Water Resources Center Annual Technical Report FY 2013

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 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 Sciences graduate major which offers both MS and PhD degrees and includes faculty and students across the Twin Cities campus as well as 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

Typically, the WRC funds approximately three research projects each year. However, the effect of sequestration on our FY13 budget allowed us to fund only one project. The report of that research is found below.

Tracing nutrient sources at the land-water interface in urban environments

Basic Information

Title:	Tracing nutrient sources at the land-water interface in urban environments
Project Number:	2012MN314B
Start Date:	2/1/2012
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	4th
Research Category:	Water Quality
Focus Category:	Water Quality, Hydrogeochemistry, Management and Planning
Descriptors:	
Principal Investigators:	Jacques C. Finlay, Sarah Hobbie

Publications

1. Importance of Hydrologic Pathways to Urban Nutrient Loading and Implications for Current Stormwater Management Practices. 2012. Minnesota Water Conference, St. Paul, MN. October 16, 2012.
2. Importance of Hydrologic Pathways to Urban Nutrient Loading and Implications for Current Stormwater Management Practices. 2012. Minnesota Water Conference, St. Paul, MN. October 16, 2012.
3. Janke, B., J. C. Finlay, S. E. Hobbie, L. A. Baker, D. Nidzgorski, R. W. Sterner, and B. N. Wilson. 2014. Contrasting Influences of Stormflow and Baseflow Pathways on Nitrogen and Phosphorus Export from an Urban Watershed. Biogeochemistry DOI 10.1007/s10533-013-9926-1

Tracing nutrient sources at the land-water interface in urban environments

Project Number 2012MN314B

Principal Investigator

Jacques Finlay, Professor, Department of Ecology Evolution and Behavior

Sarah Hobbie, Professor, Department of Ecology Evolution and Behavior

1) RESEARCH

Introduction and study objectives

In urban landscapes, excess nutrients from human activities combined with high impervious surface cover accelerate transport of water and nutrients into waterways, leading to high nutrient loading and eutrophication of urban and downstream aquatic ecosystems. Little is known, however, about the importance of different sources of nutrients as water moves from urban landscapes to streets and storm sewers, and ultimately to surface waters. This project examines tracer techniques toward improved understanding of contributions of specific nutrient sources in urban ecosystems to aquatic ecosystems. Stable isotopes of carbon (C), nitrogen (N), and phosphorus (P; as $H_2PO_4^-$) are used in conjunction with other indirect tracers of water sources and element ratios to assess the relative contribution of these sources to storm water nutrient loads across a range of sites and seasonal conditions in urban watersheds in St. Paul, Minnesota (MN) (Figure 1). Because many of these sites have permanent baseflow that contributes substantially to watershed nutrient yields (Janke et al. 2014) we have expanded studies to include tracers of baseflow nutrients. The project relies on collaborations with a local watershed district which supports instrumentation for flow monitoring and water quality monitoring via automated storm samplers. Information generated in this project could be used by managers to prioritize efforts to control specific nutrient sources (e.g. organic debris vs. soil erosion) and can contribute to long term decisions such as selection of tree species to plant on boulevards and how to change management in response to climate variations.

Research Activities

Our study sites are contained within the Capitol Region watershed (CRW), located in southeastern Minnesota, USA, encompassing sub-watersheds primarily in the city of Saint Paul and in parts of the surrounding cities of Roseville, Maplewood, Lauderdale, and Falcon Heights.

The highly urbanized watershed has an area of 106 km^2, with a total imperviousness of approximately 45% (CRWD 2010). A large variety of land cover types are present, including parks and several natural lakes, as well as dense residential, commercial, and industrial development. Most of the land surface is connected to a storm sewer system draining to the Mississippi River at 55 locations along the southern boundary of the watershed (CRWD 2010). The Capitol Region Watershed District (CRWD; http://capitolregionwd.org) has conducted extensive monitoring in the CRW since 2006.

