) of dominant species from August 2014 surveys (e.g., Figure 5).

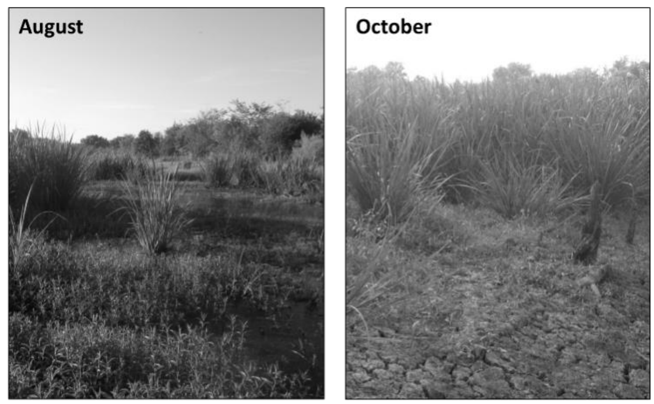

Figure 4. Example of the contrast in hydrology among seasons between late summer-early fall in some of the study sites.

Table 1. Distribution of samples among sites and sample dates, during our 2015 water quality sample collection.

Sampling trip	Samples collected	Samples per site	Sites with samples collected
March	177	4-7	28
May	142	4-7	23
August	54	6	9
October	12	6	2

We are continuing our work on determining the full suite of plant species observed in our study sites. However, analyses for March 2015 water quality data are presented here (Figure 6). One important finding in these analyses (as well as preliminary analyses we have conducted for May 2015) is that plant species identity appears poorly correlated with water quality measurements in our dataset. Plant species assemblages varied quite widely among sites, with one consequence that we have found a set of roughly six species that are quite common across sites and a large number of species that occur at 2-6 sites each. This essentially resulted in relatively unique species assemblages for each wetland, which complicates efforts at finding broad-scale patterns of correlation between plant species, per se, and water quality.

On the other hand, when we grouped plant species into their representative growth forms (vines, broad-leaved, graminoid, and woody plant species), patterns emerged from the analyses (Figure 6). For the March 2015 sampling period, significant differences among plant growth forms for our measurements of pH, conductivity, and nitrate were found. However, no significant differences among growth forms with respect to reduction-oxidation potential (ORP), turbidity, total suspended solids (TSS), or phosphate were found.

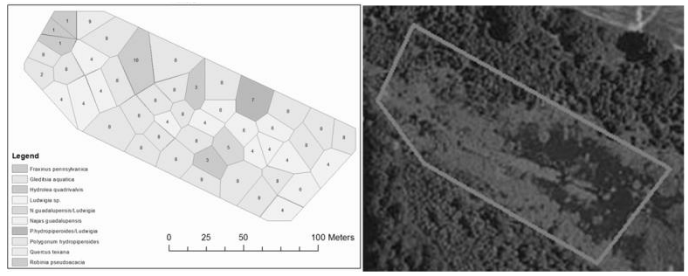

Figure 5. On the left, a map of probable plant assemblages at a site. On the right, satellite imagery of the same site at 1m resolution.

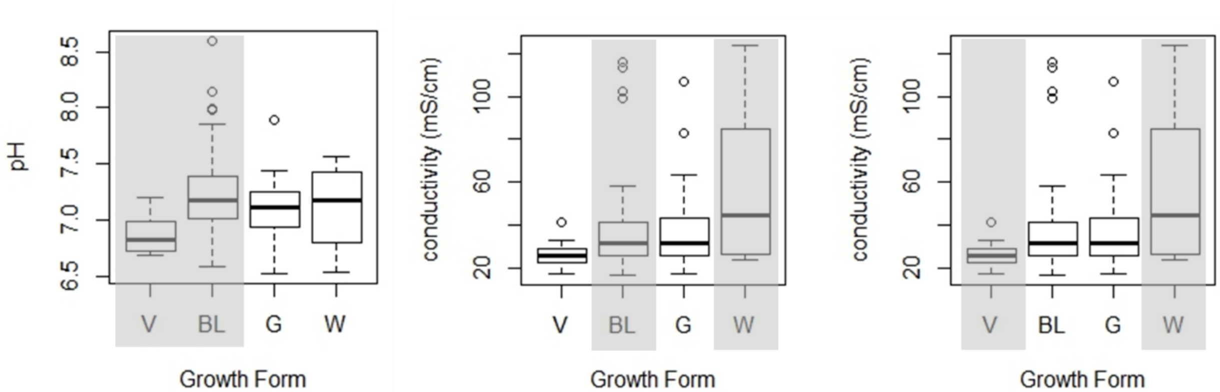

Figure 6. Plant growth form was found to be correlated with differences in some water quality parameters among wetlands. Left: stands dominated by vines exhibited significantly lower pH than stands dominated by broad-leaved species; middle: stands dominated by broad-leaved species exhibited significantly lower conductivity than stands dominated by woody species; and right: stands dominated by vines exhibited significantly lower conductivity than stands dominated by woody species.

We are conducting an additional experiment to look more closely at responses of wetland plant assemblages to nutrient and sediment inputs into Delta wetlands (Figure 7). In this study, we collected soil from three of our WRP sites and placed it into 378-L (100-gal) cattle tanks. The tanks then were randomly assigned to treatment groups receiving high or low level amendments of nitrogen fertilizer and high or level amendments of sediment, owing to the importance of nutrient and sediment serving as the most commonly cited water quality stressors for natural wetlands and those restored for conservation purposes. Sediment for this experiment was derived from the three wetlands selected for the study.

Figure 7. Tank experiment designed to test responses of wetland vegetation to nutrient and soil inputs. Soil from three WRP sites was used to establish the experiment.

This experimental study – although still underway – has suggested that there are significant differences among the three wetlands in both the plant species assemblages establishing in each but also the rates of removal of nutrients and sediment from the water column over time. These results support our finding in the field study that plant species assemblages among the individual wetlands are quite dissimilar, complicating our efforts at teasing out interrelationships among plant species and water quality. It remains to be seen, however, whether relative differences in removal rates in the experiment will correlate with relative differences in measured water quality parameters among the three wetlands in the field and whether dominant plant species in the experimental tanks may be correlated with similarly low or high levels of water quality in the field. Regardless, it appears that we may be able to draw conclusions about the role of wetland plants in water quality mediation, via the differential effects of growth forms such as vines and broad-leaved plant species on water quality parameters we have measured.

Two graduate students continue to work on aspects of this project related to their thesis projects. We anticipate one thesis, one dissertation, and at least a small number of papers to be published based on this work (Table 2). We also will be producing reports for each individual site that will be distributed to the land owners and to Kevin Nelms, of the USDA NRCS.

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PROGRESS RELATED TO STATED OBJECTIVES

1. Measure water quality parameters (changes in nutrient and sediment loads) and wetland plant species assemblages in restored and naturally occurring wetlands in the Mississippi Delta, across the available gradient of estimated nutrient loadings.

We completed four sampling trips to collect water quality data during 2015, along with two complete wetland plant surveys. The main obstacle to fully completing the objective as stated was that we found limited occurrences of outflows in our wetlands. This complicates efforts at quantifying changes in water quality parameters as water moves through the wetlands. This was one impetus for the experimental tank study that was established and is still underway. We do have data from two nutrient amendment treatments, the data for which are currently being analyzed.

2. Quantify statistical linkages among nutrients, sediment, and wetland plant species, with the objective of determining which suites of species are most closely correlated with greater reductions in nutrient and sediment loads.

We have completed analyses examining suites of species and individual species and have found few indications of consistent roles of individual species across the 30 study wetlands. However, we followed up those analyses with an examination of whether growth forms (groups of similar species) may influence water quality, and we have found indications that this is the case.

3. Translate these results into information that could be used to guide the design of future wetland restorations so as to optimize the likelihood of establishing wetland plant assemblages most likely to contribute to water quality improvements.

Individual reports on our findings for each wetland will be prepared and delivered to cooperating landowners. We anticipate having these reports delivered during Fall 2016. We have made contact with the coordinator of the Gulf Coastal Plain and Ozarks Landscape Conservation Cooperative about developing a project page to host data and information about this work. We also will be working with Kevin Nelms, of the USDA NRCS, to incorporate our findings into any potential improvements for the USDA ACEP (formerly WRP).

