Mississippi Water Resources Research Institute
Annual Technical Report
FY 2014

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 2014 104b funding cycle, research priorities recommended by the Advisory Board were broad in nature to provide flexibility to the research community. These included: water quality, surface and groundwater management, water quality management and water resources development, contaminant transport mechanisms, wetlands and ecosystems, groundwater contamination, as well as other issues addressing coastal and marine issues linking water associations through the state, and institutional needs that include capacity building and graduate student training. All 2014 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.

2014 Funded Proposals

Two projects were funded during 2014 that addressed priority water resources issues in Mississippi. These projects were:

1. Responses of Water Quality and Wetland Plant Communities to Multi-scale Watershed Attributes in the Mississippi Delta (2014MS190B - two publications to date) and

2. Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary (2014MS191B - four publications to date).

Quarterly reports for these projects are included in this document.

Additional Projects in this Report

Two research projects funded during the research cycle ending December 31, 2014 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:

• Quantifying responses of water quality and wetland plant communities is an important project that will provide the basis for a decision support tool under development by the Natural Resources Conservation Service (NRCS) for use in its Wetlands Restoration Program.

• Quantifying the impacts of recurrent phosphate spills to Bangs Lake, located adjacent to the Grand Bay Natural 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.

• Enid Lake is one of four major flood control reservoirs in north Mississippi operated the U.S. Army Corps of Engineers and is listed as impaired by Mercury by the Mississippi Department of Environmental Quality. The lake’s outlet, the Yocona River, is also listed as impaired. An assessment of the transport, fate, and risk of Mercury is essential to understand the restoration potential for these waterbodies.

• The Delta, Mississippi’s primary row-crop agricultural area, has been experiencing significant groundwater level declines due to the rapid expansion of irrigation. Quantification of recharge to the underlying Mississippi River Alluvial Aquifer is vital to develop a useful water budget and manage the resource sustainably. Recharge through wetlands is one of the components needing quantification.

Interdisciplinary Assessment of Mercury Transport, Fate and Risk in Enid Lake, Mississippi

Basic Information

Title:	Interdisciplinary Assessment of Mercury Transport, Fate and Risk in Enid Lake, Mississippi
Project Number:	2013MS182B
Start Date:	3/1/2013
End Date:	5/1/2014
Funding Source:	104B
Congressional District:	1st
Research Category:	Water Quality
Focus Category:	Water Quality, Sediments, Surface Water
Descriptors:	
Principal Investigators:	Xiaobo Chao, James Cizdziel, AKM Azad Hossain, Kristine L. Willett

Publications

1. Quarterly reports to MWRRI.
2. Chao, X., Y. Jia, A.K.M. A. Hossain and J. Cizdziel, 2013, Numerical Modeling of Flow and Sediment transport in Enid Lake, Mississippi, presented at Mid-South Annual Engineering and Science Conference (MAESC 2013), Oxford, MS, October 28-29.
3. Hossain, A.K.M. A., Y. Jia, X. Chao, M.S. Altinaker, Y. Ding and S.S.Y. Wang, 2013, Application of Remote Sensing Techniques in Modeling Flow, Sediment and Pollutant Transport in Surface Water, Mid-South Annual Engineering and Science Conference (MAESC 2013), Oxford, MS, October 28-29.
4. Chao, X., Y. Jia, and Hossain, A. K. M. A (2013). Three-dimensional Numerical Modeling of Wind-induced Flow and Mass Transport in Natural Lakes, The 35th Congress of International Association for Hydraulic Research (IAHR), September 8-13, Chengdu, China (CD-ROM).
5. Dr. Xiaobo Chao, (2014) Interdisciplinary Assessment of Mercury Transport, Fate and Risk in Enid Lake, Mississippi, Final Technical Report to Mississippi Water Resources Research Institute. Mississippi State University, Mississippi State, MS, 23 pgs.
6. Cizdziel, J. and G. Brown (2014). Distribution and Cycling of Mercury Species in Wetlands and Reservoirs in Northern Mississippi, oral and poster presentation at 2014 Mississippi Water Resources Conference, Jackson, MS, April 1-2, 2014, p. 3 and p. 90. www.wrri.msstate.edu.

Project Final Report

Interdisciplinary Assessment of Mercury Transport, Fate and Risk in Enid Lake, Mississippi

Principal investigators:

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Mississippi Department of Environmental Quality, Jackson, MS

Abstract

Enid Lake is one of the important large recreation lakes in Mississippi, and the mercury level is relatively high compared with other large lakes. This research brought together a team of scientists that with their expertise in analytical chemistry, remote sensing technology, hydraulic modeling and risk assessment to study the transport, fate and risks of mercury in Enid Lake. Two field measurements were conducted in spring and fall to measure the flow, sediment and mercury in Enid Lake. The remote sensing technology was applied to analyze the concentration distributions of sediment and mercury in the whole lake, and the results are generally in good agreement with measured data. A numerical model was developed to simulate the flow, sediment, and mercury in the lake, and the interaction between the mercury and sediment was taken into accounted. Risk assessment was conducted to analyze the potential risk of mercury both in the environment and human fish consumption. The research results help us understand the transport mechanisms of sediment and mercury in large lakes, and provide useful information for decision makers to evaluate established TMDLs and fish consumption advisories.

INTRODUCTION

The Yazoo River Basin is the largest basin in Mississippi. Abundant streams, reservoirs and lakes are located in this region, including four large flood control reservoirs: Arkabutla Lake, Sardis Lake, Enid Lake and Grenada Lake. These lakes are significant natural and recreational resources. The soils in this region are highly erodible, resulting in a large amount of sediment discharged into water bodies. Understanding the dynamic processes of contaminated sediment movement and fate and transport of pollutants in these large recreation lakes is important to manage the water quality of the lakes and provide useful information for fish consumption advisories and potential risk assessment. The processes of contaminated sediment transport and settling in the lake are particularly critical to lake water quality because of associations between sediment and other pollutants (nutrients, PCBs, mercury, etc.).

Mississippi Department of Environmental Quality (MDEQ 2010, 2012) reports that many water bodies in this region are impaired due to contaminated sediment, and nutrients, suspended sediment (SS), DDT, PCBs, pathogens, and mercury have been identified as major pollutants. Since 1995, Enid Lake has been listed among now 14 water bodies that are under fish consumption advisories for mercury in Mississippi, reducing the recreation values of these lakes. In 2002 a Total Maximum Daily Loads (TMDLs) was developed for mercury in the Yocona River including the Enid Lake. The MDEQ adopted a criteria of 12 ng/L to protect aquatic life with a margin of safety of 50% (MDEQ 2002). Unfortunately, most of the fish and sediment data available to regulators is more than 10 years old (MDEQ 2002, Huggett et al. 2001).

Mercury is a widely distributed and persistent pollutant in the environment. The chemical forms of mercury in air, water, and sediment include elemental mercury Hg(0), inorganic ionic mercury (HgII), and the organic form methylmercury (MeHg). When mercury enters the water and soil, microorganisms transform the mercury into MeHg, which is the most toxic form and accumulated by fish, shellfish and other aquatic organisms (Selin et al.,2010). When humans consume contaminated fish, they are exposed to mercury. The adverse effects of mercury in humans include neurodevelopmental, cardiovascular, and immunological deficits (Karagas et al.,2012; Grandjean et al.,2010). The Food and Drug Administration action level restricts fish tissue mercury concentrations to less than 1.0 ppm (MDEQ 2002). Largemouth bass, carp, gar, black crappie, and catfish collected from Enid Lake have had concentrations that exceeded the 1 ppm standard (Huggett et al.,2001; MDEQ 2002). In fact, consumption advisories are in place for over 26% of the US river miles and 38% of its total lake acreage (Knightes et al.,2009). Characteristics of particular fish (e.g. growth and consumption rates, type of prey, age and length) impact mercury bioaccumulation (Ward et al.,2010).

Sediment plays an important role in the fate and transport processes of mercury in water bodies. Mercury may adsorb to sediment particles and also desorb from sediment to the water, and a linear approach can be applied to describe the processes of adsorption/desorption (Katsenovich et al 2010). Bed sediment associated mercury can be released gradually into the water column due to diffusion and sediment resuspension (Kuwabara et al 2003). Figure 1 shows the mercury cycle in a water body.

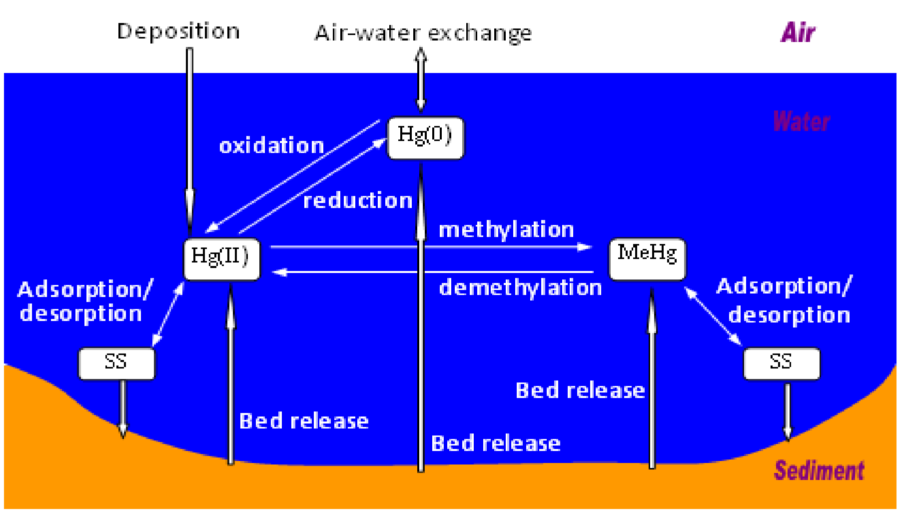


Figure 1. The mercury cycle in a water body

In this project, the concentrations of mercury in water and sediment were measured in spring and fall in Enid Lake. The fate and transport processes of mercury in the lake were studied based on field observation, remote sensing technology, numerical model, and risk assessment. Our research not only updates the fate and transport of mercury in Enid Lake, it is also directly relevant to stakeholders concerned with wildlife and human consumption of mercury. The measured and computed mercury concentrations in water, sediment, and fish have been used for a potential risk assessment. It has greatly improved our understanding of the transport mechanism of mercury by water and sediments in large lakes of Mississippi and provides more timely data on associated potential risks. It is anticipated that results from this study will be directly applicable to other large lake systems in Mississippi. The results of this research can be used by decision makers to evaluate TMDLs for the watershed feeding into the lake.

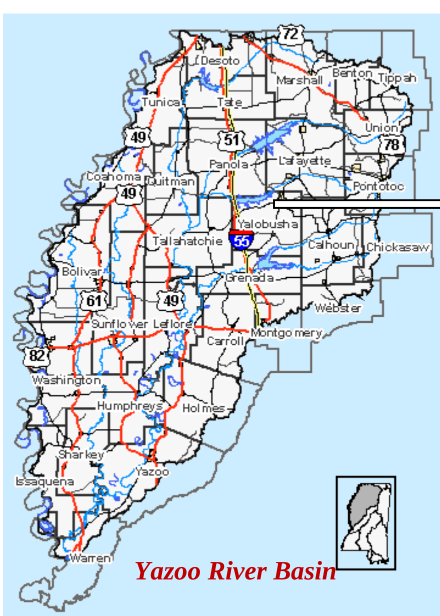
OBJECTIVES

The overall goal of this research is to study the transport, fate and risk of mercury in Enid Lake. We have brought together a team of scientists particularly well suited to: provide sensitive field measurements, utilize innovative remote sensing technologies, generate novel numerical mercury fate modeling and provide up-to-date risk assessment. To reach this goal, the following objectives were designed: (1) measurements of flow, sediment and mercury in the lake; (2) application of remote sensing technology to analyze sediment and mercury in the lake; (3) development of a numerical model to simulate the flow, sediment, and mercury distribution in the lake; (4) Assessment of the potential risk of mercury both in the environment and human fish consumption.

RESEARCH METHODS

(1) Study site

Enid Lake is a large reservoir located in Yazoo River Basin, Mississippi (Fig. 2). It is a USACE flood control structure built in 1952. It was impounded by Enid Dam on the Yocona River in Yalobusha County and covers an area of 60 square km. The soils in this region are highly erodible, and the erosion rate has been recognized as one of the highest place in the nation (Bennett and Rhoton 2009). This lake has significant natural and recreational resources. However, it is impaired by mercury, and a fish consumption advisory was issued by MDEQ in 1995. In order to reduce the mercury level in the lake, mercury TMDL has been established in the lake watershed (MDEQ 2002). The proposed research is to study the transport processes of sediment and mercury, and their interactions in water bodies based on field measurement, numerical model and remote sensing technique.



Enid Lake

Figure 2. Study Area

(2) Field sampling and measurements in Enid Lake

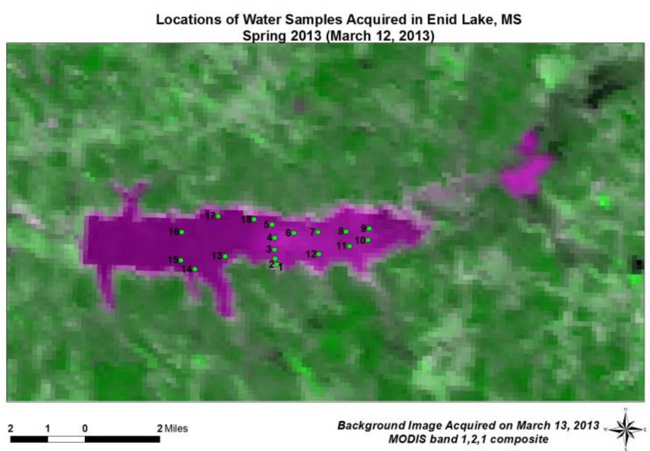
The observed flow discharges in Yocona River, and the water level data in Enid Lake can be obtained from USGS and USACE. Some bed sediment and mercury concentration in water, sediment and fish previously measured by the University of Mississippi (UM), NSL and MDEQ were used in this study (Huggett et al 2001, Bennett and Rhoton 2009). Additional field measurements were conducted in the lake to measure flow velocity, water level, suspended sediment (SS) concentration and mercury concentration in water and sediment. In this project, two field measurements were conducted on March 12 and Nov. 19, 2013. Figure 3 shows the sampling locations in the lake.

a. Flow measurements

Velocity profiles, water depth and water surface elevations at different locations (shown in Fig.3b) of the lake were measured using Acoustic Doppler Current Profiler (ADCP) by scientists at NSL. At each location (Fig. 3), the coordinates were identified using GPS, and the concentrations of SS were determined for select samples using a portable SS meter from Insite IG Inc.

b. Water sampling

Water and sediment samples were collected at each location (Fig.3). The collected samples were used to measure the SS concentration, total mercury concentration in water, and sediment.



a. Sampling locations on March 12, 2013 b. Sampling location on Nov. 19, 2013

Figure 3. Sampling locations in the lake

c. Fish sampling

Electro-shocking is a non-lethal survey method used to temporarily paralyze the fish so they can easily be collected. The fish collected from Enid Lake were of species commonly sought after and consumed by local fishermen. The fish samples with three different species, Crappie (CR), Largemouth Bass (LMB) and Channel Catfish (CC), were collected by the USDA National Sediment Laboratory (NSL).

(3) Laboratory measurements

a. Total mercury in sediments

The sampled sediment was analyzed for total mercury using automatic mercury analyzer (DMA-80; Milestone Inc., Shelton, CT) which was based on thermal decomposition (TD), amalgamation, and atomic absorption spectrometry (AAS). The approach follows US EPA Method 7473. About 0.25 g of sediment samples are weighed directly into nickel combustion boats. The boats are automatically inserted into the instrument where the samples are dried and combusted in oxygen releasing Hg vapor. The combustion products are swept through a catalyst tube where oxidation is completed, and halogens, nitrogen and sulfur oxides (which can interfere with the analysis) are trapped. The remaining gases are carried to the gold amalgamator which traps Hg. The system is flushed with oxygen to remove decomposition products. The amalgamator is then rapidly heated releasing Hg vapor into two absorbance cells which are positioned in the light path of a single wavelength AAS. Absorbance is measured at 253.7 nm as a function of Hg concentration. The instrument was calibrated using a sediment reference material (e.g. MESS-3). Another reference material (e.g. SRM 1573a) was analyzed every 10 samples for a QC check. The values obtained were deemed acceptable if they were within 15% of the certified value. During each run a subset of samples were analyzed in duplicate. The relative percent difference was less than 15%. Blanks were also run every 10 samples. The amount of Hg for the blanks were negligible (<0.1 ng); this corresponded to a concentration of ~ 0.40 ng/g using the typical weight of analyzed sample (0.25 g).

b. Total mercury in water

Total-Hg in water samples was determined using CVAFS following EPA Method 1631. Water samples were filtered and both filtered and unfiltered fractions measured. Water was passed through a pre-heated (~500°C) glass-fiber filter. The samples were preserved using ultrapure HCl or BrCl as described in the EPA method and holding times were observed. The glass fiber filter was also analyzed for particulate mercury.

c. Loss-on-Ignition

Loss on Ignition (LOI) was used to estimate Total Organic Matter. LOI was calculated by reweighing the sample boats after the total-Hg analyses. Temperatures were kept under 440ºC to prevent breakdown of carbonates which would introduce inorganic carbon into the calculation.

$$\%LOI = \frac{\left[\left(sample\ wt. + boat\ wt.\ before\ Hg\ analysis\right) - \left(sample\ wt. + boat\ wt.\ after\ Hg\ analysis\right)\right]}{\left(sample\ wt. + boat\ wt.\ before\ Hg\ analysis\right) - empty\ boat\ weight} \times 100$$

d. Sediment analysis

Total Suspended Solids was determined by passing a known volume of sample (between 150 ml to 500 ml depending on sediment load) through a 0.45 μm quartz wool filter that was combusted prior to filtering to remove any Hg. The filter was allowed to dry at room temperature under a laminar flow hood and reweighed to determine the TSS concentration using the following formula [US EPA Method 160.2]:

TSS (mg/L) = ((Residual + Filter (mg)) - Filter (mg)) / sample filtered (mL)) * 1000 (mg/L)

To determine PBM, the filters were then analyzed by combustion atomic absorption spectrometry using a direct mercury analyzer (DMA-80) following US EPA Method 7473. The instrument was calibrated using a standard solution containing known amounts of Hg. Reference materials including MESS-3 (sediment) and Joaquin Soil were used to as calibration checks every 10 samples; recoveries were between 88 to 115 % of the certified values. Blank filters were run every 10 samples to assure that Hg was not being carried over between samples. The amount of Hg for the blanks was negligible. The method detection limit for the analysis was estimated at 0.2 ng/g. The technique has been thorough discussed in earlier chapters.