Our approach has been to combine intensive monitoring of a small number of sites with more spatially extensive surveys of a wider array of streams and storm drains in the TC area. CRWD monitoring sites located at the outlet of seven sub-watersheds serve as primary study sites for combined storm water and baseflow studies (Figure. 1). A small watershed, Arlington-Hamline Underground (AHUG), located at the inlet to an underground storm water vault, is the site of intensive studies that link dynamics of terrestrial areas to storm water runoff. The AHUG site lacks surface water and has a sewer system that lies above the water table and therefore receives no baseflow. During 2012 and 2013, we conducted several surveys during baseflow conditions that included 30 sites spread out around the Twin Cities. Sample analyses from these efforts are nearing completion. Our preliminary results, described below, combined with analyses to determine the specific form of nutrients in storm water (as part of a complementary project on urban vegetation; see http://environment.umn.edu/urbanvegetation/) will inform more efficient application of tracers during the upcoming summer.

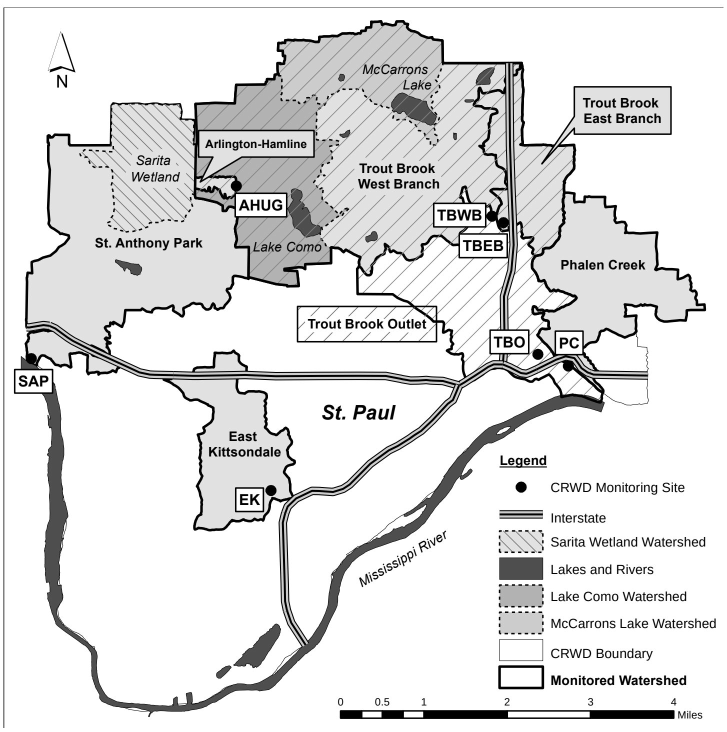

Figure 1 Map of major watersheds and study sites in CRWD.

Preliminary Results and Ongoing Research

Our preliminary results are organized with the questions we proposed to address in this project.

1) What are the sources of N, P, and C that enter storm drain systems in urban residential areas? To address this question, we are evaluating and applying tracers of specific nutrient sources including atmospheric deposition, fertilizer, soils, vegetation, pet waste, and throughfall across an annual cycle at two small residential watersheds, and for a larger number of sites from select storm events and baseflow conditions from May to November.

Samples collected in 2011 - 2013 have been analyzed for C and N isotope ratios in particulate organic matter. $\delta^{13}C$ values from most sites show values consistent with vegetation sources of organic matter with little ^{15}N enrichment of $\delta^{15}N$, suggesting little influence of denitrification (data not shown). Nitrate stable isotopes show that storm water NO_3 is derived from precipitation, as expected, while at baseflow, where concentrations are often elevated relative to stormwater and surface water, all NO_3 is derived from urban soils (Figure 2).