SIGNIFICANT FINDINGS

Information gained so far in this research project indicates that:

- Relatively large differences exist in plant species composition among Delta wetlands, even when experiencing similar management strategies.
- Individual plant species composition is relatively uninformative about water quality in Delta wetlands.
- Some water quality attributes do appear to be influenced by species mixtures or types, rather than by individual species themselves.

We will build upon these findings to develop plans for future research that could use these insights to help direct future restoration/conservation efforts in the Delta.

CONTINUED RESEARCH

Although the project performance period has ended, much of the analyses of data collected remains underway. We have collaborated with Dr. Charles Bryson and Mr. John McDonald to identify the more difficult plant species from the field surveys, and plant identification is nearing completion. We currently are engaged in data analysis for one Master's student thesis that should result in at least one peer-reviewed publication, and we anticipate at least two publications to result from the doctoral dissertation that is still in progress.

Table 2. Anticipated products not yet completed from this project.

Type	Tentative title	Anticipated completion
Dissertation	*Assessing drivers of wetland plant community dynamics in the Mississippi Delta*	December 2017
Thesis	*Functions of Wetland Plant Assemblages in Water Quality Improvement in Natural Wetlands*	August 2016
Reports	Individual site reports to be delivered to landowners who provided access to their property	Fall 2016
Online documents	We have made contact with the coordinator of the Gulf Coastal Plain and Ozarks Landscape Conservation Cooperative regarding development of a "project page" to host data and information related to this work	Fall 2016
Paper	Experimental assessment of nutrient and sediment removal by Mississippi Delta wetland communities	Fall 2016
Paper	Correlation of wetland plant assemblages with water quality in Mississippi Delta wetlands	Fall 2016

FUTURE FUNDING POTENTIAL

Dr. Ervin made contact with Florance Bass and Doug Upton, at Mississippi DEQ, regarding future research projects that could expand on the findings resulting from this work while also contributing to wetland needs within Mississippi. Plans are to continue discussions with MS

DEQ and to develop research plans that could be used to pursue potential funding opportunities that could take advantage of the information gained in this WRRI-funded project.

STUDENT TRAINING, OUTREACH, AND INFORMATION TRANSFER

Two graduate students are continuing work towards their degrees, with one planning to graduate during 2016, the other potentially as early as December 2017. These students have presented work from their projects at a number of regional conferences, resulting in one award for Best Student Presentation. The following are some of the products resulting from this research thus far.

Student Training

Name	Level	Major
Cory Shoemaker	Doctoral Student	Biological Sciences

Cory won the award for Best Student Oral presentation at the 2016 Mississippi Water Resources Conference, for a presentation on this work.

Name	Level	Major
Evelyn Windham	Master's Student	Biological Sciences

Evelyn was selected as the Department of Biological Sciences Teaching Assistant of the Year for the 2015-2016 academic year.

Publications/Presentations

Ervin, G. N. and C. M. Shoemaker. 2015. Water quality-land use interactions in restored wetlands of the Mississippi Delta. Mississippi Water Resources Conference, Jackson, MS, 08 April 2015.

Shoemaker, C.M. 2015. Drivers of wetland plant communities in the Mississippi Delta. Department of Sciences and Mathematics, Mississippi University for Women, Columbus, MS, September 9, 2015. (Invited lecture)

Shoemaker, C. M. and G. N. Ervin. 2015. Drivers of plant community composition in Delta wetlands. Mississippi Water Resources Conference, Jackson, MS, 08 April 2015.

Shoemaker, C. M. and G. N. Ervin. 2015. Drivers of plant community compositionin restored wetlands. Society of Wetland Scientists annual conference, Providence, RI, 03 June 2015.

Shoemaker, C.M. and G. N. Ervin. 2015. Drivers of wetland plant assemblages in restored and naturally occurring wetlands in Mississippi. MidSouth Aquatic Plant Management Society Conference, Mobile, AL, September 16, 2015

Windham, E.L., C. M. Shoemaker, and G. N. Ervin. 2015. Functions of wetland plant assemblages in water quality improvement in natural wetlands. MidSouth Aquatic Plant Management Society Conference, Mobile, AL, September 16, 2015.

Shoemaker, C.M., E.L. Windham, and G.N. Ervin. Effects of land use on wetland plant diversity in Mississippi. Mississippi Water Resources Conference, Jackson, MS, 06 April 2016.

Windham, E.L., C. M. Shoemaker, and G.N. Ervin. Functions of wetland plant assemblages in water quality improvement. Mississippi Water Resources Conference, Jackson, MS, 06 April 2016.

In the Mississippi Delta, agriculture and wetlands are often seen as different, separate systems. This and other projects in which we are engaged attempt to blur the boundaries of the two types of systems by considering wetlands within their landscape context. A better understanding of how wetlands function in agriculturally dominated landscapes is of interest to wetland scientists but also to producers with land in conservation programs or those who are considering enrollment. Information developed through this project will provide new data that may affect how various Delta stakeholders manage land and prioritize enrollment ACEP sites.

Planned web-based hosting of data and information

Final products from the project will be made available to scientists and the general public through Ervin's membership in the Gulf Coastal Plain and Ozarks Landscape Conservation Cooperative (GCPO LCC). In particular, geospatially referenced data products resulting from this work can be made available, with landowner permission, via the GCPO LCC Conservation Planning Atlas (http://gcpolcc.databasin.org/).General information about the project and findings will be hosted through a GCPO LCC project page (gcpolccapps.org). All products made available in this manner will adhere to the data management best practices developed by the GCPO LCC.

Collaboration with Kevin Nelms of the USDA NRCS.

We have cooperated directly with the USDA NRCS in determining sites on which to conduct the research, but we also plan to maintain that collaboration to aid in information dissemination. Incorporation of our findings into the USDA NRCS WRP ranking tool will ensure that the most complete information is being applied to assessment and prioritization of WRP efforts within the region.

Towards an understanding of surface and groundwater exchange within tailwater recovery systems

Basic Information

Title:	Towards an understanding of surface and groundwater exchange within tailwater recovery systems
Project Number:	2015MS203B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	3rd
Research Category:	Water Quality
Focus Category:	Water Quantity, Agriculture, Groundwater
Descriptors:	None
Principal Investigators:	Eric D Dibble, Beth Harlander Baker, Joby Prince Czarnecki

Publications

1. Quarterly reports submitted.
2. Czarnecki, J. M.; A. R. Omer, 2015. Assessment of tailwater recovery system and on-farm storage reservoir efficacies: Quantity issues. Oral presentation at 2015 Mississippi Water Resources Conference, April 7-8, 2015, Jackson, MS.
3. Omer, A. R., 2016. Assessment of tailwater recovery system and on-farm storage reservoir water and nutrient harvesting. Oral presentation at 2016 Mississippi Water Resources Conference, April 5-6, 2016, Jackson, MS.
4. Rogers, J., B. Baker, J. Czarnecki. Towards an understanding of surface and groundwater exchange through tailwater recovery system. Poster presented at 2016 Mississippi Water Resources Conference, Jackson, MS, April 5-6, 2016.
5. Czarnecki, J. M.; A. R. Omer, 2015. Assessment of tailwater recovery system and on-farm storage reservoir efficacies: Quantity issues. Proceedings from 2015 Mississippi Water Resources Conference, April 7-8, 2015, Jackson, MS, pg. 75, www.wrri.msstate.edu/pdf/2015_wrri_proceedings.pdf
6. Omer, A. R., 2015. Assessment of tailwater recovery system and on-farm storage reservoir water and nutrient harvesting. Proceedings from 2015 Mississippi Water Resources Conference, April 7-8, 2015, Jackson, MS, pg. 75, www.wrri.msstate.edu/pdf/2015_wrri_proceedings.pdf
7. Baker, B. H., J. M. Prince Czarnecki, J. R. B. Barlow, E. Dibble, A. R. Omer, J. Rogers, 2016. A preliminary investigation of surface and groundwater exchange within tailwater recovery systems in the Mississippi Delta. Final technical report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 22 pg.