For particle size distribution analysis, sediments were homogenized in their container by stirring with a Teflon-coated spatula. A portion of the sediment was transferred to plastic weighing boats and allowed to air-dry in a clean laminar flow hood. Once dry, the sample was crushed using a clean mortar and pestle and a few grams were set aside for total-Hg analyses. The remaining portion was weighed and placed into a beaker with DI water and sonicated for 1 hour to break up adhering particles. The sample was then wet-sieved through stainless steel meshed screens with openings of 1000 µm, 500 µm, 250 µm, and 125 µm. The screen contents were visually inspected to confirm that there were no clumps; if necessary a spatula was used to further gently break up adhering materials. The screens were then allowed to air-dry and the contents were weighed. Particle size distribution was determined on a weight percent basis. The difference between the initial starting weight and the combined weights of sediment collected on the screens was used for the <125 µm category.

For determination of total-Hg and loss-on-ignition in sediment, total-Hg was measured in the bulk sediment and in each size fraction using a direct mercury analyzer (DMA-80) based on thermal decomposition, amalgamation, and atomic absorption spectrometry following EPA Method 7473. Quality assurance protocols were the same as discussed earlier. To obtain Hg data for the <125 µm fraction, samples were dry sieved and the material passing through the fine mesh was analyzed. Loss-on-ignition (LOI), which is used as an estimate of organic matter, was determined by weighing the boats before and after combustion.

e. Fish mercury analysis

Once collected, the fish were placed on ice and taken to laboratory for analysis. In the laboratory the fish were dissected. The muscle and liver tissues were used for total-Hg analysis, while other organs including gills, gonad, kidney, heart, sperm, and eggs were preserved for use in other analyses. All samples were stored in individual vials and bags and frozen until analyzed (Brown 2013). For the present study, only data for the muscle for crappie, largemouth bass, and channel catfish were used.

(4) Estimation of suspended sediment and mercury concentration using remote sensing technology

SS concentration has been estimated and mapped successfully using remote sensing for the last three decades. Different approaches and algorithms had been developed over time for SS concentration estimation/mapping using optical satellite data. The available techniques can be categorized into four general groups: (1) simple regression (correlation between single band and in-situ measurements)[e.g., Williams and Grabau (1973) – Chesapeake Bay early in 1973], (2) spectral unmixing techniques, (3) Band ratio technique using two and more bands [e.g., Lathrop ,1992; Populus et al., 1995; Wang et al., 2003], and (4) multiple regressions[e.g., Binding et al., 2005].

Hossain et al. (2010) developed a remote sensing based index and determined the co-efficients that can be used in riverine/lake environments quantitative mapping of the SS concentrations. Normalized Difference Suspended Sediment Index (NDSSI) (Eq.1) was calculated using the Landsat data and was correlated to the near real-time in-situ measurements of SS concentrations using a power equation (Eq.4) for quantitative estimation of SS concentration in the Mississippi River.

This technique, using the obtained coefficients was applied to estimate/map the SS concentration in the Mississippi River during the 2008 US Midwest flood and in Lake Pontchartrain during (1) Bonnet Carre Spillway opening event and (2) before and after Hurricane Katrina. The results were compared by the simulation results of CCHE2D (a numerical model developed at NCCHE) and found in a good general agreement qualitatively and quantitatively (Figure 4). The results indicate that (1) NDSSI has the potential to estimate (relative variation) and map the spatial distribution of SS concentration in both river and lake environments, (2) NDSSI can be used for quantitative estimation of SS concentration in these environments when coupled with two coefficients in a power equation, and (3) the same approach can be used to estimate SS concentration in both river and lake water within reasonable error limits using NDSSI.

$$NDSSI = \frac{\rho_B - \rho_{NIR}}{\rho_B + \rho_{NIR}} \quad (1)$$

$$SSC = a \times NDSSI^{-b} \quad (2)$$

Where, ρ_B and $\rho_{NIR,}$ are the reflectance values of Landsat 5/7 TM/ETM+ Band 1, Band 3 and Band 4 respectively.

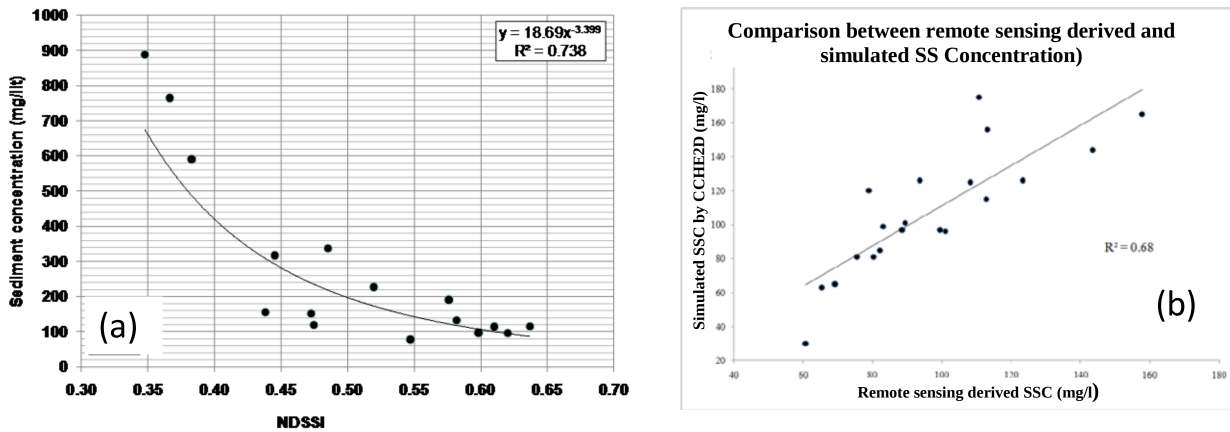


Figure 4. (a) Relationship between NDSSI and in-situ measurements of SS concentrations in water; (b) Quantitative comparison between simulated SS concentration (by CCHE2D) and remote sensing derived SS concentration estimation (By NDSSI) (Hossain et al., 2010).

In Enid Lake, NDSSI was calculated using Landsat TM imagery for different seasons to map the relative variation of suspended sediments. However, due the limitation of cloud coverage and coarse temporal resolution it was not possible to use Landsat TM imagery to quantitative estimation of suspended sediments and associated mercury. MODIS imagery was available after the studied storm events and were used for quantitative estimation of suspended sediments and associated mercury concentration. The MODIS imagery used and corresponding in situ measurements of suspended sediments and mercury concentration are shown in Figure 3. The detail of MODIS based suspended sediments and mercury concentration estimation are discussed in the results section.

(5) Numerical modeling of flow, sediment and mercury in the lake

The National Center for Computational Hydroscience and Engineering (NCCHE) of the University of Mississippi has developed a three-dimensional hydrodynamic and sediment transport model, CCHE3D. This model has been verified against analytical solution, and validated using experimental data and field measurements (Jia et al. 2005, 2009, Wang 2008). Inspired by the success of the CCHE3D model, in recent years, a three-dimensional water quality model, CCHE3D_WQ has been developed for simulating temporal and spatial variations of water quality with respect to phytoplankton, nutrients, dissolved oxygen, suspended sediment and salinity. In this model, the effects of suspended and bed sediment on the water quality processes were considered. It has been applied to studies of sediment, water quality and chemical contamination problems in nature lakes (Chao et al 2006, 2007, 2008).

In this research, a numerical model was developed based on CCHE3D for simulating the fate and transport of mercury in large lakes. Total mercury in water and sediment was simulated, and the processes including advection, diffusion, adsorption/desorption, bed release, settling, etc., were considered in the model. The developed module has been integrated into CCHE3D for simulating flow, sediment, and mercury in Enid Lake.

Flow modeling

The governing equations of continuity and momentum of the three-dimensional unsteady hydrodynamic model can be written as follows:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{3}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu \frac{\partial u_i}{\partial x_j} - \overline{u_i' u_j'} \right) + f_i \tag{4}$$

where u_i *(i=1,2,3)* are Reynolds-averaged flow velocities (*u*, *v*, *w*) in Cartesian coordinate system (*x*, *y*, *z*); *t* is the time; ρ is the water density; *p* is the pressure; ν is the fluid kinematic viscosity; $-\overline{u_i' u_j'}$ is the Reynolds stress; and f_i are body force terms.

The free surface elevation (η_s) is computed using the following equation:

$$\frac{\partial \eta_s}{\partial t} + u_s \frac{\partial \eta_s}{\partial x} + v_s \frac{\partial \eta_s}{\partial y} - w_s = 0 \tag{5}$$

where u_s, v_s and w_s are surface velocities in *x*, *y* and *z* directions; η_s is the water surface elevation.

Wind stress is one of the most important driving forces for lake water movement. The wind shear stresses (τ_{wx} and τ_{wy}) at the free surface are expressed by

$$\tau_{wx} = \rho_a C_d U_{wind} \sqrt{U_{wind}^2 + V_{wind}^2} \tag{6}$$

$$\tau_{wy} = \rho_a C_d V_{wind} \sqrt{U_{wind}^2 + V_{wind}^2} \tag{7}$$

where ρ_a is the air density; U_{wind} and V_{wind} are wind velocity components at 10 m elevation in *x* and *y* directions, respectively. Although the drag coefficient C_d may vary with wind speed (Koutitas and O'Connor 1980; Jin et al. 2000), for simplicity, many researchers assumed the drag coefficient was a constant on the order of 10^{-3} (Rueda and Schladow 2003). In this study, C_d was set to 1.0×10^{-3}, and this value is applicable for simulating the wind driven flow in Deep Hollow Lake in the Mississippi Delta (Chao et al 2010).

Sediment transport modeling

The governing equation for cohesive sediment transport is based on the three-dimensional mass transport equation:

$$\frac{\partial C}{\partial t} + \frac{\partial (uC)}{\partial x} + \frac{\partial (vC)}{\partial y} + \frac{\partial (w - w_s)C}{\partial z} = \frac{\partial}{\partial x}(D_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(D_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(D_z \frac{\partial C}{\partial z}) \tag{8}$$

in which *C* is the concentration of cohesive sediment; D_x, D_y and D_z are mixing coefficients in *x*, *y* and *z* directions, respectively; and w_s is the settling velocity.

To solve the 3D cohesive sediment transport equation (8), the boundary conditions at the free surface and bottom are needed. At the free surface, the vertical sediment flux is zero and the following condition is applied:

$$w_s C + D_z \frac{\partial C}{\partial z} = 0 \tag{9}$$

At the bottom, the following condition is applied:

$$w_s C + D_z \frac{\partial C}{\partial z} = D_b - E_b \tag{10}$$

where D_b and E_b are deposition rate and erosion (resuspension) rate at bottom, respectively (kg/m^2/s).

Based on Krone (1962) and Mehta and Partheniades (1975), the deposition rate can be calculated by:

$$D_b = \begin{cases} 0 & \tau_b > \tau_{cd} \\ w_s C\left(1 - \dfrac{\tau_b}{\tau_{cd}}\right) & \tau_b \le \tau_{cd} \end{cases} \tag{11}$$

Erosion rate is generally expressed as Partheniades (1965)

$$E_b = \begin{cases} 0 & \tau_b < \tau_{ce} \\ M\left(\dfrac{\tau_b}{\tau_{ce}} - 1\right) & \tau_b \ge \tau_{ce} \end{cases} \tag{12}$$

where τ_b is the bed shear stress (N/m^2); τ_{cd} is the critical shear stress for deposition (N/m^2); M is the erodibility coefficient relating to the sediment properties, the reported values are in the range of 0.00001 to 0.0004 $kg/m^2/s$ (van Rijn 1989); τ_{ce} is the critical shear stress for erosion (N/m^2).

Total mercury modeling

In the water column, the concentration of total mercury can be expressed by the following mass transport equation:

$$\frac{\partial C_m}{\partial t} + \frac{\partial (uC_m)}{\partial x} + \frac{\partial (vC_m)}{\partial y} + \frac{\partial (wC_m)}{\partial z} = \frac{\partial}{\partial x}(E_x \frac{\partial C_m}{\partial x}) + \frac{\partial}{\partial y}(E_y \frac{\partial C_m}{\partial y}) + \frac{\partial}{\partial z}(E_z \frac{\partial C_m}{\partial z}) + \sum S_m \tag{13}$$

in which *u, v, w* are the water velocity components in *x*, *y* and *z* directions, respectively; C_m is the concentration of the total mercury; E_x, E_y and Ez are the diffusion coefficients in x, y and z directions, respectively; ΣS_m is the effective source term of mercury, which can be calculated by:

$$\sum S_m = S_{load} + S_{decay} + S_{air-w} + S_{bed-w} + S_{sed} \tag{14}$$

in which S_{load} is the external loads from upstream/ tributaries, etc.; S_{decay} is the sink term due to biodegradation; $S_{air\text{-}w}$ is the exchange term at the air-water interface; $S_{bed\text{-}w}$ is the bed release term; S_{sed} is the source term due to sediment erosion/ deposition. Those source terms can be expressed by:

$$S_{air-w} = k_a(\frac{C_g}{H_e} - f_d C_m) \tag{15}$$

$$S_{decay} = -K_b C_m \tag{16}$$

$$S_{Bed-w} = \frac{k_f}{D}(S_d - C_d) \tag{17}$$

$$S_{sed} = J_e + J_d = \max(E_b - D_b, 0)\frac{S_T}{1-p'} + \min(E_b - D_b, 0)\left(\frac{f_p}{c_v}\right)C_m \tag{18}$$

in which k_a is the overall volatilization transfer coefficient; C_g is the concentrations of total gaseous mercury in air; H_e is the Henry's constant; f_d is the fraction of total dissolved mercury; K_b is the overall degradation rate; k_f is the mass diffusion coefficient; S_d is the dissolved mercury concentration in bed sediment; C_d is the dissolved mercury concentration in water column; S_T is the total mercury concentration at bottom; E_b and D_b are the sediment erosion and deposition rates; p' is the porosity of bed sediment; f_p is the particulate mercury fraction; and c_v is the volumetric concentration of sediment in water column.

Numerical method

The numerical model was developed based on CCHE3D hydrodynamic model and water quality model (Jia et al. 2013, Chao et al. 2007, 2010). In this model, the staggered grid is adopted. The grid system in the horizontal plane is a structured conformal mesh generated on the boundary of the computational domain. In vertical direction, either uniform or non-uniform mesh lines are employed.

The unsteady equations are solved using the time marching scheme. A second-order upwinding scheme is adopted to eliminate oscillations due to advection. In this model, a convective interpolation function is used for this purpose. This function is obtained by solving a linear and steady convection-diffusion equation analytically over a one-dimensional local element. Although there are several other upwinding schemes, such as the first order upwinding, the second order upwinding and Quick scheme, the convective interpolation function is selected in this model due to its simplicity for the implicit time marching scheme.

The velocity correction method is applied to solve the pressure and enforce mass conservation. Provisional velocities are solved first without the pressure term, and the final solution of the velocity is obtained by correcting the provisional velocities with the pressure solution. The system of the algebraic equations is solved using the Strongly Implicit Procedure (SIP) method.

Flow fields, including water elevation, velocity components, and eddy viscosity parameters were computed by CCHE3D. After getting the effective source terms, the total mercury concentration distribution can be simulated by solving pollutant transport equation (13) numerically.

(6) Potential risk assessment of mercury on fish

The MDEQ has issued fish consumption advisories for Grenada and Enid Lakes in the Yazoo River Basin as a result of elevated mercury concentrations. This study involved a statistical analysis of mercury data for Crappie (CR), Largemouth Bass (LMB), and Channel Catfish (CC) collected from Enid Lake in Northern Mississippi. Total Hg concentrations were compared between species. A mercury risk assessment for consumption of fish from the lake was also conducted using various assumption values to evaluate the effectiveness of the existing fish consumption advisories.

