# Water Resources Center
# Annual Technical Report
# FY 2011

# Introduction

The Minnesota WRRI program is a component of the University of Minnesota's Water Resources Center (WRC). The WRC is a collaborative enterprise involving several colleges across the University, including the College of Food, Agriculture and Natural Resource Sciences (CFANS), University of Minnesota Extension, and the Minnesota Agricultural Experiment Station (MAES). The WRC reports to the Dean of CFANS. In addition to its research and outreach programs, the WRC is also home to the Water Resources Science graduate major which offers both MS and PhD degrees and includes faculty and students from both the Twin Cities and the University of Minnesota - Duluth. The WRC has two co-directors, Professor Deborah Swackhamer and Faye Sleeper, who share the activities and responsibilities of administering its programs.

# Research Program Introduction

The WRC funds 3-4 research projects each year, and the summaries of the current projects are found in the rest of this report.

# The Role of Sulfate Reduction in Sediment of the St. Louis River Estuary

## Basic Information

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| **Title:** | The Role of Sulfate Reduction in Sediment of the St. Louis River Estuary |
| **Project Number:** | 2010MN269B |
| **Start Date:** | 7/1/2010 |
| **End Date:** | 6/31/2011 |
| **Funding Source:** | 104B |
| **Congressional District:** | MN 8th |
| **Research Category:** | Water Quality |
| **Focus Category:** | Sediments, Toxic Substances, Geochemical Processes |
| **Descriptors:** | |
| **Principal Investigators:** | Nathan Johnson |

## Publication

1. Beck, B. F. and N. W. Johnson. 2011. Sulfur and Carbon Controls on Methylmercury in St. Louis River Estuary Sediment. SETAC North America, Boston, MA. Beck, B. F. and N. W. Johnson. 2011. Characterizing the Relationship Between Sulfate Reduction and Mercury Methylation in St. Louis River Sediment. Minnesota Water Resources Conference, St. Paul, MN.

**The Role of Sulfate Reduction in the St. Louis River Estuary**

**Principal Investigator**
**Nathan Johnson, Assistant Professor, Department of Civil Engineering**

**Funding Source: USGS –WRRI 104B/CAIWQ Grants Program**

**Project Duration:** **7/1/2010-6/31/2011**
**Reporting Period:** **3/1/2011-2/28/2012**

**Project Status**

The project reported on in this report is part of a two year study that was funded jointly by the USGS and MnDNR. The first phase was completed during Summer 2010 through winter 2011, and a final report was submitted last year. The second phase (described herein) has been ongoing from Summer 2011 through Summer 2012. An extension for the project was requested and granted through August 2012. As such, some data is still being analyzed and this should be considered an interim report, with a complete report to follow by early Fall, 2012.

**Introduction and Objectives**

The St. Louis River watershed is located in Northeast Minnesota, which ultimately discharges into Lake Superior near Duluth, Minnesota. It has been demonstrated that the St. Louis River main stem and estuary are impacted by mining activities, artificially raising sulfate concentrations (Berndt and Bavin, 2010). This report is a continuation of the investigation on the relationship between water column sulfate concentration and methylmercury. While the Berndt and Bavin 2010 study focused primarily on watershed scale relationships between methylmercury and sulfate in the water column, this study is attempting to understand the mechanisms of mercury methylation in a sediment matrix.

Sulfate reducing bacteria have been implicated as the prime methylators of mercury, creating methylmercury, a bioaccumulative neurotoxin (Ratcliffe et. al., 1996). Sulfate reducing bacteria occur in anoxic, aquatic environments, and require two substrates to exist, sulfate and organic carbon

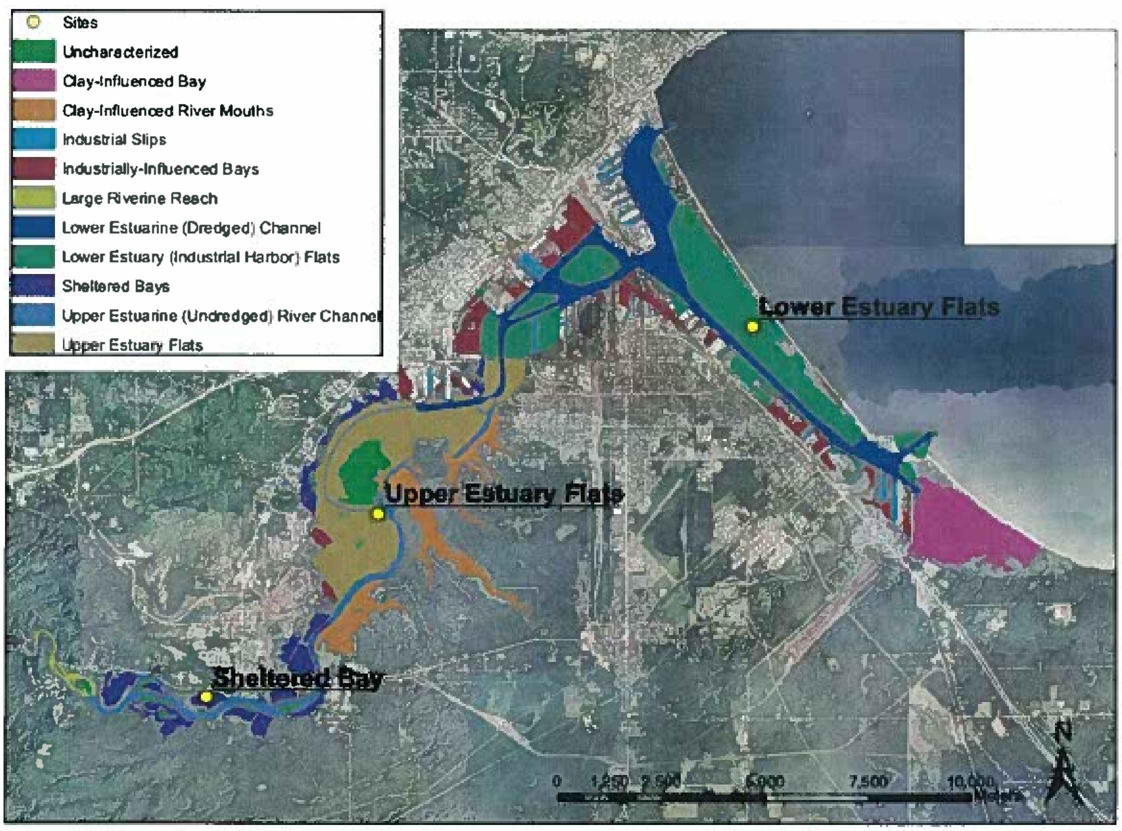


Figure 1. The St. Louis River Estuary with the Habitat Zones delineated and tites (yellow symbols) that were sampled in August 2011 to obtain cores for sulfate addition experiment.

(Froelich et. al., 1979). A traditional thought model exists in which sulfate and organic carbon limit sulfate reducing bacteria's ability to transform inorganic mercury to methylmercury (Gilmour, et. al. 1991; Lambertsson and Nilsson, 2006). Although these limiting factors have been observed in both freshwater and estuarine systems, a linear relationship does not exist between sulfate and methylmercury in all cases (Harmon et. al., 2007; Benoit et. al, 1999). There are complex biogeochemical mechanisms that control mercury cycling in sediment, which is why it cannot be assumed that increasing water column sulfate concentrations will necessarily increase methylmercury concentrations in the sediment and ultimately the water column (Benoit et. al., 2003).

In the St. Louis River Estuary, an ongoing investigation is being conducted to understand that relationship between sulfur geochemistry and methylmercury production. The first phase study's objective was to quantify the in-situ parameters to understand the bulk geochemical characteristics of a sulfate impacted system (Johnson and Beck, 2011). The results from the first phase study were used to guide the decision making for the phase of the study. The objective of the second year study is to understand the mechanisms which limit or promote mercury methylation in a variety of sediment types. This objective will be met by incubating three different sediment types with varying sulfate concentrations to ultimately determine if sulfate is the limiting factor for mercury methylation in sediments of the St. Louis Estuary.

The objectives of this study are two-fold, a management related objective and a scientific related objective. The management related objective is to determine whether or not increasing or decreasing sulfate in the overlying water will increase or decrease mercury methylation. Since the dynamics of methylmercury are complex, an in depth mechanistic study may provide evidence whether changing water column sulfate concentrations will alter production of MeHg. Secondly, a scientific question will be answered at the conclusion of this experiment. While there have been investigations into sulfate influences in saltwater estuaries and freshwater wetlands, there have been few studies determining MeHg limitations in sulfate-impacted freshwater estuaries. These experiments will give additional insight into the geochemical dynamics of freshwater estuary sediments related to methyl mercury production.

## Methods, Procedures, and Experimental Design

### Site Selection

Sites were selected along a reach of the St. Louis Estuary from upstream to downstream, to obtain a variety of habitat zones that have been outlined by the St. Louis River Alliance (SLRA). The three different habitat zones that were selected were the Lower Estuary Flats (LEF), Upper Estuary Flats (UEF), and Sheltered Bays (SB) which are shown in Figure 1. The sites were selected for two reasons. First the sites are known to have varying geochemical and physical parameters (Johnson and Beck, 2011) likely to influence mercury-related geochemistry. Sites were selected along an organic carbon gradient, since organic carbon (in the solid phase) can influence the production of methylmercury (Lambertsson and Nilsson, 2006). The most upstream site (Sheltered Bay) has been characterized as having the highest TOC solid phase concentrations while the most downstream site has the lowest solid phase TOC concentrations (Johnson and Beck, 2011).

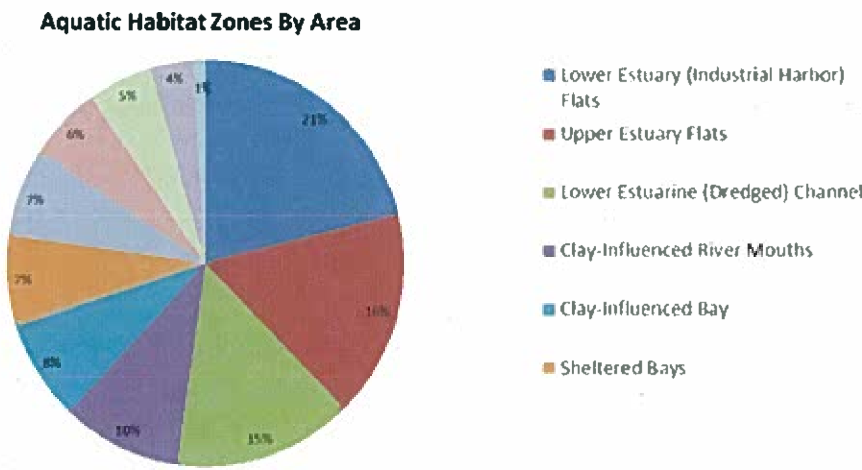


Figure 2. Each habitat zone by percent area within the St. Louis River Estuary. The four zones select for this study accumulate to 45% of the total area in the estuary.

The second criterion for site selection was to sample areas that were the most prevalent (in terms of areal coverage). The sites selected for this study are from habitat zones that cover 45% of the entire estuary/harbor (Figure 2).

<u>Field and Analytical Methods</u>

The cores obtained from the field were allowed to equilibrate in the experimental conditions (20° C and 60% relative humidity) for 1 week, after which a microelectrodes were used to measure porewater sulfide ($S^{2-}$), ferrous iron ($Fe^{2+}$), and manganese ($Mn^{2+}$) (Brendel and Luther, 1995) (Figure 4). Microcosms were then sub-cored in triplicate (~1" diameter sub-core) and split into three depths (0-4cm, 4-10cm, and 10-20 cm), placed in 250 mL sample jars and placed in an oxygen free atmosphere within 15 minutes of extrusion. Sediment samples were then homogenized under a nitrogen atmosphere and subsampled for each analysis. If solid phase samples were not immediately analyzed, aliquots of sediment were placed in acid cleaned scintillation vials and placed in a -20° C freezer.

Porewater sulfate and was measured after centrifuging the extruded sediment, using an ion-chromatograph (Dionex 1100). Acid volatile sulfides (AVS) were measured using the Brouwer diffusion method (Brouwer and Murphy, 1994). Solid phase ferrous iron was measuring using an oxalic acid extraction followed by colorimetric analysis (Phillips and Lovley, 1987). Methylmercury and total mercury were measured using isotope dilution and ion-coupled mass spectrometer (GC-ICP-MS), respectively (Bloom, 1989). Sulfate reducing bacteria abundance as measured using quantitative PCR (qPCR) after a solid phase extraction using a Mo-Bio Powersoil. extraction kit (Schippers and Neretin, 2006).

<u>Experimental Design</u>

As mentioned above, the objective of this study is to determine the limiting factor for mercury methylation in the St. Louis River Estuary sediment. In light of ongoing and proposed mining operations on the Mesabi Iron Range, as well as discussions about state regulations for sulfate, it is possible that sulfate loading to the St. Louis River watershed could increase or decrease in the relatively near future.

The experiment in this report was designed to answer the question of whether sulfate is limiting the component in the St. Louis River sediment relative to the methylation of mercury.

Three replicate microcosms (sediment cores) were obtained from each habitat zone (Figure 1) using a custom fabricated sediment corer and transported to a climate control chamber. To determine if sulfate is the limiting factor in mercury methylation in the St. Louis River Estuary, each sediment type (LEF, UEF, and SB) had three different treatments applied for a period of 6 months. The treatments were applied by allowing water amended with a high (50 mg/L), control (15 mg/L), and low (2.5-5 mg/L) amount of sulfate to recirculate over each type of sediment to allow sulfate to passively diffuse into the sediment, as it would in a riverine environment. To ensure a carbon limitation was not imposed on the in-situ microbial communities, water from the Cloquet River, was used as the experimental treatment matrix. Cloquet River water was selected as the experimental matrix because it has low sulfate (2.5-5 mg/L $SO_4^{2-}$) while having similar DOC concentrations to the St. Louis River (~30-40 mg/L).

Two different types of sampling methods were used in this study, destructive and non-destructive techniques. The destructive techniques required sub-cores to be removed from the microcosms. The destructive techniques could only be used to characterize the geochemical and microbial initial and final conditions. Voltammetric electrodes (non-destructive analytical method) were used every 1.5 months to measure redox sensitive parameters in the microcosm porewaters (Figure 4). These were used to observe whether there were any temporal changes in the redox conditions due to the treatments being applied to the microcosms over a 6 month period. Although porewater measurements were obtained every 1.5 months, only the initial will be presented in this report.

## Results and Discussion

## Porewater

Figure 3a-f depicts sulfate concentrations in each microcosm with depth. The sediment microcosm initial conditions display sulfate consumption in all cores (3a-c) with sulfate being consumed most rapidly in the SB cores, relative to the LEF and UEF cores. There was no detectible sulfate within the upper 4 cm of the sediment in the SB cores, while the UEF and LEF cores both had sulfate in the 0-4 cm interval. It is likely that due to higher organic carbon availability in the SB site, sulfate reduction occurred at a higher rate relative to the LEF and UEF cores. There was a clear relationship between sulfate penetration and microcosm treatment type (Figures 3d-f). In all microcosm treatments, sulfate was completely consumed at the 10-20 cm depths (Figure 3d-f) at the close of the experiment.

Porewater concentrations of redox sensitive analytes are displayed in figure 4a-j. The porewater in upper Upper Estuary Flats and Lower Estuary Flats displayed significant dissolved $Mn^{2+}$ with no detectible $Fe^{2+}$ or $S^{2-}$ (Figure 4a-f). The Sheltered Bay site porewater had trace amounts of sulfide (3-10 uM $S^{2-}$) and higher ferrous iron concentrations (150-400 uM $Fe^{2+}$), with no detectible $Mn^{2+}$ (Figure 4g-j). Thermodynamically, manganese reduction is a more favorable reaction, which means this will occur before sulfate and iron reduction in the sediment column. It was observed that the sheltered bay site was thermally stratified, which indicated an anoxic hypolimnion. In the case of a stratified hypolimnion, it is likely that manganese reduction had moved into the water column, moving iron reduction and sulfate reduction closer to the sediment water interface, at depths the microelectrodes can measure (0-15cm). It is possible that iron and sulfate reduction may occur deeper in the sediment column at UEF and LEF, past the reach of the electrodes. Although measurements were taken at four different time points, only the initial conditions will be presented in this report for redox sensitive porewater concentratrions.

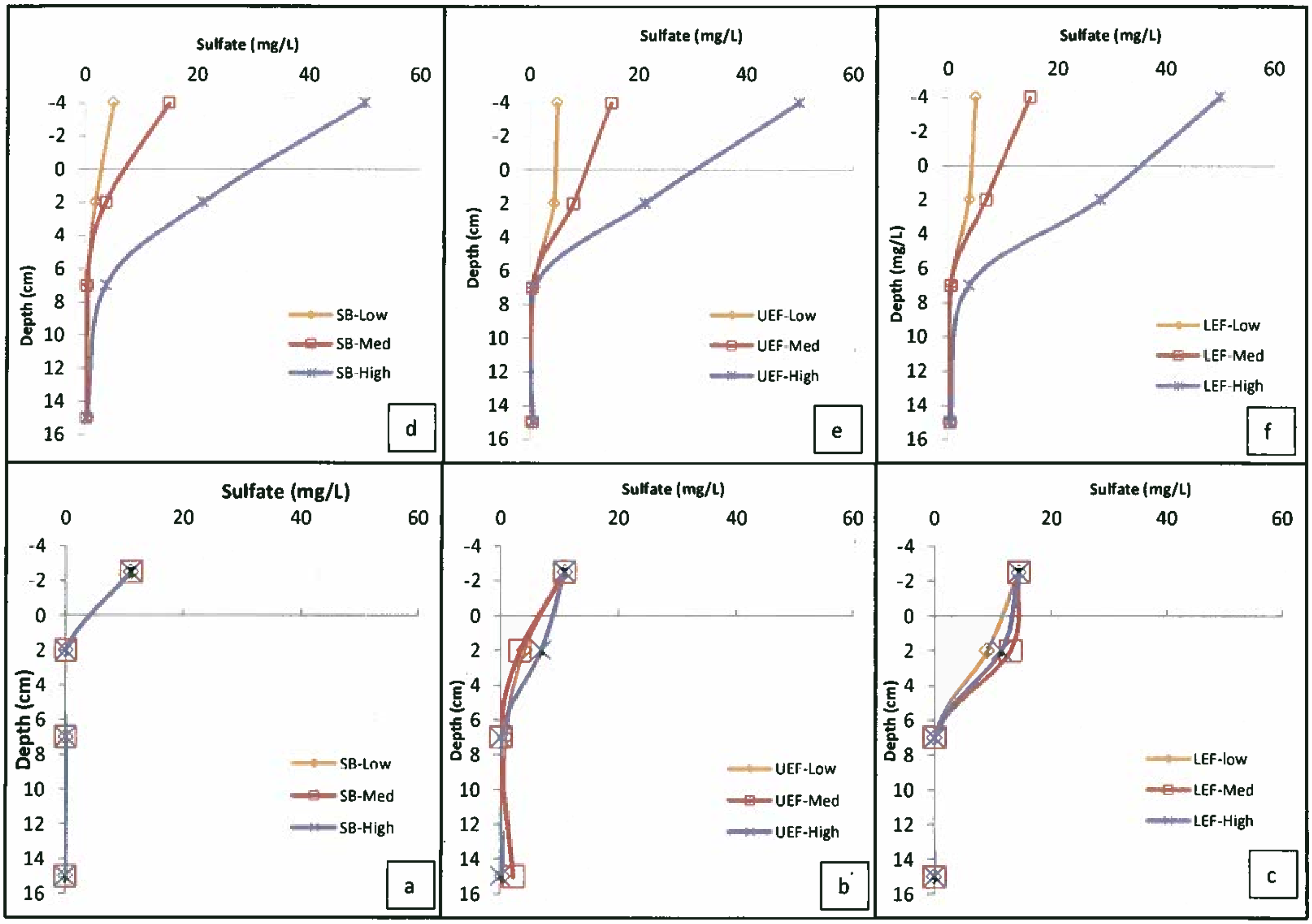


Figure 3. Porewater sulfate profiles for each treatment for the Initial Condition(a-c) and Final Conditions (d-f) Sheltered Bays (SB), Upper Estuary Flats(UEF), and Lower Estuary Flats (LEF).

## Solid Phase

Solid phase AVS is depicted in figure 5a-f for all microcosms initial and final conditions. The SB site had the highest abundance of AVS (figure 5a). Conversely, the LEF and UEF (Figures 5b and c) sites had the lower AVS which agrees with the lower diagenetic activity displayed in Figure 4. Higher organic carbon (Johnson and Beck 2011) and anoxic water column conditions at the SB site likely lead to higher in-situ sulfate reduction relative to the upper estuary and lower estuary flat sites.

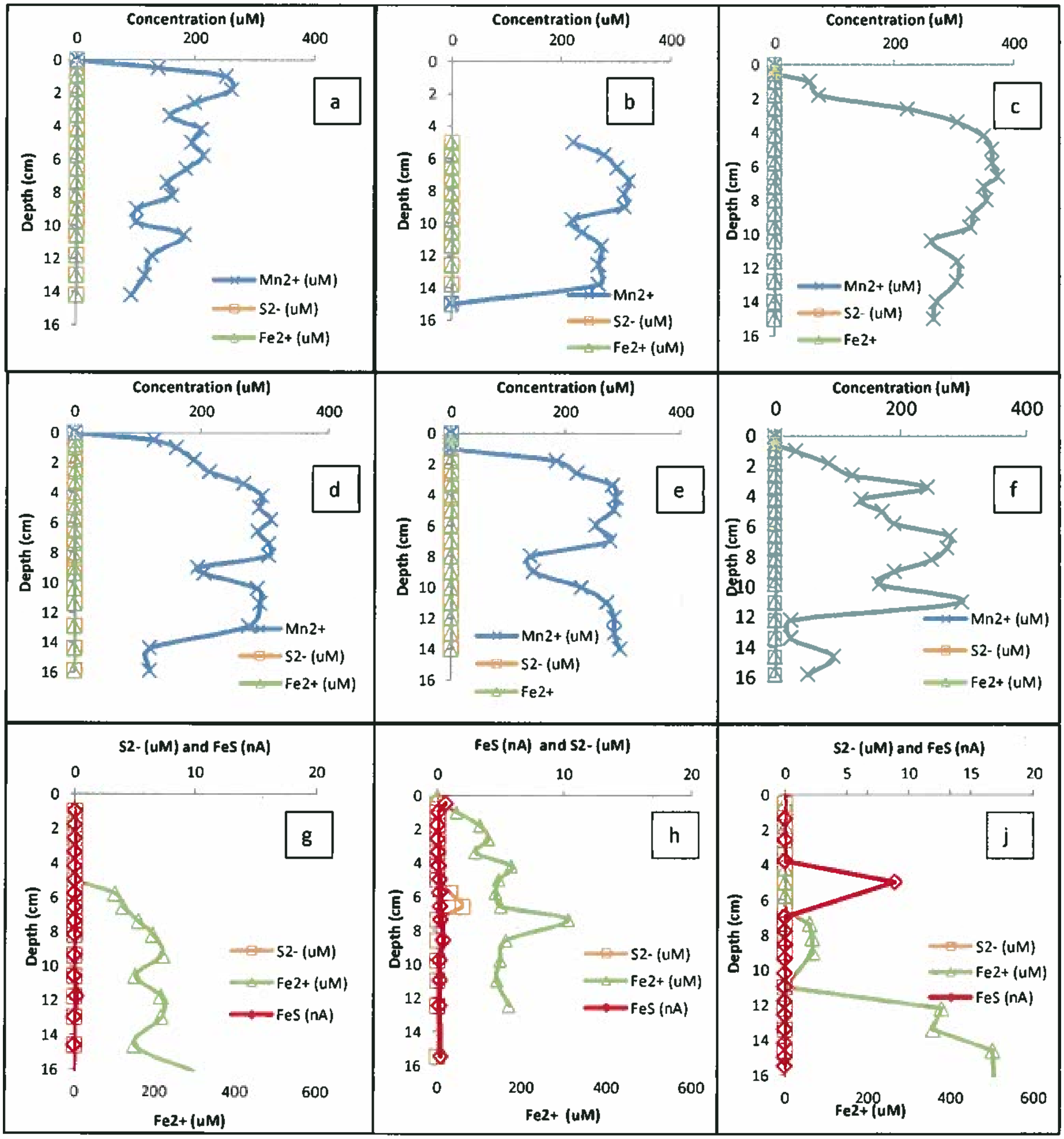


Figure 4. Initial condition porewater redox profiles for the LEF (low (a), medium (b), high(c)), UEF (low(d), medium(e), and high(f)), and SB (low (g), medium (h), and high(j).

AVS appears to change from initial conditions moste in the surface of SB sediment (due to oxidation from oxygen-containing overlying waters) and from 4-10cm in UEF for sulfate amended treatments.

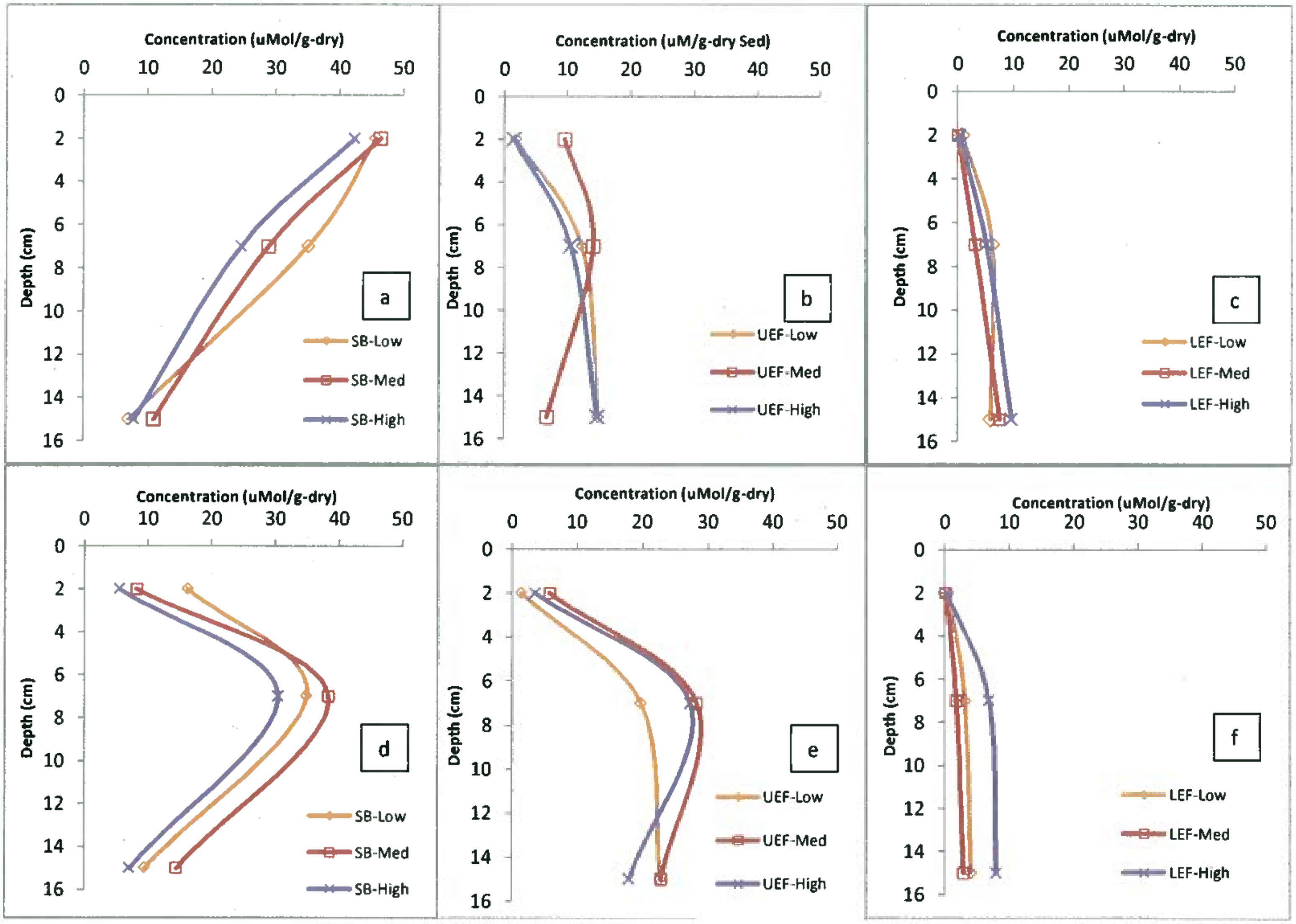


Figure 5. Acid Volatile Sulfide profiles for each treatment for the Initial Condition(a-c) and Final Conditions (d-f) Sheltered Bays (SB), Upper Estuary Flats(UEF), and Lower Estuary Flats (LEF).