A preliminary investigation of surface and groundwater exchange within tailwater recovery systems in the Mississippi Delta

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Abstract

Substantial withdrawals from the Mississippi Alluvial Aquifer for irrigation have resulted in a long-term trend of decreasing groundwater levels. Agricultural producers are adopting tailwater recovery systems, a best management practice for capturing surface water for re-use, but scientific data is lacking on the ability of these systems to mitigate aquifer depletion. One current area of interest is the potential for these systems to serve as a recharge mechanism. It is proposed that instrumenting tailwater recovery systems of varying age with piezometers, equipped with multiple loggers that measure temperature, atmospheric pressure, and depth, will provide data for a groundwater flow and heat transport model developed using VS2DH. Quantification of ground and surface water exchange indicated that over the observation period some influence from surface water was likely being exerted on groundwater stores. However, gradual changes in well temperature indicate low hydraulic flow rates between compartments. Additionally, gradual temperature changes were observed to change at a greater rate in the new (<1 year old) tailwater recovery system, indicating that age of the system does impact groundwater – surface water interaction. Surface water quality analysis resulted in low nutrient concentrations. Low flow rates and nutrient concentrations result in minimal concern for groundwater leaching from TWR/OFS systems.

Introduction

Irrigation accounts for the largest use (98%) of the Mississippi Alluvial Aquifer (Thornton, 2012), which is the primary groundwater source for agriculture in the Mississippi Delta. Substantial withdrawals from the Aquifer without equivalent recharge have resulted in a cone of depression in the central Mississippi Delta, and depletion of the Aquifer as a whole (Barlow and Clark, 2011). Producers in this region have been eligible for federal cost-share assistance through the US Department of Agriculture National Resource Conservation Service (NRCS) to implement tailwater recovery systems (TWR), with or without an additional on-farm storage reservoir (OFS). A TWR (with or without an OFS) is designed to capture surface runoff, reducing outflow of nutrients to receiving waters and simultaneously providing an alternative source for irrigation (Figure 1). This dual benefit is important because it addresses both quality and quantity of water, which are equally important in Mississippi and many other areas. As of August 2014, 184 TWR/OFS have been cost-shared under practice code 436 by NRCS in the State of Mississippi (Paul Rodrigue, NRCS, personal communication); over 50% of these systems are located within the cone of depression (Figure 2). Despite their prevalence on the landscape and their popularity with producers and government agencies, much research remains to be done to quantify the water quality and quantity benefits of TWR/OFS.

To accurately model levels within the Aquifer, it is necessary to determine the rate of ground and surface water exchange. Field observations at one research site reported water level losses due to leakage from a TWR and OFS between 0.5 to 3 feet per month over a six-month period (REACH, unpublished data). A primary hypothesis is that infiltration rates decrease over time as these systems compact and fill-in with silt due to head pressure from overlaying water, but the time required for systems to seal is unknown. During this time where water losses are high, a significant potential for groundwater – surface water exchange exists. The recharge potential for these systems must be quantified to assign additional value to continued investment in these systems. An additional factor of consideration is the potential of TWR to become a source for nutrient leaching as these systems accumulate and hold nutrient loads leaving agriculture fields. Thus it is important to examine groundwater – surface water exchange from a quantity *and* quality perspective. This information will be immediately useful to federal agencies that are under pressure to provide accurate accounting of the status of the Aquifer, agencies and producers making investment in these best management practices, and scientists working within the water quality and quantity arenas.

Barlow and Clark (2011) examined various conservation scenarios for the Mississippi Delta to determine their benefit on Mississippi Alluvial Aquifer levels. Scenarios investigated that specifically targeted the cone of depression resulted in the greatest improvements within the cone; however, Delta-wide scenarios resulted in greater broad area improvements in water level. Ultimately, it was the major conclusion of the authors that focusing conservation efforts within the cone of depression led to the greatest improvements in storage within the Aquifer. With the majority of TWR/OFS being implemented within the cone, it is imperative that their contribution to recharge be studied because this is the area with the most need, the area with the greatest density of TWR/OFS, the area where the most benefit Delta-wide is likely to be seen, and the area where the consequences of limited recharge will be felt first and most severely. The cost-benefit ratio of this project cannot be overstated. The data collection effort for this project is extremely straightforward, relatively simple to implement, and comparably low-cost; however, the results that these data will yield represent a major step forward in the understanding of the benefits of TWR and provide additional data for those tasked with estimating Aquifer levels. Ultimately this data will assist policymakers in designing strategies and guidelines to appropriately manage this vital resource

The objectives of the proposal are: 1) quantify the recharge contribution of TWR/OFS to the Mississippi Alluvial Aquifer; 2) quantify transport of nutrients between groundwater and surface water within TWR/OFS; and 3) determine if age of TWR/OFS impacts magnitude of groundwater – surface water exchange. Research priorities applicable to this research project include utilizing innovative approaches to estimate aquifer recharge via assessment of GWSW interactions within TWR/OFS using piezometers with pressure and temperature transducers to quantify TWR/OFS contribution to Aquifer recharge. Performance and effectiveness of innovative and established nutrient and sediment management methodologies via assessment of nutrient transport between groundwater underlying and surface water within TWR/OFS will be conducted. Prediction of future impacts from proposed infrastructure on water resources via quantification of quality and quantity benefits of TWR/OFS and additional model parameters related to system age as it relates to groundwater – surface water exchange. Methods, procedures, and facilities.

Materials and Methods

Potential recharge of the Mississippi Alluvial Aquifer from TWR/OFS was investigated at two sites within the Mississippi Delta region. Groundwater – surface water exchange was documented at two locations within each site using piezometers with loggers which measure and record real-time atmospheric pressure, water temperature and water level. Each site was instrumented with two piezometers as shown in Figure 3 and Figure 4; installation occurred between November 5, 2015 in System 1 and December 9, 2015 in System 2. Sites were equipped with additional temperature probes and an additional logger, located above the reach of surface water to provide a reference for barometric correction of the loggers within the piezometer. At each piezometer location, pressure and temperature were recorded from groundwater (at a 1 to 2 m depth), the sediment bed, and from surface water. Sediment and surface data was collected from August 22, 2015 to February 17, 2016. However, groundwater data was not collected from November 5, 2015 to February 17, 2016 due to constraints implementing piezometers in the systems. Figure 3 illustrates how these key data collection points are connected. Data was downloaded from loggers every other week from to ensure the loggers are working correctly and subsequent data loss. Data analysis required using a two-dimensional groundwater flow and heat transport model developed using VS2DH, a program developed by the U.S. Geological Survey. The VS2DH model quantifies groundwater – surface water exchange over the data collection period. Data from loggers is necessary to the successful development of the model within VS2DH, which requires daily groundwater levels and temperature values at identified collection points for model parameter specification.

Samples for water-quality analysis were collected every other week from surface water held within the TWR/OFS from September 9, 2015 to January 29, 2016, however, attempts at extracting groundwater samples from piezometers using Teflon tubing and a peristaltic pump, following nationally consistent sampling protocols (Koterba et al., 1995), were not successful. Personal communications with the landowner revealed that it is common for manually implemented shallow wells to become clogged due to clay particles. All surface water samples were handled, collected, and transported according to EPA quality assurance/quality control guidelines (USEPA, 2002). Water samples were transported (in coolers, on ice at ~4°C) from field sampling locations to the Mississippi State University Water Quality Laboratory for analysis. Samples were analyzed for total inorganic phosphorus, dissolved inorganic phosphorous, ammonia, nitrate, and nitrite. Quality-control data, including field blanks and field duplicates were collected along with routine samples to ensure that unintended contamination did not occur at any point in the sample collection and laboratory analysis. Field duplicate samples were collected for approximately 10% of all routine samples. Water quality data was intended to be used to determine the magnitude of nutrient leaching from TWR/OFS; in the absence of groundwater samples, water quality data was used to speculate potential groundwater leaching from surface concentrations.

Site selection was strategic and includes one TWR/OFS for which there is some preliminary data (REACH, unpublished data). System 1 is located in Coahoma County, MS and is approximately five-years old. System 2 is located in Sunflower County, MS and was less than one year old at the beginning of the project. Strategic site selection allows for comparisons of TWR/OFS based on age. Appropriate statistical methods for time series comparison will be employed to determine how age of TWR/OFS influences groundwater – surface water exchange over time, and will be based on comparison of the old system against the new system. As previously stated, a primary hypothesis is that infiltration rates decrease over time as these systems compact and fill-in with silt. By examining systems at two different ages, it is anticipated that the research will not only show the potential for groundwater recharge and nutrient leaching from these systems, but also an indication for the duration of these risks (i.e., the trend in recharge and leaching over time) so that any necessary management changes can be made to maximize water-use efficiencies or mitigate pollution risks.