Exposure to MeHg via fish consumption was estimated using methods outlined by the EPA (Huggett et al 2001). The risk assessment includes calculations of intake rate, hazard index (HI), and monthly consumption limit (CR_{mm}) for both adults and children. The equations used are as follows:

$$\text{Intake (mg/kg/d)} = (CF \times IR \times EF \times ED) / (BW \times AT) \qquad (19)$$

Where CF is the mercury concentration in fish (mg/kg), IR is the ingestion rate (kg/meal), EF the exposure frequency (meals/yr), ED is the exposure duration (yr), BW is the body weight (kg) and AT is the averaging time (ED × 365d/yr). Initial calculations will use 8 oz for a fish meal (0.227 kg), 48 d/yr for 30 yr, and 70 kg body weight. Additional assessments can also be done to consider subsistence fish consumers and/or pregnant women or children.

A hazard index (HI) is a ratio of an individual's actual exposure over a time period (here, 30 years) to the reference dose established by the EPA. When $HI < 1$, the expected potential for toxicity is low, and the exposure is considered safe. When $HI > 1$, there is an elevated potential for toxicity associated with the exposure. Once HI is calculated, monthly consumption limits are calculated. The hazard index will be calculated for each fish species by dividing the intake by 1.0×10^{-4} mg/kg-d, the reference dose (RfD) for methylmercury. A calculated hazard index greater than one suggests human adverse effects would occur at the representative intake and consumption advisories are supported.

In addition to conducting the risk assessments described above, sediment, water, and fish concentrations measured in Enid Lake will be compared to historical values from Enid, other MS waterways, and the nation. If values are significantly elevated, this may suggest that atmospheric deposition is increasing in Enid Lake and should be considered in the TMDL assessment.

RESEARCH RESULTS

(1)Field measured data

In this project, two field trips were taken on March 12 and Nov. 18, 2013, and the water depth, flow velocity, water level, suspended sediment (SS) concentration and mercury concentration in water and sediment at each measured location (shown in Fig.3) were obtained. The measured data can be used to evaluate the sediment and mercury levels in the lake, and validate the results obtained using remote sensing technology and numerical model.

Upstream flow discharge and water surface elevation at lake outlet were obtained from USGS and US Army Corp of Engineers. Fig.5 shows the flow discharge and water surface elevation during a storm event that occurred in March, 2013.

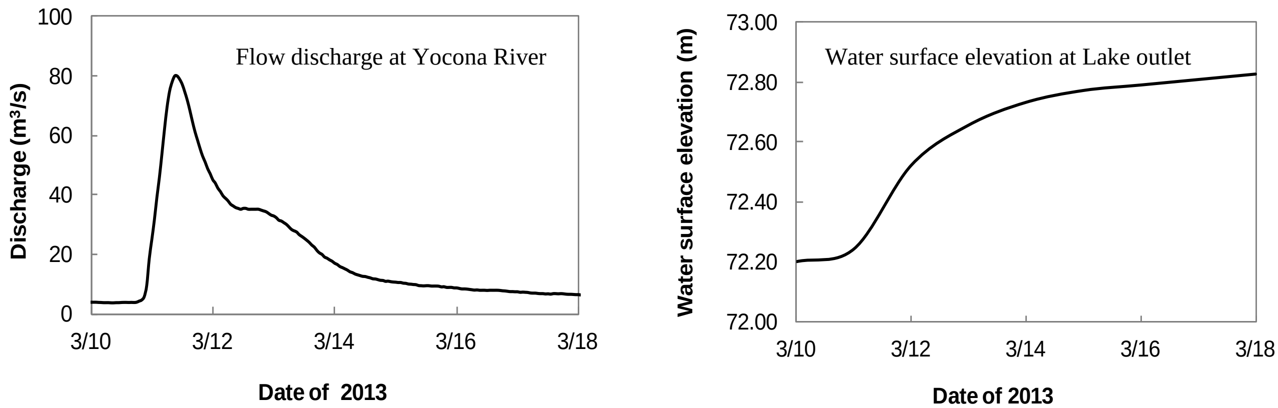


Figure 5. Flow conditions at boundary (3/10/13-3/18/13)

Wind is one of the most important driven forces for lake circulation. Fig. 6 shows the wind speed and direction near the lake.

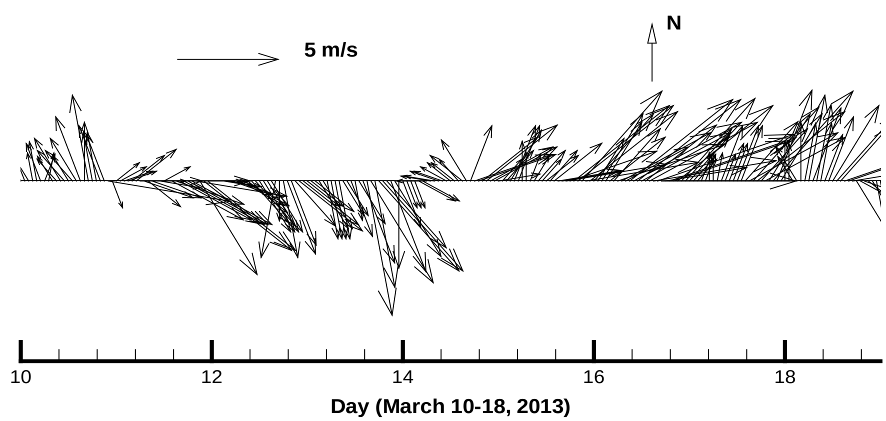


Figure 6. Wind speeds and directions near Enid Lake

Tables 1 and 2 show the measured SS and mercury data in Enid Lake.

Table 1. Mercury concentrations and water quality data for Enid Lake on 3/12/2013.

Sample Site ID	Location		T (°C)	Cl-	TDS (mg/L)	DO (mg/L)	ORP (mV)	Cond. (μs/cm)	TSS (mg/L)	K_d (L/Kg)	Total-Hg (ng/L)		PBM (ng/g)	PBM (pg/L)
	N	W									Unfiltered	Filtered		
1	34°.08.687	89°49.033'	11.8	4.9	42.3	9.1	331.5	48.3	39.6	4.4	10.1	6.6	157	6.2
3	34°.08.552'	89°48.967'	12.3	6.7	37.7	10.3	281.6	43.8	24.3	4.3	8.1	8.4	164	6.2
4	34°.08.894'	89°49.053	12.6	10.4	42.9	9.3	313.7	50.7	60.4	4.2	8.9	7.4	125	5.8
5	34°.09.174'	89°49.054'	12.4	5.1	43.6	9.1	332.3	50.9	38.9	4.1	7.4	7.8	106	4.1
6	34°.09.469'	89°49.142	11.7	4.6	42.9	9.5	338.4	49.5	33.7	4.1	6.6	9.4	108	5.8
7	34°.09.291'	89°48.527'	12.1	4.6	43.6	9.1	341.8	50.4	48.1	4.2	7.9	7.6	124	3.2
8	34°.09.328'	89°47.855'	12.1	3.4	37.7	8.7	343.2	44.0	65.6	4.2	12.5	9.0	140	3.2
9	34°.09.358'	89°47.136'	11.8	2.5	33.2	8.3	347.5	38.3	55.2	4.1	16.3	12.3	170	7.5
10	34°.09.439'	89°46.424'	12.4	2.3	34.5	8.9	347.9	40.0	55.7	4.3	12.8	8.6	159	4.1
11	34°.09.175'	89°46.445'	11.6	2.3	33.2	9.1	347.5	38.3	44.3	4.0	14.3	14.4	135	3.6
12	34°.09.023'	89°46.961'	11.4	2.3	33.2	8.3	344.7	37.6	50.2	4.1	14.8	12.0	163	6.0
13	34°.08.816'	89°47.806'	12.6	2.8	35.1	8.3	341.3	41.4	45.2	4.6	12.7	5.3	227	9.2
14	34°.08.656'	89°50.280'	11.6	3.7	39.0	9.9	329.6	44.3	20.5	4.5	4.9	4.3	150	9.4
15	34°.08.393'	89°51.268'	11.1	3.7	37.7	9.7	332.1	42.4	15.2	4.8	6.0	3.9	224	8.9
16	34°.08.594'	89°51.663'	10.7	3.9	37.7	9.7	330.1	42.5	11.7	4.7	5.9	4.5	224	6.0
17	34°.09.246'	89°51.662'	10.6	3.9	38.4	9.7	330.1	43.0	14.6	4.6	5.8	4.6	201	8.2
18	34°.09.700'	89°50.657'	10.5	4.3	39.7	9.5	322.9	44.0	14.3	4.6	8.0	4.2	170	10.3
19	34°.09.580'	89°49.644'	11.1	5.0	40.3	9.2	272.5	45.3	8.6	5.0	6.2	3.8	371	3.1
Mean			11.7	4.2	38.5	9.2	329.4	44.2	35.9	4.4	9.4	7.5	173.1	3.4
Median			11.8	3.9	38.0	9.2	332.2	43.9	39.3	4.3	8.1	7.5	160.9	2.6
SD			0.7	1.9	3.6	0.6	21.2	4.3	18.5	0.3	3.6	3.2	61.8	2.9
Min			10.5	2.3	33.2	8.3	272.5	37.6	8.6	4.0	4.9	3.8	106.5	2.4
Max			12.6	10.4	43.6	10.3	347.9	50.9	65.6	5.0	16.3	14.4	370.6	3.2

Table 2. Mercury concentrations and water quality data for Enid Lake on 11/18/2013

Sample Site ID	GPS Coordinates	Water Depth (m)	Temp. (^oC)	Cl (mg/L)	TDS (mg/L)	DO (mg/L)	Cond. (μs/cm)	ORP (mV)	TSS (mg/L) Lab Data	TSS (mg/L) Field Probe	Mercury (ng/L)	
											Unfiltered	Filtered
1	N 34 09.096 W089 48.306	1.3	11.0	6.8	93.0	8.2	110.6	-126.3	58.0	48.3	11.24	5.8
2	N 34 08.767 W089 48.278	1.0	10.3	5.8	97.5	8.4	112.3	-98.7	66.0	68.7	22.59	3.3
3	N 34 08.720 W089 48.793	1.3	11.5	6.3	95.6	8.3	112.8	-135.2	67.6	71.0	41.92	18.7
4	N 34 08.720 W089 48.379	2.3	12.0	8.0	98.2	8.1	117.7	-138.9	74.0	75.7	6.29	3.8
5	N 34 08.784 W089 49.915	2.7	11.5	8.7	96.4	8.5	115.1	-138.9	53.2	39.7	9.21	48.1
6	N 34 09.132 W089 48.826	1.8	11.5	6.6	93.0	9.0	110.2	-112.1	34.4	31.3	6.41	4.8
7	N 34 09.471 W089 48.843	0.8	11.0	6.5	92.7	9.0	109.6	-92.1	31.6	25.3	5.26	3.1
8	N 34 09.586 W089 49.366	1.1	11.2	6.2	92.5	9.1	109.7	-120.0	47.6	38.7	10.02	3.0
9	N 34 09.22 W089 49.371	2.5	11.5	7.3	92.3	9.2	110.0	-119.3	33.6	19.7	7.53	7.1
10	N 34 09.245 W089 49.932	3.4	12.5	7.6	93.4	8.9	111.5	-115.7	25.6	16.7	5.37	3.7
11	N 34 09.587 W089 49.968	1.1	11.5	7.7	93.4	9.2	109.3	-112.5	41.6	30.0	9.29	4.3
12	N 34 09.59 W089 50.451	2.7	12.5	8.5	93.6	9.1	111.8	-98.2	28.8	19.0	5.19	7.6
13	N 34 09.254 W089 50.443	3.7	12.0	8.1	93.6	9.3	112.0	-111.5	21.2	15.0	6.56	7.3
14	N 34 08.799 W089 50.433	3.9	11.5	8.3	92.5	9.3	110.7	-90.7	29.6	19.3	7.16	4.9
15	N 34 08.354 W089 50.508	1.4	11.5	10.0	106.6	9.0	128.8	-124.5	68.8	66.3	8.33	4.3
16	N 34 08.186 W089 50.526	0.6	11.5	8.7	110.3	9.4	132.7	-93.5	82.0	74.7	6.30	9.1
17	N 34 08.805 W089 50.990	3.7	11.5	8.8	92.1	9.5	110.1	-128.4	29.2	15.3	6.58	32.5
18	N 34 09.264 W089 50.984	4.2	11.5	9.6	92.5	9.4	110.8	-136.8	19.2	14.0	4.07	8.6
19	N 34 09.232 W089 51.547	4.3	11.5	8.5	93.2	9.3	111.8	-119.4	16.8	17.0	4.50	7.5
20	N 34 09.226 W089 52.094	4.4	11.0	7.9	92.3	9.0	110.1	-125.8	20.4	19.3	4.57	22.3
21	N 34 08.771 W089 52.093	4.5	11.3	7.8	92.3	9.2	110.2	-109.9	14.4	15.0	3.96	4.2
22	N 34 08.469 W089 52.126	1.0	11.0	8.2	93.4	9.7	111.4	-129.3	40.0	29.7	6.35	11.4
23	N 34 08.457 W089 53.165	1.6	11.0	8.0	92.3	9.7	110.1	-117.8	26.0	19.3	7.25	6.7
24	N 34 08.811 W089 53.136	2.3	11.0	9.1	92.3	9.4	110.3	-132.9	12.0	15.7	7.85	36.3
25	N 34 08.216 W089 53.666	2.0	11.0	9.7	92.3	10.1	107.6	-137.0	27.2	22.3	6.33	13.6
26	N 34 08.51 W089 54.079	0.8	11.0	8.1	91.7	10.5	106.8	-93.6	33.2	21.7	7.76	19.9
27	N 34 08.938 W089 54.18	6.7	10.7	8.9	91.7	9.5	109.2	-134.7	19.6	14.3	6.92	8.6
28	N 34 09.399 W089 54.09	5.7	10.5	9.3	91.0	9.3	108.6	-128.6	20.4	10.3	5.10	11.0
29	N 34 09.815 W089 53.027	2.1	10.7	9.8	93.4	9.3	110.3	-139.6	24.0	20.3	4.55	24.1
30	N 34 09.223 W089 53.182	5.2	11.0	8.1	92.3	9.2	110.2	-130.9	16.4	16.0	3.82	2.2
31	N 34 12.25 W089 40.733	<1	11.0	19.4	123.1	10.2	137.1	-141.6	8.8	2.3	26.68	5.8

On 11/18/2013, flow velocities in the lake were measured using ADCP by scientists at NSL. At each sampling location (Fig. 3b), the *u* and *v* velocities were measured from near surface to the near bottom. The field measurements can be used to calibrate the numerical model results.

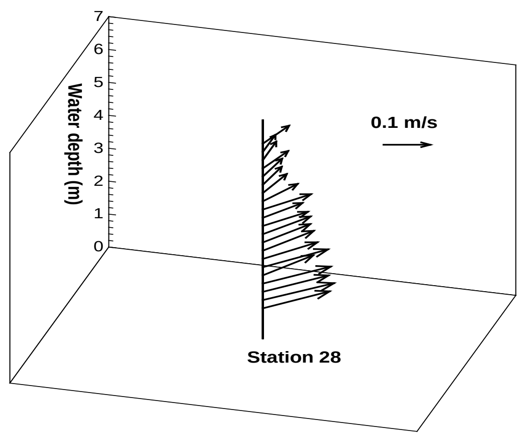


Figure 7. Measured velocity fields in the lake (11/19/2013)

(2) Remote sensing based suspended sediments and associated mercury concentration estimation

Several studies had success in estimating TSS using simple linear regression techniques involving MODIS VNIR bands and in situ measurements (e.g., Richard et al., 2004; Wang et al., 2009). A similar approach was used in this study to estimate TSS in Enid Lake. The correlation coefficient of the regression equation was obtained using near-real time in situ measurements of total suspended sediments and the reflectance values of the red (R) and near infra-red (NIR) bands of the Moderate-resolution Imaging Spectroradiometer (MODIS) (Band 1 and Band 2) imagery acquired on March 12, 2013 and November 20, 2013. The March and November datasets include 18 and 30 in situ measurements, respectively. The concentration of mercury (unfiltered) in the obtained suspended sediment samples was measured and correlated with the MODIS reflectance values for the corresponding samples.

Fig.8 shows the correlation between MODIS Reflectance of R and NIR Bands (Band 1 and Band 2) and TSS respectively for March 12, 2013. Fig. 9 shows the correlation between MODIS Reflectance of R and NIR Band (Band 1 and Band 2) and Total Hg (Unfiltered) for March 12, 2013.