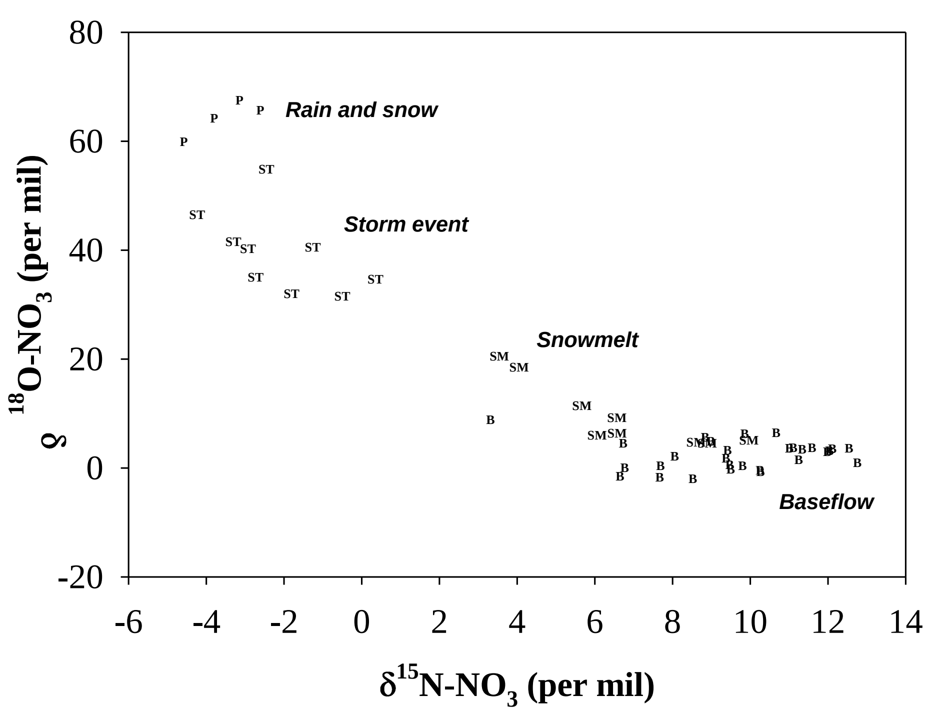

Figure 2 Nitrate stable isotope data for precipitation (P), stormwater (ST), snowmelt (SM), and baseflow (B) conditions. Data are from sites shown in Figure 1. Storm event and snowmelt represent mixture of precipitation and soil derived nitrate, indicating that nitrate isotopes effectively separate sources of nitrate within streams and drains in the watershed.

Sampling efforts in one of the small urban watersheds (AHUG) involved collection of runoff temperature and conductivity data, the latter of which may be used to determine the presence of ions in runoff, and particularly to distinguish "first flush" conditions from samples collected later within individual events. During snowmelt and early spring rains, winter road salt applications wash into storm drains and provide a tracer for impervious surfaces. An example is shown in Figure 3 for a snowmelt and rainfall event on March 8-10, 2013. A small flow peak due entirely to snowmelt occurred on March 8, with a corresponding large peak in conductivity presumably due to road salt, likely due to a large contribution of runoff from the major roads in this watershed. Rainfall on the morning of March 9 produced a brief peak in conductivity before the flow peak arrived, diluting the conductivity source, suggesting that portions of the watershed with little or no road salt (side streets, alleys, rooftops) were contributing runoff at this point. A second example using temperature and conductivity is shown for a rainfall event occurring on May 23, 2012 (Figure 4). Both runoff temperature and conductivity peak at the onset of runoff due to the influx of runoff from directly-connected streets, which are warmer than vegetated surfaces and also serve as collectors for atmospheric deposition (which likely explains the increase in conductivity, as no road salt would be present at this time). A rapid decrease in conductivity (less pronounced in runoff temperature) suggests runoff contribution from vegetated surfaces. Samples collected during rainfall and snowmelt events, both at the watershed outlet and within the watershed, will be analyzed for C and NO_3 isotopes and