Results and Discussion

Analysis of groundwater – surface water data via V2SDH models, proposed conducted a by USGS collaborator; was not completed at the time of reporting. Subsequent analysis of temperature patterns was conducted to address project objectives. Project objective 1 aimed to quantify the recharge contribution of TWR/OFS to the Mississippi Alluvial Aquifer. Temporal surface water, sediment, and within shallow wells (approximately 10 ft depth) temperature data from each sampling location were plotted together to identify patterns (Figures 5-8). At all locations variability in surface water and sediment followed changes in atmospheric temperature and displayed some instances diurnal cycling. However, well temperature remained fairly stable, showing gradual temperature decreases toward surface sediment and surface water temperatures over time. Given the lack of surface and sediment variability echoed in well temperature patterns (and vice a versa), data indicates that hydraulic flow rates through sediment are low, such that potential groundwater – surface water exchange would be occurring at a slow rate. Decreases in well temperature over the three month period toward sediment and surface water temperatures (while atmospheric temperature is rising) indicate that some surface water is influencing groundwater stores. However, low hydraulic flow indicates high potential for water treatment during movement through sediment.

Project objective 2 was to quantify transport of nutrients between groundwater and surface water within TWR/OFS. As attempts toward collecting groundwater samples failed, data only allowed for the forecasting of potential nutrient transport from measured surface water contributions. Water quality results revealed nutrient and sediment concentrations in TWR/OFS systems to be lower than previously reported runoff in the Mississippi Delta region (Littlejohn et al. 2014; Baker et al. 2016). Mean nutrient concentrations were found to be below 1 mg/L and total suspended sediment concentrations were found to be below 150 NTU. Given the low hydraulic flow rate indicated by temperature data and low observed surface water nutrient concentrations, concern for nutrient seepage to groundwater stores is minimal.

Project objective 3 was to determine if age of TWR/OFS impacts magnitude of groundwater – surface water exchange. Temperature differentials between well – sediment data at all sampling locations were plotted (Figure 9 (a-d)). Temporal temperature differences were plotted and linear trendlines with slope and r-squared equations were calculated to evaluate if these parameters differed between the two systems. Linear trendline slopes calculated for System 2 (<1 year old) were greater than System 1 (>5 years old), indicating a faster rate of change in temperature differences over the three month observation period. Results indicate that groundwater – surface water interactions were greater within system two, supporting the hypothesis that age of TWR/OFS impacts magnitude of groundwater – surface water exchange. These results, while notable, are not concerning bearing in mind that results supported low hydraulic flow rates at all locations. Furthermore, data from System 1, indicates that groundwater – surface water exchange will decline overtime.

Conclusion

Investigation of potential recharge of the Mississippi Alluvial Aquifer from TWR/OFS at two sites within the Mississippi Delta region yielded data indicating that any groundwater –

surface interactions are occurring at low hydraulic flow rates, such that daily or weekly interactions were not apparent and potential for significant groundwater recharge is minimal. Low hydraulic flows combined with low nutrient concentrations equate to minimal concern for nutrient leaching to groundwater stores. Decreasing trends in well temperature at all study locations over the study period do, however, indicate potential contribution of surface water to groundwater stores. This preliminary data should be interpreted with caution given the small observation period and number of replications. Future research is warranted to build a larger body of data toward project objectives.

Acknowledgements

Authors would like to thank the Mississippi Water Resources Research Institute for their funding support for this research. We would also like to thank Farm Bureau Federation for their support of this project. Along with the administrative support from the Department of Wildlife, Fisheries, and Aquaculture and the Water Resources Research Institute at Mississippi State University.

Student Training

One undergraduate student, Jonathon Rogers, received full-time experiential learning and research experience as a result of this funding. The student presented research at the Mississippi Water Resources Conference (below). Additionally, this student found immediate employment following May 2016 Graduation.

Presentations

*Jonathon Rogers, **Beth Baker**, Joby Czarnecki, and Jeannie Barlow. "Towards an understanding of surface and groundwater exchange through tailwater recovery systems." Mississippi Water Resources Conference. Jackson, MS. April 5-6, 2016.*

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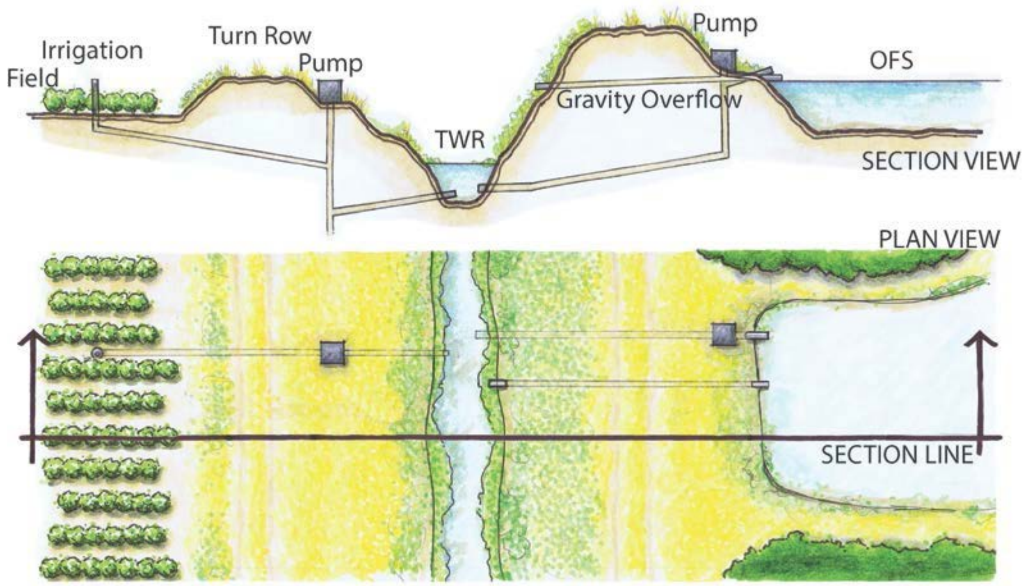

Figure 1. Schematic of a tailwater recovery system and on-farm storage reservoir in section and plane view.

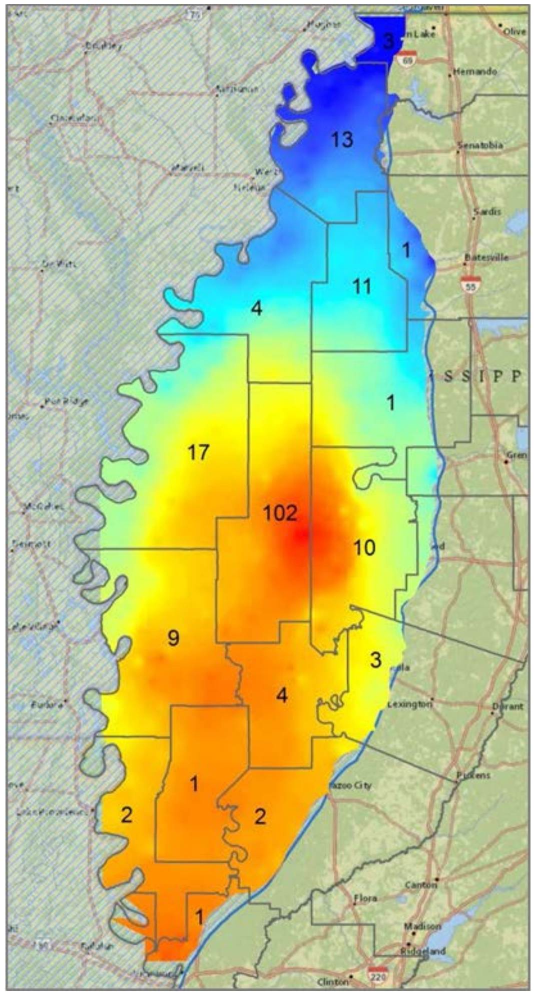

Figure 2. The Mississippi Delta counties with number of TWR/OFS cost-shared by NRCS within each county. Aquifer levels decrease from blue to red, with red representing the cone of depression. Aquifer levels based on data from Mr. Mark Stiles, Yazoo Mississippi Delta Joint Water Management District.