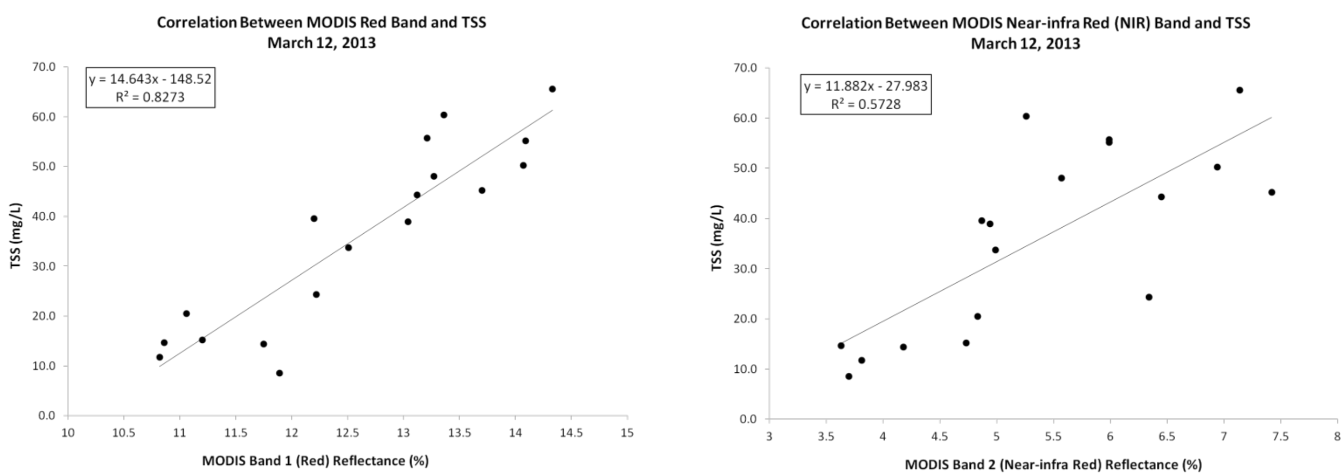


Figure 8. The correlation between MODIS Reflectance of R and NIR Bands (Band 1 and Band 2) and TSS respectively for March 12, 2013.

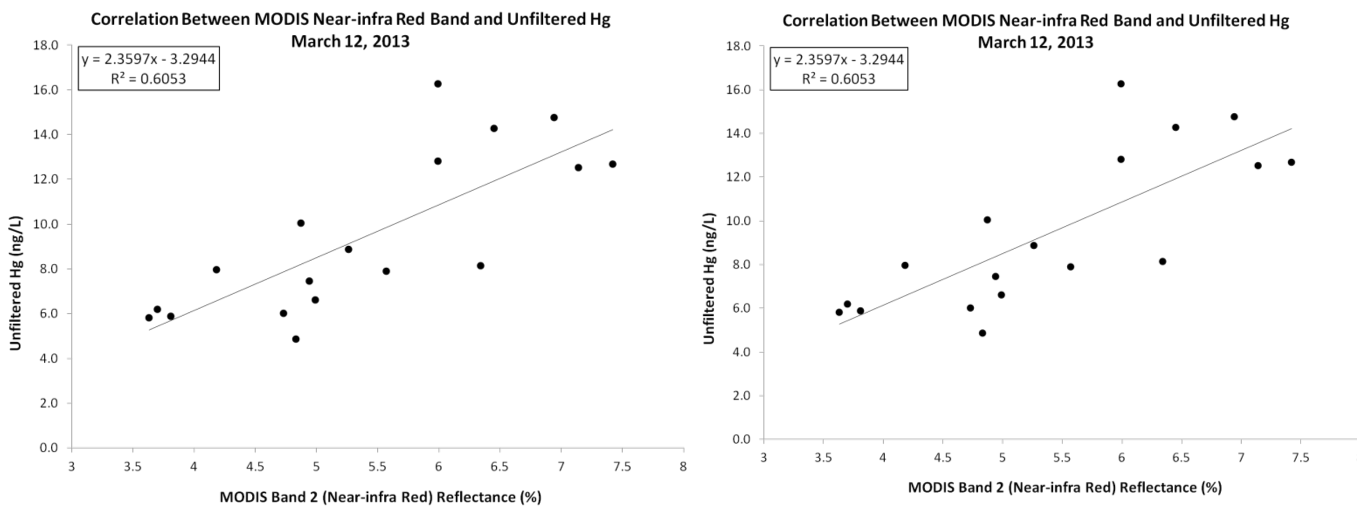


Figure 9. The correlation between MODIS Reflectance of R and NIR Band (Band 1 and Band 2) and Total Hg (Unfiltered) for March 12, 2013.

The obtained regression equations were applied on the water pixels of the MODIS NIR imagery to estimate the suspended sediments and associated mercury concentrations in the lake at 250 m spatial resolution. These 250 m resolution measurements were then used to interpolate 1 m resolution estimation of suspended sediments and associated mercury in the lake water. Fig.10 shows the distribution of the estimated SS. It can be found, the SS concentration cannot be determined in some areas where the water depth is very shallow using the remote sensing technology. Fig. 11 shows the distribution of the estimated suspended sediments associated with mercury concentration in the lake water.

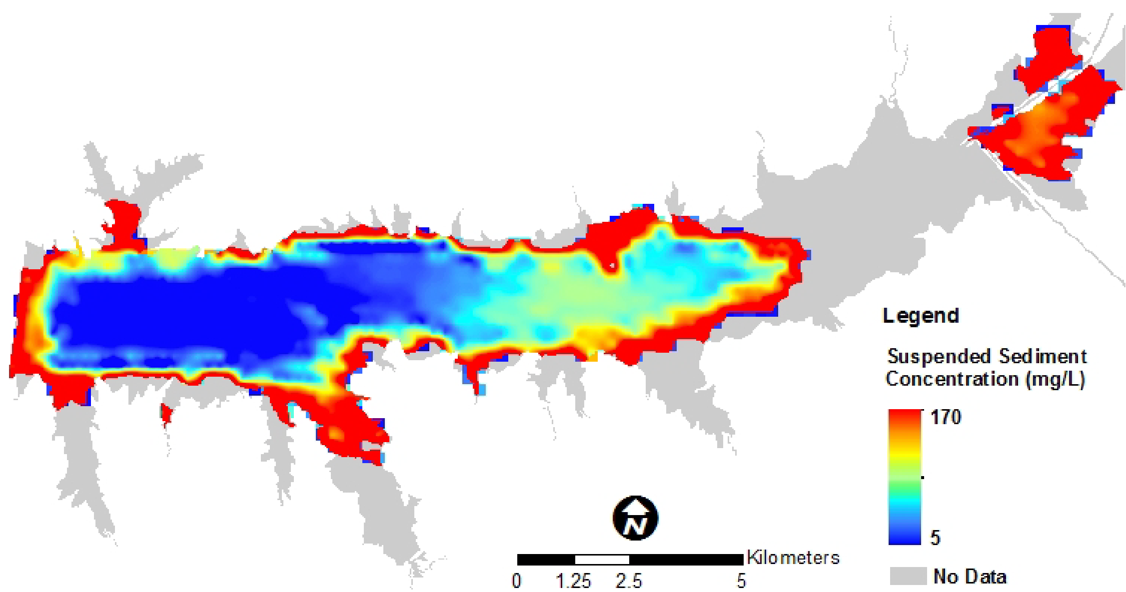


Figure 10. Distribution of SS in Enid Lake estimated by MODIS imagery acquired on March 12, 2013.

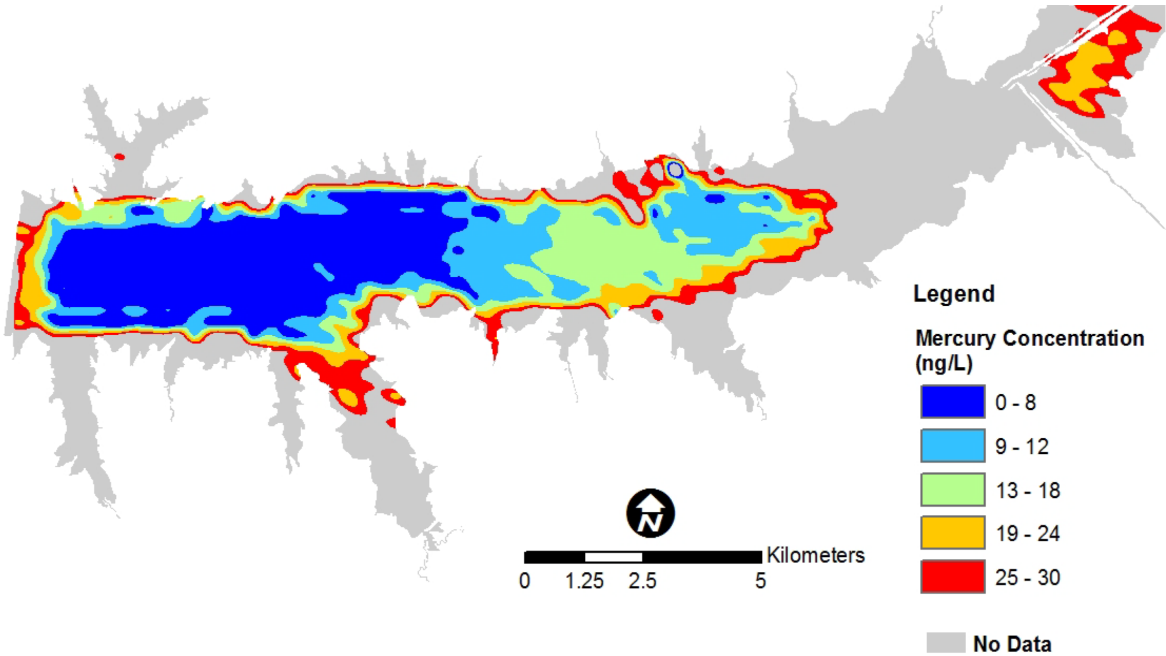


Figure 11. Distribution of total mercury concentration in SS of Enid Lake estimated by MODIS imagery acquired on March 12, 2013.

(3) Numerical model results

Based on initial bed elevation data (Fig. 12), the computational domain was discretized into a structured finite element mesh using the CCHE Mesh Generator. In the horizontal plane, the computational domain was represented by a mesh with 353×171 nodes. In the vertical direction, the domain was divided into 8 uniform layers. A simulation period from March 10 to 18, 2013, was selected for model test. After obtaining the boundary conditions shown in Fig. 5, the developed model can be applied to simulate the flow, SS and mercury distributions in the lake.

Fig. 13 shows the flow velocities on the water surface and near the bed, which was induced by the upstream river discharge as well as the wind forces.

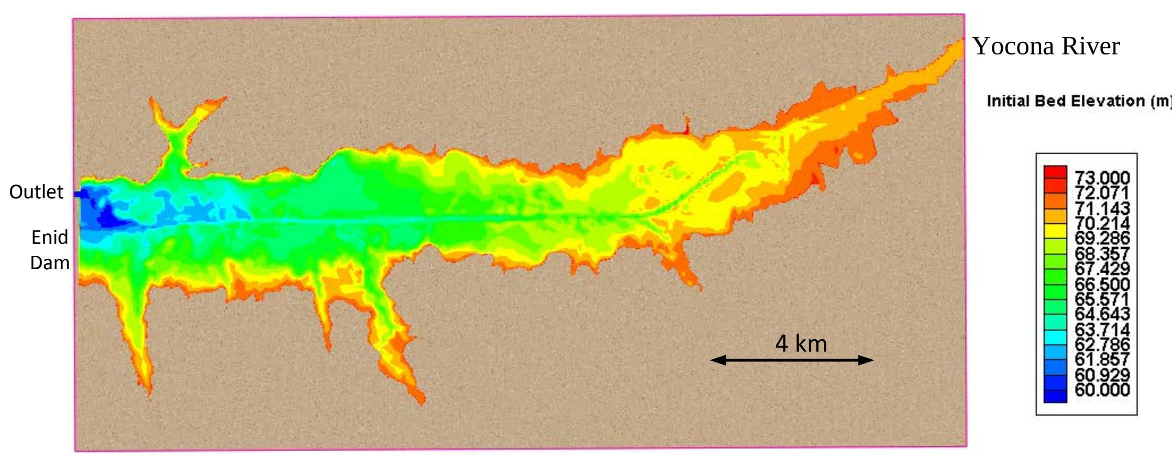


Figure 12. Initial bed elevation of Enid Lake

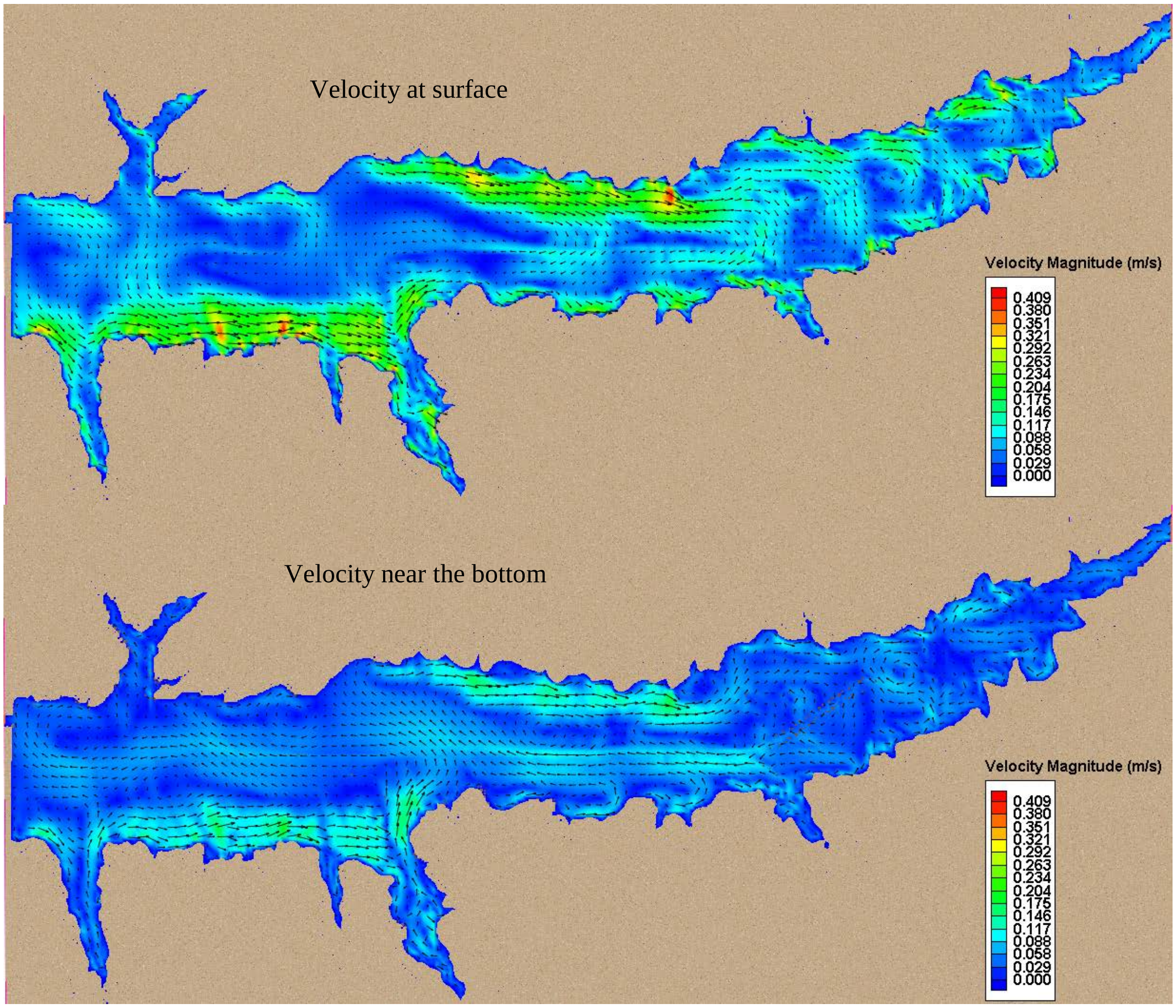


Figure 13. Simulated flow patterns in Enid Lake

Fig. 14 shows the simulated concentration of SS in the lake on March 12, 2013. It is generally in good agreement with the results obtained based on remote sensing technology (Fig. 10). The SS concentrations were higher near the river mouth and shoreline area, while the concentration of SS was much lower in the deeper water near the dam. Some differences between numerical results and remote sensing data can be observed near northwest shoreline. The numerical model underestimates the SS concentration in this area. It may be the reason that the effect of wind induced wave on the sediment resuspension was not taken into account in the numerical model.

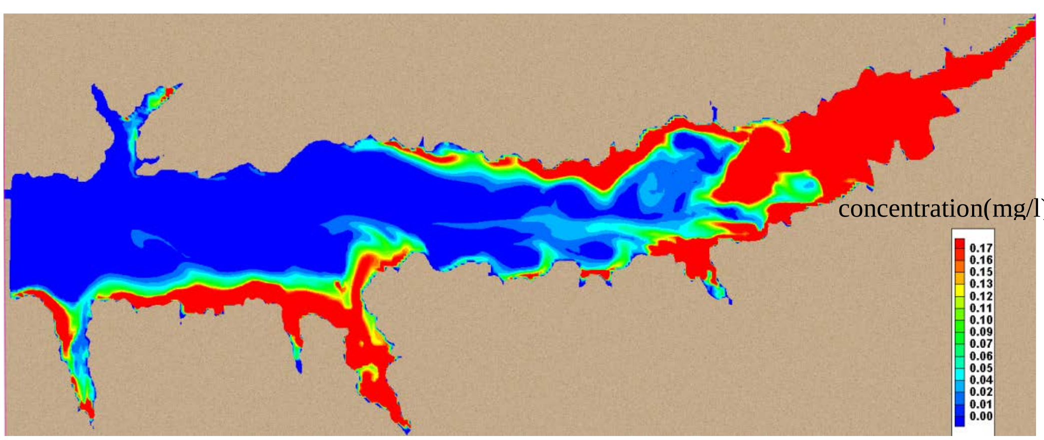


Figure 14. Simulated concentration of SS in Enid Lake (compared with Fig. 10)

Fig. 15 shows the simulated concentration of total mercury in the lake on March 12, 2013. It is generally in good agreement with the results obtained based on remote sensing technology (Fig. 11). Some differences between numerical results and remote sensing data can be observed near northwest shoreline. It may be the reason that the numerical model underestimated the SS concentration in these areas. So the concentration of sorbed mercury on the sediment was also underestimated by the numerical model.