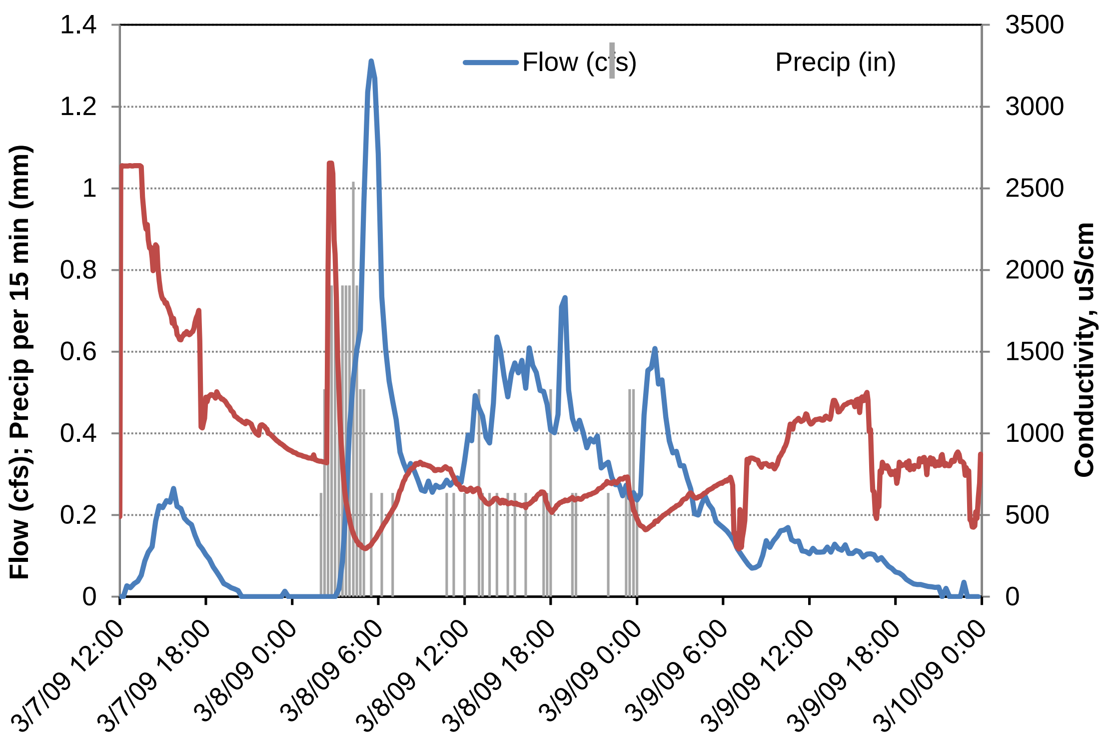

Figure 3 Runoff flow rate (cfs) and conductivity (uS/cm) measured at the outlet of a small (42-ac) watershed for a snowmelt and rainfall-runoff event on March 8-10, 2013. Precipitation (mm) shown on left axis. Peaks in conductivity are associated with road salt dissolved in the first flush of snowmelt and stormwater.

particulate nutrients to determine more specific source areas within the watershed, e.g., vegetation vs. soil or streets vs. lawns. The relative importance of these source areas for different types of storms (i.e. low-intensity vs. high-intensity) or within storms may also be investigated with nutrient tracer data.