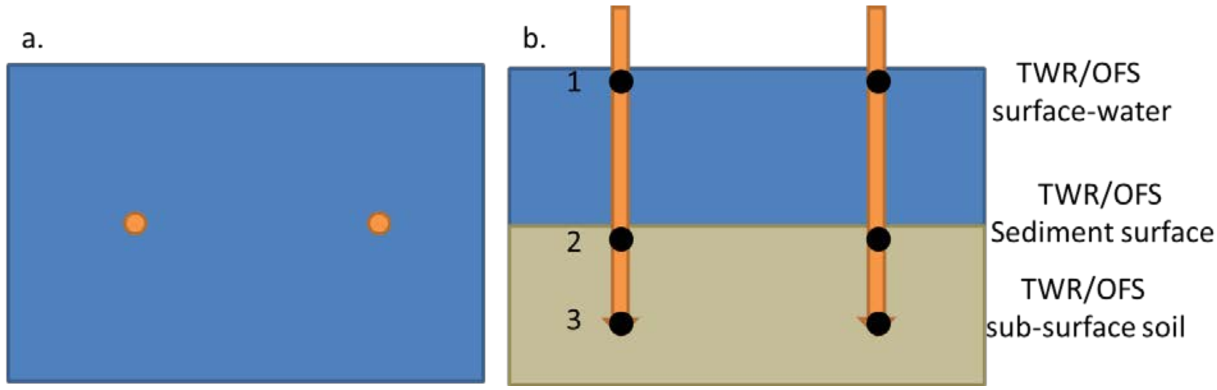

Figure 3. The image on the left (a) shows an aerial view of piezometer placement within the TWR/OFS. The image on the right (b) shows a transect of the horizontal plane to depict piezometer placement within the TWR/OFS extending from 1 to 2 m below the sediment surface to above the surface water level. Numbers 1, 2, and 3 indicate placement of respective data loggers, which will record pressure, water level, and temperature from surface water, from the sediment bed, and from groundwater, respectively.

Figure 4. Actual piezometer placed in TWR/OFS placed in System 1. Image A shows PVC pipe housing pressure gauge wiring and sample tubing along bank from the piezometer; Image B shows the PVC pipe where it connects to the piezometer and enters the sediment in System 1; Image C shows wiring and tubing housed in plastic bin on top of the TWR/OFS bank for accessible data downloading.

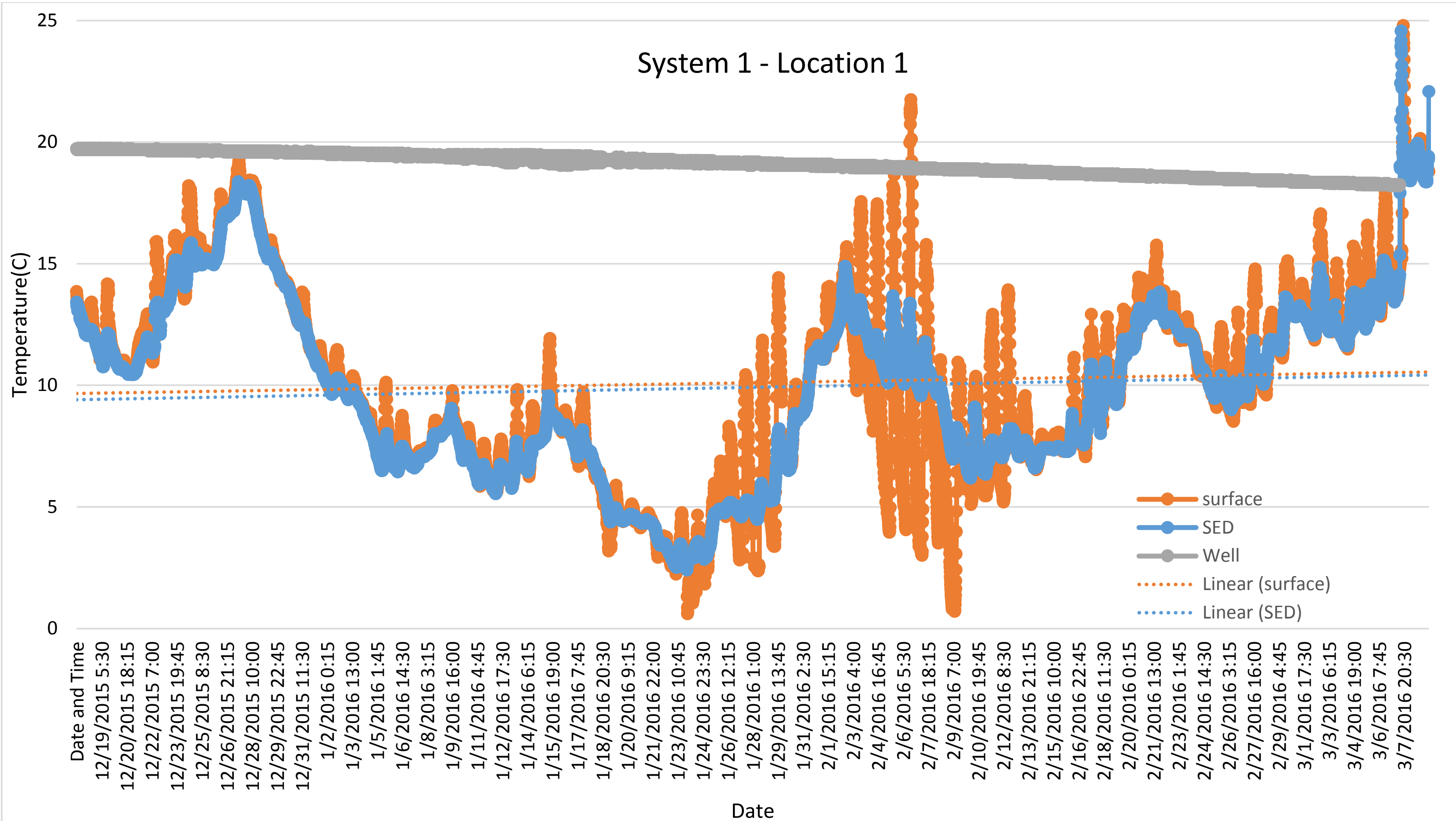

Figure 5. Temperature data collected from December 17, 2015 to March 7, 2016 at location 1 within TWR/OFS System 1 (>5 years old). Temperature data collected from surface water, sediment, and groundwater well are included, trend lines for surface water and sediment were added to better summarize trends over time in comparison to groundwater well data.