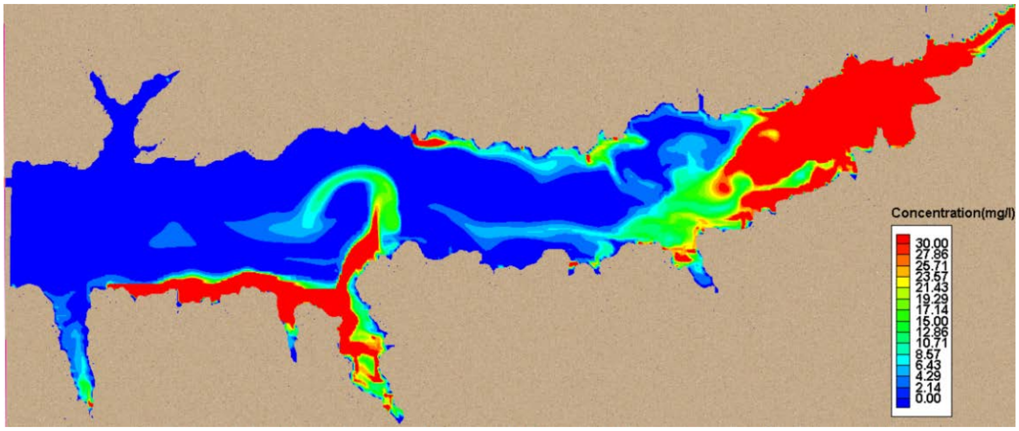


Figure 15. Simulated total mercury concentration in Enid Lake (compared with Fig. 11)

(4) Risk assessment of mercury on fish

Linear regression analysis of length vs. weight suggested that LMB and CC exhibited similar growth trends. The relationship between length and weight for CR from Enid Lake was statistically different from that of CR from other lakes, suggesting that environmental factors unique to Enid Lake may affect the growth of CR there.

Of the fish analyzed, LMB consistently had the highest mean mercury concentrations (in mean ± SE, 386 ± 76 ng/g), followed by CC (152 ± 14 ng/g) and then CR (214 ± 10 ng/g) (shown in Table 3). The average Hg concentration in LMB exceeded the threshold concentration of 300 ng/g that is enforced by the EPA.

Table 3. Mean mercury concentrations for CR, LMB, and CC in Enid Lake (red represents Hg exceeding the EPA standard (300 ng/g). Blue exceeds MDEQ value (750 ng/g), n=number of fish).

Lake	**Enid Lake**		
Hg (ng/g)	**CR n=16**	**LMB n=9**	**CC n=14**
Mean	214	386	152
Standard Error (1 SE)	10	76	14
Min	120	184	84
Max	285	954	272
Median	215	344	146

Linear regression analysis of length vs. Hg concentration showed that only LMB have a strong relationship between length and Hg concentration. Because the existing fish consumption advisories are length-based, the lack of relationship between length and Hg concentration means they may be insufficient to protect the public from exposure to MeHg.

Seven variations of risk assessment calculations yielded hazard index (HI) and monthly consumption limit (MCL) values that further discredit the existing consumption advisories and many consumption recommendations (Table 4). In four of the seven methods ("Hugget", "Ingestion Rate 15 lbs/person/year", "Body Weight (Portier 2007)" and "Body Weight (EPA 2011)"), LMB from Enid Lake had an adult HI>1.

All fish species from the lake yielded HI>1 for children.

Table 4. Comparison of Mean HI (Hazard Index) and MCL (Mean Consumption Limit in meals/month) for each set of risk assessment assumptions (red: above EPA's standard of HI = 1).

Risk Assessment Method			Species		
			CR	LMB	CC
Hugget	Mean HI	Adult	0.91	1.6	0.65
		Child	4.4	8.0	3.1
	MCL	Adult	4.5	3	7
		Child	1	0.5	1.5
Ingestion Rate (15 lbs/person/year)	Mean HI	Adult	0.57	1.0	0.41
		Child	2.8	5.0	2.0
	MCL	Adult	7.5	5	11
		Child	1.5	1	2.5
Ingestion Rate (3 oz/meal)	Mean HI	Adult	0.34	0.62	0.24
		Child	1.7	3.0	1.2
	MCL	Adult	12	8	18
		Child	2.5	1.5	4
Consumption Frequency	Mean HI	Adult	0.46	0.82	0.33
		Child	2.2	4.0	1.6
	MCL	Adult	4.5	3	7
		Child	1	0.5	1.5
Body Weight (Portier 2007)	Mean HI	Adult	0.85	1.5	0.61
		Child	3.8	6.8	2.7
	MCL	Adult	5	3	7.5
		Child	1	0.5	1.5
Body Weight (EPA 2011)	Mean HI	Adult	0.80	1.4	0.57
		Child	4.0	7.2	2.8
	MCL	Adult	5	3.5	8
		Child	1	0.5	1.5
Ingestion Rate & Body Weight (EPA 2001)	Mean HI	Adult	0.50	0.90	0.36
		Child	2.2	4.5	1.8
	MCL	Adult	8	5.5	12.5
		Child	1.5	1	2.5

DISCUSSION

The transport, fate and risk of mercury in Enid Lake have been studied based on field observation, laboratory measurement, remote sensing technology, numerical model, and risk assessment. This study indicates that the major sources of mercury in Enid Lake include river inflow from Yocona River, and runoff from surrounding watersheds. It has been observed that the mercury are generally bounded with sediment and introduced to the lake due to the transport of sediments (Garry 2013). The movement of sediment and deposition/erosion processes are greatly affect the distribution of mercury in the lake.

Measured Hg and water quality data showed there were differences between the sites nearer the dam (e.g., sites 15, 16, 17) and those closer to the Yocona River (e.g., sites 9, 10, 11, 12). The deeper water near the dam tended to be cooler, with higher dissolved oxygen, and slightly higher total dissolved solids and conductivity. However, the biggest difference was total suspended solids, which averaged 13.6 ± 1.9 mg/L near the dam and 48.9 ± 5.3 ng/L away from the dam (for the spring storm). This likely reflects the deposition (loss) of particles as the water slows as it traverses the lake. This gradients in TSS and Hg were also observed in satellite imagery and numerical model results.

For the spring event, concentrations of Hg averaged 9.4 ± 3.6 ng/L (1 SD, n=18) and ranged from 4.9 to 16.3 ng/L for unfiltered water; Hg in the dissolved fraction (<0.45 µm) averaged 7.5 ± 3.2 ng/L and ranged from 3.8 to 14.4 ng/L. Mercury concentration was correlated with TSS ($r=0.683$, $p<0.05$). Concentrations in the sediment averaged 65.2 ng/g, and ranged from 40.7 to 89.7 ng/g. The bulk of the sediment (>80%) consisted of particles <125 µm in diameter. Concentrations of Hg in these fines were greater than the larger size fractions, not surprising given that Hg^{+2} is surface reactive. Mercury also has an affinity for organic matter. Indeed levels of Hg and organic matter were higher in the sediment from the more shallow part of the lake near the mouth of the Yocona River compared to the deeper water areas near the dam.

Remote sensing technology has been successfully used to estimate and map the distributions of SS and mercury on the entire lake surface following a storm event. It also provided useful information for numerical model calibration and validation. Overall, this study shows that suspended sediment particle size, organic matter, and water flow characteristics are important factors controlling the distribution of Hg in the lake, and that modeling suspended solids and Hg transport using spectral data acquired remotely by satellites is not only feasible but a powerful way to provide timely data on the dynamics of Hg in reservoirs. Moreover, the results from this study are directly applicable to other large lake systems in Mississippi and elsewhere.

A numerical model has been developed to predict the dynamic flow fields, and the temporal and spatial concentrations of sediment and mercury in the entire lake. Based on the upstream river flow discharge, download water surface elevation, and wind conditions, the flow fields, including velocity, water level, eddy viscosity, etc. can be solved. After obtaining flow information, the model can be applied to simulate the concentrations of SS and mercury in the lake. The developed model was used to simulate a spring storm event and the modeling results of SS and Hg were generally in good agreement with satellite imagery. In general, the concentrations of SS and Hg were higher near the river mouth and shallow shoreline area than that in the deeper water areas near the dam. The model provides a useful tool to predict the long time trend of mercury in the lake.

Risk assessment analysis shows that the mercury concentration in LMB collected from Enid Lake exceed the maximum concentrations allowed by the EPA (300 ng/g). Compared with the data collected by Hugget (1999), Hg in all fish species in Enid Lake have decreased, likely as a result of MDEQ recently refocused efforts to locate possible sources of mercury and monitor water quality (MDEQ 2012). For Hazard Index, all fish species from Enid Lake yielded HI>1 for children. CR and CC from the lake had an HI<1 for adult. In four of the seven methods (“Hugget”, “Ingestion Rate 15 lbs/person/year”, “Body Weight (Portier 2007)” and “Body Weight (EPA 2011)”), LMB from Enid Lake had an adult HI>1.

SIGNIFICANT FINDINGS

- The major sources of mercury in Enid Lake include river inflow from Yocona River, runoff from surrounding watersheds, and atmospheric deposition.
- Mercury concentration can be measured in both water and sediment samples.
- Mercury is generally absorbed on sediment and introduced to the lake due to the transport of sediments.
- Remote sensing technology can be used to estimate the concentrations of SS and Hg on the entire lake surface.
- Numerical model is an effective tool to predict the dynamic flow fields, and the temporal and spatial concentrations of sediment and mercury and in large lakes.
- In Enid Lake, the concentrations of SS and Hg are generally higher near the Yocona River mouth and shallow shoreline area compared to the deeper water areas near the dam.
- The measured data shows that the Hg concentration in LBM from Enid Lake exceed the maximum concentration of 300 ng/g allowed by the EPA.
- Hg level in all fish species in Enid Lake have decreased compared to the data obtained 10 years ago.
- All fish species from Enid Lake yielded HI>1 for children, which means there is an elevated potential for toxicity associated with the exposure. For CR and CC, HI was less than 1 for adult, and the expected potential for toxicity was low. For LMB, among seven risk assessment methods, results from four methods show LMB from Enid Lake had an adult HI>1.

FUTURE RESEARCH

In this project, the proposed research tasks have been successfully studied. Due to the limitations of funds and time, we could not address all the questions we found during the project period. They might be interesting topics for our future research.

Although we have obtained the general distributions of sediment and associated mercury concentration in the lake, the amount of mercury absorbed on the suspended sediment or deposited to the lake bottom is still a question to be answered to assess the mercury mass balance in the lake. This can be achieved by understanding the mercury sedimentation processes, such as adsorption/ desorption of mercury by sediment and mercury release from bottom sediment.

In Yazoo River Basin, spring and fall are the major raining seasons. A large amount of sediment is discharged into Enid Lake due to storm events, resulting in high level mercury introduced into the lake and greatly affect the mercury concentration in the lake, as well as in the fish. Although we have obtained the sediment and mercury distributions during a storm event, to understand the amount of mercury deposited to the lake, the long term historic storm events and associated sediment/mercury transport need to be studied.

The impact of the mercury released from the bottom sediment is critical for proper risk assessment of mercury for the lake. In addition to the understanding of the fate and transport of mercury in Enid Lake, it is also important to provide useful information about the mercury concentrations in water, suspended sediment, bottom sediment, and fish tissue, which are directly relevant to stakeholders concerned with wildlife and human consumption of mercury.

STUDENT TRAINING

Stacy Wolff graduated from the University of Mississippi's Honors College with a Bachelor of Science Degree in Forensic Chemistry. Her thesis was titled "Mercury in fish in north Mississippi reservoirs: statistical analysis and risk assessment". She was involved in the water and fish analyses.

Garry Brown, who graduated with a Ph.D. in Analytical Chemistry in August 2013, made significant contributions to this work. His dissertation was titled "Studies of mercury in water, sediment, and fish in Mississippi: concentrations, speciation, cycling, and isotopic composition".

Sara Adams, a summer 2013 REU (research experience for undergraduates) student, was also involved in the fish analyses.

Derek Bussan, a graduate student in chemistry, helped with the field work.

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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

Basic Information

Title:	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
Project Number:	2013MS183B
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End Date:	12/31/2014
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Congressional District:	1st
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Focus Category:	Wetlands, Hydrology, Management and Planning
Descriptors:	
Principal Investigators:	Gregg R. Davidson

Publications

1. Quarterly reports to MWRRI.
2. Davidson, G.R. and C. Lahiri (2014). Preferential flow paths in oxbow wetlands: oxidizing saturated soils and groundwater recharge through clay. Vancouver, British Columbia, October 19-21, 2014, Geological Society of America Abstracts with Programs, vol. 46, no. 6, p. 482. https://gsa.confex.com/gsa/2014AM/webprogram/Paper249085.html.
3. Lahiri, C., G.R. Davidson and S.T. Threlkeld (2014). Water Depth in an Oxbow Lake-Wetland and its Influence on Soil Chemistry, Cypress Tree Growth, and Groundwater Recharge presented at 2014 Mississippi Water Resources Conference, April 1-2, 2014, Jackson, MS, www.wrri.msstate.edu, p. 95.
4. Lahiri, C. and G.R. Davidson (2015) Mississippi oxbow wetlands: Influence of preferential flow paths on soil redox, tree growth, and groundwater recharge. Chattanooga, TN, March 19-20, 2015, SE GSA sectional meeting, Geological Society of America Abstracts with Programs, vol. 47, no. 2, p. 69 https://gsa.confex.com/gsa/2015SE/webprogram/Paper252837.html
5. Lahiri, C., G.R. Davidson and S.T. Threlkeld (2015). Heterogeneous Vertical Flow through Oxbow-Wetlands: Soil Chemistry, Wetland Tree Growth, and Groundwater Recharge, presented at 2015 Mississippi Water Resources Conference, Jackson, MS, April 7-8, 2015.
6. Davidson, G.R. (2015). 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. Final Technical Report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 11 pgs.

Final Report

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

January 15, 2015
(revised April 15, 2015)

Gregg Davidson
Geology & Geological Engineering
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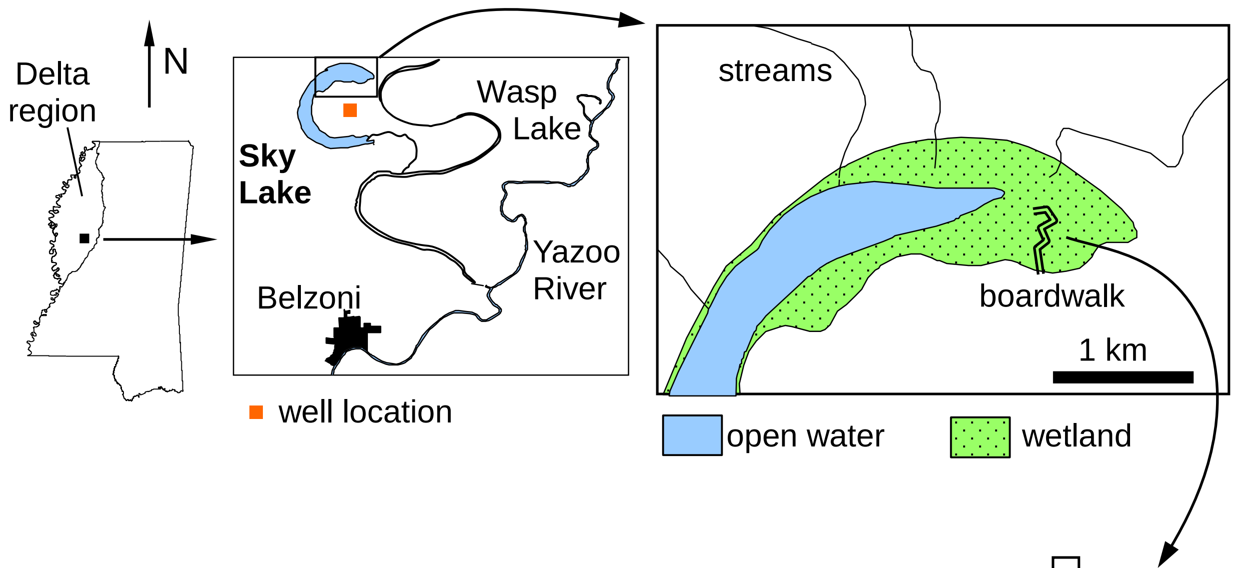
BACKGROUND

Many oxbow lake-wetland systems in the Mississippi River floodplain are perched above the regional water table, resulting in a downward hydraulic gradient. Fine grained sediments that accumulate in these environments limit downward flow, but fallen tree trunks and limbs introduce heterogeneity and isolated pockets of higher hydraulic conductivity. Normally, flux is proportional to the gradient, but previous work by the PI suggested that the relationship between water depth and downward flow in these systems can be non-linear. Studies in Sky Lake, in the Delta region of Mississippi, have documented minimal vertical movement of water until a threshold water depth is reached. Above the threshold, abrupt changes in soil chemistry have been observed as water begins moving downward, which may in turn influence the growth of wetland trees. The role of oxbow lakes as points of groundwater recharge is also largely unknown. Though oxbow-lake bottom-sediments typically serve as barriers to flow, the heterogeneity that exists in the wetland perimeters may provide conduits for vertical flow that bypasses the surficial clay and silt deposits.