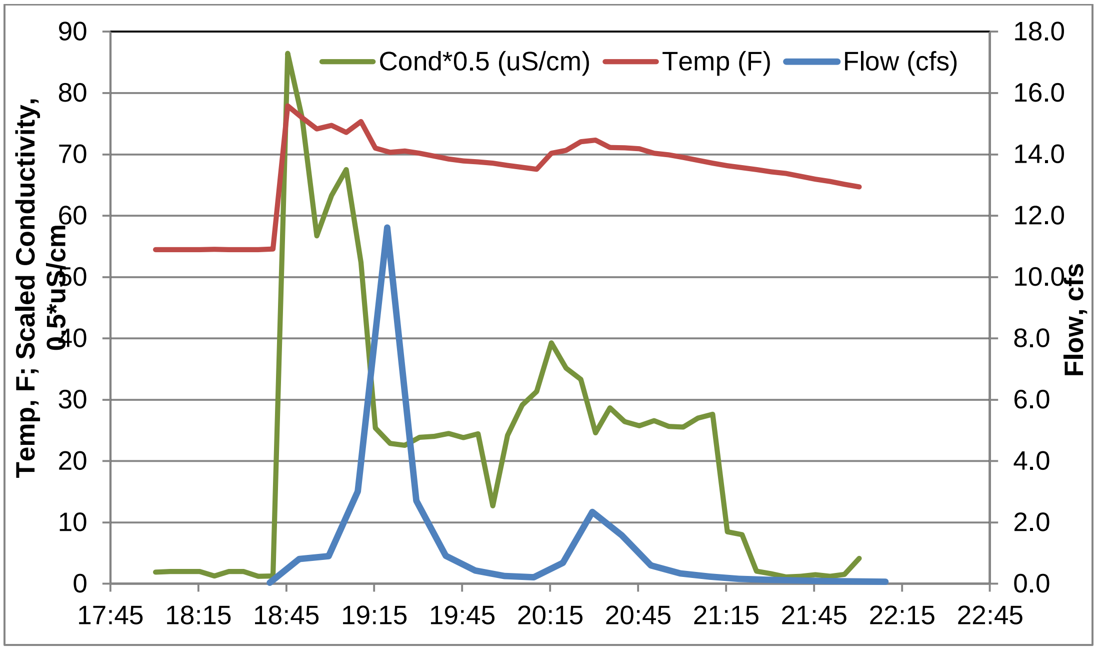

Figure 4 Runoff flow rate (cfs), runoff temperature (˚F), and conductivity (0.5 * uS/cm) measured at the outlet of the AHUG site for a storm event on May 23, 2012. Peaks in temperature and conductivity are associated with first flush runoff from road areas.

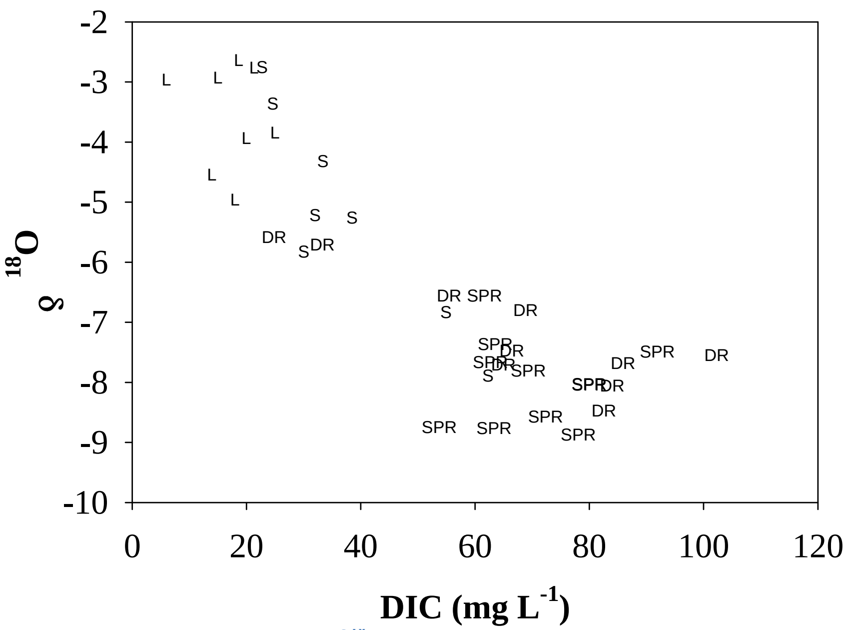

Figure 4 Oxygen stable isotopes (δ¹⁸O) and dissolved inorganic carbon (DIC) effectively separate water sources in urban streams. L=lake outlet, S=stream, SPR= spring, DR= storm drain

(2) ***What are the sources of N and P entering urban streams at base flow?*** Water sources for urban streams and storm drained channels in our study system include surface waters such as wetlands and lakes, groundwater and storm runoff. Contributions of base flow and storm flow to nutrient loading during the 6 month warm season are variable among sites. For example,

baseflow carries 8% to 34% of total P loading, and 33% to 68% of N loads (Janke et al. in review). We have explored geochemical and stable isotope tracers to help understand the origin of water and nutrients in baseflow at our sites.