SRB abubundace was measured in the solid phase and is depicted in Figures 6a-f. Initially, the SB site had the largest abundance of SRB, which would agree with the higher AVS concentration in the SB (Figure 5a). The LEF and UEF sites have smaller abundance of SRB (Figure 6 b and c) initially, similarly to the AVS solid phase concentrations. The final conditions indicate that there was an increase in SRB abundance in the top 4 cm of the SB microcosms (Figure 6d). Oxidation of solid phase sulfide in the top 4 cm coupled with anoxic conditions led to an increase in sulfate reducers in the SB high and medium treatments. Both the UEF and LEF cores saw an increase in SRB abundance in the high treatments, which likely was a result of the sulfate treatment directly stimulating the sulfate reducers. Unlike the SB site, there was not a large source of reduced sulfur that was made available due to oxidation and mobilization.

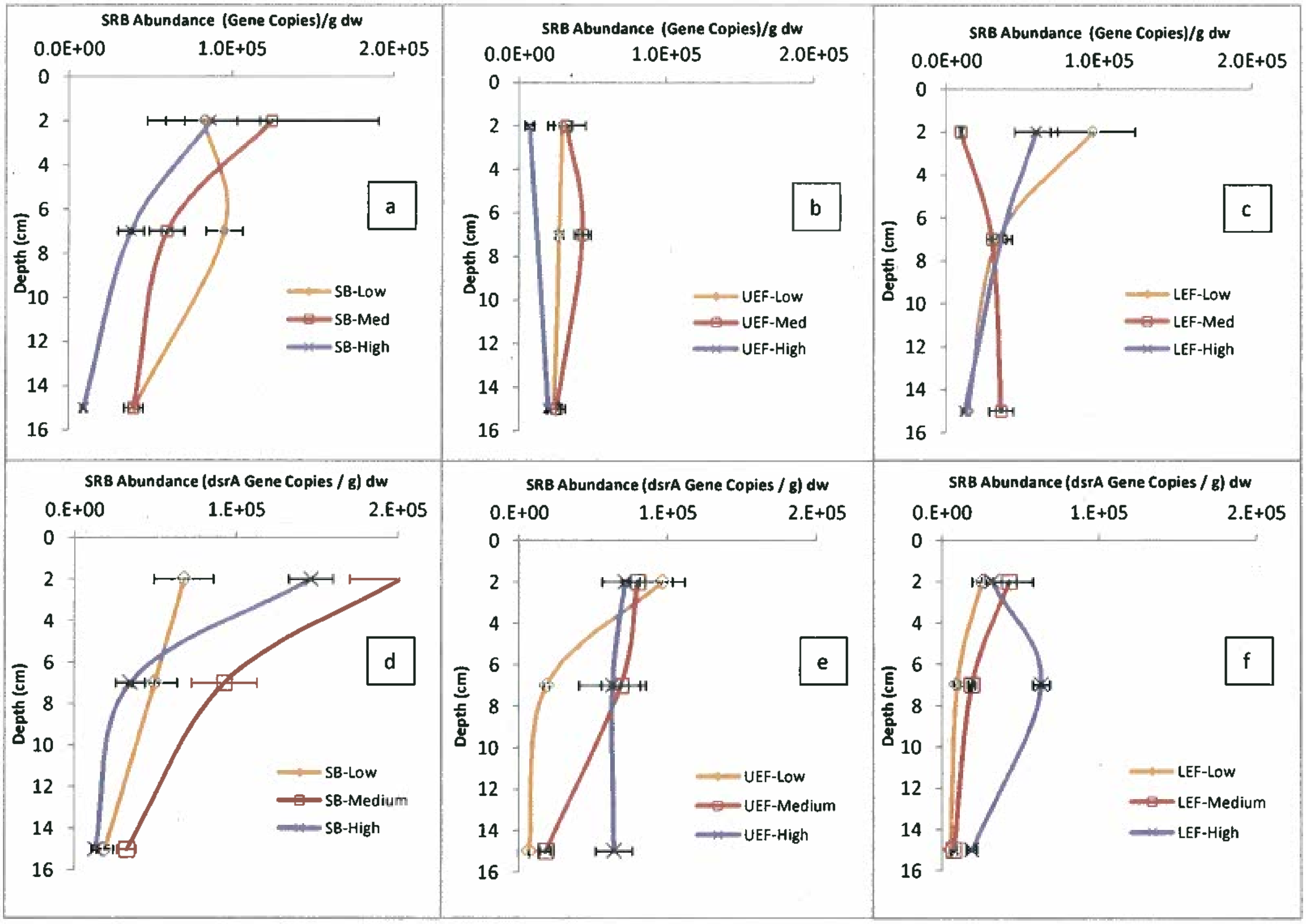


Figure 6. Sulfate Reducing Bacteria abundance for each treatment of the Initial Condition(a-c) and Final Conditions in the (d-f) Sheltered Bays (SB), Upper Estuary Flats(UEF), and Lower Estuary Flats (LEF) sites.

Solid phase ferrous iron was measured in each core, which are displayed in figure 7a-f. The LEF and SB cores had the relatively low solid phase ferrous iron (20-40 uM) compared to the UEF cores (30-240 uM). There was little change between the initial and final conditions in the LEF and UEF cores (Figure 7b, c, e, and f). Interestingly, the SB core solid phase ferrous iron increased from the initial to final sampling time points (Figure 7a and d). The change in ferrous iron concentrations is likely coupled with the change in redox conditions in the SB cores.

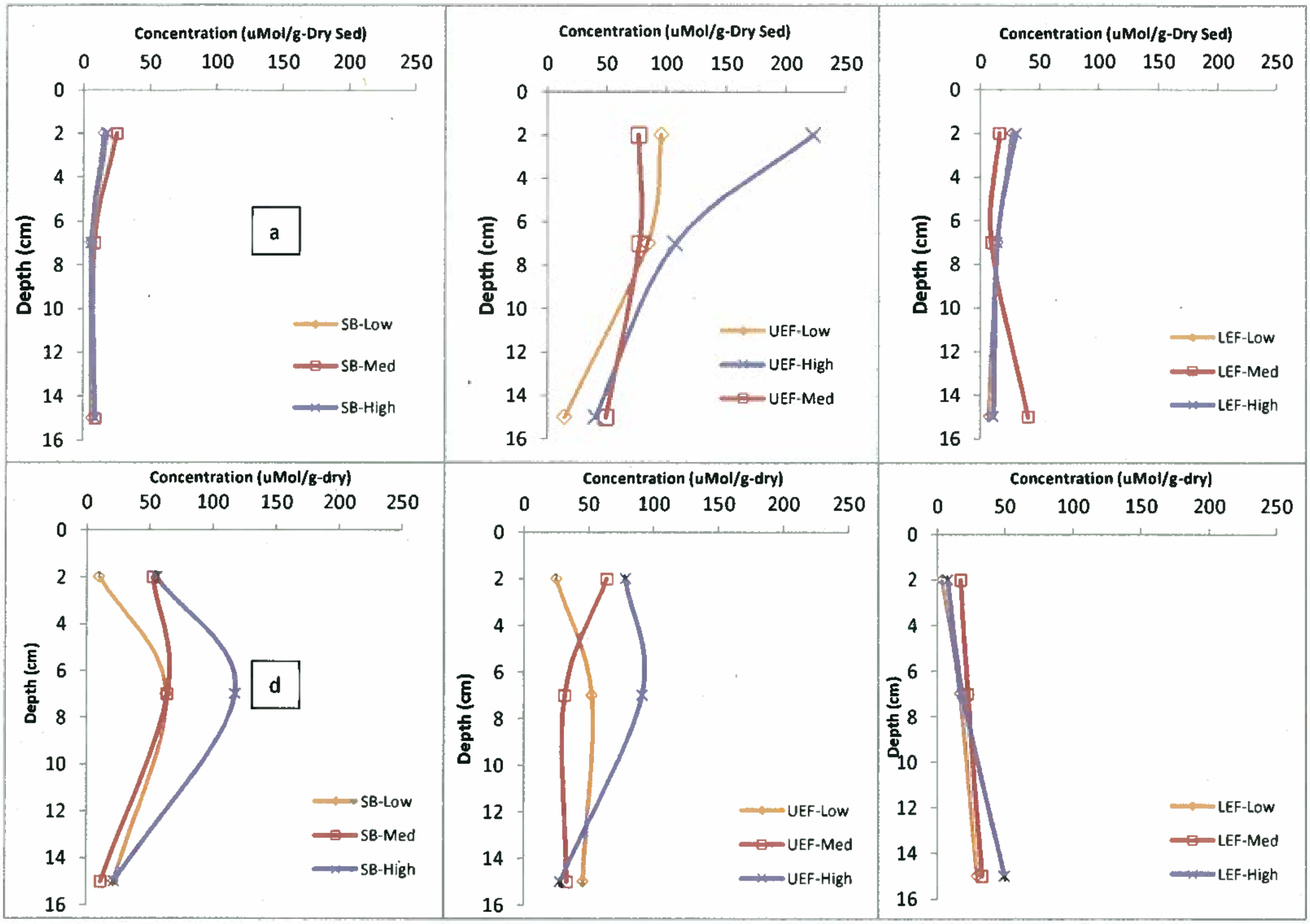


Figure 7. Solid Phase Ferrous Iron profiles for each treatment for the Initial Condition(a-c) and Final Conditions (d-f) Sheltered Bays (SB), Upper Estuary Flats(UEF), and Lower Estuary Flats (LEF).

Initial mercury results are shown in Figure 8a, b and c for THg, MeHg, and percent MeHg. The results for each site (low, medium and High) were averaged to observe trends in the initial conditions. The final time point for THg and MeHg are still being analyzed and will not be included in this report. The SB site had higher MeHg and THg concentration relative to the UEF and LEF sites (Figure 8). Although the MeHg concentrations were the smallest in the UEF site, it was a slightly more efficient methylator of mercury, using the percent MeHg as a proxy for methylation efficiency (Figure 8c). This suggests that although the SB has the highest SRB abundance and AVS, it does not produce methyl mercury much more efficiently than other sites.

## Conclusions

There are clear biogeochemical differences among the sites which are known to influence the production of methylmercury. The LEF and UEF sites can be characterized from the initial condition time point as having lower sulfate and iron reduction, due to lower organic carbon in the solid phase (Johnson and Beck 2011) and a fully oxic water column year round. The SB site is drastically different with a seasonally anoxic water column and organic carbon supplied by primary production, in a lake type ecosystem. This site has higher sulfate reduction as indicated by AVS (Figure 5) and SRB abundance (Figure 6).

Although there is higher SRB abundance, AVS, and THg, the SB site is not the most efficient methylator of mercury. Further investigation is necessary but reduced availability of inorganic mercury to SRB due to strong interactions with organic matter or sulfide ligands may be limiting the efficiency of methylation. The UEF site has the highest percent MeHg, indicating that, of the three sites, it is able to most efficiently methylate mercury. Preliminary evidence suggests that this intermediate habitat zone may contain sufficient organic carbon content to drive SRB but not an excess to limit the available pool of inorganic mercury. High porewater sulfide concentrations have been shown in some sites to limit mercury methylation but no sites in this study had porewater sulfide concentrations >10 uM.

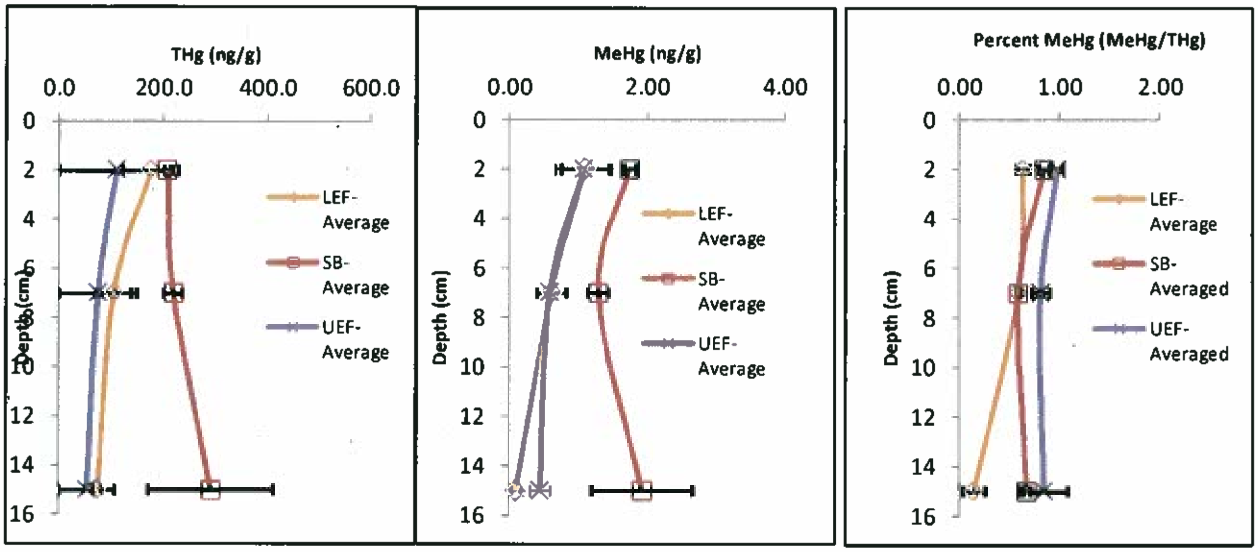


Figure 8. MeHg(a), THg (b), and Percent MeHg (c) solid phase intial condition profiles for each habitat zone.

Although MeHg and THg results have not been reported for the end of our 6 month experiment, other geochemical parameters indicate that changes in methylmercury-related biogeochemistry were induced in some sulfate treatments. All habitat zones had increased AVS and SRB abundance in the high treatments, in addition to the medium treatments (Figures 5 and 6). Both of these lines of evidence would suggest that the activity of sulfate reducing bacteria were stimulated by increased sulfate in the overlying water. Although there is evidence of stimulated sulfate reducers, a full understanding of the mechanisms of mercury methylation will be aided by the solid-phase THg and MeHg data.

## Future work

The final analytes, MeHg (solid phase and porewater), THg (solid phase and porewater), TC, TS, and DOC, need to be analyzed, which is necessary for a complete interpretation of the production of methylmercury in sediment. Once the last parameters have been analyzed a thorough explanation of the limiting factors behind mercury methylation in the St. Louis River can be synthesized. A complete analysis should answer the scientific and management related questions related to MeHg production in freshwater estuary systems and more specifically, the St. Louis River Estuary.

Although production of methylmercury is an important piece of mercury cycling, understanding the transport of MeHg from sediment into the water column is equally critical. A twofold approach to understanding transport will be taken to quantify and model the transport of MeHg. First, partitioning coefficients will be measured given porewater and solid phase MeHg and THg concentrations. Partitioning information will supply insight into the mobility of MeHg in a specific type of sediment. Secondly, flux experiments have been conducted but the analysis is not finished for MeHg. After the data is compiled and analyzed, spatially discretized models can be constructed for the St. Louis River Estuary to estimate total load to the water column. Currently, the magnitude of the MeHg load from the sediment relative to the load from upstream is currently unknown. If the sediment is a large source of MeHg and future management decisions may influence MeHg production, understanding relative loading is critical to informed decision making.

# Constraints and Opportunities Around Watershed-wide Riparian Zone Management at the Urban-rural Interface

## Basic Information

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|---|---|
| **Title:** | Constraints and Opportunities Around Watershed-wide Riparian Zone Management at the Urban-rural Interface |
| **Project Number:** | 2010MN275B |
| **Start Date:** | 5/1/2010 |
| **End Date:** | 4/30/2012 |
| **Funding Source:** | 104B |
| **Congressional District:** | 4 |
| **Research Category:** | Social Sciences |
| **Focus Category:** | Management and Planning, Non Point Pollution, Law, Institutions, and Policy |
| **Descriptors:** | |
| **Principal Investigators:** | Mae A. Davenport |

## Publications

1. Davenport, M.A. 2011. Community Capacity Rapid Assessment: Getting to Know your Community. Community Assessment Workshop, Minnesota Pollution Control Agency, St. Paul, MN, March 29, 2011.
2. Davenport, M.A. 2011. Building Capacity for Watershed Management in Local Communities. 2011 Water and Watersheds Conference, Minnesota Pollution Control Agency, St. Paul, MN, February 9, 2011.
3. Davenport, M.A. 2010. Understanding Adaptive Capacity for Sustainable Watershed Management. Water Resources Science Seminar. St. Paul, MN, December 3, 2010.
4. Davenport, M.A. 2010. The Human Dimensions of Watershed Science and Management. Metropolitan Association of Soil and Water Conservation Districts. Arden Hills, MN, November 18, 2010.
5. Davenport, M.A. 2010. Drivers and Constraints Affecting Community Capacity for Watershed Management. Cache River Symposium. Vienna, Illinois, October 12, 2010.
6. Davenport, M.A.and A. Pradhananga. 2012. Perspectives on Minnesota Water Resources: A Survey of Sand Creek and Vermillion River Watershed Landowners. St. Paul, MN: Department of Forest Resources, University of Minnesota. 84 pp. Davenport, M.A. and A. Pradhananga. 2011. Exploring a Moral Obligation Model of Riparian Buffer Management Among Landowners. Abstract. In Abstracts of the American Water Resources Association Annual Water Resources Conference, Albuquerque, NM. Davenport, M.A., A. Pradhananga, and A. Sames. 2011. The Influence of Local Governance on Watershed Management in Minnesota: Capacities, Constraints, and Catalysts of Change. Abstract. In Abstracts of the International Symposium on Society and Resource Management, Madison, WI.
7. Davenport, M.A. and A. Pradhananga. 2011. Exploring a Moral Obligation Model of Riparian Buffer Management Among Landowners. American Water Resources Association Annual Water Resources Conference, Albuquerque, NM. Yaeger, C., M. A. Davenport, K. Eckman, and E. Seekamp. 2011. Evaluating Watershed Outreach Interventions: Informing Future Outreach and Evaluations Through an Integrative Model. Poster. Minnesota Water Resources Conference, St. Paul, MN. Sames, A., A. K. Pradhananga, and M. A. Davenport. 2011. The Influence of Local Governance on Watershed

Management in Minnesota: Capacities, Constraints and Catalysts of Change. Poster. Minnesota Water Resources Conference, St. Paul, MN. Davenport, M.A., A. Pradhananga, and A. Sames. 2011. The Influence of Local Governance on Watershed Management in Minnesota: Capacities, Constraints, and Catalysts of Change. The International Symposium on Society and Resource Management, Madison, WI.

8. Pradhananga, A. and M. A. Davenport. 2012. Landowner Perspectives on Water Resource Management in the Sand Creek Watershed. Scott Watershed Management Organization Watershed Planning Commission Meeting, St. Paul, MN. Davenport, M. A.. 2012. A Social Science-based Approach to Civic Engagement and Stewardship in Watershed Management. Clean Water Council Meeting, St. Paul, MN. Davenport, M.A. and P. Nelson. 2012. Putting Targeting into Practice: Understanding and Winning the Confidence of Landowners. Freshwater Society Precision Conservation: Technology Redefining Local Water Quality Practices Conference, St. Anthony, MN. Davenport, M.A.. 2012. Community Capacity for Sustainable Watershed Management: Assessment Tools from the Social Sciences. Ecological and Water Resources Division, Minnesota Department of Natural Resources Seminar Series, St. Paul, MN. Davenport, M.A.and A. Pradhananga. 2012. Landowner Perspectives on Water Resource Management in the Vermillion River Watershed. Vermillion River Watershed Joint Powers Organization Meeting, Apple Valley, MN. Davenport, M.A. and A. Pradhananga. 2012. Landowner Perspectives on Water Resource Management in the Vermillion River Watershed. Vermillion River Watershed Technical Advisory Group Meeting, Apple Valley, MN. Davenport, M.A.. 2011. Assessing Community Capacity for Sustainable Watershed Management: Models and Tools from the Social Sciences. Minnesota River Interagency Study Team Modeling Focus Group, St. Paul, MN. Davenport, M.A. 2011. Civic Engagement and Water Stewardship: Promoting Sustainable Behaviors for Water Resources. Minnesota Association of Watershed Districts Annual Conference Communications Workshop, Alexandria, MN. Pradhananga, A. and M. A. Davenport. 2011. What Drives Conservation Behavior? A Study of Riparian Landowners and Behavior Change. University of Minnesota Duluth Outdoor Education Seminar Series, Duluth, MN. Davenport, M.A. 2011. Human Community Assessment in Watershed Projects: From Theory to Practice. St. Croix Basin Implementation Team Meeting, St. Croix Falls, WI. Davenport, M.A. and A. Pradhananga. 2011. Examining Drivers of Landowner Engagement in Water Resources Conservation: From Theory to Action. Scott County Watershed Management Organization Meeting, Shakopee, MN. Davenport, M.A. 2011. Increasing Stakeholder Engagement in Water Resources Management: From Theory to Action. WaterShed Partners Meeting, Capitol Region Watershed District, St. Paul, MN.

**Constraints and Opportunities around Watershed-Wide Riparian Zone Management at the Urban-Rural Interface**

**Principal Investigator**
**Mae A. Davenport**

**Funding Sources: USGS-WRRI 104B/CAIWQ Competitive Grants Program**

**Project Period: 3/31/2010-2/28/2011**
**Reporting Period: 3/1/10-2/28/11**

**1. Research Synopsis**

**Study Background**

This report describes the findings of a landowner survey administered in the Sand Creek and Vermillion River watersheds, Minnesota. The project was conducted by the Department of Forest Resources at the University of Minnesota in collaboration with Scott and Dakota Counties. The purpose of the study is to assist water resource professionals and community decision-makers in better understanding landowners' beliefs, attitudes, and behaviors associated with water resources and conservation practices. The study also focuses in more detail on landowner beliefs about streamside buffers as a conservation practice. Specific study objectives were to assess (1) landowner values and beliefs about their communities, the environment, water quality issues, and water resource management; (2) landowner current and future conservation behaviors; and (3) who or what influences landowners' conservation decisions.

Water resource managers and other professionals are increasingly investing often scarce resources in communication, education, and outreach programs that promote citizen and landowner adoption of conservation practices. However, as environmental practitioners and social scientists have long known, changing human behavior can be a daunting task. To be effective and efficient, programs intended to change behaviors, whether regulatory, incentive-based or voluntary in nature, must respond to the values and beliefs of their targeted audiences. A compounding challenge for water resource professionals is that in the world of water, audiences can be quite diverse with varying socioeconomic backgrounds, land and water connections, environmental and cultural values, and beliefs about environmental problems, consequences, and solutions. Water resource programming aimed at engaging citizens and landowners should be shaped by a baseline understanding of who stakeholders are, how they relate to water, and what influences their decision-making around conservation practices. Programs informed by a combination of social science and local practitioners' expertise are most likely to find success in both responding to stakeholder needs and promoting conservation practices that will protect water resources. This study builds on long-standing theories of behavior and behavior change from the social sciences that converge on the notion that values, beliefs about consequences, concern for consequences, sense of responsibility, personal norms, and social norms drive human behavior (Ajzen, 1999; Schultz, 2011; Schwartz, 1994; Stern, 1999). Importantly, it also is grounded in local resource issues (e.g., riparian buffer maintenance) and practical insight from resource professionals who collaborated with us throughout this project.

**Study Design and Methods**

The study was conducted through a self-administered survey of a stratified, random sample of riparian landowners in the Sand Creek and Vermillion River watersheds. The Sand Creek watershed, a subwatershed of the Minnesota River watershed, stretches across Scott, Le Sueur, and Rice counties (see map in Appendix D, pg. 47). The Vermillion River watershed, a subwatershed of the Lower Mississippi River watershed, stretches across Scott, Dakota, and Goodhue counties (see map in Appendix C, pg. 44). The surveys were administered from March through August 2011.

A list of property owners within the Sand Creek watershed living within 300 feet of a stream or ditch was obtained from the Scott County Watershed Management Organization. The list was based on publicly available property tax records and was restricted to property owners living in Scott County within the Sand Creek watershed. The Sand Creek Watershed Total Maximum Daily Load & Impaired Waters Investigation Stream Inventory (2008), which maps both intermittent and perennial streams and waterways, was used to select streamside landowners in the Sand Creek watershed. A proportionate sample of streamside landowners (approximately 63%) from each of 11 subwatersheds within the Sand Creek watershed and Scott County was randomly selected, yielding a sample of 1,000 streamside landowners. A list of property owners within the Vermillion River watershed and living within 300 feet of a stream or ditch was obtained from Vermillion River Watershed Joint Powers Organization (JPO). This list was also based on publicly available property tax records and includes all landowners within the Vermillion River watershed's hydrologic boundaries. The Wetland and Waterways Inventory and Assessment (Dakota County Soil and Water Conservation District, 2007), which maps both intermittent and perennial streams and waterways, was used to select streamside landowners in the Vermillion River Watershed JPO. A proportionate sample of streamside landowners (approximately 21%) from each of the 11 subwatersheds was randomly selected, yielding a sample of 1,000 streamside landowners. Thus, a total of 2,000 surveys were distributed by U.S. mail.

Survey instruments (Appendix A) were designed based on an extensive literature review and feedback from a pre-test and a pilot test of the instrument. The survey questionnaire included a variety of fixed-choice and scale questions. The Moral Obligation Model was used as a framework for designing the questionnaire. Several questions were adapted from survey instruments used in previous studies of attitudes, beliefs, and values of conservation behaviors (Blasczyk, Your views on local water resources, 2010; Harland et al., 2007; Matsumoto et al., 1997; Prokopy et al., 2009; Seekamp, Davenport, and Brehm, Lower Kaskaskia River Watershed Resident Survey, 2009; Schultz, 2001; Schwartz, 1977; Stern, Dietz and Guagnano, 1998; Stern et al., 1993). Each questionnaire was labeled with a unique identification number (ID) matching the IDs assigned to each name and address in the landowner lists to track responses for subsequent mailings.

An adapted Dillman's (2009) Tailored Design Method was used to increase response rates. The survey was administered in four waves: a pre-notification letter/pre-notice postcard (Appendix B); the questionnaire (Appendix A) with a cover letter (Appendix C), watershed map, and self-addressed, stamped return envelope; a reminder postcard (Appendix D); and a replacement questionnaire with cover letter (Appendix E) and envelope. Standard protocol recommends a pre-notification letter as the first contact with the sample pool. However, in the Sand Creek watershed study, reminder postcards were delivered ahead of schedule, prior to the pre-notification postcard and questionnaire. Thus, in the Sand Creek watershed survey we adapted the standard Tailored Design Method to achieve a desirable response rate.

After completed questionnaires were returned and logged into the respondent database, questionnaire data were numerically coded and entered into a database using Statistical Package for Social Sciences (SPSS release 17.0). Basic descriptive statistics were conducted to determine frequency distributions and averages of individual variables. Inferential statistics were also conducted to test for significant differences between respondents who reported maintaining streamside buffers and those who reported not maintaining streamside buffers on their property.

**Study Findings**

Overall, 750 landowners completed and returned the survey for a response rate of 40% (adjusted for 118 surveys returned undeliverable). Response rates of 46% and 34% were achieved in the Sand Creek (n=432) and Vermillion (n=318) watersheds, respectively. To address concerns about non-response bias, we compared sociodemographic statistics of our sample respondents to those reported in the 2010 U.S. Census for Dakota and Scott Counties. When compared to county-wide statistics, the survey sample represents some observable differences.

Compared with county-wide statistics, the sample represents a higher proportion of men, white and non-Latino populations, individuals with a bachelor's degree or higher, and individuals with incomes of $100,000 or more. The median age of our respondents is also higher than county-wide statistics demonstrate. While these differences suggest our sample may not be representative of county-wide populations, our study specifically targeted streamside property owners, a subpopulation within the counties. To reduce the effects of non-response bias, we used a probability sampling approach. We also conducted a wave analysis of early and late survey respondents to examine the potential effect of non-response bias (Lankford et al., 1995).

Understanding late respondents provides some insight into the characteristics of populations not represented in the sample (i.e., non-respondents). There were no significant differences between early and late respondents in sociodemographic characteristics, except in age. Early respondents (mean = 55) were slightly older than late respondents (mean = 53). Early respondents also were more likely to report that their land/property borders a stream/ditch or has a stream/ditch running through it. Late respondents agree to a greater extent than early respondents that streamside buffers reduce the value of land. Late respondents agree to a greater extent than early respondents that what they do on their land does not make much difference in overall water quality. Late respondents also agree to a lesser extent than early respondents that it is their own personal or all landowners' responsibility to protect water quality.