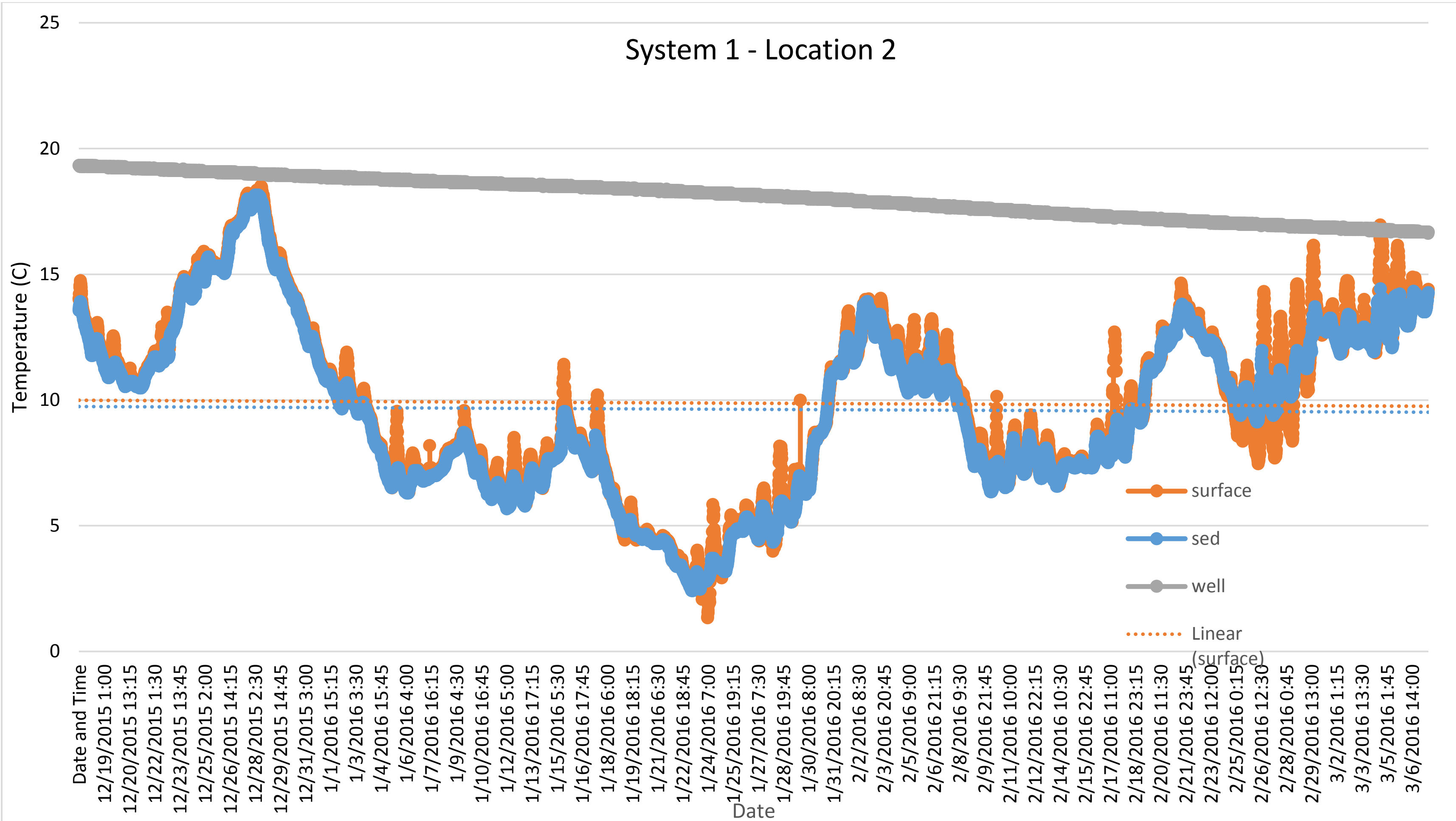

Figure 6. Temperature data collected from December 17, 2015 to March 7, 2016 at location 2 within TWR/OFS System 1 (>5 years old). Temperature data collected from surface water, sediment, and groundwater well are included, trend lines for surface water and sediment were added to better summarize trends over time in comparison to groundwater well data.

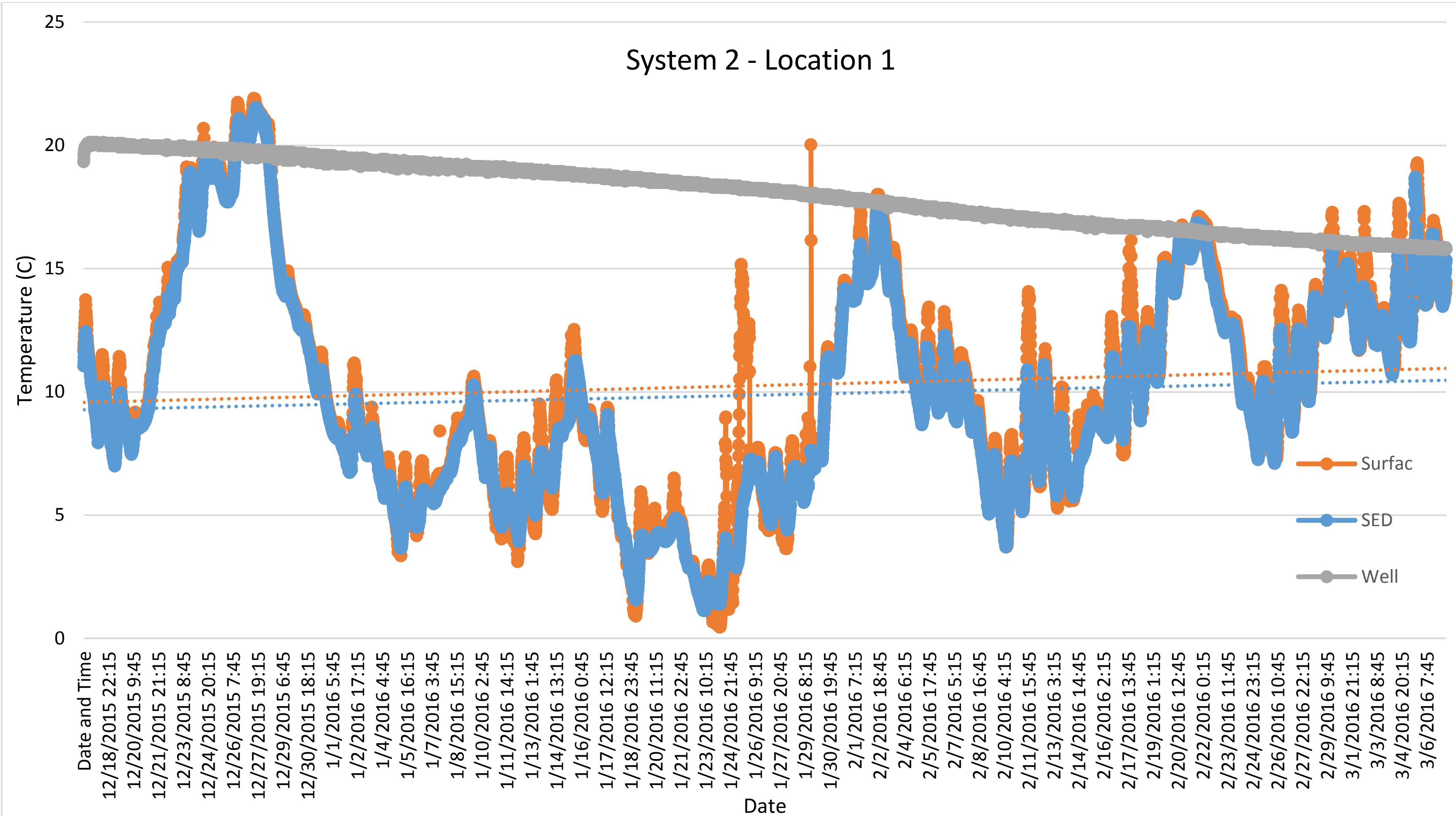

Figure 7. Temperature data collected from December 17, 2015 to March 7, 2016 at location 1 within TWR/OFS System 2 (<1 year old). Temperature data collected from surface water, sediment, and groundwater well are included, trend lines for surface water and sediment were added to better summarize trends over time in comparison to groundwater well data.