The project focused on the influence of changing water depth in Sky Lake, MS, in Humphreys County, where an elevated boardwalk into the heart of an old-growth bald-cypress wetland made it possible to mount equipment for long-term monitoring of a variety of environmental parameters (Fig. 1). The study focused on both the identification of non-linear responses to changing water depth, and its potential impact on tree growth and groundwater recharge. Possible non-linear downward flux in response to increases in wetland water depth was investigated using a series of redox probes at two depths in the sediment to monitor changes in redox potential that might accompany changes in water depth. Significant downward flow of oxygenated surface water should result in a shift to higher redox potentials. The impact on bald-cypress tree growth was assessed using two sets of tree measurements: radial growth and sap flow rates. In order to link any changes in tree growth to water level, a series of additional variables were also measured that could also influence growth and mask a water-depth effect. These included temperature, relative humidity, and precipitation. Groundwater response was monitored by measuring the level of water in an abandoned irrigation well in the center of the oxbow meander loop.



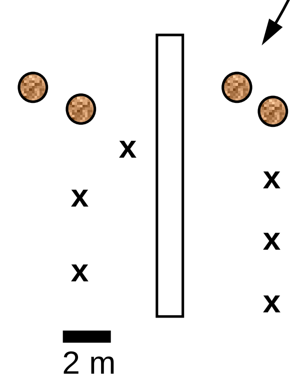


Figure 1. Sky Lake with enlargement of the northern wetland, and layout of the experimental area (to the right). The central rectangle represents the elevated boardwalk. Circles represent cypress trees outfitted with dendrometer bands and sap flow sensors. Locations of the redox measurements are marked with an **x**. Redox probes were placed at 30 and 60 cm at each site.

RESULTS

The project began part way into the 2013 growing season, so the data collection phase was extended to include a second growing season. Data for this report was completed in October, 2014, though investigations at the site will continue into the future.

Wetland water depth

Water depth in the wetland varied considerably over the course of the study (Fig. 2). During the first year (2013), water levels remained high earlier in the growing season, followed by a period of several months with no water above ground surface. Water level in the second year (2014) was much more episodic, with only a few days when the wetland was not flooded.

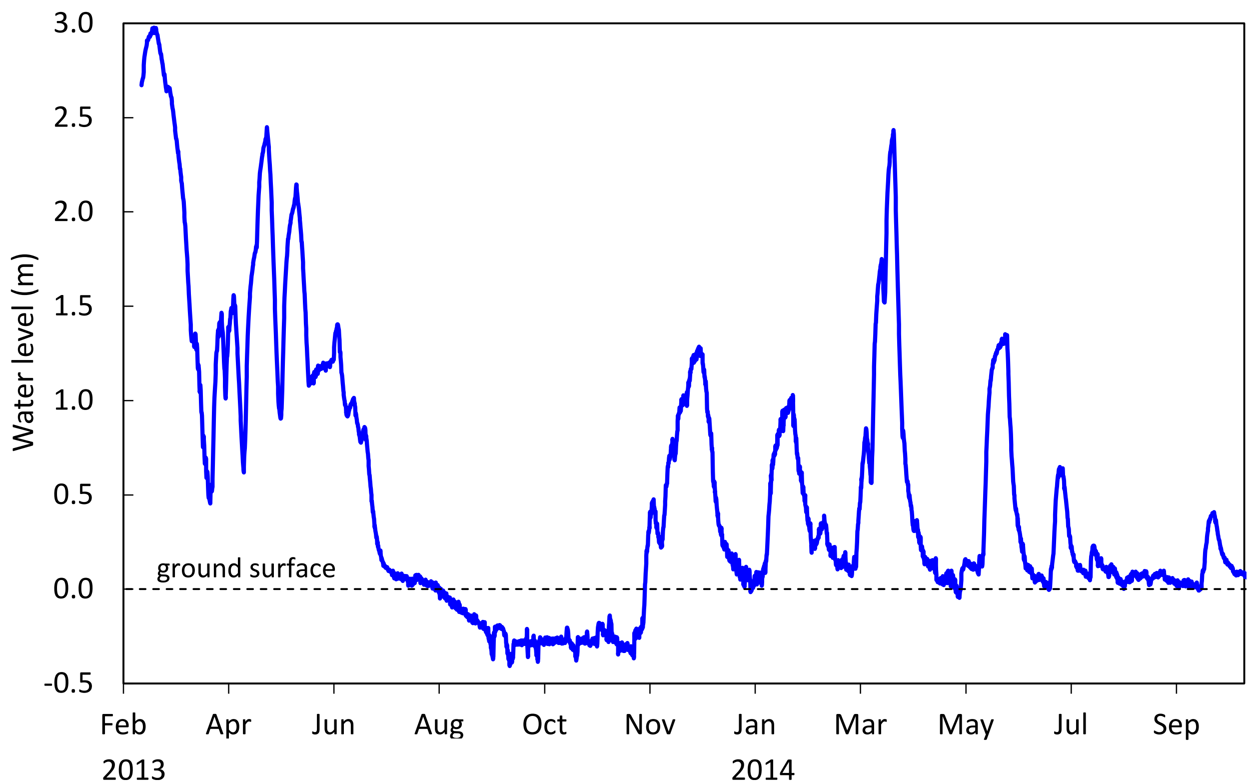


Figure 2. Water depth at the boardwalk in Sky Lake. Values less than zero represent times when the wetland was dry and water levels are the depth to saturated soils.

Redox potential

Redox potential measurements provide strong evidence of preferential flow pathways through the wetland sediments (Fig. 3). Six stations were set up, with separate probes inserted at depths of 30 and 60 cm at each location. In three stations, the redox potential showed no apparent response to changing water level. In two stations, rising water levels resulted in higher redox potential, consistent with the movement of oxygenated surface-water through the root zone at these localized points in the wetland.

Redox potential is not a good proxy for oxygen if trying to *quantify* the concentration of oxygen present. However, the presence or absence of oxygen should be expected to produce generally high or low redox conditions that should also be reflected by high or low Eh, respectively. In a plot of water depth vs Eh, we find a clustering of data in the high-Eh, high-water-level quadrant at two locations (middle row of Fig. 3). Significantly, plots at 30 and 60 cm at these locations show the same general relationship, suggesting downward flow of oxygenated surface water through each depth, but only when surface water levels rise above approximately 1 m. At one additional location, a high Eh response to rising water depth is only seen at 60 cm, not at 30 cm. Because tree limbs often become buried at an angle, the most likely explanation is that an angled preferential flow path was encountered at the 60 cm depth here.

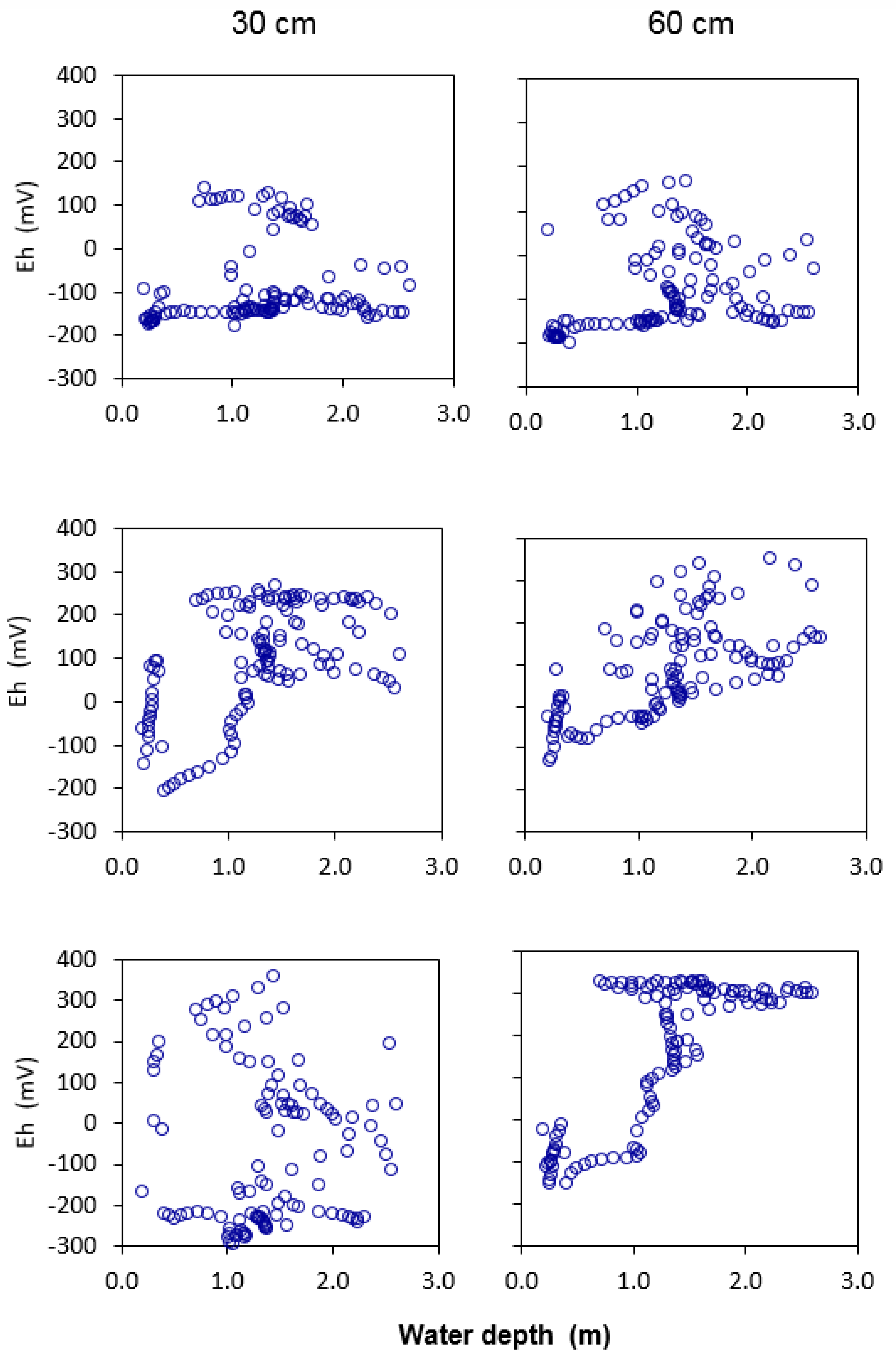


Figure 3. Top row shows no relationship between water depth and Eh (no vertical flow), middle row shows higher Eh with deeper water (flow when water depth exceeds 1 m), and third row shows only a response in the 60 cm probe (possible angled preferential flow path).

The data supports earlier observations of an apparent threshold before significant downward movement begins, though the lack of an Eh response for water levels below 1 m could also be explained by the rapid consumption of oxygen as it enters the system under low hydraulic gradients.

Radial tree growth

An effective, low-tech method for continuous monitoring of radial tree growth was employed by installing dendrometer bands around four bald cypress trees and fixing a time-lapse camera to take daily photographs of the gap in the dendrometer band (Fig. 4). The digital photos were later processed with pixel counts to determine the daily change in growth.

One unexpected result was that the settling of the dendrometer band can take several months. The growth data for the first growing season is much more erratic than the second (Fig. 5). Assessment of any impacts of changing water depth (and associated soil chemistry) during the first year is thus limited. When plotted as cumulative growth, the rate of growth for each tree (all roughly century-old) during the second year was very similar (Fig. 6). No consistent changes in growth rate are found repeated in all four trees except for a modestly slower growth rate at the start of the growing season. The R^2 value for all four trees taken together is very high at more than 0.98 for data up through the end of July, 2014. The highly linear growth rate shows no evidence of being enhanced or diminished by changes in water level over the same time period.

Figure 4. Time lapse camera and dendrometer band.

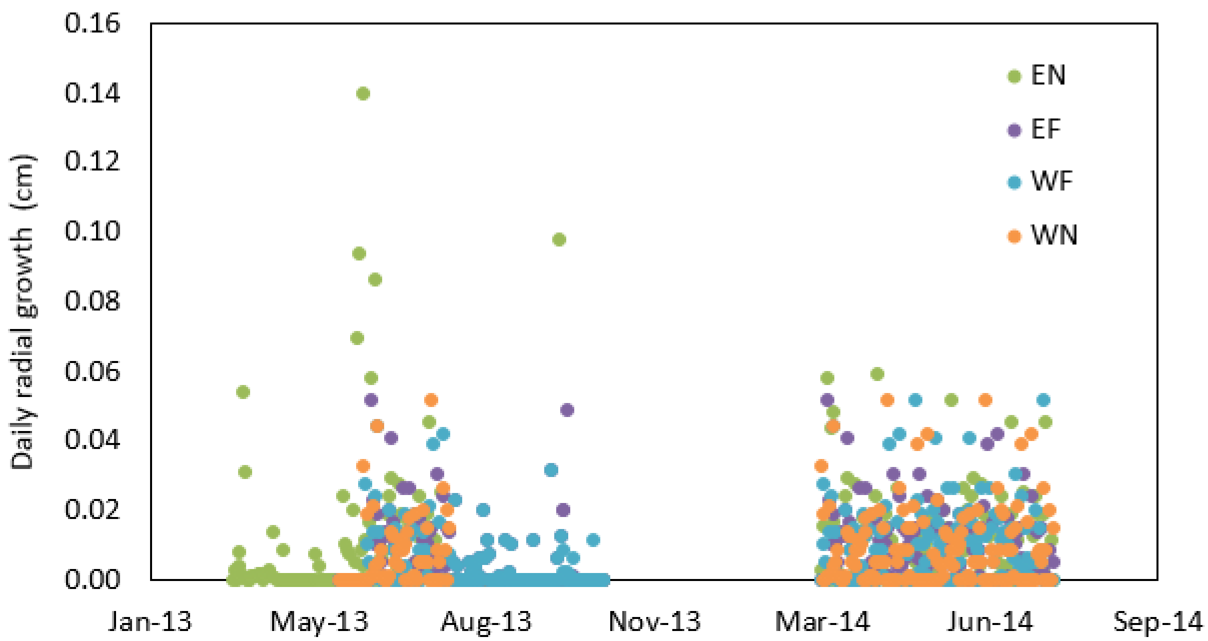


Figure 5. Daily radial growth in four bald cypress trees. Trees were named using their position relative to the boardwalk (east-near: EN, east-far: EF, west-near: WN, west-far: WF).

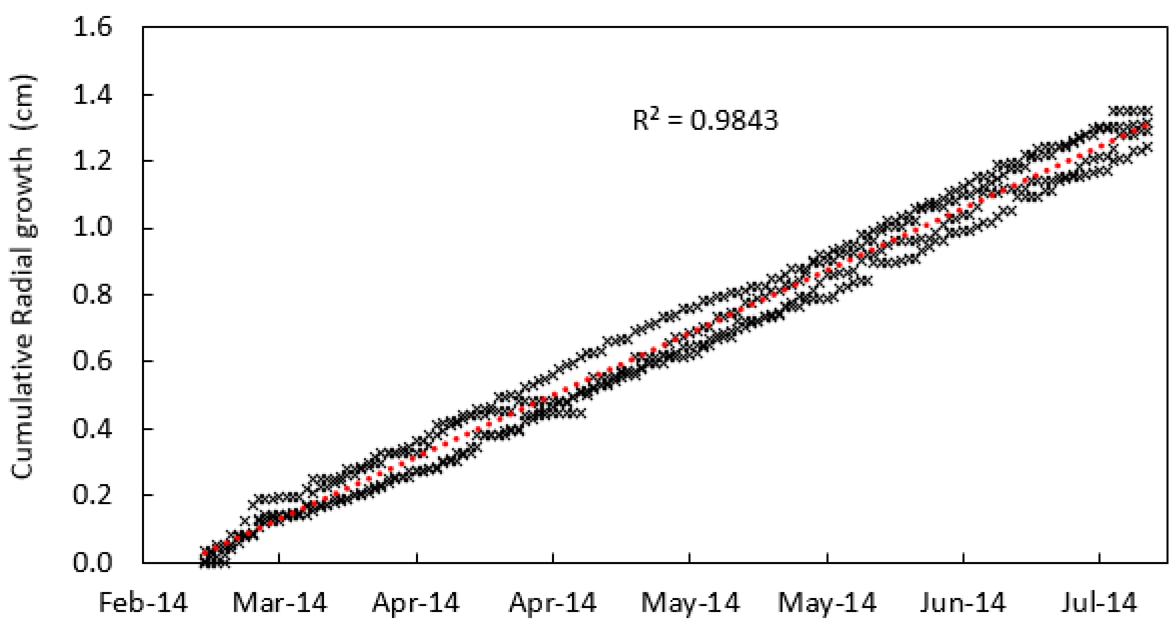


Figure 6. Cumulative growth of all four trees during the second year plotted together and a best fit line.