Late respondents are more likely than early respondents to be influenced in their conservation decisions by property rights organizations. Late respondents are not as likely as early respondents to use conservation practices or maintain a streamside buffer on their land/property. Late respondents agree to a lesser extent that they would be more likely to maintain streamside buffers on or adjacent to their property if they could learn how to maintain streamside buffers for water quality. Late respondents agree to a lesser extent that they feel a personal obligation to maintain a streamside buffer on their land/property. Late respondents are less likely to have engaged in civic actions such as discussing water quality issues with community members, or voted for a candidate in part because he or she was in favor of strong environmental protection. A brief synopsis of study findings are presented below.

## I. Sociodemographic and Property Characteristics

### *1. Who are respondents and what are their property ownership characteristics?*

- The majority of respondents in Sand Creek (78%) and Vermillion River watershed (67%) were male. More than one-third of Sand Creek (35%) and Vermillion River (47%) watershed respondents had attained at least a college degree.
- The median age of Sand Creek and Vermillion River watershed respondents was 55 and 52, respectively.
- The vast majority of the respondents were white (>95%) and not of Hispanic or Latino descent (>98%).
- More than one-third of respondents in Sand Creek and Vermillion River watersheds (>35%) reported an annual household income of at least $100,000.
- Sand Creek respondents reported living 27 years in the community (median), while Vermillion River watershed respondents reported living in the community for 15 years (median).
- A minority of respondents in Sand Creek (39%) and Vermillion River watershed (18%) reported using their land/property for agricultural production. Most respondents in Sand Creek (68%) and Vermillion River (79%) watersheds do not depend on their property for income.
- Most Sand Creek watershed respondents owned 6 or more acres (60%), while most Vermillion River watershed respondents owned less than one acre (53%).
- A majority of respondents (77%) owned and managed their land/property. Most respondents in Sand Creek (87%) and Vermillion River (82%) watershed made their own decisions about how to manage their land/property.
- The majority of Sand Creek respondents (76%) reported owning or renting land with a stream or ditch located on or bordering their property. Slightly fewer than half (45%) of Vermillion River respondents reported that they own or rent land with a stream/ditch located on or bordering their property.

### *2. How do respondents define their community?*

- A large majority of respondents in both watersheds define “their community” as the city or township in which they live (>90%).
- Most respondents (>73%) also define their community as their nearest neighbors.

## II. Cultural and Environmental Values and Beliefs about Water Issues

### *3. What cultural and environmental values are important to respondents?*

- Overall, respondents in both watersheds rated cooperating with and helping other members of their community as the most important cultural value.
- On average, respondents in both watersheds rated “respecting the earth” as the most important environmental value. Protecting private property rights also was rated “very important” to “extremely important” by a majority of Sand Creek respondents (75%) and Vermillion River respondents (66%).

### *4. What are respondents’ beliefs about water quality problems and links to land uses?*

- In the two watersheds, most respondents (>60%) agreed that the effects of water pollution on public health are worse than we realize.
- A majority of Sand Creek (80%) and Vermillion River (68%) respondents agreed that streamside buffers help to improve water quality. In addition, most respondents in both groups (>67%) agreed that buffers should be protected because they provide habitat for wildlife.

- When asked about their agreement with the belief that buffers reduce the value of their land, more than one-third of Vermillion River respondents (35%) and Sand Creek respondents (41%) were either neutral or agreed with the statement.
- Respondents were asked to rate the quality of water in the stream or ditch on or adjacent to their property. Less than half of Sand Creek respondents (45%) and less than one-third of Vermillion River respondents (27%) characterized the quality of water in the stream or ditch on or adjacent to their property as good to very good. Almost two-fifths of Vermillion River respondents (39%) and one-fifth of Sand Creek respondents (19%) did not know the quality of the water in their stream or ditch.

5. ***Are respondents concerned about the consequences of water pollution?***
   - An overwhelming majority of respondents in both the watersheds expressed concern about the consequences of water pollution for future generations (>92%), wildlife (>88%) and aquatic life (>87%).
6. ***Who do respondents think should be responsible for responding to water quality issues?***
   - A large majority of the respondents in both watersheds (>86%) agreed that it is their own personal responsibility to help protect water quality.
   - Most respondents in Vermillion River (82%) and Sand Creek (75%) also agreed that the local government should be responsible for protecting water quality.
7. ***Do respondents feel personally obligated to do something about water quality issues?***
   - Most respondents in both the watersheds agreed that they feel a personal obligation to do whatever they can to prevent water pollution (>86%) and to use conservation practices on their land/property (84%). However, fewer respondents feel the same obligation to work with other community members on (<52%) or talk to other community members about conservation practices (<45%).

## III. Current and Future Conservation Behaviors

8. ***Do respondents maintain riparian buffers in streams/ditches on or adjacent to their property?***
   - A majority of Sand Creek watershed respondents (54%) reported maintaining buffers on at least some of the streams/ditches on or adjacent to their property.
   - Fewer Vermillion River watershed respondents (30%) reported maintaining buffers on at least some of these waterways.
   - It should be noted that more than half of Vermillion River watershed respondents (53%) reported that they do not have streams/ditches on or adjacent to their property. Less than 30% of Sand Creek watershed respondents reported the same.
9. ***What civic actions have the respondents engaged in the past 12 months related to environmental issues?***
   - Of all the actions listed, the action most commonly engaged in was reading newsletters, magazines or other publications by environmental groups (>45%).
10. ***How likely are respondents to take future conservation actions to protect water resources?***
    - A majority of respondents in both watersheds (>83%) reported that they are somewhat to very likely to use conservation practices on their land/property in the future. However, fewer respondents were as likely to work with other community members to protect the environment (<53%) or talk to others about conservation practices (<46%) in the future.
    - More Sand Creek respondents (62%) reported being likely to maintain a streamside buffer on their land/property in the future than Vermillion River respondents (51%). Once again, it is important to note that more than half of Vermillion River watershed respondents (53%)

reported that they do not have streams/ditches on or adjacent to their property. Less than 30% of Sand Creek watershed respondents reported the same.

## IV. Influencing Conservation Behaviors

### *11. Who influences respondents' conservation practices?*

- Overall, respondents in both watersheds rated family as most likely to influence their decisions about conservation practices. Respondents' county Soil and Water Conservation District, MN Department of Natural Resources, the local Water Management Organization and neighbors were also highly rated overall by respondents in both groups as influential in their decision-making.
- Vermillion River respondents were more likely (69% rated at least "somewhat likely") to be influenced by the MN Pollution Control Agency than Sand Creek respondents (57% rated at least "somewhat likely").

### *12. Do respondents and their communities have the ability to protect water resources?*

- Most respondents in both the watersheds (>65%) agreed that their community has the ability to change the way land will be developed in the future to protect water resources.
- Most respondents in both groups (>58%) also agreed that they personally had the knowledge and skills to take care of their land.
- However, a minority of respondents (<24%) agree that their community has the leadership it needs to protect water resources.

### *13. What would increase the likelihood that respondents would maintain riparian buffers?*

- For Sand Creek respondents, having access to financial resources to help them plant and maintain buffers and learning how to maintain buffers for water quality were most likely to increase their riparian buffer maintenance.
- For Vermillion River respondents, learning how to maintain streamside buffers for water quality and knowing more about how to plant and maintain streamside buffers were most likely to increase their riparian buffer maintenance.
- In addition, more than half of respondents in both groups agreed that they would be more likely to maintain streamside buffers if they could learn how to maintain streamside buffers for wildlife benefits and soil conservation.

### *14. How do respondents who maintain streamside buffers differ from those who do not maintain streamside buffers?*

- Respondents who maintain streamside buffers (adopters) and those who do not (non-adopters) shared many qualities including sociodemographics, property characteristics, values, problem awareness, concern, sense of responsibility, and social influences.
- Highly significant differences between adopters and non-adopters were revealed in their beliefs, sense of personal obligation, perceived ability, future conservation behaviors, and past engagement in civic action. Non-adopters had more negative beliefs than adopters about streamside buffers. They agreed to a lesser extent that they have the ability to change the way they use their land to protect water resources. They feel less of a personal obligation to use conservation practices including streamside buffers on their land. Adopters were more likely to have engaged in various civic actions associated with the environmental issues in the past.

## V. Attitudes toward Water Resource Management in Minnesota

### *15. What do respondents think about management actions to protect the quality of water in Minnesota?*

- On average, Sand Creek watershed respondents rated expanding incentive-based programs that offer payments for conservation as most likely to protect the quality of Minnesota's water resources. However, Vermillion River watershed respondents rated enforcing existing land use laws and regulations as most likely to protect Minnesota's water resources.
- The majority of respondents in both watersheds believed that promoting voluntary adoption of conservation practices through education and outreach (>65%), coordinating land use and water planning across communities (>63%), and engaging more citizens in decision-making (>61) will be at least "somewhat likely" to protect the state's water resources.
- A greater proportion of Vermillion River respondents (74%) believed that conducting more water quality research and monitoring will be at least "somewhat likely" protect water quality in the state than Sand Creek respondents (64%).
- On average, the lowest rated management action was increasing regulations that specifically address water resource management. Fewer Sand Creek respondents (44%) rated this action positively (at least "somewhat likely" to protect water resources) than Vermillion River respondents (57%).

**Discussion and Recommendations**

This study has provided much-needed insight on several critical questions identified by local resource managers. These questions include who are streamside landowners, how do they relate to water, and what factors influence their decision-making around conservation practices. Specifically, this study documents streamside landowner values and beliefs about their communities, the environment, water quality issues, and water resource management; it identifies landowner current and future conservation behaviors; and it establishes who or what influences landowners' conservation decisions and behaviors. This type of social science-based research complements biophysical and geochemical research in helping resource managers identify drivers and consequences of water resource problems grounded in the perspectives of resource users.

We believe the study findings will inform, enhance, and facilitate future community and water resource planning and management initiatives in the two study watersheds and across the state. We encourage resource professionals and community leaders to incorporate the four recommendations highlighted below into the design and implementation of communication, education, and outreach programs.

In sum, a multiple-strategy approach is recommended in conservation programming that encourages personal commitment to conservation, promotes a sense of civic responsibility for water resources, and addresses landowner constraints through tailored education and incentive programs. Further, this multiple-strategy approach should be presented to landowners in a coordinated and consistent manner across resource management organizations.

**Recommendation 1: Raise awareness about local stream conditions and encourage personal commitment to conservation.**

Study findings suggest that streamside landowners from both watersheds have a high level of general concern about the effects of water pollution on public health, future generations, wildlife, and aquatic life. However, they are less concerned about the consequences of water pollution on people within their community. Findings also indicate either a lack of knowledge or uncertainty among landowners about local water resource conditions, such as the extent to which their community's water resources are adequately protected. Similarly, many landowners do not know the quality of the water in the stream or ditch on their property. Thus, while general concern about water pollution may be high, awareness of problems or certainty about conditions at the local level is relatively low.

To address uncertainty and limited knowledge about local conditions, we recommend landowner-tailored informational strategies aimed at changing perceptions and knowledge. To be effective, the information should be relevant and significant to targeted stakeholders. Thus, communication campaigns should directly articulate local conditions and problems (i.e., impairments in stream reach A or neighborhood B), their potential consequences (i.e., impacts to aquatic life in A or B), and solution alternatives (i.e., streamside buffer installation or wetland restoration near A or B).

Individualized shoreland audits, in which water resource professionals assess stream and shoreland conditions on a landowner's property and provide technical advice about how to plant and maintain buffers for certain benefits (i.e., wildlife or soil conservation) would be most effective. Individualized, specific, and timely information will make issues more personal to landowners and, when paired with programs aimed at encouraging commitment to conservation practices, are more likely to result in behavior change. Mass media campaigns are believed to be far less effective in changing behavior than personalized approaches (Abrahamse et al., 2005).

Whereas information campaigns alone have had somewhat mixed results, asking for personal commitments, setting goals, and providing feedback has shown more promise (Abrahamse et al., 2005). Personal commitment in the form of a verbal or written pledge to change (or maintain) a behavior establishes personal (if made to oneself) or social (if made public) norms. These promises become even more impactful when matched with a commitment to a particular plan of action (e.g., I promise to install a streamside buffer next spring by planting native grass species and by not mowing along the stream) (Steg & Vlek, 2009).

Goal-setting has also been an effective strategy for promoting behavior change and is frequently used in combination with providing feedback. For example, local resource professionals might set streamside buffer goals of 80% of streamside landowners with buffers or 90% of shoreland miles buffered within a township or municipality. Providing frequent feedback on the extent to which goals are being met to a neighborhood or to a group of landowners living along a stream creates a social norm in favor of buffer adoption and further connects landowners to water resources and to each other. In similar studies of household energy conservation, combinations of strategies including encouraging personal commitments, setting goals, and providing feedback to households or groups has been effective at promoting behavior change (Abrahamse et al., 2007).

**Recommendation 2: Foster community-building around water and promote a sense of civic responsibility for water resource protection.**

Our study findings indicate that streamside landowners' communal or collective value orientations appear to be strong. Cooperating with community members and nurturing or helping other community members were among the most important cultural values to respondents. This civic-mindedness, however, may not translate well when it comes to conservation practices and water resource protection.

Though a large majority of landowners may feel personally obligated to do whatever they can to prevent water pollution, including using conservation practices on their own land, considerably fewer landowners feel obligated to engage with their community around conservation issues, specifically to work with other community members to protect the environment or to talk to others about conservation practices. Further, as our study revealed, more than three-quarters of respondents admitted they had not discussed water quality issues with other community members in the past 12 months, despite their high concern about water pollution.

As a result, many landowners may not know what their fellow neighbors or community members are thinking or doing with respect to conservation practices on their land. This gap between individual and collective knowledge and action can stymie the diffusion of knowledge and adoption of innovative solutions (Rogers, 1995). Strategies that build social support for and role modeling of conservation practices through peer-to-peer networks, community events, demonstration areas, and citizen recognition programs build the notion that like-minded landowners have adopted conservation practices and, furthermore, that being a proactive member of the community means doing what one can to protect local water resources.

Landowner commitment to water resource protection can be dramatically influenced by the “citizen effect” or social norms and pressures favoring certain behaviors (Morton, 2011). Information exchange around the successes of conservation practices such as streamside buffers also has the effect of reducing uncertainty and perceptions of risk, often a barrier in behavior change (Rogers, 1995).

While respondents felt individually responsible for the protection of water resources, they also believed it is the responsibility of landowners within the community and local government to protect water resources. Thus, it is clear that landowners recognize that water resource protection requires the collective action of individuals and community leadership. Given prevailing communal value orientations among landowners and their strong sense of personal obligation and responsibility for conservation practices, it would seem that promoting cooperation would have great potential within these watersheds. Cooperation further expands resources available to landowners by pooling knowledge, increasing access to technology and equipment, fostering trust, and building community pride in accomplishments.

The scale of community-engagement strategies is an important consideration. Study findings reveal that when landowners think of “their community,” they tend to think of the city or township in which they live and their nearest neighbors, more so than their county or watershed. Thus, coordination on a large scale in watersheds with diverse settlement patterns may prove difficult (O’Neil et al., 2005). Further, traditionally underrepresented or disadvantaged groups may continue to be difficult to engage at a watershed scale. Water resource-focused strategies for building social support and modeling behavior should consider a smaller scale. Neighborhood “block” parties or programs targeted to smaller geographic areas, settlement types, or social groups may be more effective at building social networks and civic engagement than county- or watershed-wide programs (O’Neil et al., 2005). Similarly, recruitment strategies for engaging landowners in programs must be specific and tailored to targeted groups.

**Recommendation 3: Address constraints to streamside buffer adoption through landowner-tailored education and incentive programs.**

Study findings suggest that many streamside landowners seem to have an understanding of the connection between land use and water quality and that they feel personally responsible for protecting water quality. Yet specific attitudes and resource constraints may prevent adoption of streamside buffers. For example, our study reveals some skepticism exists about the benefits of streamside buffers among landowners in the two watersheds. Among respondents, those with doubts about streamside buffers represent a relatively small minority, yet these beliefs appear to be a differentiating characteristic between non-adopters and adopters. Specifically, non-adopters held stronger beliefs that buffers reduce the value of land and weaker beliefs that buffers improve water quality than adopters.

Expression of these types of negative attitudes toward conservation practices, that they are likely to have higher risks than rewards, requires interventions that address both real and perceived costs and benefits. Direct types of interventions may encourage or reward (e.g., financial incentives, public recognition) "good" behavior or, alternatively, they may discourage or punish (e.g., fines, public admonition) "bad" behavior. Incentives and rewards are generally favored over sanctions because they tend to promote positive feelings and social support around the desired behavior. However, rewards have their limits. Monetary incentives, in particular, have been shown to have only short-term effects on behavior change because the behavior and outcomes are less likely to be internalized (Abrahamse et al., 2005; Steg & Vek, 2009). A less direct but perhaps more long-lasting strategy for incentivizing conservation behavior is through offering information and assistance that better enable individuals to attain the specific benefits they desire.

Although our study indicates the majority of landowners believe they have the knowledge and skills they need to take care of their land, we also discovered that knowledge and skills may be a constraint to 4 out of every 10 streamside landowners. Furthermore, when asked about information or other incentives that would increase their adoption of streamside buffers, four out of five of the highest ranked items were educational in nature. Findings suggest that the majority of streamside landowners would be more inclined to adopt or maintain existing buffers if they could learn how to maintain buffers for water quality, soil conservation, and wildlife benefits. Most landowners also would be more likely to adopt buffers if they knew more about how to plant and maintain buffers. Thus, it appears that more specific information about streamside buffers and their particular benefits is desired.

At the same time, we learned that perceptions of financial constraints exist. Study findings show that about 5 out of 10 landowners perceive financial resources as a constraint to their ability to take care of their land. Similarly, findings suggest that access to financial resources to help plant and maintain buffers will increase the likelihood of adoption for 5 or 6 out of every 10 streamside landowners.

Given these findings, we recommend that attitudinal and resource constraints be addressed through landowner-tailored education programs, supplemented when possible with short-term opportunities for financial incentives. As discussed above, mass media information campaigns encouraging behavior change are less likely to be effective than informational programs tailored to the specific characteristics and needs of the targeted audience. In the study watersheds, we have learned that streamside landowners want more educational opportunities to learn about maintaining buffers specifically for water quality, soil conservation, and wildlife benefits. Specific knowledge and training around planting and maintaining streamside buffers that is focused on producing these benefits would be well-received.

**Recommendation 4**: **Coordinate a multiple-strategy approach for water resource protection across the state, and maintain consistent messaging from resource organizations about water resource issues.**
In the context of land use and water resource management, local government and non-governmental organizations play the most intensive role in influencing the day-to-day decisions and behaviors of landowners. Thus, townships, municipalities, and county governments, as well as special resource organizations such as Soil and Water Conservation Districts (SWCDs) and watershed management

organizations (WMOs), tend to have the most direct responsibility for implementing programs in their watersheds that ultimately protect water resources throughout the state.

We asked study respondents to weigh in on various management actions intended to protect Minnesota's water resources. Findings indicate that streamside landowners believe a multiple-strategy approach is needed. Based on our study, more than half of streamside landowners believe enforcing existing land use laws and regulations, conducting more water quality research, expanding payment programs for conservation practices, coordinating land use and water planning across communities, promoting voluntary adoption through increased education and outreach, and engaging citizens in decision-making will be likely to protect water quality in Minnesota.

Study findings suggest that streamside landowners' conservation decision-making is most likely to be influenced by family, their county's SWCDs, and the MN Department of Natural Resources. Additionally, in both the study watersheds, about 6 out of every 10 landowners view the local WMOs as influential in their conservation decisions. The majority of respondents reported that they would be at least somewhat likely to be influenced by 7 of the 12 groups listed. These findings indicate that landowners are likely to consult or consider the advice of many individuals and groups when deciding whether to adopt certain conservation practices on their land.

Implications of this finding for resource organizations are twofold. First, many agencies and organizations appear to have the attention of landowners and the legitimacy needed to influence their conservation behaviors. This makes carefully planned and tailored intervention strategies more likely to be successful. Second, given that many agencies and organizations are influential, the need for coordinated and consistent messaging from both government and non-government agencies and across local, state, and federal levels is critical.

# USGS Award No. G10AP00050 Data Management and GIS Analysis for the Ecosystem Technical Work Group

## Basic Information

| | |
|---|---|
| **Title:** | USGS Award No. G10AP00050 Data Management and GIS Analysis for the Ecosystem Technical Work Group |
| **Project Number:** | 2010MN276S |
| **Start Date:** | 2/1/2010 |
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| **Descriptors:** | |
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## Publications

There are no publications.

# Final Technical Report for G10AP0050: Data management and GIS Analysis for the Ecosystem Technical Working Group.

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## Contents



## Report format

This final technical report follows the instructions on page four (section C.2.b) of the Assistance Award.

## Deliverables

The deliverables listed in the Assistance Award are:

1. Database to warehouse data collected from field work and secondary research.
2. Summary of the data set contents, geospatial relationships, and metadata.
3. Develop and implement a database system to serve GIS and related data sets/documents from web and map servers; and host multi-user collaborative project intranet sites.
4. Maps, display, and geospatial coverage that illustrate and summarize project results and recommendations.

Work for deliverables 1 and 2 was was done in conjunction with the umbrella project's Information Management (IM) group. This subproject funded Terry Brown's participation in the IM group (co-ETWG liaison, meeting in Ottawa, twice monthly conference calls).

The first clause of deliverable 3 was superseded by the Information Management group. The product developed by this subproject to fulfill the requirements of the second clause of deliverable 3 is described in the Multi-user collaborative intranet site section below.

Work for deliverable 4 is described in the Activities section below.

# Multi-user collaborative intranet site

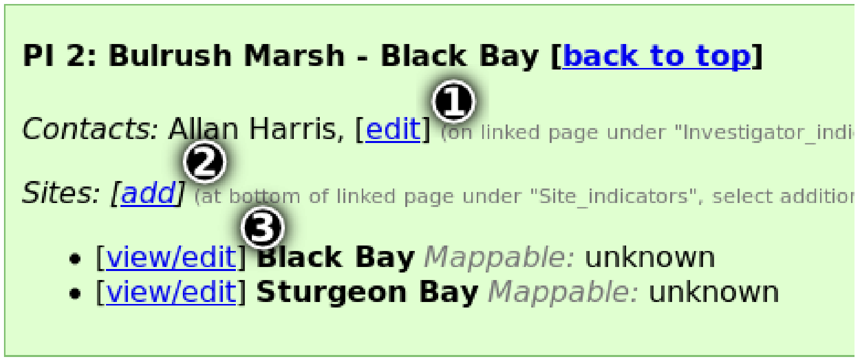
Them multi-user collaborative intra-net site developed by this subproject was used to integrate site information and related Performance Indicator (PI) analyses and datasets.

The first stage of the process involved compiling the list of study sites associated with one or more Performance Indicators:

| site | name | km2 | map | site | name | km2 | map |
|---|---|---|---|---|---|---|---|
| 1 | Saginaw Bay | 2331.8 | F | 2 | Chequamagon Bay | 83.2 | T |
| 3 | Black Bay | 9.0 | T | 4 | Sturgeon Bay | 2.2 | T |
| 5 | Arcadia Marsh | 0.9 | T | 6 | Eastern Georgian Bay | 2985.4 | F |
| 7 | Lake St. Clair | 1539.9 | F | 8 | Long Point | 212.2 | T |
| 9 | Turkey Point | 17.7 | T | 10 | Inner Bay | 141.8 | T |
| 11 | Fish Point | 0.7 | T | 12 | Outer Bay | 138.2 | T |
| 13 | Northern Lake Huron | 49554.5 | F | 14 | Northern Lake Michigan | 66554.6 | F |
| 15 | Les Cheneaux | 113.1 | T | 16 | Saginaw / Michigan / Huron fringing wetlands | 325919.6 | F |
| 17 | Tadenac Bay | 116.8 | T | 18 | North Bay | 60.2 | T |
| 19 | Saginaw / Michigan / Huron drowned rivermouths | 341887.5 | T | 20 | Northern US wetlands | 323347.0 | F |
| 21 | St. Marys River | 1250.9 | F | 22 | Mackinac Bay | 5.7 | T |
| 23 | Batchawana Bay | 313.5 | T | 26 | Duck Bay | 2.9 | T |
| 27 | Pinconning - marsh | 3.0 | T | 28 | Bradleyville-King Roads | 31.9 | T |
| 29 | Dickinson Island | 57.4 | T | 30 | South-Eastern Georgian Bay | 323.7 | T |
| 31 | Pokegama Bay | 2.2 | T | 32 | Allouez Bay | 5.4 | T |
| 33 | Fond Du Lac | 0.8 | T | 34 | Oconto | 5.7 | T |
| 35 | Long Tail Point | 13.7 | T | 36 | Sawyer Harbor | 3.4 | T |
| 37 | Egg Harbor | 2.9 | T | | | | |

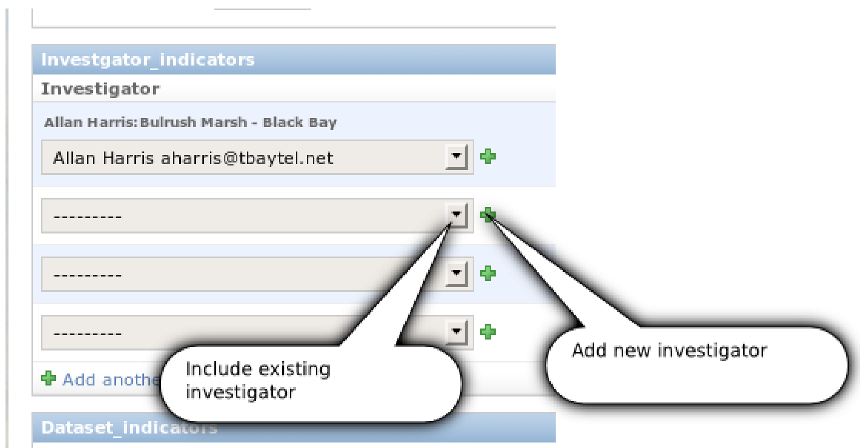
# Collaborative intranet documentation

The online interface for the collaborative intranet tool is described by the site's instructions, reproduced in the following figures:



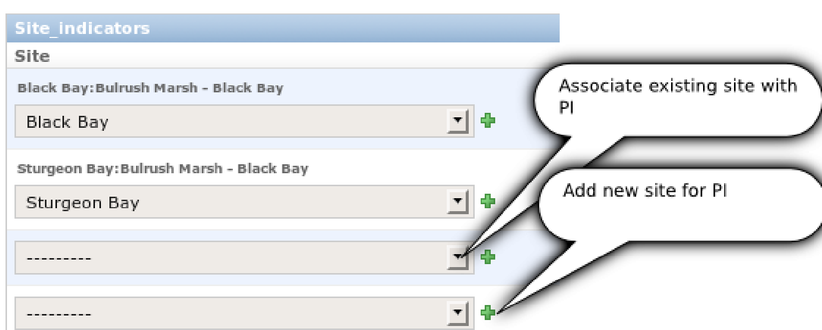

*Overview of system components*

You can change the list of investigators associated with each PI by clicking the [edit]❶ link after the Contacts list for the PI. To add new sites for a PI, or associated additional existing sites with a PI, click the [add]❷ link at the top of the Sites list for each PI. To view and edit the sites themselves, click the [view/edit]❸ link next to the site's name (on the main page).



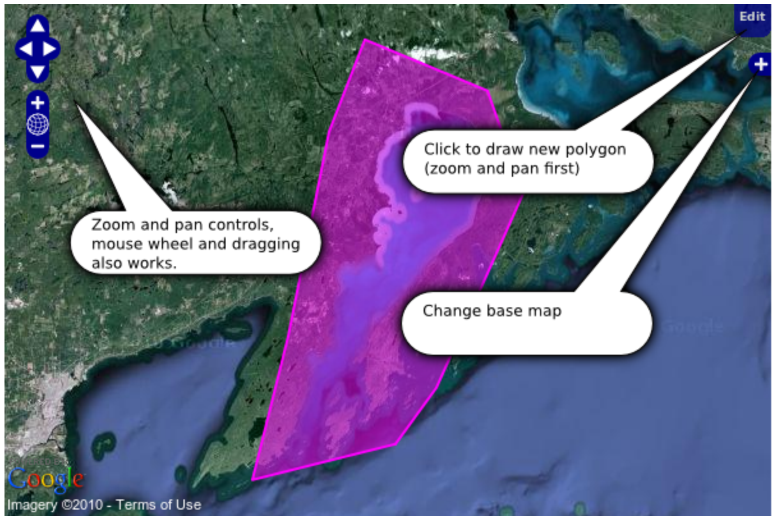

❶ *Changing the investigators associated with a PI*

The investigators for the PI are listed in the 'Investigator' section on the page which appears when you click '[edit]'. Select additional investigators from the list or use the green '+' to add new investigators.