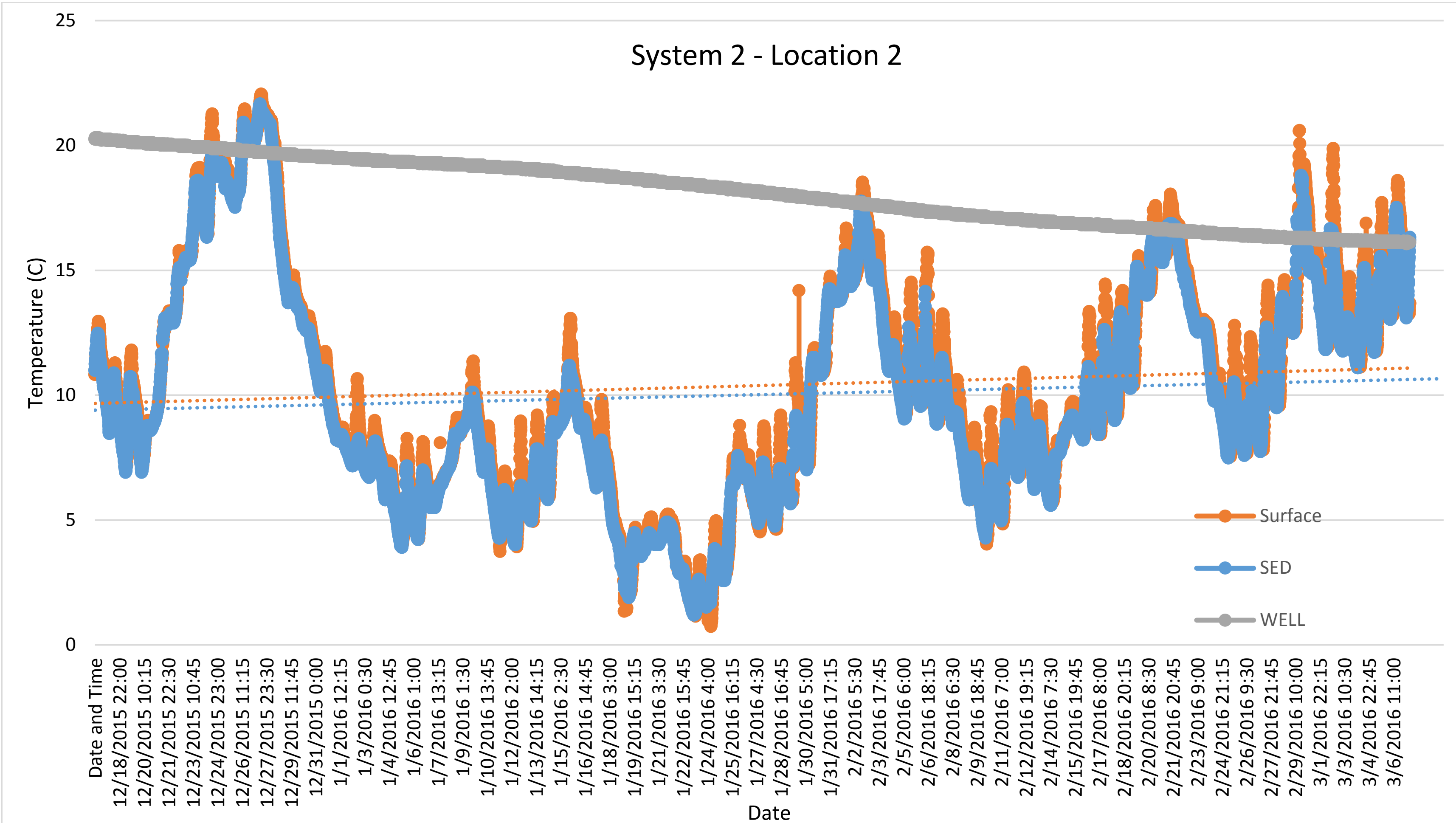

Figure 8. Temperature data collected from December 17, 2015 to March 7, 2016 at location 2 within TWR/OFS System 2 (<1 year old). Temperature data collected from surface water, sediment, and groundwater well are included, trend lines for surface water and sediment were added to better summarize trends over time in comparison to groundwater well data.

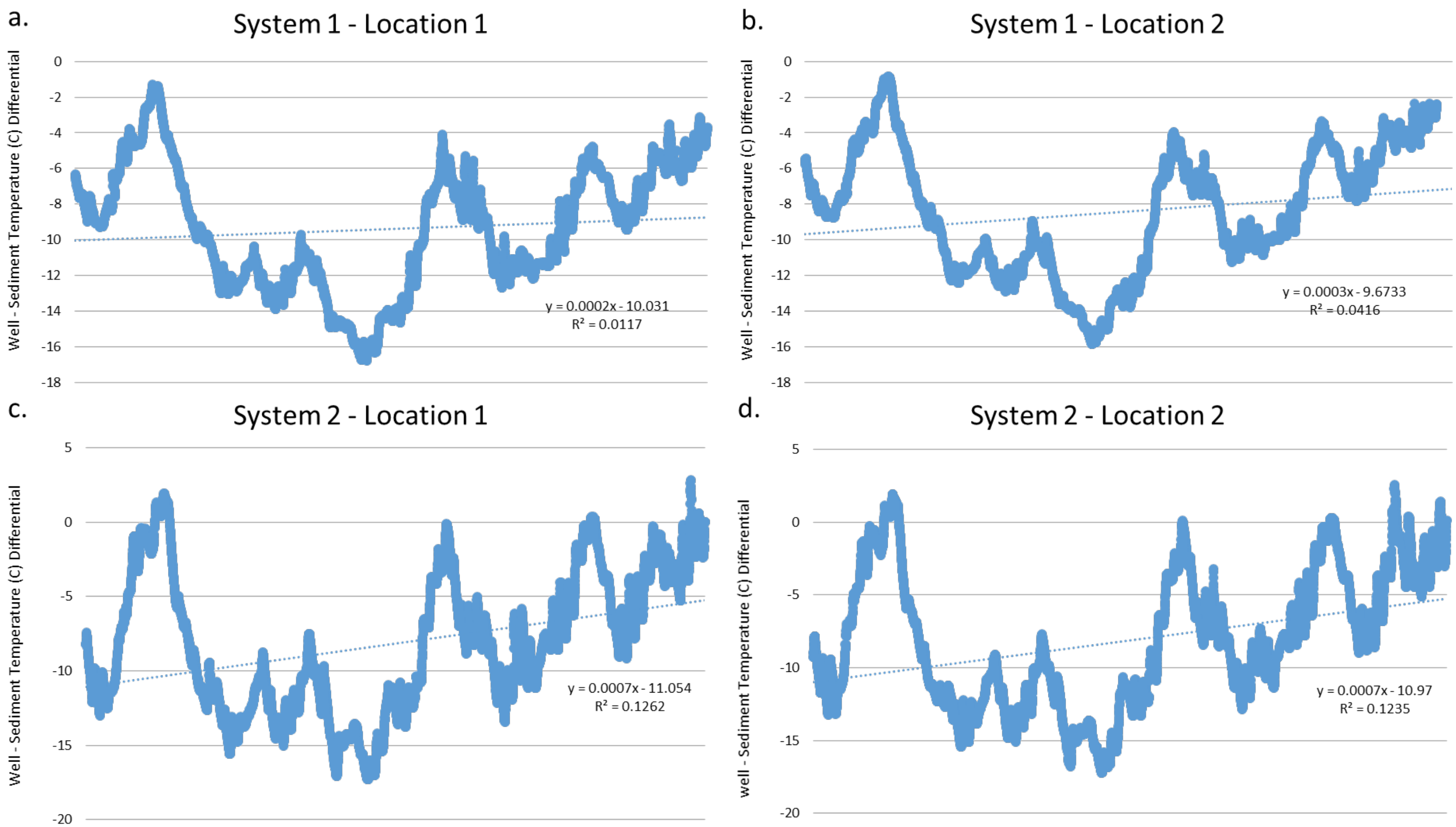

Figure 9. Well – Sediment temperature (C) differentials were calculated from temperature data over the observation period at System 1 – Location 1 (a) and 2 (b) and System 2 – location 1 (c) and 2 (d). Trend lines with associated slopes and r-squared values were calculated from well – sediment temperature differentials to compare rates of change within locations.

Table 1. Nutrient and sediment concentrations of surface water samples collected from both TWR/OFS systems. Minimum, maximum, mean, and median concentrations for samples. Samples that were measured below detection limits are reported as <BDL.

	System 1						System 2					
	NH3 (mg/L)	PO4 (mg/L)	NO2 (mg/L)	NO3 (mg/L)	TIP (mg/L)	Turbidity (NTU)	NH3 (mg/L)	PO4 (mg/L)	NO2 (mg/L)	NO3 (mg/L)	TIP (mg/L)	Turbidity (NTU)
Min	0.000	0.016	<BDL	0.004	0.01	30	0.025	0.006	<BDL	0.005	0.32	26
Max	0.467	0.411	<BDL	1.360	1.43	170	0.349	0.115	<BDL	0.150	1.78	528
Mean	0.118	0.077	<BDL	0.221	0.75	65	0.187	0.038	<BDL	0.046	0.90	154
Median	0.102	0.037	<BDL	0.100	0.78	53	0.195	0.031	<BDL	0.020	0.86	121

Information Transfer Program Introduction

Use of Extension and REACH Program. The research approach described in this document is designed to inform water resources planners and managers by providing them with the scientific information and understanding that they need. Also, the effective transfer of knowledge to water users and stakeholders is essential for a well-informed public in order to realize the overarching goal of sustainable water resources and ecosystems of good quality and ample quantity while sustaining a good economy and quality of life for current and future generations. Working closely with MSU's Extension Service and REACH (Research and Education to Advance Conservation and Habitat) Program as well as other Institutions of Higher Learning, MWRRI is uniquely positioned to advance and sustain the transfer and application of knowledge gained through MWRRI's integrated water resources research and management approach. As a function of its role as an information hub on water resources issues within the state and region, MWRRI actively utilizes its 916–participant ListServe, maintains its easily accessible website (www.wrri.msstate.edu/), leverages with MSU Extension and the REACH Program, and uses individual presentations to transfer its research findings to the public in addition to the outreach provided by its cooperators through published articles, formal presentations, technical poster sessions, and other outreach materials.