Sap flow

Sap flow was measured at half-hour intervals during the daytime when active photosynthesis is taking place. The four trees with dendrometer bands were also outfitted with sap flow sensors. For the purpose of this study, the actual velocity of sap flow is less important than relative changes in flow rate over time. Electronic output from the sensors is shown in Fig. 7 as unitless values.

Anomalously high values of sap flow (in excess of 100) were observed in year 1 for one tree over a period of two months during the summer. In the following year, similar anomalous values were observed for a different tree for a one month period, also during the summer. No reason is known for the aberrant results.

In general, one would expect sap flow to increase with increasing average daily temperature and with decreasing relative humidity (easier to move water from leaf stomata into drier air). A plot of the ratio of temperature/relative-humidity vs sap flow shows an overall positive correlation as expected (Fig. 8).

As with the radial growth data, there is no consistent pattern in sap flow over time that suggests enhanced or diminished flow with changes in water depth within a season. Only one abrupt shift in sap-flow rate is observed in mid-August 2013 (Fig. 7). Flow rates in three trees increased significantly over one day. The timing roughly matches when the root zone became desaturated. Subsequent declines in sap flow rate are consistent with daylight hours shortening and average temperatures declining. Sap flow rates were generally higher in year 2, however, indicating a possible effect of water depth over longer time scales. Water depth was low for the second half of the growing season in the first year and sap flow rates were lower. It is conceivable that the greater water depths during the growing season in the second year resulted in more oxygenated water reaching the root zone and enhancing nutrient uptake.

Groundwater response

Water levels in a single well completed near the center of the oxbow meander loop were measured every four hours. Changes in water level are consistent with recharge directly from the overlying oxbow (Fig. 9). Groundwater levels rose during periods of inundation of the wetland and fell when the wetland was dry, with lag times between peak surface-water depth and peak groundwater levels of approximately four weeks. Groundwater levels only rose when water depth in the lake exceeded approximately 1 m. Several periods of flooding of the wetland to depths less than 1 m did not produce increases in groundwater level. However, the rate of groundwater decline during this time was less than when the wetland was dry, which suggests that recharge may be occurring, but at a rate less than groundwater outflow.

While the data is consistent with recharge from the oxbow, there are other possible explanations. It is possible that the lake and groundwater both rise as a result of increases in local precipitation, with recharge to the groundwater via regional infiltration or through the Yazoo River streambed. Regional groundwater flow in the area is reported to be toward the west (Yazoo River is east of Sky Lake). More wells will be needed to characterize whether there is a groundwater mound beneath the lake (consistent with recharge from above), or a general gradient toward the west (consistent with recharge from the Yazoo River). Other wells are present in the area, though heavy pumping during the summer limits their usefulness for continuous monitoring.

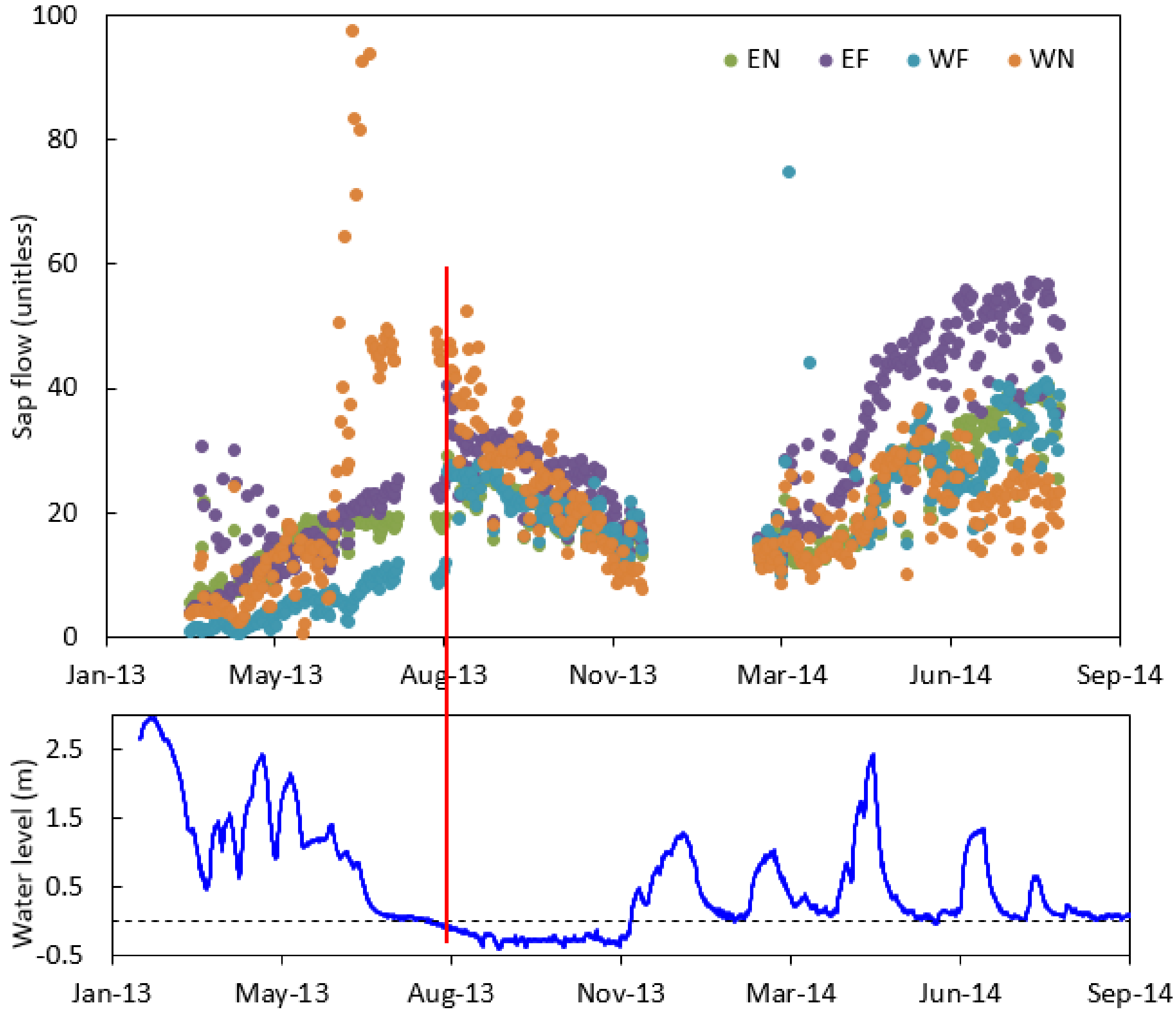


Figure 7. Sap flow (unitless) for four bald cypress trees (see Fig. 6 for key), compared to water depth over the same time period. The red line marks a time when sap flow rates in three trees (all but WN) increased significantly over a one day period. Gaps represent equipment malfunction.

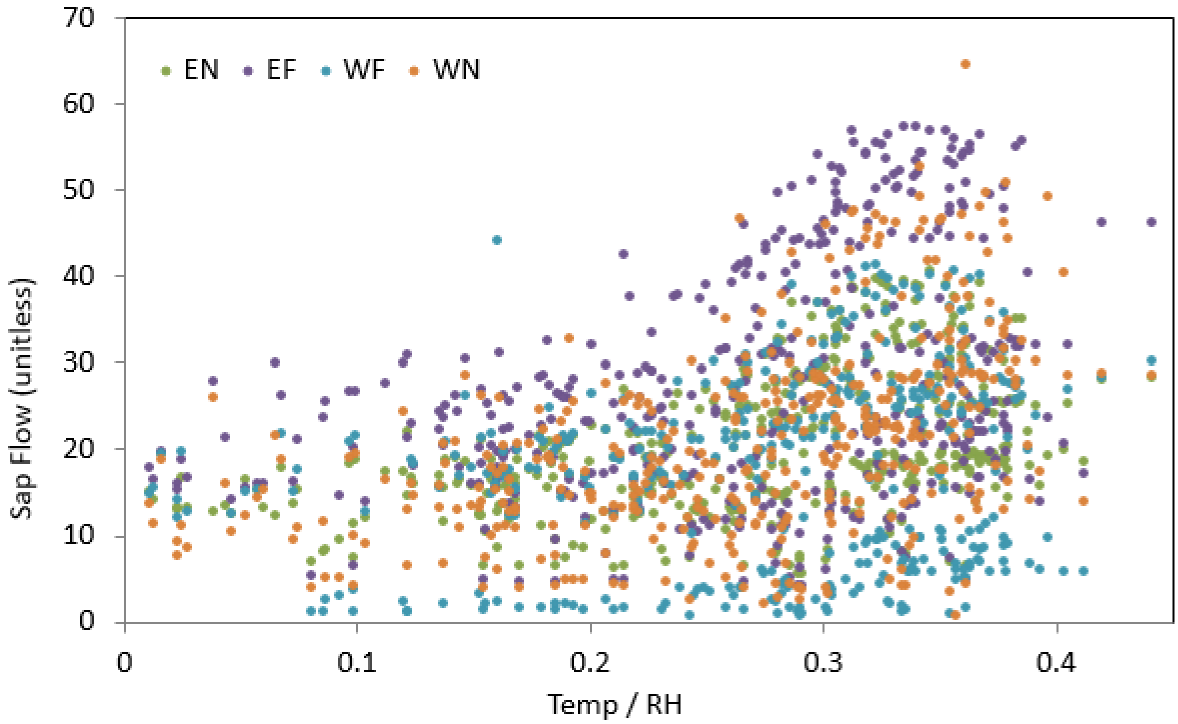


Figure 8. The ratio of temperature and relative humidity vs sap flow rate (anomalously high sap flow data not included).

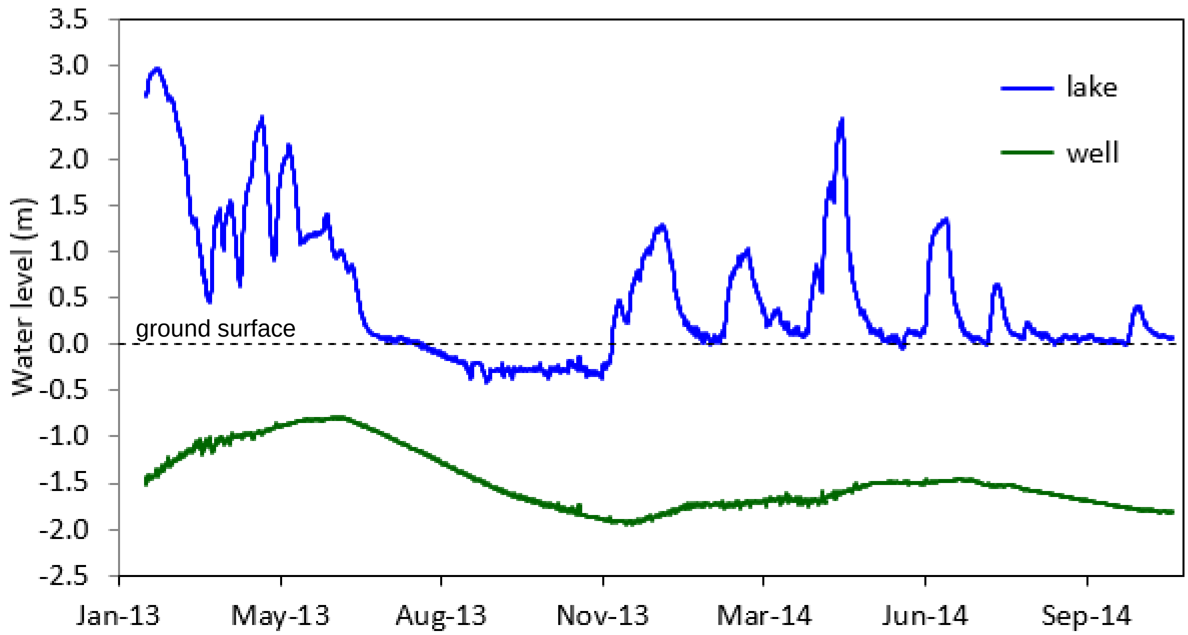


Figure 9. Water depth in the wetland and water level in the well in the center of meander loop (see Fig. 1). Water depth in the wetland and groundwater level are on the same scale, but the actual distance of the water table below ground surface is greater than shown.

Conclusions

Evidence of preferential vertical flow pathways is present in the Eh data where some sites show a clear response to changing water depth and others do not. The data is also consistent with a threshold depth requirement to either initiate flow, or to increase the delivery rate of oxygenated water to the point where it exceeds the oxygen consumption rate caused by respiration and decomposition reactions. The apparent response of groundwater to changes in lake-water depth is consistent with leakage of water from the oxbow along preferential pathways. At present, the sap flow and radial growth data do not appear to indicate short-term growth dependency on water depth. It is possible that long-term flooding of trees might have a measurably impact, but growth over a single season does not appear to be influenced by water depth.

FUTURE WORK

The results of this study point to the need for additional work on at least two fronts. First, a groundwater study with additional wells, as noted above, is needed to determine if there is direct recharge occurring to the groundwater from the overlying oxbow lake. Second, a longer-term study of tree growth is needed to determine the effect of water depth on time scales of three or more years. Plans are underway to further investigate these issues.

STUDENTS MENTORED

Chayan Lahiri, Ph.D. student
Hunter Landry, B.S. student, Geological Engineering

PUBLICATIONS / PRESENTATIONS

Results have been presented at the 2014 and 2105 WRRI annual conferences, the 2014 national meeting of the Geological Society of America (GSA), and the SE GSA regional meeting in Chattanooga, TN, in March. The two GSA citations and published abstracts are printed below.

Davidson, G.R. and C. Lahiri (2014) Preferential flow paths in oxbow wetlands: oxidizing saturated soils and groundwater recharge through clay. Vancouver, British Columbia, October 19-21, 2014, Geological Society of America Abstracts with Programs, vol. 46, no. 6, p. 482. https://gsa.confex.com/gsa/2014AM/webprogram/Paper249085.html

> Recent studies in Sky Lake, an oxbow lake-wetland system in northwest Mississippi, challenge two commonly held assumptions. The first assumption is that the fine-grained sediments that typically infill oxbow lakes create a barrier to vertical flow, effectively eliminating the lakes as a source of groundwater recharge. However, many of the oxbow lakes in the region have perimeter wetlands that host forests of cypress and tupelo trees

with extensive root systems. Decaying roots and fallen limbs have the potential to create preferential pathways to the underlying sands. Preliminary water-level results from a well in the center of the meander loop suggest the local aquifer is receiving recharge directly from the surrounding oxbow. A second assumption is that saturation of wetland sediment leads to reducing redox potential that is independent of subsequent changes in water depth. At Sky Lake, however, long-term measurement of soil redox potential at depths of 0.3 and 0.6 m have found isolated zones where the redox potential consistently rises to oxidizing conditions when wetland water depths exceed approximately 1 m. The response is attributed to the downward movement of oxygenated surface water through preferential flow pathways.

Lahiri, C. and G.R. Davidson (2015) Mississippi oxbow wetlands: Influence of preferential flow paths on soil redox, tree growth, and groundwater recharge. Chattanooga, TN, March 19-20, 2015, SE GSA sectional meeting, Geological Society of America Abstracts with Programs, vol. 47, no. 2, p. 69 https://gsa.confex.com/gsa/2015SE/webprogram/Paper252837.html

The floodplain of the lower Mississippi River is littered with oxbow lake-wetland systems supporting dense forests of bald cypress and tupelo gum. Fine-grained sediments infilling the oxbows form low hydraulic conductivity plugs that should minimize communication between surface water and underlying groundwater, and produce pervasive reducing conditions in the soils during flooding. In forested oxbows, however, extensive root networks and decaying fallen trees have the potential to produce zones of higher conductivity and preferential vertical flow pathways. Evidence of preferential flow paths has been documented in Sky Lake, an abandoned meander loop of the Mississippi River in northeastern Mississippi. Redox potential measured hourly over an 18 month period revealed isolated zones that became oxidizing when surface water levels exceeded one meter. Changes in groundwater levels in a well located inside the meander loop were also consistent with recharge from the overlying oxbow. Advective delivery of oxygen through portions of the root zone has the potential to enhance tree growth during periods of extended inundation. Several cypress trees have been outfitted to continuously monitor sap flow and radial expansion to identify possible links between growth and changes in soil redox potential that accompany changes in water depth.

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:	2/28/2015
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.

Mississippi Water Resources Research Institute (MWRRI)

Quarterly Report – (From) 03/01/14– (To) 03/31/15

Reports due: 1st (March 31); 2nd (June 30); 3rd (Sept. 30); 4th (Dec. 31)

Note: Please complete form in 11 point font and do not exceed two pages. You may reference and append additional material to the report.

SECTION I: Contact Information

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

Principal Investigator: Dr. Gary Ervin
Institution: Mississippi State University
Address: Department of Biological Sciences
PO Box GY
218 Harned Biology Building, 295 East Lee Blvd.
Mississippi State, MS 39762
Phone/Fax: 662-325-1203
E-Mail: gervin@biology.msstate.edu

SECTION II: Programmatic Information

Approximate expenditures during reporting period:

Federal: $20,144 (est.), Non-Federal (MWRRI): $7,000, Non-Federal (Dept.): $4,000, In-Kind: $0, Total Cost Share: $19,927

Equipment (and cost) purchased during reporting period:

None

Progress Report (Where are you at in your work plan):

As of 6/30/14
Currently all WRP sites have been selected with assistance from Kevin Nelms of the USDA-NRCS in Greenwood MS. Landowners have been contacted and permission granted for all 24 proposed WRP wetlands. Additionally, all six reference (naturally occurring) wetlands have been identified. All sites were visited in May/early June and vegetation surveys, water sampling, and soil sampling conducted at that time. During this round of sampling, water level loggers were placed in a subset of the wetlands. Plant voucher specimens are in the process of being identified to the lowest possible taxonomic level. All water samples collected have been analyzed for parameters of interest, and we are in the process of creating maps using GIS software for use in future spatial analysis.