❷ *Changing / Adding sites associated with a PI*

The sites for the PI are listed in the 'Site_indicators' section at the bottom of the page which appears when you click 'add'. Select additional sites from the list or use the green '+' to add new sites.




❸ *Viewing / editing sites associated with a PI*

To edit a site, pan and zoom the map until it covers the area in which you wish to delineate the site, then click the map's "Edit" button (top right) and draw a simple polygon surrounding the site. The maps will be rectangular, so there's no immediate need to follow wetland edges, a simple bounding box will do.

Mappable sites should be at most 10x10 km, smaller is better.

Not all PIs require mappable sites. For example "Northern US wetlands" is not mappable. It would still be helpful to adjust the site outline for this "site" so that it correctly reflects the region intended.

Some PIs will require multiple sites, for example the Wild Rice PI may need "Chequamagon Bay 1" and "Chequamagon Bay 2" (or more appropriate localized names).

**PI 3: Northern Wetland Macroinvertebrates [back to top]**

*Contacts:* Valerie Brady, [edit] (on linked page under "Investigator_indicators", select additional existing, or + for new)

*Sites:* *[add]* (at bottom of linked page under "Site_indicators", select additional existing, or + for new)

- [view/edit] **Allouez Bay** *Mappable:* True
- [view/edit] **Egg Harbor** *Mappable:* True
- [view/edit] **Fond Du Lac** *Mappable:* True
- [view/edit] **Long Tail Point** *Mappable:* True
- [view/edit] **Northern US wetlands** *Mappable:* False
- [view/edit] **Oconto** *Mappable:* True
- [view/edit] **Pokegama Bay** *Mappable:* True
- [view/edit] **Sawyer Harbor** *Mappable:* True

*An example of the interface for a particular PI*

# Activities

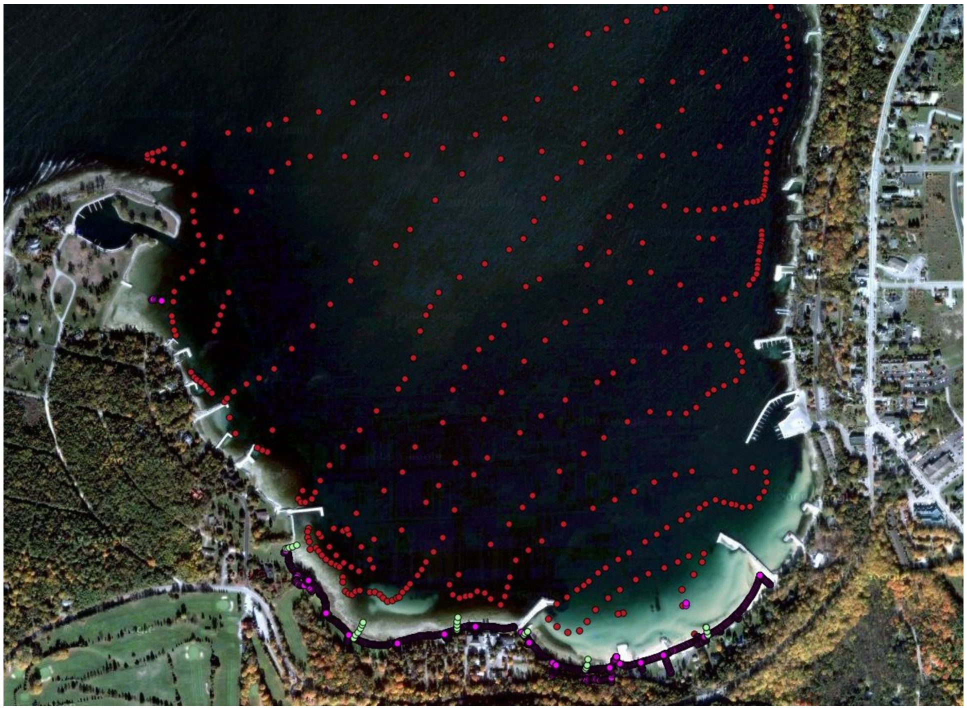
- Aerial imagery and topographic map imagery was collected for most PI development sites ("sites" which were really regional or lake-wide wetland complexes were excluded, see preceding table)
- Maps of regional and local areas of apparent vulnerability to water level change were produced.
- New bathymetry data collection and digitization for water level change risk analysis:

- field collection of differentially corrected GPS data was managed
- raw data was converted to Digital Elevation Models

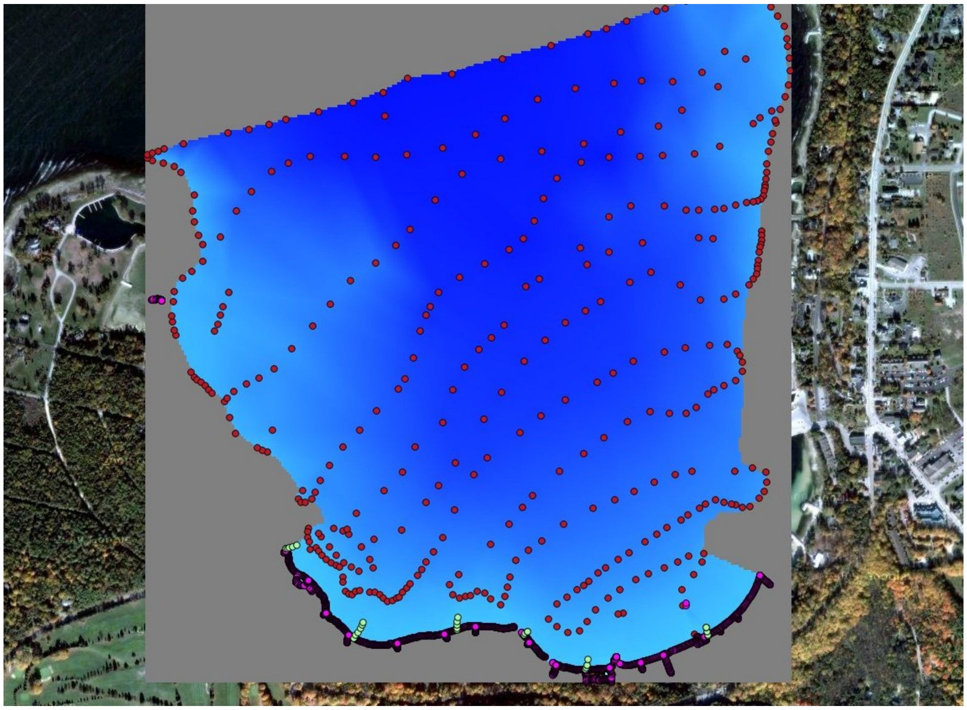
- The spatial framework and parameterization necessary for the construction of the Performance Indicators was discussed and refined in large and small group meetings.

## Bathymetry analysis

Bathymetry analysis required rental of appropriate equipment, training of field crews, downloading and correcting data, assembling data and generating GIS products.



*Collection of bathymetry points from shoreline and open water*



*Generated elevation grid, light-blue to dark-blue; shallow to deep*

# Publications

While this project contributed to the publications and other products produced by the Ecosystem Technical Working Group, it did not produce any publications itself.

# Stratigraphic Distribution and Mineralogical Sources of Arsenic to Minnesota Glacial Aquifers

## Basic Information

| | |
|---|---|
| **Title:** | Stratigraphic Distribution and Mineralogical Sources of Arsenic to Minnesota Glacial Aquifers |
| **Project Number:** | 2011MN288B |
| **Start Date:** | 3/1/2011 |
| **End Date:** | 2/28/2012 |
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| **Research Category:** | Water Quality |
| **Focus Category:** | Groundwater, Geochemical Processes, Toxic Substances |
| **Descriptors:** | |
| **Principal Investigators:** | Brandy Marie Toner, Edward A Nater |

## Publications


1. Toner, B. M., S. L. Nicholas, L. J. Briscoe, A. R. Knaeble, J. A. Berg, and M. L. Erickson. 2011. Natural Sources of Arsenic to Minnesota Groundwater. CURA Reporter 41, 3-10.
2. Toner, B. M., 2012. State-of-the-science Tools for Measuring Arsenic Speciation in Glacial Sediments. Water Resources Science seminar, University of Minnesota, St. Paul, MN. Nicholas, S. L., B. M. Toner, M. L. Erickson, L. G. Woodruff, A. R. Knaeble, and G. N. Meyer. 2011. Mineral Sources of Arsenic from Glacial Aquifer Sediments to Well Water in Minnesota, USA. Goldschmidt, Prague, Czech Republic. Mineralogical Magazine 75. Nicholas, S. L., B. M. Toner, M. L. Erickson, A. R. Knaeble, L. G. Woodruff, and G. N. Meyer. 2011. Speciation and Mineralogy of Arsenic in Glacial Sediments and their Effect on Arsenic Concentrations in Groundwater, Minnesota, USA. Geological Society of America, Minneapolis, MN, 283-5. Nicholas, S.L. 2011. Identifying Mineral Sources of Arsenic Affecting West-Central Minnesota Well-Water. Invited talk. Annual meeting of the Minnesota chapter of the American Waterworks Association, Duluth, MN. http://www.mnawwa.org/news/breeze/Fall2011Breeze.pdf
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Implications for Minnesota. CURA Reporter. Minneapolis, MN, Center for Urban and Regional Affairs. 34: 7. Erickson, M. L. and R. J. Barnes. 2005a. Glacial Sediment Causing Regional-Scale Elevated Arsenic in Drinking Water. Ground Water 43(6): 796-805. Erickson, M. L. and R. J. Barnes. 2005b. Well Characteristics Influencing Arsenic Concentrations in Ground Water. Water Research 39: 4029-4039. Farquhar, M. L.and J. M. Charnock, et al. 2002. Mechanisms of Arsenic Uptake from Aqueous Solution by Interaction with Goethite, Lepidocrocite, Mackinawite, and Pyrite: An X-ray Adsorption Spectroscopy Study. Environmental Science and Technology. 36: 1757-1762. Goldberg, S. and C. Johnston 2001. Mechanisms of Arsenic Adsorption on Amorphous Oxides Evaluated Using Macrosopic Measurements, Vibrational Spectroscopy, and Surface Complexation Modeling. Journal of Colloid and Interface Science 234: 204-216. Harris, K. L. 2006. Surficial Geology. Regional Hydrogeological Assessment, RHA-6, part A, Plate 1, University of Minnesota, Minnesota Geological Survey: Traverse-Grant Area, West-Central Minnesota. Itai, T. and Y. Takahashi, et al. 2010. Variations in the Redox State of As and Fe Measured by X-ray Absorption Spectroscopy in Aquifers of Bangladesh and their Effect on As Adsorption. Applied Geochemistry 25(1): 34-47. Kanivetsky, R. 2000. Arsenic in Minnesota Ground Water: Hydrogeochemical Modeling of the Quaternary Buried Artesian Aquifer and Cretaceous Aquifer Systems. Minnesota Geological Survey Report of Investigations 55: 23. Keon, N. E.and C. H. Swartz, et al. 2001. Validation of an Arsenic Seqential Extraction Method for Evaluating Mobility in Sediments. Environmental Science and Technology. 35: 2778-2784. Kneebone, P. E. and P. A. O'Day, et al. 2002. Deposition and Fate of Arsenic in Iron-and Arsenic-enriched Reservoir Sediments. Environmental Science and Technology. 36: 381-386. Nicholas, S. L.and L. J. Briscoe, et al. 2009. Molecular Environmental Science at the Landscape Scale: X-ray Absorption Spectroscopy Studies of Arsenic Geochemistry in Glacial Tills. Geological Society of America. Portland, OR. Polizzotto, M. L. and C. F. Harvey, et al. 2006. Solid-phases and Desorption Processes of Arsenic within Bangladesh Sediments. Chemical Geology 228(1-3): 97-111. Saalfield, S. L. and B. C. Bostick. 2009. Changes in Iron, Sulfur, and Arsenic Speciation Associated with Bacterial Sulfate Reduction in Ferrihydrite-Rich Systems. Environmental Science and Technology 43(23): 8787-8793. Schreiber, M. J. and J. Simo, et al. 200O. Stratigraphic and Geochemical Controls on Naturally Occurring Arsenic in Groundwater, Eastern Wisconsin, USA. Hydrogeology Journal 8: 161-176. Smedley, P. L. and D. G. Kinniburgh 2002. A Review of the Source, Behaviour and Distribution of Arsenic in Natural Waters. Applied Geochemistry 17: 517-568. Smith, P. G. and I. Koch, et al. 2005. X-ray Absorption Near-edge Structure Analysis of Arsenic Species for Application to Biological Environmental Samples. Environmental Science and Technology 39(1): 248-254. Thoral, S. and J. Rose, et al. 2005. XAS Study of Iron and Arsenic Speciation During Fe(II) Oxidation in the Presence of As(III). Environmental Science and Technology 39(24): 9478-9485. Toner, B. and A. Manceau, et al. 2006. Zinc Sorption to Biogenic Hexagonal-birnessite Particles within a Hydrated Bacterial Biofilm. Geochimica et Cosmochimica Acta 70: 27-43. Toner, B. M. and S. C. Fakra, et al. 2009. Preservation of Iron(II) by Carbon-Rich Matrices in Hydrothermal Plumes. Nature Geoscience 2: 197-201. Villalobos, M. and B. Toner, et al. 2003. Characterization of the Manganese Oxide Produced by Pseudomonas putida strain MnB1. Geochimica et Cosmochimica Acta 67(14): 2649-2662. Warner, K. L. 2001. Arsenic in Glacial Drift Aquifers and the Implication for Drinking Water - Lower Illinois River Basin. Ground Water 39(3): 433-442. Waychunas, G. A. and B. A. Rea, et al. 1993. Surface Chemistry of Ferrihydrite: Part 1. EXAFS Studies of the Geometry of Coprecipitated and Adsorbed Arsenate. Geochimica et Cosmochimica Acta 57: 2251 2269. Welch, A. H. and D. B. Westjoin, et al. 2000. Arsenic in Ground Water of the United States: Occurence and Geochemistry. Ground Water 38(4): 589-604.

**Stratigraphic Distribution and Mineralogical Sources of Arsenic to Minnesota Glacial Aquifers**

**Principal Investigator**

**Brandy Toner, Assistant Professor, Department of Soil, Water and Climate**
**Ed Nater, Professor, Department of Soil, Water and Climate**

**Funding Source: USGS –WRRI 104B/CAIWQ Grants Program**

**Project Duration: 3/1/2011-2/28/2012**
**Reporting Period: 3/1/2011-2/28/2012**

1) _Research_: A synopsis

## Stratigraphic Distribution and Mineralogical Sources of Arsenic to Minnesota Glacial Aquifers

### 1. Research Motivation and Background

Arsenic (As) concentrations in domestic well water throughout large regions of Minnesota (MN) exceed the 10 µg As $L^{-1}$ public drinking water system standard set by the U.S. Environmental Protection Agency. The scale of the problem facing MN is illustrated by the results of the Minnesota Arsenic Study (MARS): 50% of the 869 domestic wells tested in west-central MN had elevated As concentrations (greater than 10 µg As $L^{-1}$) (MDH 2001; Erickson and Barnes 2005a). In MN, it is clear that the frequency of As contamination in domestic wells poses a serious and widespread public health concern. While As-removal systems can be purchased by individuals, they are expensive, require maintenance, and do not provide alarms for high As concentrations or system failure (Erickson and Barnes 2004). In response to these challenges, the MN well code now requires that each new well – estimated at 8,000-12,000 wells annually – be tested for As. These data will provide families and businesses with important information about drinking water quality. However, the information comes only after the well has been drilled. The best practice would be to *a priori* place domestic wells where the probability of clean water is highest.

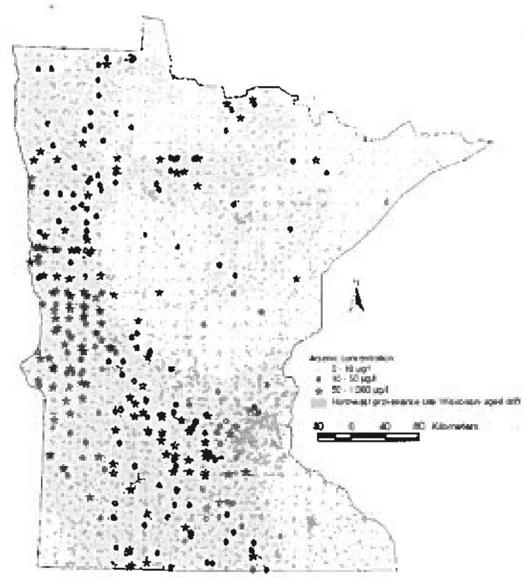


**Fig.1.** State of Minnesota map showing distribution of Des Moines lobe of Laurentian ice sheet (gray shading) with well water As concentrations, from Erickson and Barnes (2005a).

Arsenic concentrations in the solid geological materials composing MN aquifers are not exceptionally high, yet elevated aqueous As concentrations in domestic wells are commonplace. This seeming paradox is a hallmark of geologically or naturally sourced As contamination (Smedley and Kinniburgh 2002; Erickson and Barnes 2005). For example, the crustal abundance of As is about 1.8 mg As $kg^{-1}$. In glacial till sediments, which act as confining layers to MN glacial aquifers, we have measured solid phase As concentrations ranging from 4 to 10 mg As $kg^{-1}$ (Nicholas et al. 2009). This enrichment in solid phase As is hardly a smoking gun, but it is measureable and observed consistently in the glacial tills present in our rotary sonic drill core samples.

The source of As to most glacial aquifers in MN is solid geological materials. Erickson and Barnes (2005a) analyzed the geographical distribution of As in domestic wells for North

Dakota, Minnesota, and Iowa (Fig.1). Their analysis identified a positive correlation between elevated As concentrations in well water and a specific glacial formation, known as the Des Moines Lobe of the Laurentian ice sheet (Kanivetsky 2000; Welch et al. 2000; Erickson and Barnes 2005a, b). The work of Erickson and Barnes represented a huge step forward, and it has aided our understanding of the basic underpinning of the As problem in MN; specific geologic formations are more likely to result in elevated As in ground water. These findings alone, however, are insufficient to predict the likelihood of elevated As levels in well water in MN. The well water As databases tell the story best, and from those data we observe the following: wells in close geographic proximity, screened at the same depth below ground level, and having similar aqueous geochemistry can have radically different dissolved As concentrations. It is clear that living within the Des Moines lobe increases your chance of drilling an elevated As well (Fig.2). However, a second well on your property may yield low As waters. This unexplained variability in As concentrations in domestic wells currently limits our ability to predict where safe drinking water is located in the subsurface (Smedley and Kinniburgh 2002).

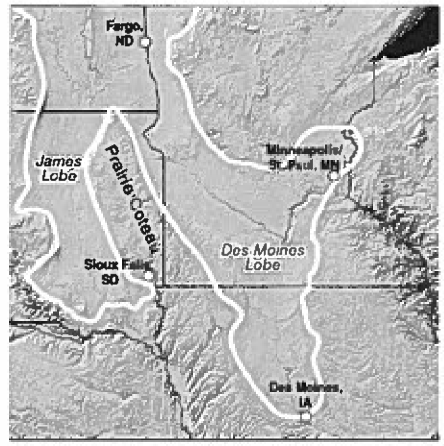



**Fig.2.** Geographical distribution of Des Moines lobe of the Laurentian ice sheet, from Jennings (2009).

Multiple MN state agencies have worked over many years on valuable studies of ground water chemistry, stratigraphy, and hydrogeology in As affected areas. However, full integration of these MN-specific databases has not been undertaken, and the natural and human-influenced processes driving As movement from geological materials to domestic drinking water remain elusive. This knowledge gap has consequences for the health of Minnesotans, and it limits the efficacy of public policies directed at wise placement and construction of new wells (Erickson and Barnes 2004).

Through the current research, we are making a strong contribution to this troubling public health problem. We bring a fresh perspective to a long-lived water quality challenge, and are leveraging our recent research activities through direct collaboration with the Minnesota Geological Survey, Department of Natural Resources – Division of Waters, and the USGS. We are collecting new As speciation and mineralogy data for 20 rotary sonic drill cores at multiple depths per core (Fig.3). We will integrate these new data with existing databases generated by MN public agency research initiatives. This data integration effort will focus first on west-central MN because this region shares a disproportionate number of elevated As wells, and the subsurface stratigraphy (Harris 2006) and hydrogeology (Berg 2008) for this area of the state are now available. In addition, we have recently participated in new drilling activities, through invitation, with the Minnesota Geological Survey. These fresh rotary sonic cores hail from south-central MN and were sampled by us in the field in 2010. Our collaborators at the Minnesota Geological Survey are actively working to complete the glacial stratigraphy for these new cores.

The results of our work will be directly transferable to other glacial aquifers of Minnesota, North Dakota, and Iowa (Erickson and Barnes 2005a). The findings may also have implications for naturally occurring As in Wisconsin aquifers where the As-bearing geological formations are different from that of MN. Once published in peer-reviewed journals, all data sets generated by this research will be made publically available. In particular, we plan to present the data to the MN Department of Health for use in water quality monitoring, well head protection, and making recommendations to the MN legislature regarding well codes.

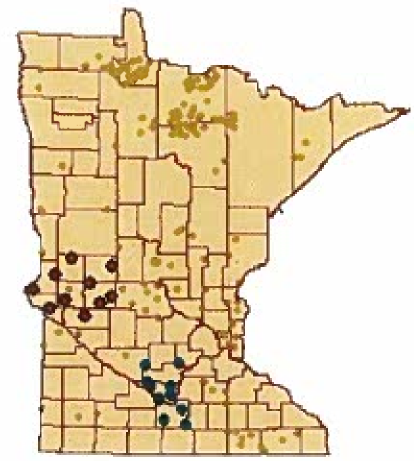


**Fig.3.** Geographic distribution of archived (red dots, west-central) and fresh (blue dots, south-central) rotary sonic drill cores that are part of this study. Small gold dots show locations of other archived cores.

## 2. Long-Term Goal of Research

The long-term goal of the research activities is to locate and preserve safe drinking water for communities in Minnesota. It has become clear to us that achieving this goal requires new analytical approaches, tightly coordinated research activities that encompass large field campaigns, extensive laboratory work, and computationally demanding integration and analysis of new and existing databases. In response to this challenge, we initiated a new collaborative group, the Arsenic Geochemistry Consortium. The purpose of the Consortium is to address this question: can we identify the sources and distribution of As-bearing glacial deposits, and use this information to place wells where water quality is highest?

The Arsenic Geochemistry Consortium consists of experienced scientists in state and federal agencies all having an active interest in As in MN groundwater: (1) USGS; (2) MN Department of Natural Resources-Division of Waters; (3) MN Department of Health; and (4) Minnesota Geological Survey. The perspectives gained through interaction with this group of scientists are:

(1) Coordinated research efforts can yield substantial progress in the understanding of As contamination of groundwater, and that collaboration adds value to mission-oriented agency activities.

(2) New scientific approaches to address the sources of As to groundwater are needed, and a shift in focus from total As concentrations to solid phase As speciation and the origin of glacial deposits were identified as key areas for collaborative efforts.

## 3. Research Objectives

The specific chemical form, or *speciation*, of As determines its behavior (e.g. adsorption-desorption, solubility, and oxidation-reduction status) in solid and aqueous phases. For almost two decades, spectroscopic research on laboratory-generated samples has addressed the chemical interactions between As and minerals thereby establishing a strong conceptual framework for As behavior in natural systems (Waychunas et al. 1993; Goldberg and Johnston 2001; Farquhar et al. 2002; Thoral et al. 2005; Saalfield and Bostick 2009; Amstaetter et al. 2010). Over the past 10 years, As XAS has also been applied in field-based studies (Kneebone et al. 2002; Polizzotto et al. 2006; Itai et al. 2010). Identification of the geologic sources and chemical forms of As is a critical first step toward understanding the biogeochemical processes liberating As to groundwater.

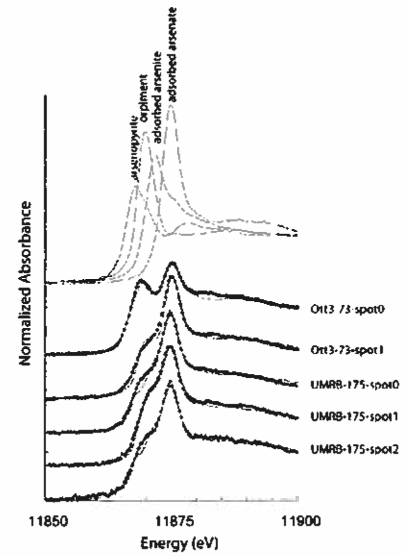



**Fig.4.** Representative "bulk" As 1s XANES data collected at APS 20-BM using a cryostat: (top) reference and (bottom) experimental spectra

Therefore, our objectives are to determine:

(1) the chemical form(s) of As in MN glacial deposits (*speciation*);

(2) how As-bearing deposits are distributed in the sub-surface (*distribution*); and

(3) the conditions leading to As release from geologic strata to groundwater (*biogeochemical processes*).

To address Objective #1, we are measuring As speciation in glacial deposits from west-central MN (archived cores) using synchrotron radiation X-ray absorption spectroscopy (XAS) and sequential extraction techniques. These data represent critical missing information, and fall squarely within the purview of the field of Molecular Environmental Science. The methods employed in this field are similar to those of chemistry and material science; however, the purpose is to understand natural systems through environmentally relevant experiments and measurements, this is PI Toner's primary field of training. Objective #2 requires data on samples from known geographic and depth locations – both criteria are met through rotary sonic drilling activities with the Minnesota Geological Survey. In addition, expertise in glacial geology, stratigraphy, and GIS are required. We collaborate closely with experts in these fields and some are

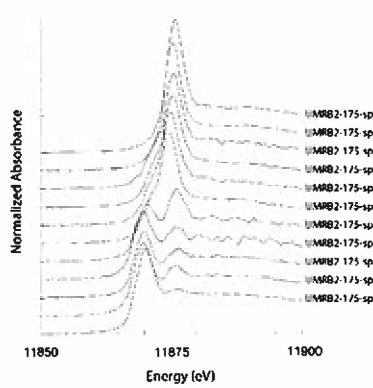



**Fig.5.** Representative micro-probe As 1s XANES data collected at ALS 10.3.2 using "quick" or QXAS.

members of Sarah Nicholas' dissertation committee: Carrie Jennings (Minnesota Geological Survey) and Melinda Erickson (USGS). Objective #3 has a time scale for completion longer than Objectives #1 and #2. We anticipate that the results derived from the current research will allow us to design an effective study to address Objective #3.

## 4. Research Approach

The minerals, rocks, and geological strata releasing As to groundwater in west-central MN are unknown. There is geological and geostatistical evidence to suggest that the As originates from the solids within or adjacent to aquifer sediments. In particular, fragments of shale, a rock type that is present in Des Moines lobe glacial deposits in MN (Erickson and Barnes 2005a) and Illinois (Warner 2001), have been implicated. However, no correlation between total solid and total dissolved As concentrations has been observed (Warner 2001; Erickson and Barnes 2005). This is the underpinning of the As paradox, because As is:

*a rock-derived trace element and a naturally occurring groundwater contaminant having solid phase concentrations with no apparent correlation to the dissolved As concentration in adjacent pore water.*

Because of this lack of correlation, it would seem that the most important information is not how much As is present, but which forms of As are present. Therefore, we hypothesize that a primary factor in As release to glacial aquifers in MN is the solid phase As speciation. To test this hypothesis, we are using synchrotron radiation X-ray absorption spectroscopy (XAS); it allows one to measure solid phase As speciation and mineralogy without chemically altering the sample. Because of the richness of information one receives, As XAS measurements have been used to identify As speciation in aquifer and reservoir sediments (Cullen and Reimer 1989; Beaulieu and Savage 2005; Smith, Koch et al. 2005; Arai et al. 2006; Polizzotto et al. 2006; Choi et al. 2009; Itai et al. 2010). However, it is important to emphasize that the proposed study is a significant challenge due to the large scope of the project and the low total As loading to the sediments. Our sample set consists of 10 west-central MN archived rotary sonic cores (253 individual samples) and 10 south-central cores (426 individual samples) having 4-10 mg As $kg^{-1}$ glacial till (Fig.3). While it is not possible for us to make XAS measurements for all 679 samples, we will use sequential extractions to screen all samples, identify unique sample sets, and then select samples for more intensive XAS analyses.

To our knowledge, direct measurements of As speciation in these glacial aquifers did not exist until we made our first preliminary measurements starting in July 2009 (Fig.4-5). Early adopters of microprobe XAS, Polizzotto et al., did apply XAS to Bangladeshi sediments in 2006 but these measurements were not routine at that time. It is now possible to apply synchrotron radiation XAS and X-ray diffraction (XRD) to samples with *trace element concentrations if* a large degree of physical heterogeneity is present at the micrometer scale. In other words, if the sediment is composed of relatively rare, but concentrated, As-bearing particles, then we can focus in on those individual particles to determine As speciation. The time is right for us to re-examine the As paradox with a new set of tools and a renewed commitment to integrative and collaborative science. For MN glacial deposits, we have been successful in making As bulk and microprobe XAS measurements despite the low total As concentrations in the solid phase (Fig.4-6).