Applications of Research. Collectively, the projects contained in this document address some of the most pressing information gaps/research needs in Mississippi. These include using the research as identified below:

The project findings of both (2015 and 2016) of the Gary Ervin, et al wetlands projects, Responses of water quality and wetland plant communities to multi-scale watershed attributes in the Mississippi Delta and Influence of wetland plant community types on water quality improvement in natural and restored wetlands of the Mississippi Delta were designed to support USDA's WRP ranking tool. This will ensure that the most complete information is being applied to the assessment and prioritization of WRP efforts within the Delta, Mississippi's predominant agricultural row-crop region, as well as providing new data that may affect how Delta stakeholders manage their lands.

Quantifying the impacts of recurrent phosphate spills to Bangs Lake, located adjacent to the Grand Bay National Estuarine Research Reserve (NERR), is a priority for the Mississippi Department of Environmental Quality, the Grand Bay NERR, and will provide baseline information for a watershed-scale restoration project. The project findings of both (2015 and 2016) of the Kevin Dillon et al projects, Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary: Year 1 and Year 2 provide critically needed baseline information that will support future restoration and protection efforts in this national estuarine reserve.

Agricultural producers in the Mississippi Delta have realized significant increases in yields and profitability through irrigation. This recognition has fueled a rapid expansion of irrigation. An adverse result is the continued lowering of the water levels of the source aquifer. Quantification of recharge to this aquifer is vital to develop a useful water budget and manage the resource sustainably. Minimal research has been conducted to quantify the water quality and quantity benefits of TWR/OFS as well as impacts on surface and groundwater exchange. Such information is needed for the development of accurate water level modeling applications which are currently being developed for the region. Ultimately, data such as this will assist policymakers in designing strategies and policies to effectively manage this vital resource.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	13	0	0	0	13
Masters	2	0	0	0	2
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	17	0	0	0	17

Notable Awards and Achievements

Red Bud–Catalpa Creek Watershed Restoration and Protection Project. Building upon its designation as a Center of Excellence for Watershed Management through a MOU with USEPA Region 4 and the Mississippi Department of Environmental Quality (MDEQ), MWRRI successfully facilitated the development of two documents that focus on the restoration and protection of the water quality, ecosystem, and stream function of the Red Bud–Catalpa Creek Watershed. Within the headwaters of the watershed is MSU's 1,200 acre H.H. Leveck Animal Research Center, which through its land use has resulted in an impairment listing and TMDL for sediment by the MDEQ.

The first document, the 139 page Water Resources Management Plan for the Red Bud–Catalpa Creek Watershed established the framework for subsequent restoration and protection activities by identifying four major teams and work groups from 18 individual University units collaborating on the project, describing the goals and objectives of the project, characterizing numerous attributes of the watershed as a baseline assessment, establishing overall restoration goals, identifying agricultural and urban management measures, presenting a monitoring and modeling strategy, and proposing an education and outreach strategy for the project. A key feature of this project is the future leveraging of the project into an ongoing Watershed DREAMS (Demonstration, Research, Education, Application, Management and Sustainability) Center to create experiential learning opportunities for faculty, students, other educators, conservation organizations, environmental agencies, and stakeholder organizations.

The second document, the 69-page Implementation Plan for the Red Bud–Catalpa Creek Watershed Phase I describes the implementation approach for Phase 1 restoration of the headwaters of the watershed, documents critical management areas and specific management measures desired for implementation within these areas, proposes comprehensive education and outreach activities, establishes an implementation schedule with measurable milestones, presents a monitoring plan, and includes a detailed budget for these activities. It is hoped that this plan will be funded through resources from MDEQ and EPA.

Using Social and Civic Engagement Indicators to Advance Nutrient Reduction Efforts in the Mississippi/Atchafalaya River Basin. During December 2015, MWRRI submitted two funding proposals in support of a multi-state research and extension organization, SERA-46, which was established through the Mississippi River/Gulf of Mexico Watershed Nutrient (Hypoxia) Task Force. The two proposals Using Social Indicators to Guide, Evaluate, and Accelerate Implementation of State-Level Nutrient Reduction Strategies and Using Civic Engagement Indicators to Assess and Encourage Non-Government Stewardship of State-Level Nutrient Reduction Strategies were submitted in response to a U.S. EPA Request for Proposals. This RFP targeted National Priority Activity III: Gulf of Mexico Hypoxia and Agricultural Nutrient Issues Outreach and Technical Assistance. Recently, MWRRI was notified of EPA's desire to fund both proposals. Co-Principal Investigators for the projects include Mississippi State University's Social Science Research Center, the University of Wisconsin–Madison's Department of Urban & Regional Planning and Extension, and the University of Minnesota's Center for Changing Landscapes. The two projects represent Phases 1 and 2 of a four phase effort to advance the implementation and sustainability of nutrient reduction strategies developed by the twelve states that are members of the Task Force.

Water quality problems that have accumulated over many decades may take decades to correct. This is the case when considering the complexity, scale, causes, and impacts of Gulf of Mexico hypoxia. Social indicators provide consistent measures of social change and can be used by planners and managers at the national, state, and local levels to estimate the impacts of their nutrient reduction efforts and resources even while a lag exists for monitored improvements in water and habitat quality. Additionally, social indicators can inform planners and managers of changes needed to their nutrient reduction strategies to increase the effectiveness of their efforts.

Civic engagement indicators focus on a policy emphasis shift to long-term sustainability and engagement of civic society. Whereas social indicators measure changes in stakeholder knowledge, beliefs, and behavior, civic engagement benchmarks assess the capacity among watershed stakeholders of all categories to assume a longer-term stewardship responsibility. For policy makers and resource agencies who must constantly allocate scarce resources for short-term projects, civic engagement measures can provide metrics useful in determining where and how benefits could be sustained from the use of those scarce resources.

Office of Research and Economic Development Cross-College Research Funding Awards. In response to an RFP from MSU's Office of Research and Economic Development (ORED), MWRRI was successful in receiving two grant awards. The first award was to support facilitation and coordination for the collaborative Red Bud–Catalpa Creek Watershed Restoration and Protection Project, and the second award was to support facilitation and coordination of MSU's coastal assets to develop and advance research and watershed-based activities related to the implementation of the RESTORE Act and to support collaborative project planning with the Gulf of Mexico Alliance's Water Resources Team.

2016 Water Resources Conference. The annual Mississippi Water Resources Conference, hosted by MWRRI, was held at the Jackson Hilton on April 5-6, 2016. Over 150 pre-registered to attend the conference – a 20% increase over 2015 – and numerous participants registered onsite. Student participation also increased significantly. Researchers and students from colleges and universities as well as water resources planners, managers, and policy-makers from state and federal agencies, industry, and other backgrounds presented 54 oral presentations in 14 topical sessions, 22 posters, and 3 plenary sessions. The conference also featured student competitions in oral technical session presentation and individual poster presentation.

Increased Legislative Funding Support. For several years, MSU administration has been working with the Mississippi Legislature to increase funding support for MWRRI. Recently, MSU was notified that base funding support from the State of Mississippi would be increased approximately 59% from that of the past several years. This increase is needed to grow MWRRI to meet its statutory responsibilities.

Other Activities. During 2015 through early 2016, MWRRI worked with multiple researchers at across the University system, multiple state and federal resource agencies, diverse stakeholder organizations, and other interests to develop and submit over 16 proposals and project concepts for funding or contractual consideration. Some that will or have already received funding have been previously identified in this section, some have been declined, while others await funding decisions. Additionally, MWRRI supports the Hypoxia Task Force's Land Grant University Initiative, known academically as SERA-46, and serves on the Gulf of Mexico Alliance's Water Resources Steering Team as it develops an implementation plan to address the coastal water resources needs of the Gulf of Mexico.

Publications from Prior Years

1. 2015MS-ADMIN ("") - Water Resources Research Institute Reports - 2015 Mississippi Water Resources Conference Proceedings, 124 pgs., www.wrri.msstate.edu/pdf/2015_wrri_proceedings.pdf
2. 2015MS-ADMIN ("") - Water Resources Research Institute Reports - 2015 Mississippi Water Resources Research Institute Annual Report, 36 pgs., http://wrri.msstate.edu/pdf/2015annual.pdf