As of 9/30/14
The last plant, soil, and water sampling events were completed during site visits in late July-early August. Plants specimens are continuing to be identified to the lowest possible taxonomic level. All water quality data has been obtained and complied. Soil samples are in the process of being prepared for transfer to the MSU soil testing lab for analysis. The database structure was completed and data entry started while construction of geospatial maps continued throughout this quarter.

As of 12/31/14
The soil samples have been processed at the Extension Service Soil Testing Laboratory and data received. The majority of vouchers collected during the late summer sampling have been identified and entered into the database. Identification is proceeding forward on the spring vouchers. Exploratory data analysis has been started on plant community data, allowing for basic questions such as wetland composition, diversity, and abundance to be answered. All sampling points have been successfully imported into ArcMap, allowing for the visualization of water depths and centers of diversity within wetlands and across the study area. Level logger data was downloaded and loggers re-deployed. All logs were successful, with fine-scale temporal hydrological trends now available for further analysis.

As of 3/31/15
Water samples from Delta wetlands were collected in March and water samples analyzed. Plant identification continued, with expert assistance on a number of voucher specimens. Spatial data analysis for land use/ land cover was begun in ArcMap. Water quality data was analyzed for significance, with the summer conductivity measurements being the significantly different between loading patterns. Analyses on soil data found that soil organic matter was correlated with the surrounding landscape, with a stronger correlation as a larger buffer around the wetland is included. Diversity indices were calculated for subset of 12 wetlands, with naturally occurring wetlands having lower diversity and evenness than restored wetlands.

Problems Encountered:

As of 6/30/14
Problems were encountered in setting up the grant fund and in our timeline for site selection. The fund was not set up until March 31, 2014. This prevented our purchasing the required research materials until one month into the intended timeline. The process of site identification also took much longer than anticipated, with the majority of landowner permission being secured in mid to late April. These factors resulted in us being unable to conduct the intended March and April water and soil sampling. Thus, our first round of vegetation sampling (which was conducted on schedule in May) was concurrent with the first water and soil sampling.

As of 9/30/14

During the sampling period in August, active management (mowing) of one wetland previously identified by the landowner as a reference wetland was discovered. Although much of the wetland was mown, enough undisturbed area remained to gather required data.

As of 12/31/14 and 3/31/15

None

Publications/Presentations (Please provide a citation and if possible a .PDF of the publication or PowerPoint):

As of 6/30/14, 9/30/14, 12/31/14
There are no publications or presentations thus far.

As of 3/31/15
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, 08 April 2015.

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

Student Training (list all students working on or funded by this project)

Name	Level	Major
Cory Shoemaker	Doctoral Student	Biological Sciences
Evelyn Windham	Master's Student	Biological Sciences

Next Quarter Plans:

As of 6/30/14
In the next quarter, we plan on conducting our late season sampling of vegetation, water, and soil at all sites. This is scheduled to occur in late July/August. Identification of voucher samples will continue as will the creation of geospatial maps for use in future analyses. Soil samples will be submitted for nutrient analysis and results compiled. Finally, a database will be created for this project to ease data compilation and analysis.

As of 9/30/14
In the next quarter, we plan to finish data compilation, including plant identification, and enter all remaining data into the database. Water level data will be downloaded from level loggers in late October-early November. USDA site history records will be obtained and landowners contacted to ascertain management history/procedures. Data analysis will begin with basic statistical tests and proceed forward, with procedures following those outlined in the proposal. Construction of geospatial maps will continue and preliminary results will be compiled.

As of 12/31/14
In the next quarter, USDA site history records will be obtained and landowners contacted to ascertain management history/procedures. All plant vouchers will be identified and data entry finished. Basic and advanced descriptions of data obtained will be formulated, including starting statistical analyses. These data will be compiled and formatting to allow for the development of presentations and publications.

As of 3/31/15
In the next quarter, USDA site history records will be obtained and landowners contacted to ascertain management history/procedures. Local (site specific) management practices will be ascertained. Sampling will occur in May, with water quality and plant cover parameters collected from all 30 sites. Level logger data will be downloaded for an understanding of winter water dynamics. Landscape land use and land cover will be quantified for varying spatial scales around wetlands and within watersheds. Diversity indices will be calculated for the remaining sites and plant identification will continue, with consultation from experts. Finally, research will be presented at local and international conferences of water and wetland professionals.

Section III. Signatures

Project Manager **Date**

Project Manager **Date**

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:	2/28/2015
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.

Mississippi Water Resources Research Institute (MWRRI)

Quarterly Report – (From) MM/DD/YY – (To) MM/DD/YY

Reports due: 1st (March 31); 2nd (June 30); 3rd (Sept. 30); 4th (Dec. 31)

Note: Please complete form in 11 point font and do not exceed two pages. You may reference and append additional material to the report.

SECTION I: Contact Information

Project Title: Water Quality in Bangs Lake: effects of recurrent phosphate spills to a coastal estuary
Principal Investigator: Kevin S. Dillon
Institution: University of Southern Mississippi – Gulf Coast Research Lab
Address: 703 East Beach Dr. Ocean Springs, MS 39564
Phone/Fax: 228-818-8018
E-Mail: kevin.dillon@usm.edu

SECTION II: Programmatic Information

Approximate expenditures during reporting period:

Federal: $22,000 (est.), Non-Federal (MWRRI): $22,000, Non-Federal (Dept.): $16,000 (est.), In-Kind: $0, Total Cost Share: $22,000 (est.)

Equipment (and cost) purchased during reporting period:

As of 6/30/14
Continuous air sampling pumps to collect airborne dust for phosphate analysis have been ordered and should arrive by July 1. Cost ($3400) was more than budgeted in the proposal so the pumps have been ordered by Dillon with his USM discretionary funds. Supplies for processing sediment cores (syringe filters, etc.) have been ordered but not yet arrived or billed.

Progress Report (Where are you at in your work plan):

As of 6/30/14
PIs and student interns had first meeting on May 29th to review the goals and methods of the research project and familiarize students with the Grand Bay NERR location and staff. The first field sampling trip was conducted on June 5. All three groups collected sediment cores for various chemical and biological analysis and phosphate adsorption experiments.

At USM, the 2 interns centrifuged 5cm core sections to extract pore water for nutrient analysis and also dried and homogenized core sections to prepare clean sediments to use in the adsorption experiments. USM interns have also been trained in lab safety and nutrient analysis.

The DISL (Carmichael) group conducted a sampling trip on June 19 to begin collecting surface sediment cores for porewater nutrient analyses, particulate organic phosphorus and Lead-210 analysis. The first set of cores, collected in Bayou Heron, have been processed but not yet analyzed.

The UWF group (Caffrey) began grain size analysis on samples collected on June 5th. A preliminary nitrogen fixation assay was conducted and analyzed by FID-GC. UWF students have had lab safety training, learned basic laboratory procedures and how to use a gas chromatograph.

As of 9/30/14

Dillon USM group

Phosphate adsorption experiments with sediment core sections are ongoing. Pore water phosphate concentrations from sediment cores collected in June 2014 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 Bayou Cumbest were much lower (<0.7 uM), likely reflecting background levels. Additional sediment cores were collected along a transect in Bangs Lake in August 2014. Analysis of particulate phosphorus concentrations in the cores is ongoing. 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 near saturation. These results show that sediments in Bangs Lake are a major sink for excess phosphate introduced to Bang Lake from industrial spills. The potential release of sediment-bound phosphate back into the water column due to sediment resuspension and/or changes in ionic strength with salinity is currently under investigation.

Air pumps for collecting atmospheric dust were deployed at the Grand Bay NERR and an inland reference site during July 2014 on modified rain collectors. Several filters have been collected from each site and are awaiting phosphorous analysis.

Caffrey UWF group

Surface sediment samples from multiple locations in Grand Bay were collected for analysis of chlorophyll a, extractable phosphorus, and ammonium. Samples were also collected for measurement of nitrogen fixation using the acetylene reduction method which has been a standard technique for measuring nitrogen fixation since the 1970s. In 2013 and 2014, sediment chlorophyll a concentrations were higher in Bangs Lake which is near the gypsum stack compared to Bayou Heron. Sediment chlorophyll a was significantly correlated with extractable phosphate concentration in sediments ($r = 0.88$), but not extractable ammonium concentrations. Sediment nitrogen fixation rates were very low compared to literature values. However, nitrogen fixation was also significantly positively correlated with extractable phosphate concentrations ($r = 0.92$) and negatively correlated with extractable ammonium concentrations ($r = -0.69$). In addition, grow out experiments with amendments of phosphorus to water and sediment samples stimulated the growth of cyanobacteria which were capable of fixing nitrogen. These data, while preliminary, suggest that phosphorus inputs can stimulate cyanobacteria and benthic microalgae in Grand Bay.

Carmichael DISL group

Two sediment cores were collected from each of four sites in Bangs Lake, and two cores were collected from each of two sites in Bayou Heron, a site more remote from the spill area. The cores were collected using an 8 cm diameter X 50 cm long PVC corer. The sediment cores were sectioned using clean methods at 1cm intervals down to approximately 24 cm. Each section was homogenized, dried, weighed for bulk density, and ground via mortar and pestle. Each core section was analyzed for grain size, particulate organic phosphorus concentration, and porewater phosphate concentratio. Core sections are being prepared for by Lead-210 activity to trace historical phosphorus inputs to each site. The average bulk densities of the sections from Bangs Lake were greater than those from Bayou Heron. These data will provide a spatial and temporal record of phosphorus additions and retention within Bangs Lake to inform companion studies on water quality and primary production as well as future studies of effects on biota.

As of 12/31/14

Dillon USM group

Airborne dust samples began to be analyzed for phosphate concentrations. Results from time series collection of filters suggest that filters should be collected every 10-14 days for best results. Dust collections continue at Grand Bay and the reference site in west Jackson County.

Caffrey UWF group

All field work and experiments have been conducted and the results are being interpreted.

Carmichael DISL group

Core sections are being prepared for by Lead-210 activity to date phosphate peaks measured in sediment cores. These data will provide a spatial and temporal record of phosphorus additions and retention within Bangs Lake to inform companion studies on water quality and primary production as well as future studies of effects on biota.

As of 3/31/15

Dillon USM group

Airborne dust samples continued to be analyzed for phosphate concentrations and extraction efficiencies were evaluated. Dust collections continue at Grand Bay and the reference site in west Jackson County.

Caffrey UWF group

All field work and experiments have been conducted and the results are being interpreted. A poster presentation of the project was presented by Caffrey at the 2015 ASLO Aquatic Science meeting in Grenada, Spain.

Carmichael DISL group

The first sediment core sections were analyzed for Lead-210 activity to date phosphate peaks measured in sediment cores. Additional analysis of remaining samples will be conducted with a no cost extension in Year 2.

Problems Encountered:

As of 6/30/14, 9/30/14, 9/30/14
None

As of 3/31/15
Our reference site dry deposition collector for phosphate in dust was repeatedly contaminated by birds. Deterrents were placed around the collector in hopes of solving this problem.

Publications/Presentations (Please provide a citation and if possible a .PDF of the publication or PowerPoint):

As of 6/03/14
None

As of 9/30/14
Three poster abstracts (one for each group) have been submitted and accepted for the upcoming Bays and Bayous 2014 conference in December.

As of 12/31/14
Three posters presented at the 2014 Bays and Bayous symposium:

1- Uptake of excess phosphate by estuarine sediments in Bangs Lake, Sarah Holcomb, Chris Griffin, Joshua Allen, Kevin Dillon, Kimberly Cressman, Mark Woodrey

2- Sedimentary records of recurrent phosphate spills to a Gulf of Mexico estuary, Jacob Hall, Pavel Dimens, Elizabeth D. Condon, Ruth H. Carmichael, Kimberly Cressman

3- Response of benthic macroalgae to phosphorus inputs in Grand Bay National EstuarineResearch Reserve, Jane Caffrey, Tashana Jones, Kaleb Price, Lorenzo Modestini, Cheyene Hunt-Alderson, Kim Cressman, Mark Woodrey

As of 3/31/15
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.

Student Training (list all students working on or funded by this project)

Name	Level	Major
Chris Griffin	senior USM	Biology
Sarah Holcomb	junior USM	Geology
Jason Hall	post-bachelor DISL	Biology
Pavel Dimens	post-bachelor DISL	Biology
Kaleb Price	junior UWF	Marine Biology
Tashane Jones	junior UWF	Biology

Next Quarter Plans:

As of 6/30/14
Sediment-phosphate adsorption experiments will be conducted with sediments collected from Bangs Lake, North Bangs Lake and Bayou Heron.

Begin collecting dust samples with air sampling pumps and dry deposition collectors at Grand Bay and inland reference sites.

Sediments will be collected for measurement of chlorophyll a and other pigments at Bangs Lake, Bangs North, Bangs Creek, Bayou Cumbest and Bayou Heron. Nitrogen fixation assays will be conducted on sediments from Bangs North, Bangs Creek and Bayou Heron.

Continue surface sediment sampling from Bayou Heron and 4 sites in Bangs Lake, complete processing of all sediment cores, begin analysis of sediment grain size, bulk density, porewater nutrients, particulate organic phosphorus, and dating.

As of 9/30/14
Continue analysis of particulate phosphate concentrations from sediment cores as well as dissolved phosphate concentrations in porewater. Lead-210 activities will be measured on sediment core sections to date the sediment core layers in 1cm increments. Additional field trips will be conducted to fill in spatial gaps in the data. Analysis of dust filters will be conducted and additional filters will continue to be collected until May 2015.

As of 12/31/14
Lead-210 activities will be measured on sediment core sections to date the sediment core layers in 1cm increments. Analysis of dust filters will be conducted and additional filters will continue to be collected until May 2015.

As of 3/31/15
Lead-210 activities will be measured on sediment core sections to date the sediment core layers in 1cm increments. Analysis of dust filters will be conducted and additional filters will continue to

be collected until May 2015.

Results will be presented at the 2015 Mississippi Water Resources meeting in Jackson, MS.

Student interns are currently being recruited and will begin working on Year 2 research in May 2015. Planning and coordination for the water tracer field experiment with partners is proceeding.

Section III. Signatures

Project Manager **Date**

Kevin S. Dillon

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 with MWRRI's member Institutions of Higher Learning, MSU's Extension Service and REACH program are uniquely positioned to advance and sustain the transfer and application of knowledge gained through MWRRI's integrated water resources research approach. As a function of its role as an information hub on water resources issues within the state and region, MWRRI routinely uses Extension and REACH 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:

Quantifying responses of water quality and wetland plant communities is an important project that will provide the basis for a decision support tool under development by the Natural Resources Conservation Service (NRCS) for use in its Wetlands Restoration Program.

Quantifying the impacts of recurrent phosphate spills to Bangs Lake, located adjacent to the Grand Bay Natural 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.

Enid Lake is one of four major flood control reservoirs in north Mississippi operated the U.S. Army Corps of Engineers and is listed as impaired by Mercury by the Mississippi Department of Environmental Quality. The lake's outlet, the Yocona River, is also listed as impaired. An assessment of the transport, fate, and risk of Mercury is essential to understand the restoration potential for these waterbodies.

The Delta, Mississippi's primary row-crop agricultural area, has been experiencing significant groundwater level declines due to the rapid expansion of irrigation. Quantification of recharge to the underlying Mississippi River Alluvial Aquifer is vital to develop a useful water budget and manage the resource sustainably. Recharge through wetlands is one of the components needing quantification.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	9	0	0	0	9
Masters	2	0	0	0	2
Ph.D.	3	0	0	0	3
Post-Doc.	0	0	0	0	0
Total	14	0	0	0	14

Notable Awards and Achievements

Center of Excellence for Watershed Management. Through the expertise and dedication of its academic and professional staff, MSU and the MWRRI have earned enviable reputations for their water resources-related work. As a result of this recognition, on April 9, 2013, MSU through the MWRRI was designated by Region 4 of the U.S. Environmental Protection Agency(EPA) 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 to maintain the designation are also identified in the MOU.

MOA with Alabama. Water resources became the focus of a newly-signed Memorandum of Agreement (MOA) with the Mississippi Water Resources Research Institute, the University of Alabama Water Policy and Law Institute, and the Auburn University Water Center. The focus of the MOA is to advance interdisciplinary water science, policy, law, economic development, ecosystems, drinking water quality, groundwater, aquifer and watershed management, and capacity building.

Other Accomplishments. MSU routinely strives to increase state support for MWRRI’s activities, and over the past several years MSU has been successful in increasing WRRI’s legislatively-supported budget by $120,000 annually. Additionally, recognizing the desirability of collaborative, integrated water resources research and management, MSU has consistently leveraged numerous university programs to support MWRRI and will continue to do so in the future.