We are generating information on the specific chemical form, or As species, in glacial sediments: tills (confining layers), sand and gravel (aquifers), and the physical interface between these two formations (contacts). We are measuring As speciation and host-phase mineralogy directly using state-of-the-science X-ray spectroscopic methods and indirectly using a wet chemistry technique called sequential extraction (see Methods). The sequential extraction method has the disadvantage of relying on operationally defined As species, but has the distinct advantage of allowing for analysis of many hundreds of samples. The advantage of the spectroscopic measurements is that we access directly the valence state and As-bearing mineral phases in glacial deposits. Spectroscopic data also allow us to ground truth the sequential extraction data, but in a smaller number of samples. As part of this proposal, we will add the As speciation data to our GIS database that was constructed with funding from the Center for Urban and Regional Affairs (CURA, PI Toner, co-PI Erickson). When coupled to existing glacial geology, stratigraphy, and hydrogeology knowledge, this new dataset will define the distribution and As-release potential of glacial deposits in west-central MN – creating information that is greater than the sum of its parts. We are working toward As speciation measurements for samples from 10 *archived* rotary sonic cores. To-date, we have sampled the 20 cores (10 archived and 10 fresh), and spectroscopic and sequential extraction data collection for the archived cores has begun (see Results).

In the present research, we must neglect at least two very legitimate components of the aquifer system in our proposed research. In particular, oxidation-reduction status of aquifers and microbial activity must be addressed for Objective #3, but are outside the scope of what we can accomplish in a two year study, with one Ph.D. student, and our current set of collaborators. Our focus on the solid phase As speciation is justified by the lack of existing knowledge regarding As sources to glacial deposits – pyrite in shale is usually implicated as the source, but the As-shale linkage has never been substantiated in sediments of the Des Moines lobe. This focus is reinforced by the limitations of rotary sonic drilling. During rotary sonic drilling we retrieve essentially no bulk water, and monitoring wells are not installed in the drill holes. With improved coordination between the Minnesota Geological Survey and the DNR-Division of Waters, we may be able to install monitoring wells in future field campaigns, but it has not been accomplished for any of our samples to date.

## 5. Methods

***Sampling Glacial Sediments*** – In consultation with Minnesota Geological Survey scientists, we identified and sub-sampled archived rotary sonic cores hailing from Traverse, Grant, Stevens, Douglas, Pope, Big Stone, and Swift counties of west-central MN (10 cores, 253 samples). The cores are curated by the Minnesota DNR, Division of Lands and Minerals, and stored in open wooden boxes in contact with ambient atmosphere. In addition to the archived material from the Grant-Traverse area, we collected fresh samples from new cores in 2010: 426 samples have been collected from 10 new cores in Sibley, Nicollet, and Blue Earth counties of south-central MN. Samples of the new cores were collected in the field, and were immediately preserved (frozen in an argon atmosphere) to prevent changes that might occur due to exposure to air. These fresh cores can be used to examine whether core storage affects As speciation. The aquifer-confining unit interface is of particular interest for As biogeochemical cycling. A typical suite of samples from a single interface or contact of sediments includes samples above, within and below stratigraphic transitions. MGS has published descriptions of the strata with depth (stratigraphy) for the archived cores sampled for this study.

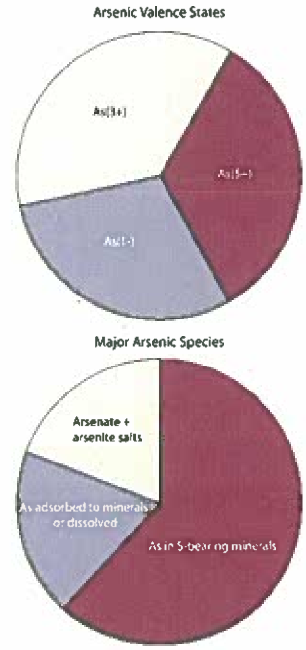



**Fig.6.** Representative results from linear least squares fitting of micro-probe As 1s XANES spectra. This is the type of information we are adding to our GIS database.

***Measuring Arsenic Speciation*** – We are using a sequential extraction procedure as a high throughput method to quantify the distribution of As among a number of species that are defined operationally. This information is used to understand how likely As is to move from the solid phase to aqueous phase and is an indicator of *lability*: ranging from weakly to strongly adsorbed As species, through co-precipitated with carbonates, sulfides, oxyhydroxides of iron and manganese, and to highly recalcitrant As-bearing minerals. The Toner group used new faculty start up funds and the CURA grant funding to ready the laboratory for sequential extractions by the method of Keon et al. 2001. The concentration (mol As $kg^{-1}$ of sediment) is calculated for each extraction step, and the sum of As extracted is compared to total As measured by a contract laboratory to verify mass balance .

We are using XAS spectroscopic measurements, in bulk and at the micron-scale, to quantify the number and abundance of As species in glacial deposits. Sub-samples of archived core materials were analyzed at the Advanced Photon Source (APS), Argonne National Laboratory, Argonne, IL. We collected As 1s XANES spectra for 6 tills at beamline 20-BM in fluorescence mode using a cryostat sample holder. The signal from the tills was very low, and many scans (up to 12) were averaged to produce the experimental spectra displayed in Fig.4. Three important results came from that initial dataset: (1) we can measure As valence state at 4 mg As $kg^{-1}$; (2) despite our best efforts to homogenize the sample, spatial heterogeneity was detected; and (3) reduced As phases persisted in the archived tills. In response to our APS data, we have begun As XANES, XRD, X-ray fluorescence (XRF) mapping using the microprobe beamline 10.3.2 at the Advanced Light Source (ALS), Lawrence Berkeley National Laboratory, Berkeley, CA, USA. With a 5-10 $\mu m^2$ beam, the valence state of As (and Fe, Mn, S) are measured by 1s XANES spectroscopy (Fig.5), and the mineralogy of the particles are determined by XRD. The microprobe XAS measurements worked very well, and indicate that: (1) As-rich particles are present even when the bulk As content is very low; (2) pyrite particles are observed but they contain low As; (3) higher quality data can be obtained using the microprobe; and (4) As EXAFS measurements of local coordination environment may be possible.

Arsenic in aquifer sediments is often reported as associated with Fe-bearing minerals such as pyrite and ferrihydrite. From the perspective of As retention and release to groundwater, these two minerals are As reservoirs with strong potential for As release when conditions in the aquifer change. Pyrite and ferrihydrite represent the low- and high-oxygen end-points where As is retained by aquifer sediments – it is the cycling between these points where As can be mobilized in groundwater. For example, pyrite is typically a stable As reservoir when dissolved oxygen is low in concentration (anoxic). When oxygen is introduced to anoxic groundwater by a domestic well, As can be released to groundwater locally (Schreiber et al. 2000). Conversely, ferrihydrite is stable in the presence of oxygen and it tends to retain As through adsorption reactions at the mineral surface – these are weak, labile associations especially when the oxygen concentrations drop (Kanivetsky 2000). We will test this conceptual framework with our data.

## 6. Results

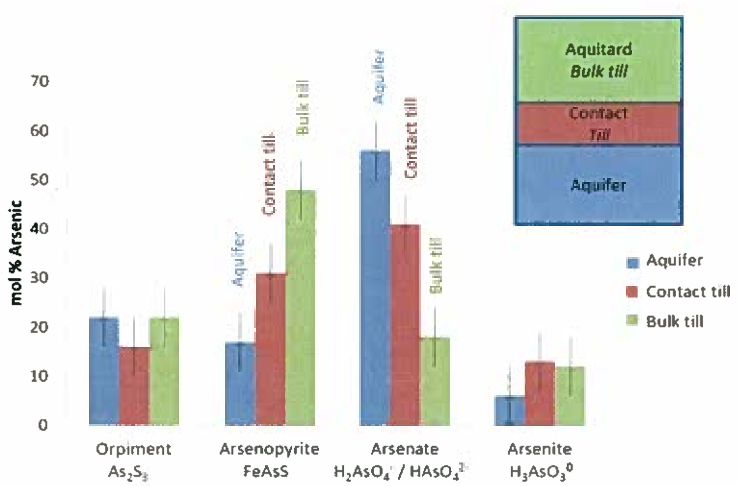



**Fig.7.** Relative proportion of arsenic species measured in a bulk till, contact till, and aquifer sample set from Ottertail County, MN, USA. The measurement was micro-probe XAS at the Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

In our most recent research activities, we have found that the proportion of oxidized As (arsenate) was high in permeable glacial outwash (aquifer), intermediate in low-permeability glacial till sediments adjacent to outwash (the "contact" till), and low within glacial till sediments (aquitard) (Fig.7). Conversely, the proportion of reduced As (arsenopyrite) was low in glacial outwash, intermediate in the contact till, and high within the glacial sediments. No changes in the proportion of As(III) species across the contact were observed. These results reveal an oxidation-reduction gradient in As across the contact till, and support the hypothesis that the till contact is an active zone of As release to groundwater.

# The Role of Sulfate Reduction in Sediment of the St. Louis River Estuary: Phase II

## Basic Information

| | |
|---|---|
| **Title:** | The Role of Sulfate Reduction in Sediment of the St. Louis River Estuary: Phase II |
| **Project Number:** | 2011MN290B |
| **Start Date:** | 6/1/2011 |
| **End Date:** | 5/31/2012 |
| **Funding Source:** | 104B |
| **Congressional District:** | MN 8th |
| **Research Category:** | Water Quality |
| **Focus Category:** | Sediments, Toxic Substances, Geochemical Processes |
| **Descriptors:** | |
| **Principal Investigators:** | Nathan Johnson |

## Publication

1. Beck, B. and N. W. Johnson. 2011. Sulfur and Carbon Controls on Methylmercury in St. Louis River Estuary Sediment. SETAC North America, Boston, MA. Beck, B. F. and N. W. Johnson. 2011. Characterizing the Relationship Between Sulfate Reduction and Mercury Methylation in St. Louis River Sediment. Minnesota Water Resources Conference, St. Paul, MN.

**The Role of Sulfate Reduction in the St. Louis River Estuary: Phase II**

**Principal Investigator**

**Nathan Johnson, Assistant Professor, Department of Civil Engineering**

**Funding Source: USGS –WRRI 104B/CAIWQ Grants Program**

**Project Duration:** **6/1/2011- 5/31/2012**
**Reporting Period:** **3/1/2011-2/28/2012**

## Project Status

The project reported on in this report is part of a two year study that was funded jointly by the USGS and MnDNR. The first phase was completed during Summer 2010 through winter 2011, and a final report was submitted last year. The second phase (described herein) has been ongoing from Summer 2011 through Summer 2012. An extension for the project was requested and granted through August 2012. As such, some data is still being analyzed and this should be considered an interim report, with a complete report to follow by early Fall, 2012.

## Introduction and Objectives

The St. Louis River watershed is located in Northeast Minnesota, which ultimately discharges into Lake Superior near Duluth, Minnesota. It has been demonstrated that the St. Louis River main stem and estuary are impacted by mining activities, artificially raising sulfate concentrations (Berndt and Bavin, 2010). This report is a continuation of the investigation on the relationship between water column sulfate concentration and methylmercury. While the Berndt and Bavin 2010 study focused primarily on watershed scale relationships between methylmercury and sulfate in the water column, this study is attempting to understand the mechanisms of mercury methylation in a sediment matrix.

Sulfate reducing bacteria have been implicated as the prime methylators of mercury, creating methylmercury, a bioaccumulative neurotoxin (Ratcliffe et. al., 1996). Sulfate reducing bacteria occur in anoxic, aquatic environments, and require two substrates to exist, sulfate and organic carbon

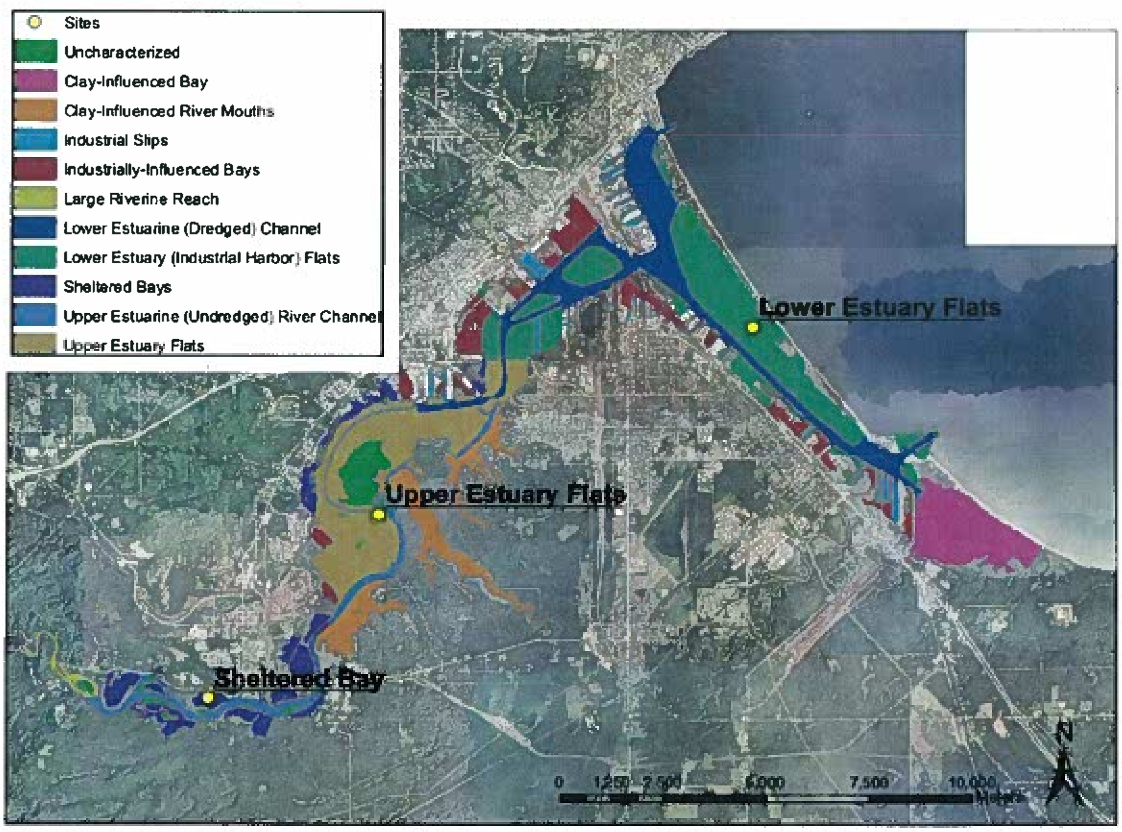



Figure 1. The St. Louis River Estuary with the Habitat Zones delineated and tites (yellow symbols) that were sampled in August 2011 to obtain cores for sulfate addition experiment.

(Froelich et. al., 1979). A traditional thought model exists in which sulfate and organic carbon limit sulfate reducing bacteria's ability to transform inorganic mercury to methylmercury (Gilmour, et. al. 1991; Lambertsson and Nilsson, 2006). Although these limiting factors have been observed in both freshwater and estuarine systems, a linear relationship does not exist between sulfate and methylmercury in all cases (Harmon et. al., 2007; Benoit et. al, 1999). There are complex biogeochemical mechanisms that control mercury cycling in sediment, which is why it cannot be assumed that increasing water column sulfate concentrations will necessarily increase methylmercury concentrations in the sediment and ultimately the water column (Benoit et. al., 2003).

In the St. Louis River Estuary, an ongoing investigation is being conducted to understand that relationship between sulfur geochemistry and methylmercury production. The first phase study's objective was to quantify the in-situ parameters to understand the bulk geochemical characteristics of a sulfate impacted system (Johnson and Beck, 2011). The results from the first phase study were used to guide the decision making for the phase of the study. The objective of the second year study is to understand the mechanisms which limit or promote mercury methylation in a variety of sediment types. This objective will be met by incubating three different sediment types with varying sulfate concentrations to ultimately determine if sulfate is the limiting factor for mercury methylation in sediments of the St. Louis Estuary.

The objectives of this study are two-fold, a management related objective and a scientific related objective. The management related objective is to determine whether or not increasing or decreasing sulfate in the overlying water will increase or decrease mercury methylation. Since the dynamics of methylmercury are complex, an in depth mechanistic study may provide evidence whether changing water column sulfate concentrations will alter production of MeHg. Secondly, a scientific question will be answered at the conclusion of this experiment. While there have been investigations into sulfate influences in saltwater estuaries and freshwater wetlands, there have been few studies determining MeHg limitations in sulfate-impacted freshwater estuaries. These experiments will give additional insight into the geochemical dynamics of freshwater estuary sediments related to methyl mercury production.

## Methods, Procedures, and Experimental Design

### Site Selection

Sites were selected along a reach of the St. Louis Estuary from upstream to downstream, to obtain a variety of habitat zones that have been outlined by the St. Louis River Alliance (SLRA). The three different habitat zones that were selected were the Lower Estuary Flats (LEF), Upper Estuary Flats (UEF), and Sheltered Bays (SB) which are shown in Figure 1. The sites were selected for two reasons. First the sites are known to have varying geochemical and physical parameters (Johnson and Beck, 2011) likely to influence mercury-related geochemistry. Sites were selected along an organic carbon gradient, since organic carbon (in the solid phase) can influence the production of methylmercury (Lambertsson and Nilsson, 2006). The most upstream site (Sheltered Bay) has been characterized as having the highest TOC solid phase concentrations while the most downstream site has the lowest solid phase TOC concentrations (Johnson and Beck, 2011).

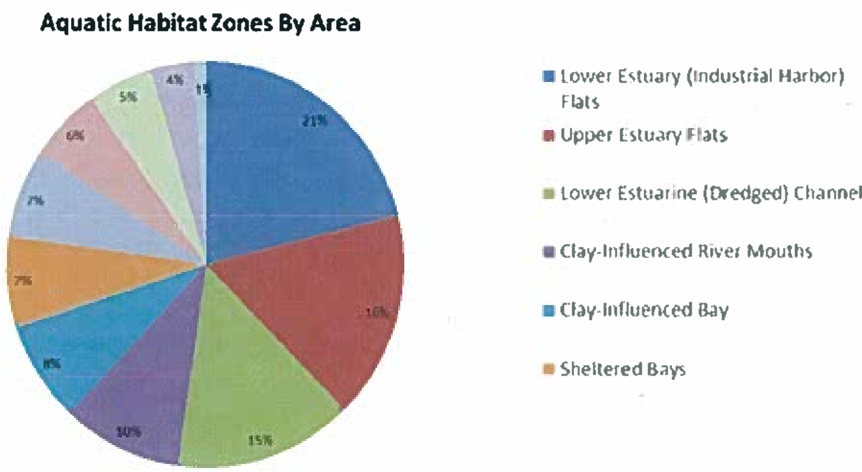



Figure 2. Each habitat zone by percent area within the St. Louis River Estuary. The four zones select for this study accumulate to 45% of the total area in the estuary.

The second criterion for site selection was to sample areas that were the most prevalent (in terms of areal coverage). The sites selected for this study are from habitat zones that cover 45% of the entire estuary/harbor (Figure 2).

Field and Analytical Methods

The cores obtained from the field were allowed to equilibrate in the experimental conditions (20° C and 60% relative humidity) for 1 week, after which a microelectrodes were used to measure porewater sulfide ($S^{2-}$), ferrous iron ($Fe^{2+}$), and manganese ($Mn^{2+}$) (Brendel and Luther, 1995) (Figure 4). Microcosms were then sub-cored in triplicate (~1" diameter sub-core) and split into three depths (0-4cm, 4-10cm, and 10-20 cm), placed in 250 mL sample jars and placed in an oxygen free atmosphere within 15 minutes of extrusion. Sediment samples were then homogenized under a nitrogen atmosphere and subsampled for each analysis. If solid phase samples were not immediately analyzed, aliquots of sediment were placed in acid cleaned scintillation vials and placed in a -20° C freezer.

Porewater sulfate and was measured after centrifuging the extruded sediment, using an ion-chromatograph (Dionex 1100). Acid volatile sulfides (AVS) were measured using the Brouwer diffusion method (Brouwer and Murphy, 1994). Solid phase ferrous iron was measuring using an oxalic acid extraction followed by colorimetric analysis (Phillips and Lovley, 1987). Methylmercury and total mercury were measured using isotope dilution and ion-coupled mass spectrometer (GC-ICP-MS), respectively (Bloom, 1989). Sulfate reducing bacteria abundance as measured using quantitative PCR (qPCR) after a solid phase extraction using a Mo-Bio Powersoil. extraction kit (Schippers and Neretin, 2006).

Experimental Design

As mentioned above, the objective of this study is to determine the limiting factor for mercury methylation in the St. Louis River Estuary sediment. In light of ongoing and proposed mining operations on the Mesabi Iron Range, as well as discussions about state regulations for sulfate, it is possible that sulfate loading to the St. Louis River watershed could increase or decrease in the relatively near future.

The experiment in this report was designed to answer the question of whether sulfate is limiting the component in the St. Louis River sediment relative to the methylation of mercury.

Three replicate microcosms (sediment cores) were obtained from each habitat zone (Figure 1) using a custom fabricated sediment corer and transported to a climate control chamber. To determine if sulfate is the limiting factor in mercury methylation in the St. Louis River Estuary, each sediment type (LEF, UEF, and SB) had three different treatments applied for a period of 6 months. The treatments were applied by allowing water amended with a high (50 mg/L), control (15 mg/L), and low (2.5-5 mg/L) amount of sulfate to recirculate over each type of sediment to allow sulfate to passively diffuse into the sediment, as it would in a riverine environment. To ensure a carbon limitation was not imposed on the in-situ microbial communities, water from the Cloquet River, was used as the experimental treatment matrix. Cloquet River water was selected as the experimental matrix because it has low sulfate (2.5-5 mg/L $SO_4^{2-}$) while having similar DOC concentrations to the St. Louis River (~30-40 mg/L).

Two different types of sampling methods were used in this study, destructive and non-destructive techniques. The destructive techniques required sub-cores to be removed from the microcosms. The destructive techniques could only be used to characterize the geochemical and microbial initial and final conditions. Voltammetric electrodes (non-destructive analytical method) were used every 1.5 months to measure redox sensitive parameters in the microcosm porewaters (Figure 4). These were used to observe whether there were any temporal changes in the redox conditions due to the treatments being applied to the microcosms over a 6 month period. Although porewater measurements were obtained every 1.5 months, only the initial will be presented in this report.

## Results and Discussion

## Porewater

Figure 3a-f depicts sulfate concentrations in each microcosm with depth. The sediment microcosm initial conditions display sulfate consumption in all cores (3a-c) with sulfate being consumed most rapidly in the SB cores, relative to the LEF and UEF cores. There was no detectible sulfate within the upper 4 cm of the sediment in the SB cores, while the UEF and LEF cores both had sulfate in the 0-4 cm interval. It is likely that due to higher organic carbon availability in the SB site, sulfate reduction occurred at a higher rate relative to the LEF and UEF cores. There was a clear relationship between sulfate penetration and microcosm treatment type (Figures 3d-f). In all microcosm treatments, sulfate was completely consumed at the 10-20 cm depths (Figure 3d-f) at the close of the experiment.

Porewater concentrations of redox sensitive analytes are displayed in figure 4a-j. The porewater in upper Upper Estuary Flats and Lower Estuary Flats displayed significant dissolved $Mn^{2+}$ with no detectible $Fe^{2+}$ or $S^{2-}$ (Figure 4a-f). The Sheltered Bay site porewater had trace amounts of sulfide (3-10 uM $S^{2-}$) and higher ferrous iron concentrations (150-400 uM $Fe^{2+}$), with no detectible $Mn^{2+}$ (Figure 4g-j). Thermodynamically, manganese reduction is a more favorable reaction, which means this will occur before sulfate and iron reduction in the sediment column. It was observed that the sheltered bay site was thermally stratified, which indicated an anoxic hypolimnion. In the case of a stratified hypolimnion, it is likely that manganese reduction had moved into the water column, moving iron reduction and sulfate reduction closer to the sediment water interface, at depths the microelectrodes can measure (0-15cm). It is possible that iron and sulfate reduction may occur deeper in the sediment column at UEF and LEF, past the reach of the electrodes. Although measurements were taken at four different time points, only the initial conditions will be presented in this report for redox sensitive porewater concentratrions.

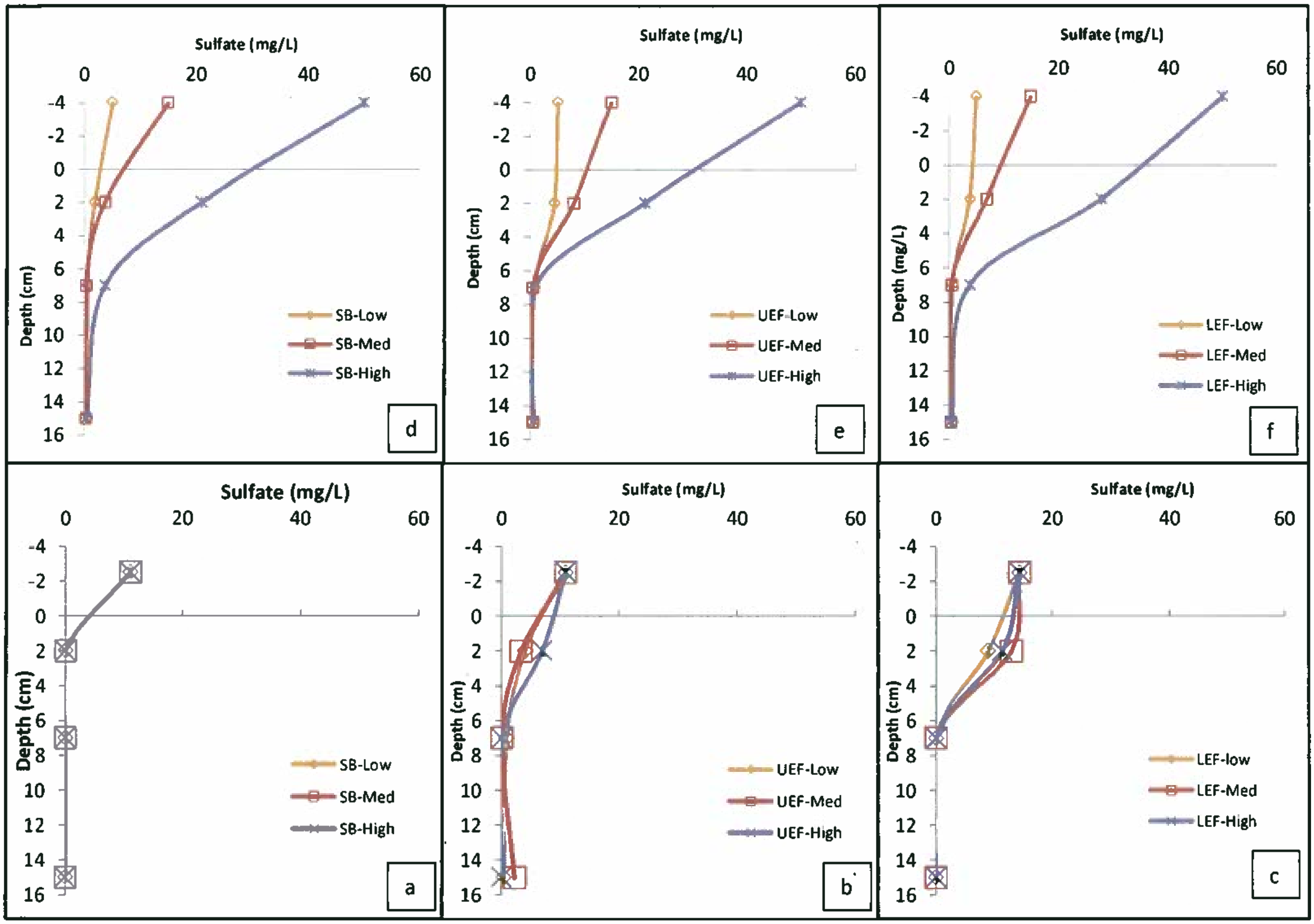



Figure 3. Porewater sulfate profiles for each treatment for the Initial Condition(a-c) and Final Conditions (d-f) Sheltered Bays (SB), Upper Estuary Flats(UEF), and Lower Estuary Flats (LEF).

## Solid Phase

Solid phase AVS is depicted in figure 5a-f for all microcosms initial and final conditions. The SB site had the highest abundance of AVS (figure 5a). Conversely, the LEF and UEF (Figures 5b and c) sites had the lower AVS which agrees with the lower diagenetic activity displayed in Figure 4. Higher organic carbon (Johnson and Beck 2011) and anoxic water column conditions at the SB site likely lead to higher in-situ sulfate reduction relative to the upper estuary and lower estuary flat sites.

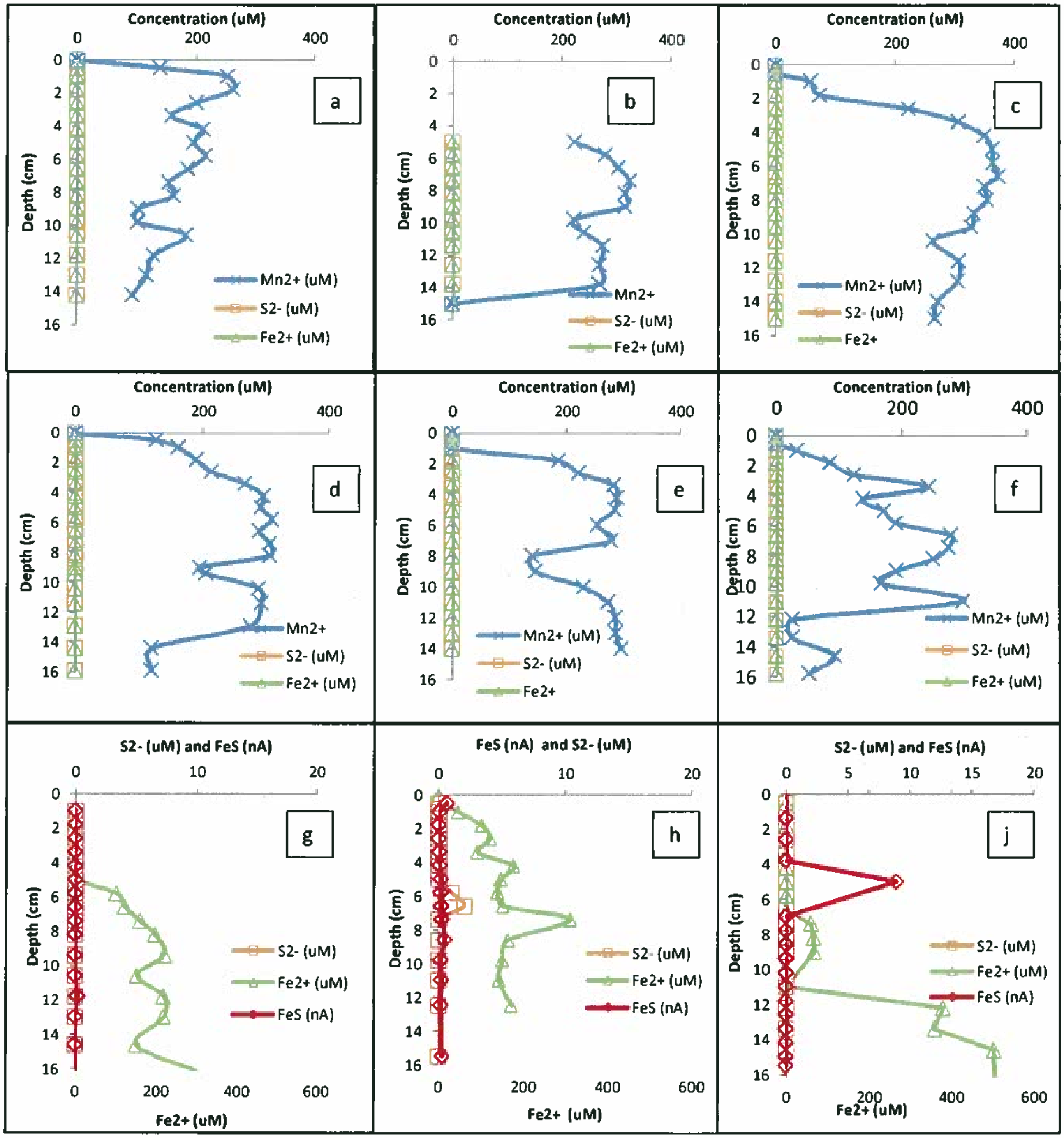



Figure 4. Initial condition porewater redox profiles for the LEF (low (a), medium (b), high(c)), UEF (low(d), medium(e), and high(f)), and SB (low (g), medium (h), and high(j).

AVS appears to change from initial conditions moste in the surface of SB sediment (due to oxidation from oxygen-containing overlying waters) and from 4-10cm in UEF for sulfate amended treatments.

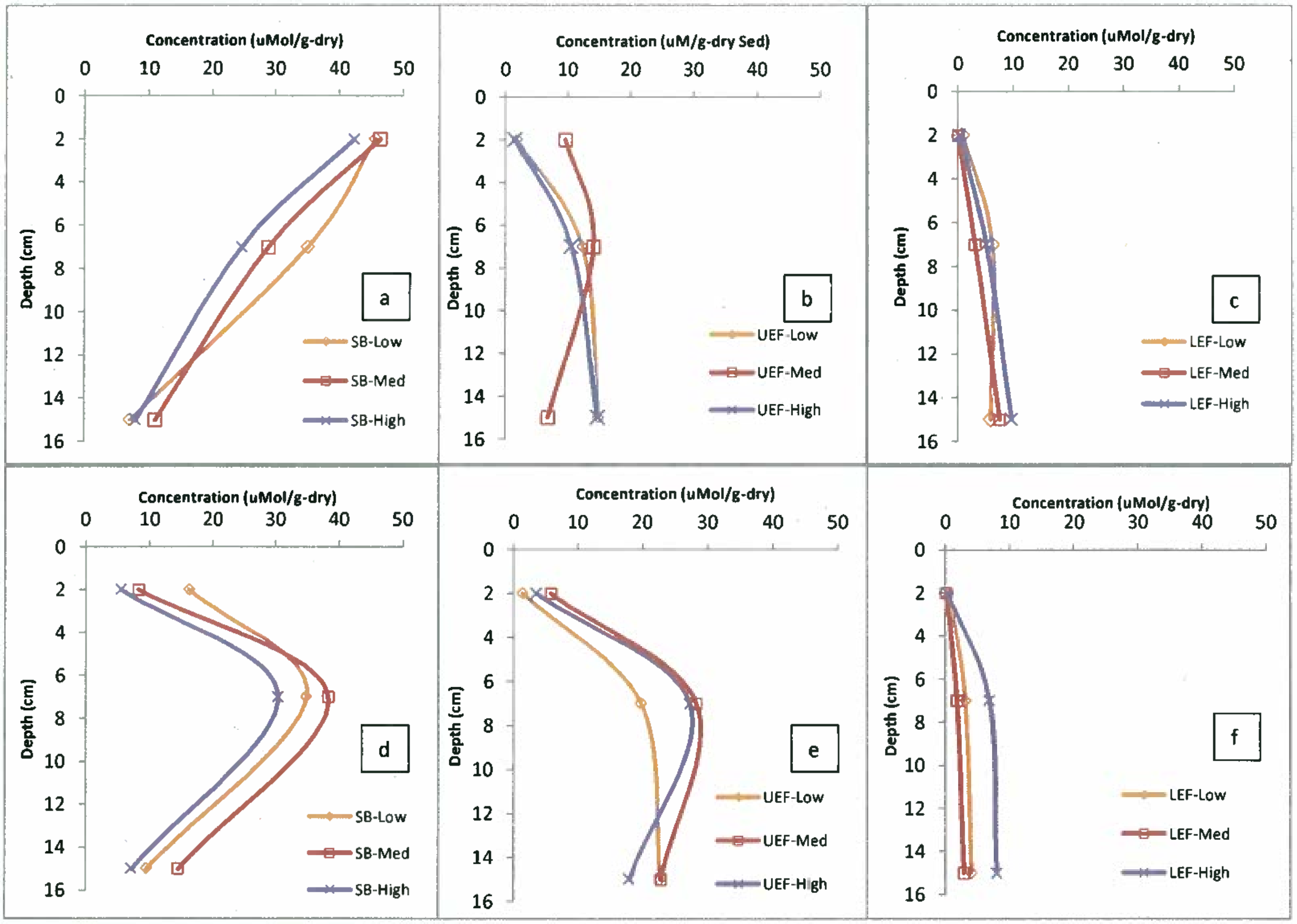



Figure 5. Acid Volatile Sulfide profiles for each treatment for the Initial Condition(a-c) and Final Conditions (d-f) Sheltered Bays (SB), Upper Estuary Flats(UEF), and Lower Estuary Flats (LEF).

SRB abubundace was measured in the solid phase and is depicted in Figures 6a-f. Initially, the SB site had the largest abundance of SRB, which would agree with the higher AVS concentration in the SB (Figure 5a). The LEF and UEF sites have smaller abundance of SRB (Figure 6 b and c) initially, similarly to the AVS solid phase concentrations. The final conditions indicate that there was an increase in SRB abundance in the top 4 cm of the SB microcosms (Figure 6d). Oxidation of solid phase sulfide in the top 4 cm coupled with anoxic conditions led to an increase in sulfate reducers in the SB high and medium treatments. Both the UEF and LEF cores saw an increase in SRB abundance in the high treatments, which likely was a result of the sulfate treatment directly stimulating the sulfate reducers. Unlike the SB site, there was not a large source of reduced sulfur that was made available due to oxidation and mobilization.

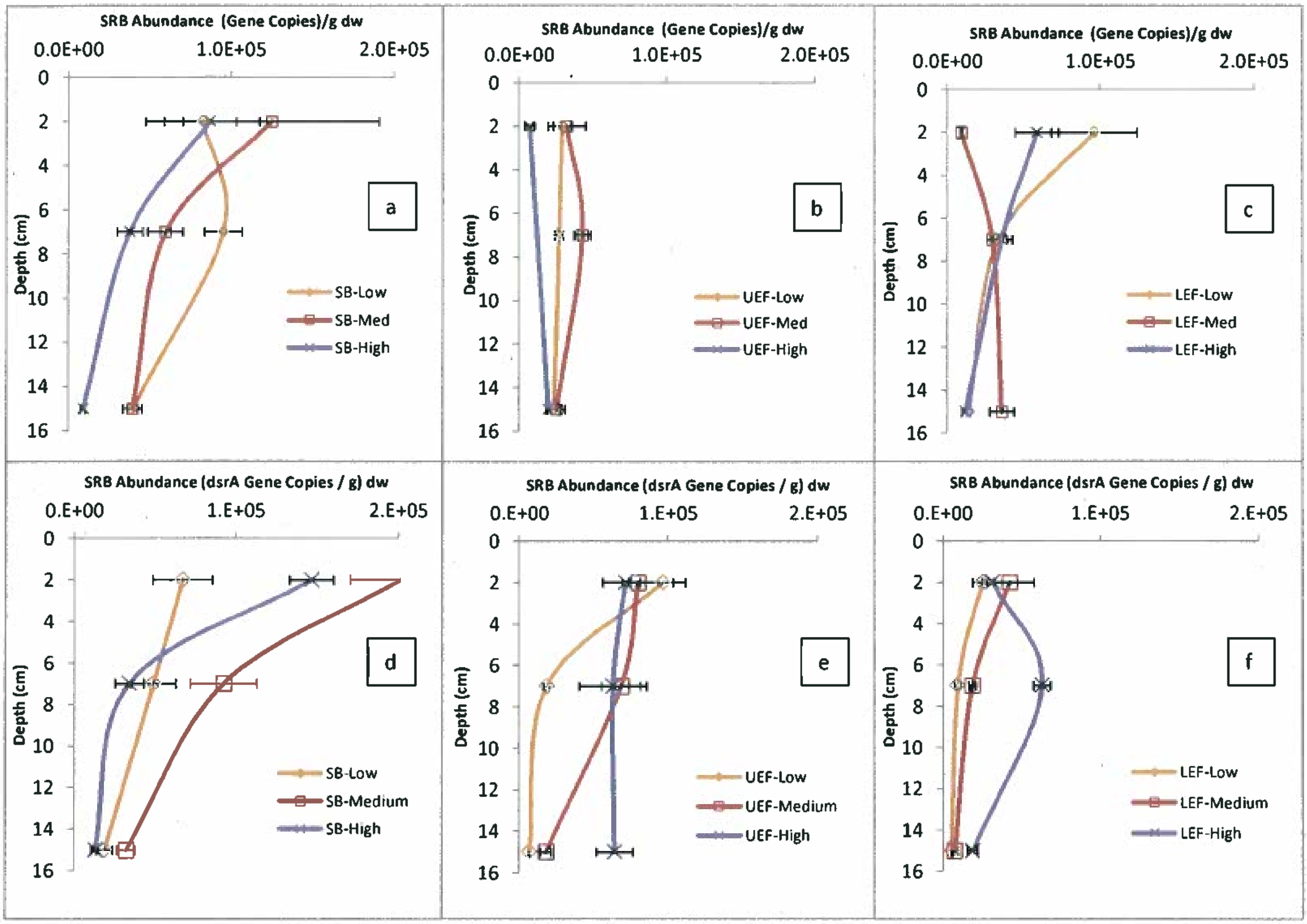



Figure 6. Sulfate Reducing Bacteria abundance for each treatment of the Initial Condition(a-c) and Final Conditions in the (d-f) Sheltered Bays (SB), Upper Estuary Flats(UEF), and Lower Estuary Flats (LEF) sites.

Solid phase ferrous iron was measured in each core, which are displayed in figure 7a-f. The LEF and SB cores had the relatively low solid phase ferrous iron (20-40 uM) compared to the UEF cores (30-240 uM). There was little change between the initial and final conditions in the LEF and UEF cores (Figure 7b, c, e, and f). Interestingly, the SB core solid phase ferrous iron increased from the initial to final sampling time points (Figure 7a and d). The change in ferrous iron concentrations is likely coupled with the change in redox conditions in the SB cores.

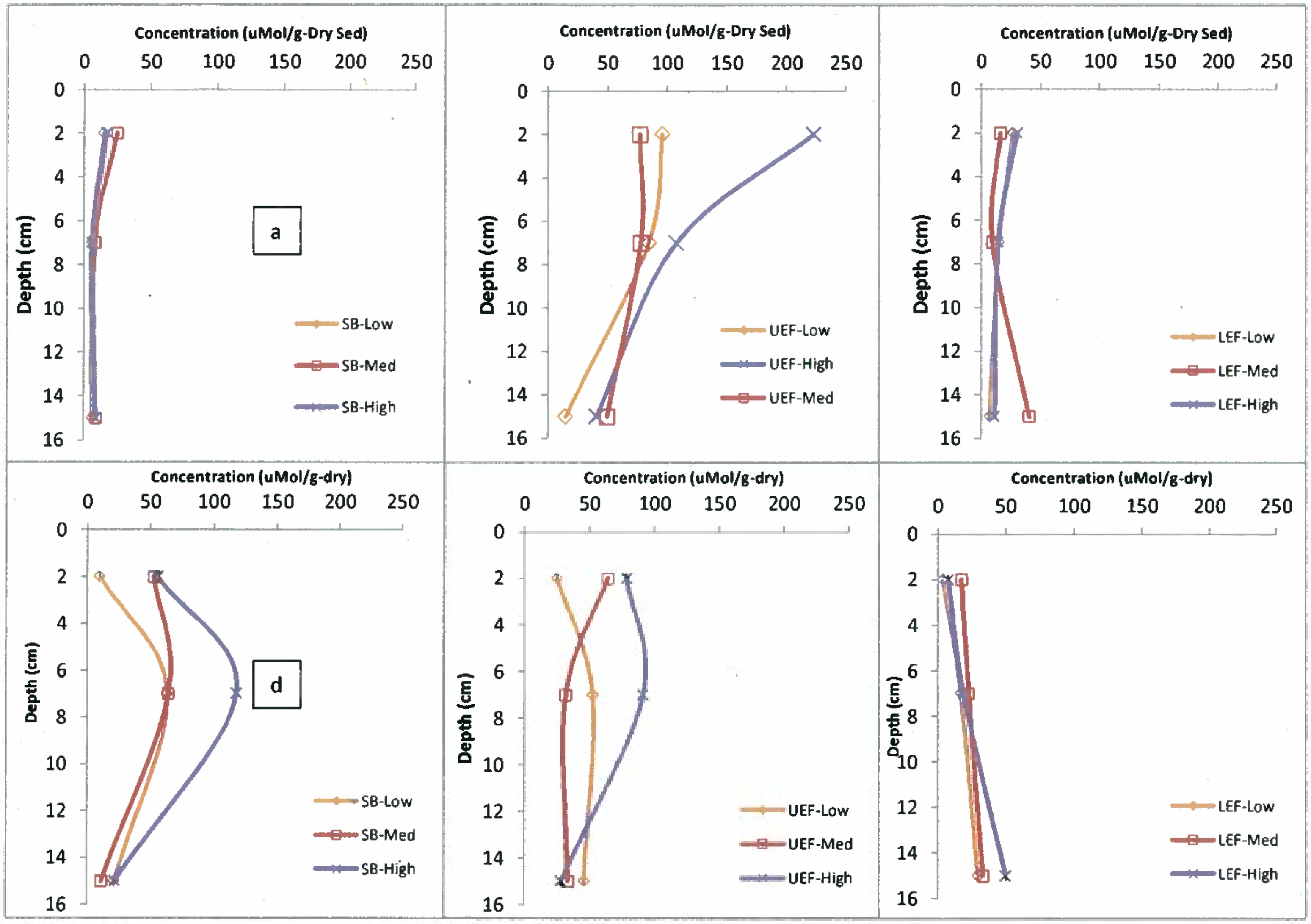



Figure 7. Solid Phase Ferrous Iron profiles for each treatment for the Initial Condition(a-c) and Final Conditions (d-f) Sheltered Bays (SB), Upper Estuary Flats(UEF), and Lower Estuary Flats (LEF).

Initial mercury results are shown in Figure 8a, b and c for THg, MeHg, and percent MeHg. The results for each site (low, medium and High) were averaged to observe trends in the initial conditions. The final time point for THg and MeHg are still being analyzed and will not be included in this report. The SB site had higher MeHg and THg concentration relative to the UEF and LEF sites (Figure 8). Although the MeHg concentrations were the smallest in the UEF site, it was a slightly more efficient methylator of mercury, using the percent MeHg as a proxy for methylation efficiency (Figure 8c). This suggests that although the SB has the highest SRB abundance and AVS, it does not produce methyl mercury much more efficiently than other sites.

## Conclusions

There are clear biogeochemical differences among the sites which are known to influence the production of methylmercury. The LEF and UEF sites can be characterized from the initial condition time point as having lower sulfate and iron reduction, due to lower organic carbon in the solid phase (Johnson and Beck 2011) and a fully oxic water column year round. The SB site is drastically different with a seasonally anoxic water column and organic carbon supplied by primary production, in a lake type ecosystem. This site has higher sulfate reduction as indicated by AVS (Figure 5) and SRB abundance (Figure 6).

Although there is higher SRB abundance, AVS, and THg, the SB site is not the most efficient methylator of mercury. Further investigation is necessary but reduced availability of inorganic mercury to SRB due to strong interactions with organic matter or sulfide ligands may be limiting the efficiency of methylation. The UEF site has the highest percent MeHg, indicating that, of the three sites, it is able to most efficiently methylate mercury. Preliminary evidence suggests that this intermediate habitat zone may contain sufficient organic carbon content to drive SRB but not an excess to limit the available pool of inorganic mercury. High porewater sulfide concentrations have been shown in some sites to limit mercury methylation but no sites in this study had porewater sulfide concentrations >10 uM.

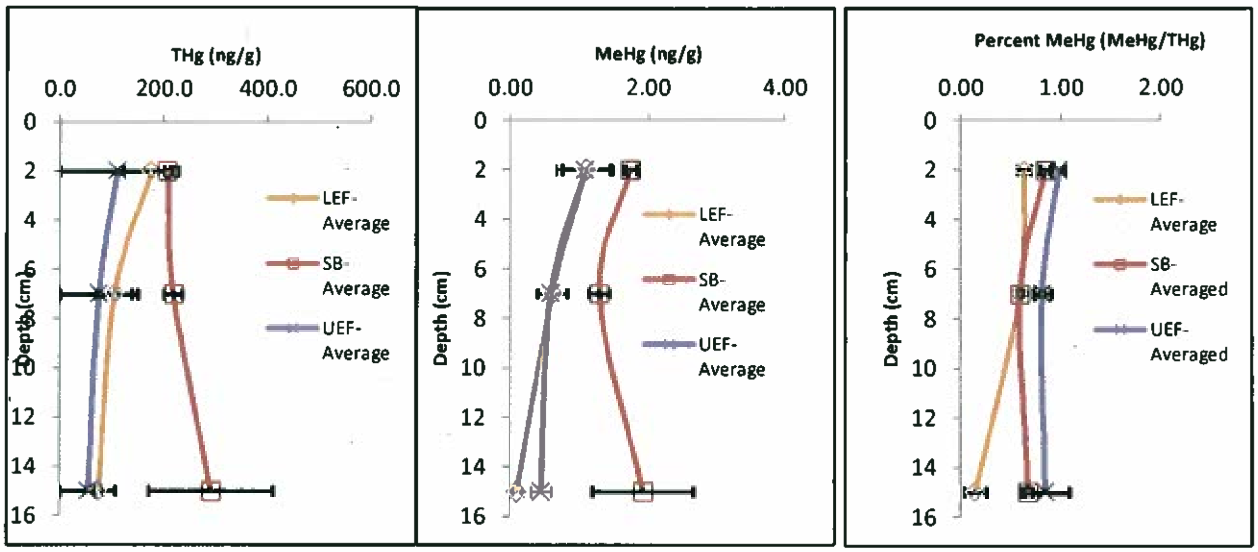



Figure 8. MeHg(a), THg (b), and Percent MeHg (c) solid phase intial condition profiles for each habitat zone.

Although MeHg and THg results have not been reported for the end of our 6 month experiment, other geochemical parameters indicate that changes in methylmercury-related biogeochemistry were induced in some sulfate treatments. All habitat zones had increased AVS and SRB abundance in the high treatments, in addition to the medium treatments (Figures 5 and 6). Both of these lines of evidence would suggest that the activity of sulfate reducing bacteria were stimulated by increased sulfate in the overlying water. Although there is evidence of stimulated sulfate reducers, a full understanding of the mechanisms of mercury methylation will be aided by the solid-phase THg and MeHg data.

## Future work

The final analytes, MeHg (solid phase and porewater), THg (solid phase and porewater), TC, TS, and DOC, need to be analyzed, which is necessary for a complete interpretation of the production of methylmercury in sediment. Once the last parameters have been analyzed a thorough explanation of the limiting factors behind mercury methylation in the St. Louis River can be synthesized. A complete analysis should answer the scientific and management related questions related to MeHg production in freshwater estuary systems and more specifically, the St. Louis River Estuary.

Although production of methylmercury is an important piece of mercury cycling, understanding the transport of MeHg from sediment into the water column is equally critical. A twofold approach to understanding transport will be taken to quantify and model the transport of MeHg. First, partitioning coefficients will be measured given porewater and solid phase MeHg and THg concentrations. Partitioning information will supply insight into the mobility of MeHg in a specific type of sediment. Secondly, flux experiments have been conducted but the analysis is not finished for MeHg. After the data is compiled and analyzed, spatially discretized models can be constructed for the St. Louis River Estuary to estimate total load to the water column. Currently, the magnitude of the MeHg load from the sediment relative to the load from upstream is currently unknown. If the sediment is a large source of MeHg and future management decisions may influence MeHg production, understanding relative loading is critical to informed decision making.

# Persistence of the Fecal Indicator Bacteroides in Sand and Sediment

## Basic Information

| | |
|---|---|
| **Title:** | Persistence of the Fecal Indicator Bacteroides in Sand and Sediment |
| **Project Number:** | 2011MN291B |
| **Start Date:** | 7/1/2011 |
| **End Date:** | 6/30/2012 |
| **Funding Source:** | 104B |
| **Congressional District:** | 5 |
| **Research Category:** | Water Quality |
| **Focus Category:** | Water Quality, Acid Deposition, Sediments |
| **Descriptors:** | |
| **Principal Investigators:** | Michael Jay Sadowsky, Randall Hicks |

## Publication

1. Eichmiller, J.J., R. E. Hicks and M. J. Sadowsky. 2012. Influence of Moisture and Temperature on the Persistence of Molecular Marker Genes to Detect Fecal Pollution in Sand and Sediment. American Society for Microbiology Annual Meeting, San Francisco, California. Eichmiller, J.J., R. E. Hicks and M. J. Sadowsky. 2011. The Distribution of Genetic Markers of Fecal Pollution on a Beach Receiving Consistent Inputs of Wastewater Effluent. University of Minnesota Biotechnology Institute Nara Institute of Science and Technology Joint Symposium, Nara, Japan.

**Persistence of the fecal indicator Bacteroides in sand and sediment**

**Principal Investigator**

**Michael Sadowsky, Professor, Department of Soil, Water and Climate**

**Funding Source: USGS –WRRI 104B/CAIWQ Grants Program**

**Project Duration: 7/1/2011-6/30/2012**
**Reporting Period: 3/1/2011-2/28/2012**

1) _Research_: A synopsis of your ongoing research project and of any research project completed during this reporting period. This includes projects funded under the base grant and the National Competitive Grants program. These reports are for a technical audience, and are posted and regularly accessed on the main USGS website. We do not do any editing of these, so please take care in their preparation. Somewhere between 5-10 pages including tables and figures is typical.

WRS funds were used to support research supply funds of Jessica Eichmiller (Grad student) who is currently being funded by SeaGrant on a project awarded to Randall Hicks and Mike Sadowsky.

## *Scope and Objectives*

The overall goal of this proposed research is to determine the spatial distribution of human-specific *Bacteroides* and its persistence and growth in sand and sediments of the Great Lakes. *Bacteroides* exhibits the traits of an ideal indicator of fecal pollution; however, the factors affecting its distribution and persistence in sand and sediment have never been thoroughly studied. The specific objectives of this proposal are:

- *Objective 1. Determine the distribution of Bacteroides in sand and sediment on a beach with continuous sewage effluent inputs.*
- *Objective 2. Examine the effect of temperature and moisture on the persistence of Bacteroides in sand and sediment.*
- *Objective 3. Assess degree of Bacteroides growth in sediments and its persistence relative to key bacterial pathogens and indicator organisms (E. coli and Enterococcus).*

Experimental microcosms combined with modern molecular methods, such as quantitative PCR (qPCR) analysis of 16S rRNA genes, will be used to address each objective. The broad goal of this research is to assess the validity of using *Bacteroides* as a fecal indicator bacterium. We hypothesize that inefficient sampling and low levels of contamination are the major factors affecting low levels of human-specific *Bacteroides* found in sand and sediment of beaches in the Duluth-Superior harbor. Results of this study will elucidate the factors controlling *Bacteroides* in Lake Superior harbor and provide a framework for understanding the dynamics of this indicator bacterium in the natural environment.

## *Progress*

*Objective 1. Determine the distribution of Bacteroides in sand and sediment on a beach with continuous sewage effluent inputs.*

**Progress:** Project completed. Manuscript is in preparation.

**Introduction:** Sand and sediment are important sources and sinks of culturable fecal indicator bacteria to the water column; however, the distribution of *Bacteroides* markers in sand and sediment, and its relationship to water column abundance is unknown.
**Methods:** A beach site located in Duluth-Superior Harbor receiving consistent input of wastewater effluent was sampled monthly for effluent, beach water, sand, and sediment in the spring to fall of 2010 and 2011. Markers for Enterococcus (Entero1), total *Bacteroides* (AllBac), and human-associated *Bacteroides* (HF183) were quantified by qPCR. *E. coli* and enterococci were quantified by culture-based methods in 2011.
**Results:** Marker concentration and bacterial counts between beach water and effluent were often similar (Fig. 1). AllBac and HF183 in beach water were also correlated with effluent marker concentrations ($R^2$=0.46 and 0.77) (Table. 1). Effluent AllBac, effluent HF183, and beach water AllBac markers were correlated with effluent turbidity ($R^2$=0.80, 0.49, 0.40, respectively). In sand and sediment, *E. coli* and enterococci assessed by culture-based methods were most abundant in the upper 1 cm. Entero1 was most abundant at 3 cm depth in sand and sediment, whereas AllBac was most abundant in the upper 1 cm (Fig. 2). HF183 was most abundant in the upper 1 cm of sand and at 7 cm depth in sediment. *E. coli* and enterococci were correlated with Entero1 and AllBac in sand and sediment, but not with HF183. The explained variation in the correlation between markers and cultured bacteria in sand and sediment from highest to lowest was enterococci>*E. coli*>AllBac>HF183>Entero1. Water column concentration of indicators was not correlated with indicator concentration in sand and sediment.
**Conclusions:** Our results indicate that effluent dynamics may govern fecal indicator concentrations in the water column at nearby sites. In addition, fecal indicator dynamics are distinct among water, sand, and sediment.

*Objective 2. Examine the effect of temperature and moisture on the persistence of Bacteroides in sand and sediment.*

**Progress:** Project completed. Manuscript is in revision.
**Introduction:** Although sand and sediment are integral to understanding microbial load to recreational beaches, the survival of genetic markers of FIB in sand and sediment is not well-studied.
**Methods:** The persistence of molecular markers for enterococci (Entero1), total *Bacteroides* (AllBac), and human-associated *Bacteroides* (HF183), was examined in microcosms containing Duluth-Superior Harbor water and sediment or sand inoculated with raw sewage influent. The effect of temperature on persistence was determined at 6, 13, 21, 30, and 37 °C, and the effect of moisture on persistence in sand was examined at 10, 20, and 30% moisture. Marker concentrations were measured by quantitative PCR.
**Results:** The decay rate of Entero1, AllBac, and HF183 markers was negatively correlated with temperature for all sample types, except for Entero1 and AllBac in sediment and water (Table 2). At 6 °C, the decay rate of AllBac and Entero1 in water was slowed relative to higher temperatures, with the exception of Entero1 at 30 °C. AllBac markers decayed more slowly at 30% sand moisture than at 10% and 20% moisture, whereas the decay of Entero1 at 30% moisture was slower than 10% or 20% moisture at temperatures above 6 °C (Fig. 3). Moisture had no clear effect on the decay rate of the HF183 marker gene in sand. AllBac markers had a positive decay rate at 6 °C and 13 °C at 30% moisture in sand, indicating possible growth within the microcosm. Entero1 and AllBac decay rates were 92% similar, whereas the AllBac and

HF183 marker decay rates were only 32% similar. In instances when HF183 and AllBac decay rates were dissimilar, the HF183 marker exhibited faster decay.
**Conclusions:** Results of these studies show that environmental conditions that affect temperature and moisture, as well as sample matrix, must be taken into account when evaluating fecal contamination using molecular marker genes. Additionally, the rapid decay of the human-associated HF183 marker supports its application for detection of recent fecal contamination events.

*Objective 3. Assess degree of Bacteroides growth in sediments and its persistence relative to key bacterial pathogens and indicator organisms (E. coli and Enterococcus).*

**Progress:** Have completed project planning and hiring of an undergraduate assistant. Project will commence May 14, 2012, and experiment will end June 15, 2012.
**Introduction:** Microbial indicators of fecal pollution are valid if they exhibit decay rates similar to human pathogens in the natural environment.
**Methods:** Quantitative PCR (qPCR) and qPCR with propidium monoazide pretreatment (PMA-qPCR) will be used to assess the decay of enterococci (Entero1), total *Bacteroides* (AllBac), human-associated *Bacteroides* (HF183), *Salmonella*, *Shigella*, *Campylobacter*, and Methicillin-Resistant *Staphylococcus aureus*. Propidium monoazide (PMA) is an intercalating DNA binding chemical that suppresses amplification of free DNA and that from dead or dying cells

## *Tables and Figures*

Table 1. Pearson product-moment correlation $R^2$ values among beach water column marker concentrations, effluent marker concentrations, and effluent turbidity.

| Variable | Beach[a, c] | | | Effluent | | |
|---|---|---|---|---|---|---|
| | Entero1 | AllBac | HF183 | Entero1 | AllBac | HF183 |
| Beach | | | | | | |
| Entero1 | – | 0.31 | 0.62** | 0.32 | 0.25 | 0.51* |
| AllBac | 0.31 | – | 0.46* | 0.07 | 0.46* | 0.35 |
| HF183 | 0.62** | 0.46* | – | 0.12 | 0.21 | 0.77*** |
| Effluent | | | | | | |
| Entero1 | 0.32 | 0.07 | 0.12 | – | 0.46* | 0.41* |
| AllBac | 0.25 | 0.46* | 0.21 | 0.46* | – | 0.50* |
| HF183 | 0.51* | 0.35 | 0.77*** | 0.41* | 0.50* | – |
| Effluent Turbidity[b] | 0.21 | 0.40* | 0.36 | 0.22 | 0.80*** | 0.49* |

[a] $Log_{10}$ (markers/100 mL)
[b] NTU
[c] * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$

Table 2. Pearson product-moment correlation of temperature with marker decay rate and marker concentration at 120 days.

| Sample type | Entero1 | | | | AllBac | | | | HF183 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Decay rate | | 120 days | | Decay rate | | 120 days | | Decay rate | |
| | Slope | $R^2$ | Slope | $R^2$ | Slope | $R^2$ | Slope | $R^2$ | Slope | $R^2$ |
| Sand - 10% | –0.0016 | 0.91* | –0.0563 | 0.86** | –0.0019 | 0.94** | –0.0796 | 089** | –0.0066 | 0.89* |
| Sand - 20% | –0.0021 | 0.98** | –0.0307 | 0.54** | –0.0020 | 0.92* | –0.0529 | 0.77** | –0.0075 | 0.90* |
| Sand - 30% | –0.0004 | 0.12 | –0.0152 | 0.09 | –0.0015 | 0.87* | –0.0763 | 0.73** | –0.0090 | 0.87* |
| Sediment | –0.0016 | 0.77 | –0.0418 | 0.54** | –0.0008 | 0.14 | –0.0673 | 0.79** | –0.0101 | 0.97** |
| Water | –0.0015 | 0.39 | –0.0437 | 0.54** | –0.0022 | 0.42 | –0.0509 | 0.56** | –0.0075 | 0.93** |

*P ≤ 0.05

**P ≤ 0.01

Figure 1. The concentration of Entero1 (A), AllBac (B), HF183 (C) markers and *E. coli* (D), and enterococci (E) in effluent (solid bars) and beach water (open bars). Sampling dates marked with an asterisk are significantly different at α=0.05 based on Tukey HSD post hoc comparisons.

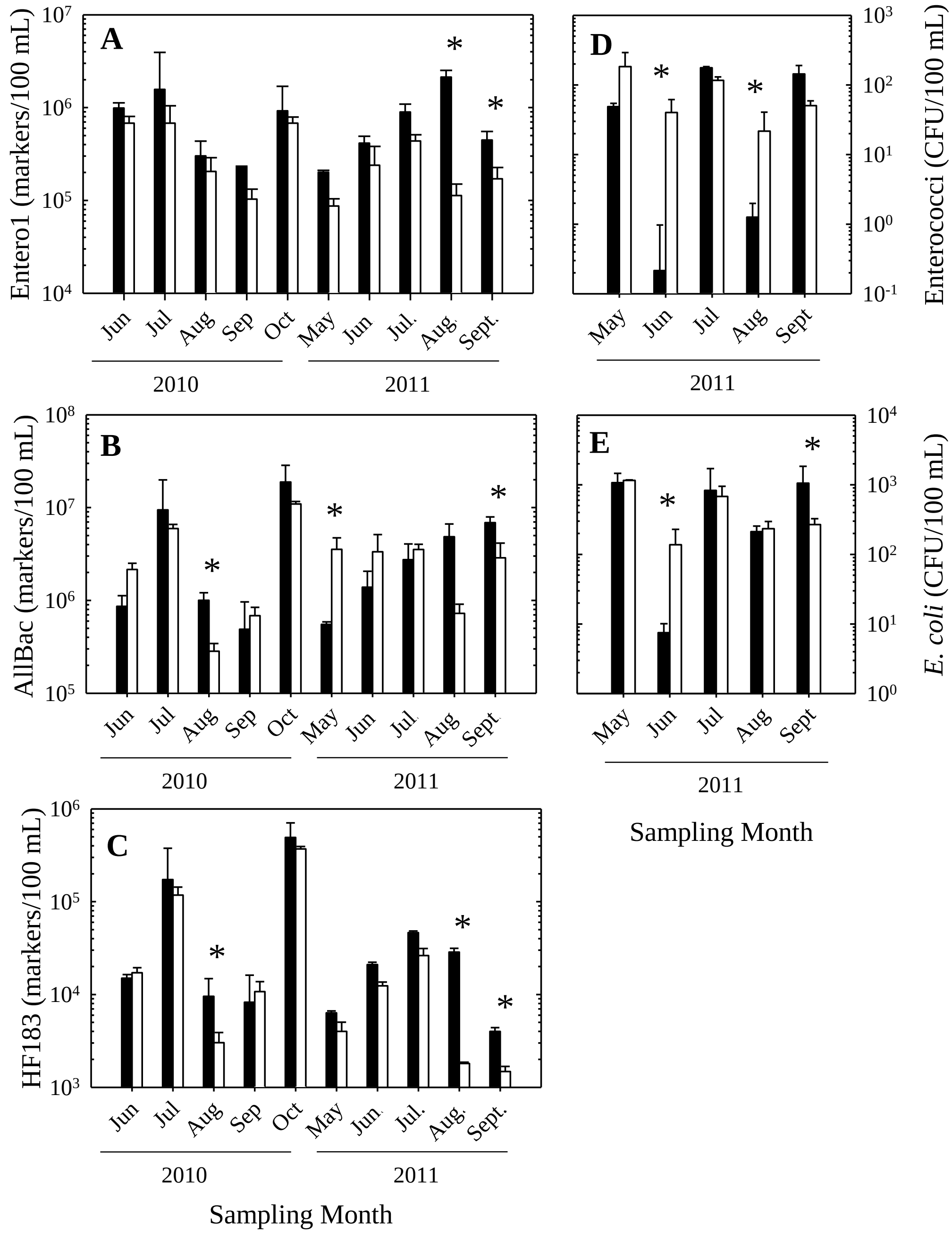


Figure 2. Box and whisker plots of Entero1 (A & D), AllBac (B &E), and HF183 (C &F) in sand (upper row) and sediment (lower row). The dotted line indicates the limit of detection.

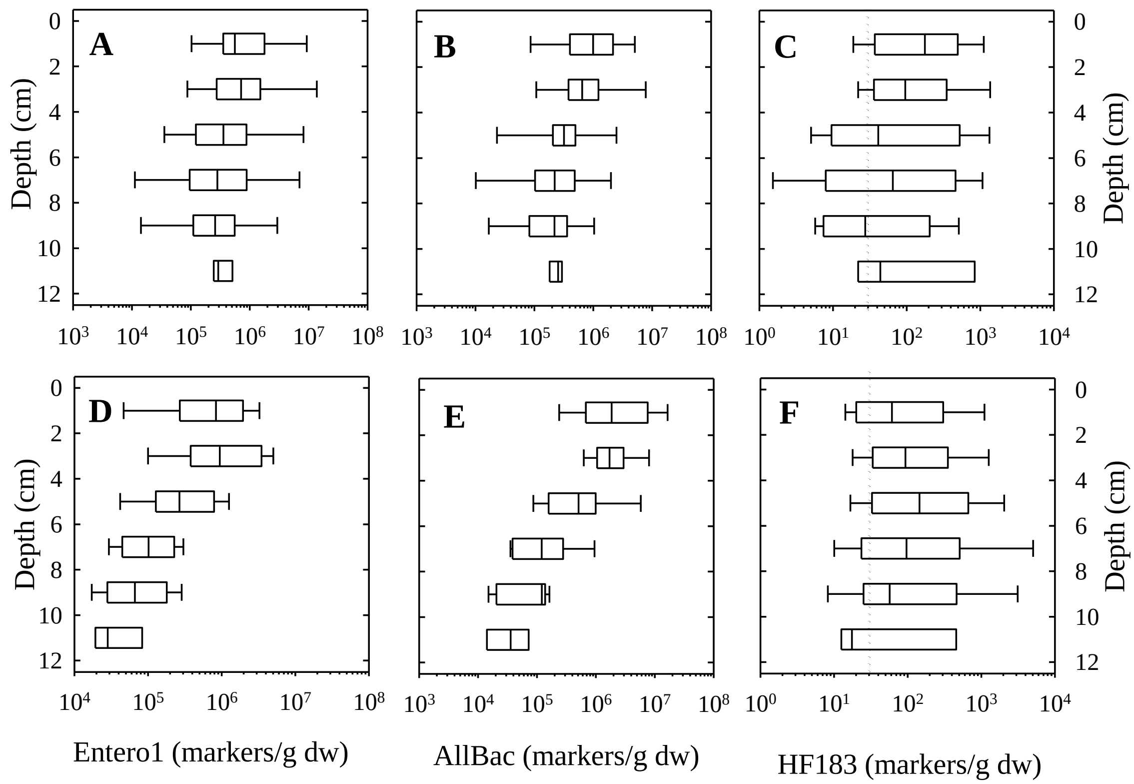
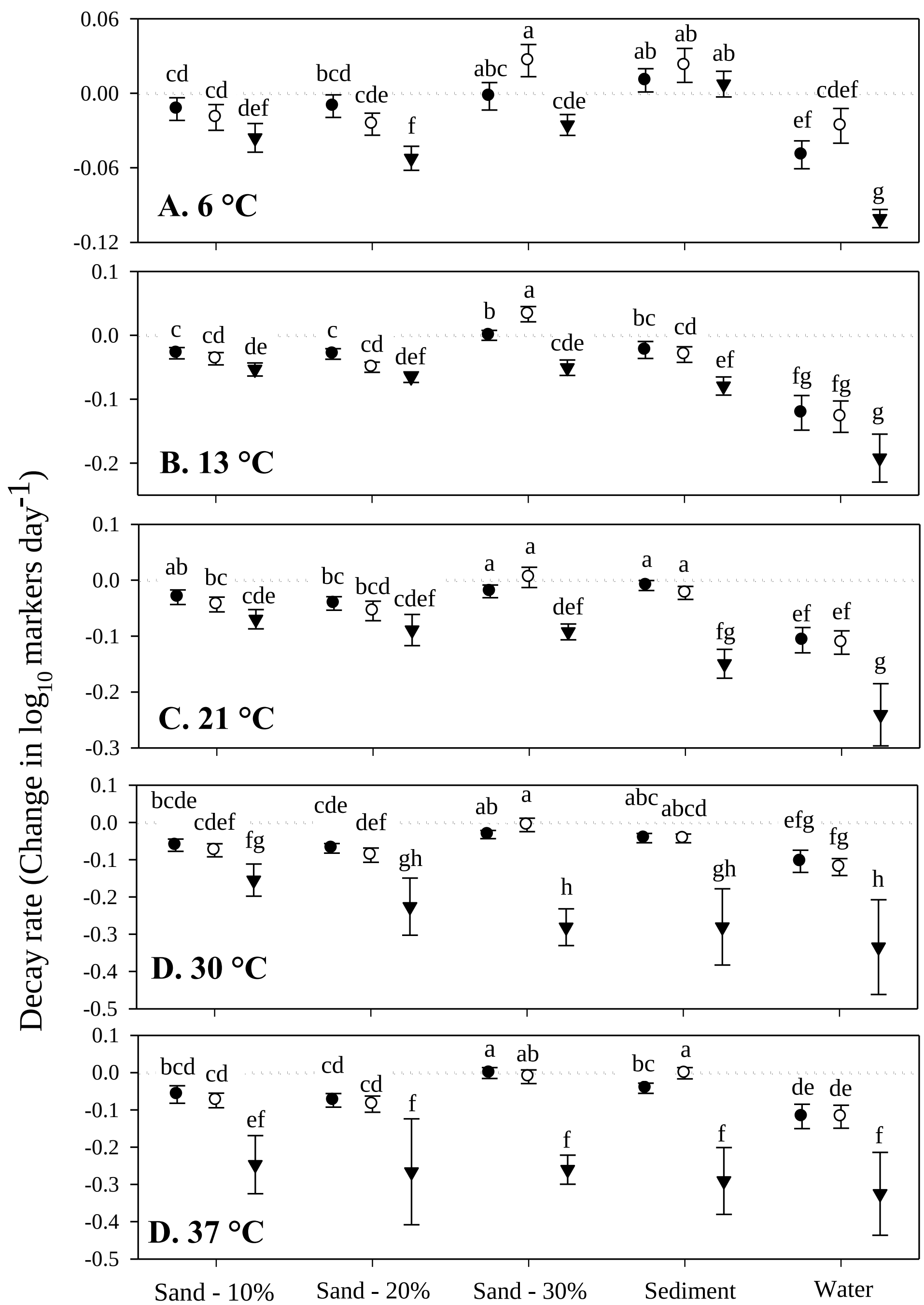


Figure 3. The decay rates of Entero1 (filled circles), AllBac (open circles), and HF183 (filled, inverted triangles) molecular markers of fecal pollution. Error bars indicate 95% confidence interval of the decay rate. Samples that are not significantly different at α=0.05 based on Tukey's range test share the same letter.



# USGS Award No. G11AP20000 Identifying and Evaluating Best Practices for the Adaptive Management of Water Resources

## Basic Information

| | |
|---|---|
| **Title:** | USGS Award No. G11AP20000 Identifying and Evaluating Best Practices for the Adaptive Management of Water Resources |
| **Project Number:** | 2011MN306S |
| **Start Date:** | 11/23/2010 |
| **End Date:** | 11/22/2012 |
| **Funding Source:** | Supplemental |
| **Congressional District:** | |
| **Research Category:** | Social Sciences |
| **Focus Category:** | Management and Planning, Law, Institutions, and Policy, None |
| **Descriptors:** | |
| **Principal Investigators:** | Deborah L. Swackhamer |

## Publications

There are no publications.

## *Identifying and Evaluating Best Practices of Adaptive Management for Water Resources*

Principle Investigators:
Deborah L. Swackhamer, University of Minnesota; William J. Focht, Oklahoma State University; Jeffrey S. Allen, Clemson University; Brian E. Haggard, University of Arkansas

Project Period: November 2010 – November 2012

### I. Statement of Results or Benefits

We are conducting a policy-level examination of adaptive management strategies that have been used by federal agencies as related to water resources management, with particular attention to the use by the US Army Corp of Engineers (USACE). We will review adaptive management policies, barriers, and opportunities for USACE, with the intent of having this analysis be useful for other agencies. Ultimately this research will identify alternatives for best practices for conducting national water management policy.

This research will promote collaboration and interaction with university researchers and USACE researchers, as well as strengthen relationships between WRRI/NIWR and IWR.

This work will also have the added benefit of training two graduate students, one at the University of Minnesota and one at Clemson University. Engaging students in this project is vital to future human resource needs in federal and state agencies, as it prepares new water resource leaders, managers, and researchers to replace a work force that is being depleted by retirements. It also provides students the opportunity to engage in applied research with federal and state water professionals.

The results of this work will benefit other federal and/or state agencies engaged in water resources management and policy, by providing an analysis of alternatives for adaptive management that may be applied to their specific situations and needs.

### II. Nature, Scope, and Objectives, with Timeline

We are responding to the following research priority:

> *"Develop definitions, descriptions, methodologies, and an identification of challenges within the Federal sector and federal-state partnerships for conducting adaptive management within the field of water resources."*

We are reviewing adaptive management practices at facilities based on literature reviews, telephone/email conversations with appropriate facility personnel, and eventually, one or two on-site meetings at facilities or with agency personnel who have exceptional best practices in place. Recommendations will also address boundaries for the use of adaptive management, i.e. what is not feasible and why.

Our **objectives** are as follows: (1) Identify and define the approaches that have been used for adaptive management of water resources ; (2) describe the specific adaptive management practices that have been used by the USACE and evaluate their rigor and effectiveness; (3) describe some selected adaptive management practices used by other federal and state agencies that have been successful, as well as selected examples of those that have not; (4) assess these cases for opportunities, barriers, lessons learned; and (5) make recommendations for best practices of adaptive management for the USACE and other federal agencies that engage in water management and policy.

Our timeline is as follows:

- Work began November, 2010 (date of award receipt).
- Literature review and identification of existing practices by July, 2011.
- Interviews and visits by Fall 2011 – Spring 2012
- Assessment and evaluation of data by September, 2012
- Final draft paper end of November, 2012.

These investigations are being conducted pursuant to provisions contained in the "Water Research" section of the Water Resources Research Act of 1984, (Public Law 98-242) and subsequent federal legislation, which amends or supersedes this Act.

## III. Review of Literature

Williams, Szaro and Shapiro (2007) define adaptive management within the federal context as "a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood." Though adaptive management exists within this U.S. Department of Interior framework and throughout the federal bureaucracy in various forms, it has not been formalized in most contexts. Bowsher (1992) and May, Workman and Jones (2008) point out that government agencies today often have little established policy direction, and bureaucratic limitations usually halt change before it can get going. The tactic of centralization and not being limited to formal procedures (a beginning point for adaptive management) helps speed action and is much more flexible in decision making, but is also less stable and more disruptive due to diffused accountability. Agencies tend to be centralized at the top, but have authority delegated to the bottom, leading to two different systems of management organization that have trouble communicating with each other. The authors provide the example of The Department of Homeland Security (DHS) with most of its authority centralized and focused too much on terrorism, leading to major problems in the other areas that it was in charge of (even though our country's level of disaster preparedness is more stable than our level of terrorism preparedness). Wise (2006) provides insight into the potential of using adaptive management within DHS for situations like the hurricane Katrina disaster. Wise noted that it was not explicitly specified who really was in charge of the total relief effort, therefore it was also unclear who to blame for the organizational problems and the lack of integrated planning capabilities hurts the government's effort to coordinate multiple agencies and groups in a relief effort.

No model is suitable for all situations, but whatever is put into place needs to account for the nature of the tasks to be performed and the nature of the environment in which these tasks are performed. Menzel (2006) and Scavo, Kearney and Kilroy (2007) echo the frustration in the FEMA response to Katrina indicating that most problems involved either decision makers on the ground level during the effort being uninformed of decisions made in the bureaucracy or in high ranking federal officials being blind to the exact kinds of efforts being made on the ground. Waugh and Streib (2006) and Kapucu, Augustin and Garayev (2009) go so far as to say there is already too much hierarchical bureaucracy in the federal system and they wonder if we should even have agencies such as FEMA, but that ideally there should exist a combination of a collaborative (adaptive) and command/control (hierarchical) approach for effective management.

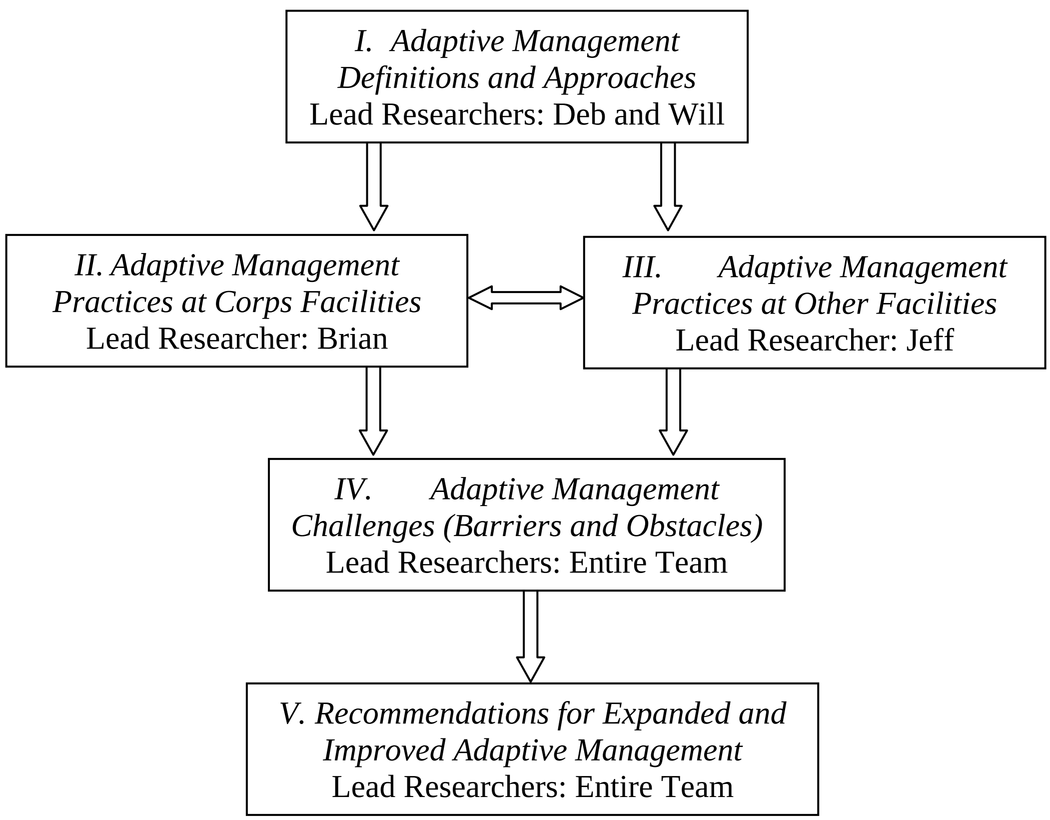
Most of the experience and experimentation in adaptive management has occurred in the natural resource and land management agencies of the federal bureaucracy. Koontz and Bodine (2008) in analyzing work within the U.S. Bureau of Land Management and the U.S.D.A. Forest Service point out that these agencies are challenged by the notion of adaptive management and that the idea of bottom-up organization is better for ecosystem management as it enables power sharing between all levels of the agency and that barriers to the enacting of adaptive management techniques stem from political, cultural, and legal traditions/policies. Gunderson and Light (2006) in their work on adaptive management in the Everglades ecosystem point out that adaptive governance works well to address complex, complicated environmental issues where many different stakeholder interests exist and that there is a difference between true adaptive management and "trial and error management"- adaptive management seeks to educate everyone on how to make the best decision, not just try things until something works. The Army Corps of Engineers has attempted adaptive management in selected sites (USACE 2007, USACE 2009), but there are still questions about implementation and true success of the projects.

Koontz (1997) highlights some of the differences between state and federal public forest management including barriers for federal agencies that keep them typically constrained by some combination of formalized planning documents, federal mandates, and various degrees of legislation. Servheen et al (1996) also indicate barriers at the federal level in terms of improved fish and wildlife management stating that in order for management to become more adaptive, the agencies must overcome the in place organizational characteristics and inertia of the bureaucracy.

Some authors have suggested avenues toward pursuing more efficient and effective governance in part through adaptive management techniques. Kettl (2002) proclaims that the transformation of governance is necessary but the bureaucracy wants to stick to the traditional hierarchical model. Presently, with the complexity of making policy decisions that model no longer works, especially when administrators are brought before Congress to take responsibility for decisions they don't really make or do not know enough about. Khademian (2009) in his work on financial regulatory reform goes so far as to say a spreading out of management to a variety of smaller agencies would help speed up decision making, and more collaboration is necessary to streamline decision making. Goldsmith and Eggers (2004) back up this idea by pointing out that the new shape of the public sector should include the network model of more small entities because it allows for more specialization (which is helped by collaboration of many different smaller, specialized groups), more innovation and more speed and flexibility in production and service delivery. The IRS has done a good job in achieving a widespread network of companies to help people file taxes online (increased reach to the public, faster, more flexible, innovation is important). Finally, Agranoff (2007) points out that most important to the success of government agencies is creating some kind of joint vertical and horizontal structure that encourages the most communication and coordination amongst the various members. The problem is, the way one manages a more vertical, hierarchical, formal structure is very different than how one manages a more horizontal, network-based, ad hoc structure, and these two kinds of management must be able to work together to create an effective and efficient system. Also, on some level, there needs to be an inner core of structured individuals with certain responsibilities to keep the organization pointed in the right direction, as well as "champions" of the cause to arouse interest and support. If a horizontal network gets too stretched out the response will not happen as efficiently as desired (especially in something like crisis management or terrorism response).

## IV. Methods, Procedures, Facilities (to be used to evaluate technical adequacy)

Our overall research design can be visualized with the following diagram:




The four Investigators on this project will work in a coordinated fashion to achieve our objectives by taking the following steps.

*Definitions and Approaches*. We have reviewed the definitions of adaptive management that appear in the literature and in government practice, and have developed a clear and transparent yet robust definition. We have completed a further more intense review of the literature of adaptive management conceptually and how it is used in practice.

*Adaptive management practices at USACE facilities*. The IWR Project Manager has provided us with the facilities and projects where adaptive management has been used by USACE. We are interviewing personnel from those projects and facilities to determine what they did, how they did it, whether it was deemed successful, what were the unintended consequences and barriers, and how it the policy being changed or how should it be changed into the future (i.e. adapting adaptive management). (See Appendix A for questions used to guide these interviews). For certain experienced or successful projects or facilities, we may choose one or two and do an on-site visit to obtain more in-depth information. An evaluative instrument for conducting these interviews is in draft form and is being refined.

*Adaptive management practices at other federal/state facilities*. A similar, parallel process with be followed for other state and federal agencies, but the time frame of this process precludes doing a thorough inventory. Using literature review and initial interviews, we will identify key agencies and projects that are actively using adaptive management, and then focus more in-depth on approximately 2 of these as case-studies. We will identify what they did, how they did it, whether it was deemed successful, what were the unintended consequences and barriers, and how it the policy being changed or how should it be changed into the future.

*Adaptive management challenges: obstacles and barriers*. We will synthesize the information we have obtained by our interviews and visits and look for common obstacles and barriers, and clear paths to success, for the use of adaptive management in water resources management and policy.

*Recommendations for expanded and improved adaptive management*. Our final report will provide all of the above information, but its main message and utility will be to provide recommendations for how adaptive management can best be incorporated into policy, what are the ways barriers can be overcome, and how the process itself can be improved. These recommendations will be directed at the USACE, but will be applicable to other agencies that utilize adaptive management for water resources decision-making.

## V. Student Training

We have involved two graduate students in this project, one from the Water Resources Science graduate program at the Twin Cities campus of the University of Minnesota, and one from the graduate program at the Strom Thurmond Institute at Clemson University. These students have completed the literature reviews, have prepared the draft assessment instrument, and are assisting in the interview process and the write-up of the final report. They will also assist with information transfer activities. These students are not only benefiting from learning the details, advantages, and disadvantages of adaptive management as it is practiced, but will have benefited from networking and interacting with federal and state agency water resource managers who are applying this technique on the ground (i.e. “real world” experience).

## VI. Information Transfer Plan

Our information transfer plan includes our final report to IWR (ACE is our primary audience), which will be posted on the NIWR website once accepted by IWR. We will also present this report to the annual NIWR meeting in Washington, DC, in February of 2013, and encourage our network of directors to bring it to the attention of their stakeholders. We will prepare a paper based on the final report to be published in the peer-reviewed literature such as in *Policy Science*, *Integrated Environmental Assessment and Management*, or *Public Administration Review* (agency practitioners are the primary audience). We will also arrange to present our findings and recommendations to professionals at federal and state facilities via seminars and visits. For example, we will request to present our findings to the Midwest Natural Resources Group, a formal working group composed of the Regional Directors of all the Federal Agencies in the Midwest (USACE, USFWS, USFS, USGS, DOT, USPS, etc). Finally, we will present our findings at professional meetings that have considerable interest in the application of adaptive management, or those with significant government agency participation (e.g. Society of Environmental Toxicology and Chemistry; 1/3 of its membership and leadership is federal government managers and scientists).

There have been no publications or presentations to date. This project has not offered the opportunity for follow-on funding at this time.

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## APPENDIX A: **Questions for Interviews**

(initial questions can determine if talking to right person)

### I. General Overview

- General discussion of the project (if needed)
- Discussion of AM policy/guidelines, if any, and application to this project
  - Who promulgated the policy? Where in organization? When? History of policy?
  - How do they define AM for this project? Who determined this definition?
  - Was AM included from the beginning or added later?
  - Ask questions to determine whether the AM was active or passive
    - Did your design include testing of alternatives, experiments to reduce uncertainty or optimize project outcomes? (e.g. hypotheses; to determine if active)
    - How were alternatives determined/selected?
- Goals and objectives of AM for this project
- AM participants: decision-makers, experts, and stakeholders
  - Include organizational location, titles, AM responsibilities (project organizational chart would be helpful)
  - Discuss communication and coordination and management lines
  - Discuss continuity in management (versus turnover)
- Was the project considered successful? Define success (does it include project goals and objectives, etc.). Explain.
- Was the AM process considered successful? Why or why not? How did the project benefit from AM? (did AM add value to the project?)
- How did the project suffer from AM? Could the project goals have been achieved w/o AM?
- What obstacles arose in the conduct of AM and how were these overcome (if they were overcome)?
- What opportunities presented themselves to make AM successful?
- If you had to do this project again using AM, what should have been done differently?
- How should AM be implemented in future projects?

### II. Constraints and Facilitations

- Discuss how the time frame of project constrained/facilitated AM
- Discuss how the budget for project constrained/facilitated AM
- Discuss how staffing and staff competence constrained/facilitated AM
- Staffing turnover, management turnover
- Discuss how the organizational hierarchy and organization culture constrained/facilitated AM
- Describe what statutes, regulations, laws affect the implementation of AM and of project?

### III. Process - Institutional

- Describe the organizational culture (risk averse, vertical command and control, collegial, conservative, etc.)

- Describe the organizational decision-making processes (approvals, locus of control, authorities, timing, formalities, etc.)
- How is AM supported (or not) by organizational leadership?
- Describe flexibility in project planning and implementation
- Describe partnerships with other organizations
- Describe relationships with public stakeholders
- Describe the institutional processes that mitigate conflict among stakeholders
- What incentives are provided, if any, to encourage effective use of AM?

**IV. Stakeholder Participation**

- Discuss how stakeholders were identified
- Discuss how stakeholders were selected
- Discuss how stakeholders were involved
- Discuss the influence that stakeholders were given in AM
- Discuss benefits, costs, and risks of stakeholder involvement
- Discuss how decisions were made in stakeholder groups
- Discuss process in terms of fairness, inclusiveness, empowerment, transparency (did they get training, documents, were documents accessible to audience in tone, were they informed of meeting times with advance notice)

**V. Process – Evaluation of Outcomes**

- Describe how AM was used to monitor outcomes (against goals and objectives)
- Discuss how these results were used to adjust project implementation
- Where were the decision points in the AM process
- How responsive was the plan – how often did you gather data, and evaluate the data for purposes of evaluating plan
- What tools did you use to evaluate data on AM monitoring?
- Who is accountable for management of adaptation?
- Are there third-party reviews built into AM process
- Are there program reviews of AM in the organization?

**VI. Process – Reduction of Uncertainty**

- Discuss what types of uncertainty were associated with the project outcomes?
- Discuss whether and how AM was used to reduce uncertainty (e.g., field experiments, hypothesis testing, etc.)
- Discuss how these results were used to adjust project implementation
- Discuss the processes to communicate the uncertainty in the science, social, and management data across models and to the relevant decision-makers?
- How does the project differentiate failure from uncertainty?

**VII. Process – Institutional Change**

- Discuss how AM changed how the institution conducts similar projects elsewhere

**VIII. Lessons learned**

- What would they do differently in this project, what would they carry forward to future projects

IX. **Who else should we talk to in your organization or project management**

***Items to be reviewed for inclusion for on-site interviews:***

a. Who is involved in ranking the alternatives?
b. What are the different criteria or categories for setting the priorities?
c. What is the process for evaluating hypothesis?

What is the process for identifying the key variables to evaluate the hypothesis?

d. Once the data on the variables is collected, how is it integrated with other collected data to reduce the uncertainty in the system?

How are hypotheses linked with objectives achievable, given current capacity and resources?

To what extent did the project develop management decision-making tools (matrices, conceptual models, etc) that links goals and objectives with monitoring, alternatives, and management options?

Evaluation of Data: What processes assess and communicate the project data to the appropriate decision-making entities

Please briefly describe the data collection methods for the project? (type, temporal and geographic scale, scope)

Does the project collect baseline data?

a. If yes, how is it used in comparing with hypothesis testing?
b. If no, how does the project evaluate the data from different hypothesis?

How was monitoring designed to support timely management adjustments to changing resource conditions?

How are the data results from monitoring related to the decision-making process?

Is there an adaptive management evaluation team?

c. If yes, who selects participation on the evaluation team?

What processes are in place to determine quality control of data collection?

Over the lifespan of the project, how often are monitoring data used to re-assess project goals or objectives?

# Information Transfer Program Introduction

We have not funded Information Transfer projects.

| Student Support | | | | | |
|---|---|---|---|---|---|
| Category | Section 104 Base Grant | Section 104 NCGP Award | NIWR-USGS Internship | Supplemental Awards | Total |
| Undergraduate | 2 | 0 | 0 | 0 | 2 |
| Masters | 2 | 0 | 0 | 0 | 2 |
| Ph.D. | 2 | 0 | 1 | 0 | 3 |
| Post-Doc. | 0 | 0 | 0 | 0 | 0 |
| Total | 6 | 0 | 1 | 0 | 7 |

# Notable Awards and Achievements

Brezonik, Patrick, staff, 2011 Excellence in Review Award from the journal Environmental Science & Technology

Engstrom, Daniel, staff, Academy of Science and Engineering, UMD Swenson College of Science Award given to distinguished UMN alumni of Swenson College of Science & Engineering

Erickson, Andrew, staff, 2011 Matthew J Huber Award for Excellence in Transportation Research & Education UM Center for Transportation Studies

Johnson, Thomas, staff, Fellow of the American Geophysical Union (AGU). Fellows are limited to 0.1% of the membership.

Knight, Joseph, staff, College of Food and Natural Resources Sciences (CFANS) Distinguished Teaching Award - Undergraduate Faculty

Newman, Raymond, staff, UMN Distinguished Teaching Award - Outstanding Contributions to Post baccalaureate, Graduate, and Professionalism

Newman, Raymond, staff, UMN Graduate-Professional Teaching Award

Perry, Jim, staff, College of Food and Natural Resources Sciences (CFANS) Student Board Outstanding Professor Award

Saar, Martin, staff, UMN College of Science & Engineering's 2011 George W. Taylor Career Development Award. Recognizes exceptional contributions to teaching by a candidate for tenure.

Vondracek, Bruce, staff, USGS Star Award For extraordinary service to graduate programs at UMN

Fairbairn, David, Ph.D. student , Smith Partners Sustainability Fellowship. From Smith Partners PLLP

Groten, Joel, M. S. student , 2011 William L Wilson Scholarship in Karst Sciences From the Karst Waters Institute

Kruger, Brittany, Ph.D student, 2011 Butler and Jessen Water Resources Science Fellowship

Rittenhouse, Jennifer, M. S. student , 2011 Soil and Environmental Quality Student Poster Award (2nd place), Soil Science Society of America

Tsui, Martin, Ph. D. student, 2011 UCOWR Ph.D. Dissertation Award - Honorable Mention

The annual Minnesota Water Resources Conference was held October 18-19, 2011 with over 600 participants. Co-sponsors were the UM Department of Civil Engineering, the Minnesota Section of American Society of Civil Engineers, the MN Sea Grant Program, and the Center for Water and Environment at UM Duluth. The conference facilitated interaction among water resources professionals including resource managers; researchers; local, state, and federal agency staff; consultants and practicing engineers; and students in the field.

The 5th Annual Minnesota Wetlands Conference hosted by the MN Wetland Delineator Certification Program and the MN Wetland Professionals Association, was held January 18, 2012. This conference focused on the three parameters of wetland identification, featuring some of the less-commonly seen topics. This is an excellent opportunity for working professionals, researchers, students, scientists, consultants, regulators, and wetland enthusiasts to come together and share their wetland knowledge.

The Minnesota Wetland Delineator Certification-Program hosted 11 training workshops across Minnesota, with a total of 160 attendees. The University of Minnesota's Wetland Delineator Certification Program (WDCP) delivers cutting-edge content featuring the know-how of the region's top wetland, soil, vegetation and water experts. Wetland delineator certification adds credibility and customer confidence to a variety of wetland related professions by formally recognizing the training and expertise that goes into delineation. Re-certification keeps you up-to-date on changing requirements and technologies in the field.

The Water Resources Center administers the Onsite Sewage Treatment Program (OSTP), This partnership between the Minnesota Pollution Control Agency and the College of Food, Agriculture, and Natural Resources Science provides training to those that design, install, inspect or take care of septic systems in Minnesota. Between 3/1/2011 and 2/29/12, this program conducted 56 workshops across the state with 2117 attendees. The OSTP also educates septic system owners, community leaders, and real estate agents in addition to conducting research and providing technical assistance.

Maximizing the Economic Benefits of Manure to Reduce Nutrient Loading, workshops for agricultural producers and professionals for them to calculate the economic value of manure on their farms under a range of field application scenarios, using the Value of Manure Excel spreadsheet. The workshops were held in March, November and December, 2011, with an average of 8 participants each. Two presentations were made on the value of manure calculations at the alfalfa-corn field days in July, 2011, with 14 and 27 producers each attending.

Ecological Ranking Tool for GIS Specialists, in conjunction with the Board of Soil and Water Resources, three workshops in outstate Minnesota, with 42 conservations professionals attending. Ecological ranking of parcels for prioritizing conservation activities across the landscape, a live Webinar for 75 people.

Como KAP Training Workshop, for Como Lake TMDL, St. Paul, MN, March 14, 2011, 15 attendees.

Community Assessment Workshop, with Minnesota Pollution Control Agency, March 29, 2011, 15 attendees.

Evaluating the Impacts of a Paired-Watershed Study on Local Residences, at the IAGLR 54th annual conference-DECC Duluth, MN June 2, 2011, 100 attendees.

Buffalo-Red Watershed Water Quality Project with Minnesota Pollution Control Agency, Detroit Lakes, MN, June 27, 2011, 25 attendees.

The Como Neighborhood KAP Study: First-Round Results, for Como Lake TMDL, CRWD CAC Meeting, St. Paul, MN, September, 14, 2011, 25 attendees.

Water in the World, Natural Resources Science and Management 3251/5251, University of Minnesota, St. Paul, MN, 35 attendees.

Understanding the Social Impacts of Nongovernmental Organization Water Projects: Lessons from Western Kenya, with Valerie Were, American Evaluation Association annual conference November 2 2011, Anaheim, CA, 30 attendees.

Strategies for Dealing with Scale Issues When Evaluating Natural Resources Projects,American Evaluation Association annual conference November 3, 2011, Anaheim, CA, 40 attendees.

Como Neighborhood KAP Study Training Workshop, for Como Lake TMDL, November, 14, 2011, 10 attendees.

Lessons from Turtle Lake: Engaging Shoreland Property Owners in Native Buffers, 2011 Midwest Fish and Wildlife Conference, Des Moines, IA, December 6, 2011, 40 attendees.

Evaluating Social Outcomes in Water Resources Projects: Experience from Twenty Minnesota Projects, Social Metrics for Clean Water Tracking Framework Working Group, December 14, 2011, 15 attendees.

Evaluating Social Outcomes in Water Resources Projects: Experience from Twenty Minnesota Projects, St. Croix River Basin Team's Implementation Subcommittee, St. Croix Falls, WI, January 19, 2012, 30 attendees.

# Publications from Prior Years

1. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Dalzell, B.J. 2008. Climate Change as a Factor in Export of Dissolved Organic Matter from Agricultural Watersheds. Oral presentation in symposium titled "Global Climate Change and Agriculture: Interactions, Land-Use Patterns, and Educational Connections" at the 93rd annual meeting of the Ecological Society of America. August 3-8, 2008. Milwaukee, WI.
2. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Dalzell, B. J., J. Y. King, D. J. Mulla, J. C. Finlay, and G. R. Sands. 2008. The Influence of Landscape Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems. Oral presentation given at the annual fall meeting of the American Geophysical Union. December 2008. San Francisco, CA.
3. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Dalzell, B. J. 2008. Effects of Landscape Drainage on Dissolved Carbon Export. Presentation given at the Minnesota/Iowa Drainage Research Forum. December 2008. Owatonna, MN.
4. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Results from this research were also incorporated into lecture materials on global carbon cycling and impacts of land use change for a class on "Biogeochemical Processes" (EEB 4611) University of Minnesota – Spring Semester, 2008.
5. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Preliminary results from this research have also been presented in smaller group discussion sessions in the Departments of Soil, Water, and Climate and Ecology, Evolution, and Behavior at the University of Minnesota.
6. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Other Publications - 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Other Publications - Steen, P.O.; Grandbois, M., McNeill, K.; Arnold, W.A. 2009. Photochemical Formation of Halogenated Dioxins from Hydroxylated Polybrominated Diphenyl Ethers (OH-PBDEs) and Chlorinated Derivatives (OH-PBCDEs). Environmental Science and Technology. accepted.
7. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Other Publications - 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Other Publications - Buth, J.M., Grandbois, M., Vikesland, P.J., McNeill, K., Arnold, W.A. 2009. Aquatic Photochemistry of Chlorinated Triclosan Derivatives: Potential Source of Polychlorodibenzo-p-dioxins. Environmental Toxicology and Chemistry. accepted.
8. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Book Chapters - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Book Chapters - Arnold, W.A., and K. McNeill. "Abiotic Degradation of Pharmaceuticals: Photolysis and Other Processes" to appear in Analysis, Fate And Removal Of Pharmaceuticals In The Water Cycle Eds. M. Petrovic and D. Barcelo, 2007.

9. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Arnold, W.A., 2007. Solar Photochemistry of Pharmaceutical Compounds. American Water Works Association Water Quality Technology Conference, Advanced Oxidation Technologies in Water Treatment: Fundamentals and Applications Workshop, November 4, 2007.
10. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - McNeill, K., 2009. Incineration or Liquid Handsoap: Which is the Larger Source of Dioxins to the Aquatic Environment? College of St. Catherine, St. Paul, MN.
11. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - McNeill, K., 2009. Incineration or Liquid Handsoap: Which is the Larger Source of Dioxins to the Aquatic Environment? Gustavus Adolphus College, St. Peter, MN.
12. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Buth, J.M., W. A. Arnold, and K. McNeill. 2008. Photochemical Fate of Chlorinated Triclosan Derivatives. Poster. Gordon Research Conference, Environmental Sciences: Water, Holderness, NH.
13. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Steen, P.O., M. Grandbois, W.A. Arnold, and K. McNeill. 2008. Hydroxylated Polybrominated Diphenyl Ether Photolysis Quantum Yields and Product Identification. Environ. Chem. Div., American Chemical Society National Meeting, Philadelphia, PA, 48(2), 608-611.
14. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Steen, P.O., M. Grandbois, W. A. Arnold, and K. McNeill. 2008. Hydroxylated Polybrominated Diphenyl Ether Photolysis: Quantum Yields and Product Identification. Minnesota Water Conference, St. Paul, MN.
15. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Steen, P.O.,M. Grandbois, K. McNeill, and W. A. Arnold. 2009. Photolysis of Hydroxylated Polybrominated Diphenyl Ethers. Micropol & Ecohazard 2009. 6th IWA/GRA Specialized Conference on Assessment and Control of Micropollutants/Hazardous Substances in Water, San Francisco, CA.
16. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Buth, J.M., W. A. Arnold, and K. McNeill. 2009. Formation and Occurrence of Chlorinated Triclosan Derivatives (CTDs) and their Dioxin Photoproducts. Micropol & Ecohazard 2009. 6th IWA/GRA Specialized Conference on Assessment and Control of Micropollutants/Hazardous Substances in Water, San Francisco, CA.
17. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Buth, J.M., W. A. Arnold, and K. McNeill. 2009. Formation and Occurrence of Chlorinated Triclosan Derivatives (CTDs) and their Dioxin Photoproducts. Micropol & Ecohazard 2009. 6th IWA/GRA Specialized Conference on Assessment and Control of Micropollutants/Hazardous Substances in Water, San Francisco, CA.

18. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Dissertations - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Dissertations - Jeremiah, J. M.S. Thesis, University of Minnesota, Department of Civil Engineering. Stream Water Quality Monitoring using Wireless Embedded Sensor Networks. 2007.
19. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Henjum, M.B., C. R. Wennen, M. Hondzo, R. M. Hozalski, P. J. Novak, and W. A. Arnold. 2009. Linking Near Real-Time Water Quality Measurements to Fecal Coliforms and Trace Organic Pollutants in Urban Streams, 2009 Joint Assembly (AGU), Toronto, CA, 2009.
20. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Kang, J.M., S. Shekhar, M. Henjum, P. Novak, and W.A. Arnold. 2009. Discovering Teleconnected Flow Anomalies: a Relationship Analysis of Dynamic Neighborhoods (RAD) Approach. 11th International Symposium on Spatial and Temporal Databases, Aalborg, Denmark accepted. (peer-reviewed)
21. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Kang, J.M., S. Shekhar, C. Wennen, and P. Novak. 2008. Discovering Flow Anomalies: A SWEET Approach. In: IEEE International Conference on Data Mining. (2008) 851–856. (peer-reviewed)
22. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Arnold, W.A. 2009. The WATERs Project: Wireless Sensor Technologies for Urban Water Quality Management, Urban Ecosystems Seminar Series, University of Minnesota, St. Paul, MN, 2009
23. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Novak, P.J. 2009. Sensor Networks for Urban Water Quality Monitoring. Environmental Sciences: Water Gordon Research Conference, Plymouth, NH, 2009.
24. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Wennen, C.R., M. B. Henjum, R. M. Hozalski, P. J. Novak, and W. A. Arnold. 2008. Application of Wireless and Sensor Technologies for Urban Water Quality Management: Pollutant Loading in Stormwater Ponds. Minnesota Water Conference, 2008, St.Paul, MN.
25. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Henjum, M., C. Wennen, M. Hondzo, R. M. Hozalski, P. J. Novak, and W. A. Arnold. 2008. Application of Wireless and Sensor Technologies for Urban Water Quality Management: Pollutant Detection in Urban Streams. Minnesota Water Conference, 2008, St. Paul, MN.
26. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Novak, P., J. Jazdzewski, S. Kim, W. Arnold, R. Hozalski, and M. Hondzo. 2007. Wireless Technologies and Embedded Networked Sensing for Urban Water Quality Management. Presentation at the Association of Environmental Engineering and Science Professors Education and Research Conference, Blacksburg, Virginia, July 2007.

27. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Hozalski, R., S. Kim, J. Jazdzewski, M. Hondzo, P. Novak, and W. Arnold. 2007. Wireless Technologies and Embedded Networked Sensing: Application to Integrated Urban Water Quality Management, World Environmental and Water Resources Congress 2007, May 15-18, Tampa, FL.
28. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Hondzo, M. ,W. A. Arnold, R. M. Hozalski, P. J. Novak, and P. D. Capel. 2006. Wireless Technologies and Embedded Network Sensing: Options for Environmental Field Facilities. Presented at International Research and Education Planning Visit: Cyberinfrastructure based water research: towards the next generation of environmental observatories. August 31-Sept 1 Delft, The Netherlands and Sept. 2-3, Newcastle upon Tyne (UK), 2006.
29. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Arnold, W.A., R. M. Hozalski, M. Hondzo, P. J. Novak, and P. D. Capel. 2006. Wireless Technologies and Embedded Network Sensing: Options for Environmental Field Facilities.. Presented at CLEANER Planning Grant PI meeting, March 2006, Arlington, VA
30. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Kim, S.-C., M. Hondzo, R. M. Hozalski, P. Novak, W. Arnold, J. D. Jazdzewski, N. Jindal, and P. D. Capel. 2006. Integrated Urban Water Quality Management: Wireless Technologies and Embedded Networked Sensing. Poster presented at the American Geophysical Union National Meeting, San Francisco, CA. December 2006.
31. 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - 2006MN187G ("Application of Wireless and Sensor Technologies for Urban Water Quality Management") - Conference Proceedings - Jazdzewski, J.D., M. Hondzo, and W. A. Arnold. 2006. Stream Water Quality Monitoring Using Wireless Embedded Sensor Networks. Poster presented at the Minnesota Water 2006 and Annual Water Resources Joint Conference, Brooklyn Center, MN, October 24-25, 2006.
32. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Other Publications - 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Other Publications - Steiger-Meister, K. 2009. The Drama of the Commons and Its Impact on Adaptive Management. conference proceeding paper, American Water Resource Association Specialty Conference: Adaptive Management of Water Resources II, Snowbird, UT. (6/09) In review
33. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Other Publications - Steiger-Meister, K., and D. R. Becker. Connecting Environmental Policy with Citizen Engagement: A Comparative Study between Minnesota’s Lake Improvement Districts and Wisconsin’s Lake Districts. Manuscript in preparation for Journal of the American Water Resources Association.
34. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Other Publications - 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Other Publications - Steiger-Meister, K., and D. R. Becker.

Citizen Stewardship of Water Resources: A Look at How Water Policy can Create and Coordinate Citizen Action in Minnesota for Environmental Change. Manuscript in preparation for Publications from Prior Years 3 Water Policy.

35. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Other Publications - 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - Steiger-Meister, K. 2008. When Ripples Become Waves: Building Synergy Among Local Stakeholders to Affect Top-down Water Policy. Presented at the 14th International Symposium on Society and Resource Management (ISSRM) on June 13, 2008, University of Vermont in Burlington, VT.
36. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - Steiger-Meister, K. 2009. Minnesota's Lake Improvement Districts. Panelist at the Lakes and Rivers Conference hosted by Minnesota Waters, Rochester, MN. (5/2009) Abstract accepted
37. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - Steiger-Meister, K. 2009. The Drama of the Commons and Its Impact on Adaptive Management. American Water Resource Association Specialty Conference: Adaptive Management of Water Resources II, Snowbird, UT. (6/2009) Abstract accepted.
38. 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - 2007MN204B ("The Role of Local Stakeholders in Water Resource Management: Characterization and Diffusion of Minnesota Lake Improvement Districts") - Conference Proceedings - Steiger-Meister, K. 2009. Connecting Environmental Policy with Citizen Engagement: A Comparative Study between Minnesota's Lake Improvement Districts and Wisconsin's Lake Districts. Minnesota Water Resources Conference, University of Minnesota in Saint Paul, MN. (10/2009) Abstract in review.
39. 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - Orr, C. H., A. F. Lightbody, and R. Bronk. 2009. Determination of the Short-term Response of Aquatic Macroinvertebrate Communities to Suspended Sediment Loading. North American Benthological Society Annual Meeting, May 17-22, Grand Rapids, MI.
40. 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - Lightbody, A., P. Belmont, J. Marr, C. Orr, and C. Paola. 2008. Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads. Water Resources Conference, St. Paul, MN, October 27, 2008.
41. 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - J. Sayers. 2009. Outdoor StreamLab—From Construction Phase to Research Phase. St. Cloud State University Research Seminar, St. Cloud, MN.
42. 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - 2008MN231B ("Determination of Appropriate Metric(s) for Sediment-related Total Maximum Daily Loads (TMDLs) ") - Conference Proceedings - J. Sayers. 2009. Outdoor StreamLab--from Construction Phase to Research Phase, Including

Determination of Groundwater Flow with In-bank Flood Simulations. Poster presentation: NorthStar STEM Alliance Student Research Symposium, University of Minnesota Bell Museum of Natural History

43. 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Other Publications - 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Other Publications - Weiss, P., G. LeFevre, and J. Gulliver. 2008. Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices: A Literature Review. University of Minnesota, St. Anthony Falls Laboratory Project Report No.515.
44. 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Other Publications - 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Other Publications - Hozalski, R.,G. LeFevre, and J. Gulliver. 2009. Assessment of the Stormwater Infiltration and Pollutant Removal Capacities of Rain Gardens. Proceedings to EWRI/ASCE Thailand 09: An International Perspective on Environmental and Water Resources
45. 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Conference Proceedings - 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Conference Proceedings - Lefevre, G., and Almer. 2009. Minnesota Ground Water Association Conference: Impacts of Stormwater Infiltration on the Groundwater System.
46. 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Conference Proceedings - 2008MN235B ("Enhanced Degradation of Stormwater Petrochemicals within the Rhizosphere of Raingarden Bioretention Cells") - Conference Proceedings - Levevre, G., P. Novak and R. Hozalski. Petrochemical Runoff into Raingarden Soils—Remediation or Residuals. 23nd Annual Conference on the Environment: Water Environment Association, Air & Waste Management Association, Minneapolis, MN.
47. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Book Chapters - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Book Chapters - Arnold, W.A., and K. McNeill. 2007. Transformation of Pharmaceuticals in the Environment: Photolysis and Other Abiotic Processes In M. Petrovic and D. Barcelo, Eds. Analysis, Fate and Removal of Pharmaceuticals in the Water Cycle, Volume 50. Amsterdam, Netherlands, Elsevier Science. 600 pp.
48. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Arnold, W.A. 2007. Solar Photochemistry of Pharmaceutical Compounds. American Water Works Association Water Quality Technology Conference, Advanced Oxidation Technologies in Water Treatment: Fundamentals and Applications Workshop, November 4, 2007.
49. 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - 2007MN203B ("Triclosan and triclosan-derived dioxins in the Mississippi River sediment record") - Conference Proceedings - Buth, J., W. A. Arnold, and K. McNeill. 2008. Photochemical Fate of Chlorinated Triclosan Derivatives. Poster. Gordon Research Conference, Environmental Sciences: Water, Holderness, NH, June, 2008.
50. 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - 2007MN205B ("The Influence of Drainage on Biogeochemical Cycling of Carbon in Agricultural Ecosystems") - Conference Proceedings - Dalzell, B.J. 2008. Climate Change as a Factor in Export of Dissolved Organic Matter from Agricultural Watersheds. Oral presentation in symposium titled “Global Climate Change and Agriculture: Interactions, Land-Use Patterns, and Educational Connections” at the 93rd annual meeting of the Ecological Society of America. August 3-8, 2008. Milwaukee, WI.

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