We are using tracers to distinguish among lake, groundwater, and stream derived water sources and as tracers of nutrient sources during base flow conditions. Figure 5 shows mean values of DIC concentration and oxygen stable isotope ratios of oxygen ($\delta^{18}O$) as measured in 2011 and early 2012 in a variety of water sources and at the main CRWD monitoring sites during baseflow periods. A clear distinction is present between surface water sources (lake and pond outlets, streams, and wetlands) and groundwater sources (springs and groundwater flowing in shallow storm drains). Baseflow at several main monitoring sites (TBEB, EK, PC) appears to be primarily groundwater, while the remaining sites (TBWB in particular) are influenced to some extent by surface water, a sensible result given that TBWB, TBO, and SAP have upstream lakes and wetlands connected to the storm drains. This information is proving useful in understanding variation in both nitrogen and phosphorus in these watersheds because lakes can substantially modify the concentration of both nutrients (Janke et al. 2014, unpublished

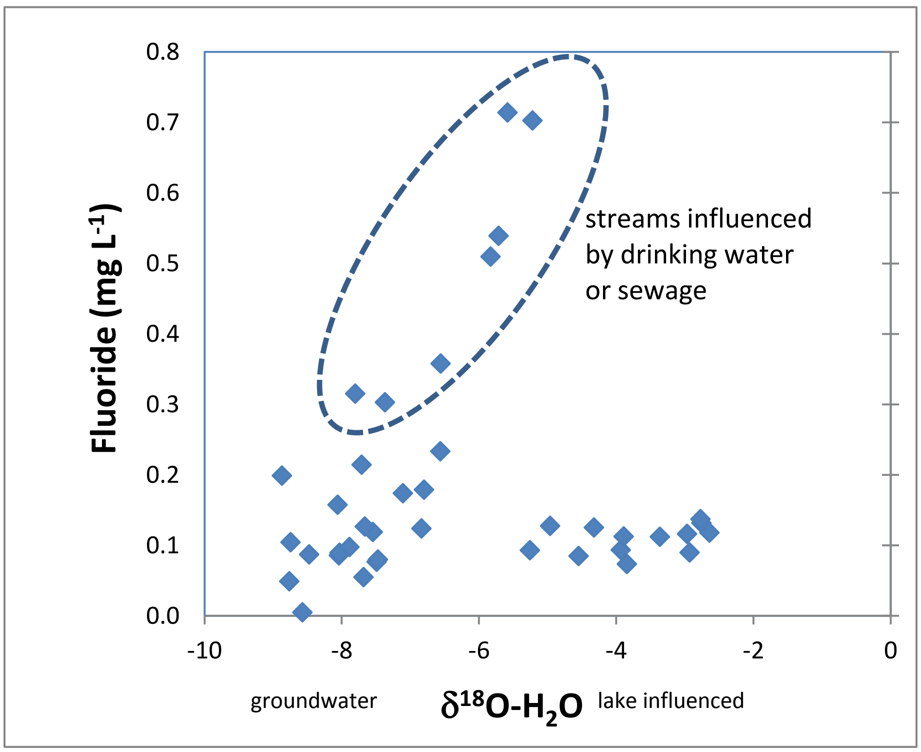

Figure 6 Baseflow concentrations of fluoride (Fl) and water stable isotopes in streams and storm drains in St. Paul. The drinking water plant releases high Fl water to Trout Brook as seen by concentrations declining with distance downstream (i.e. 0.7. 0.5, 0.5, 0.2 mg L^{-1}). The other high Fl concentration sites (between 0.3 to 0.7 mg L^{-1}) are storm drains that apparently are affected by leaking drinking or domestic sewer pipes

data).

Fluoride (Fl) is a potentially useful trace of domestic treated water sources, and analyses of Fl concentrations in a survey of streams and drains in 2012 shows that some storm drain sites are influenced by leaking pipes (Figure 6).

(3) ***How well do management activities (street sweeping, catch basin clearing) perform in reducing sources of urban nutrient runoff?*** In the AHUG watershed, we are examining stormwater nutrient concentration and yields before and after these activities. We are measuring the amount of material on streets and will assess fluxes observed in runoff in relation to street material present before and after management activities.

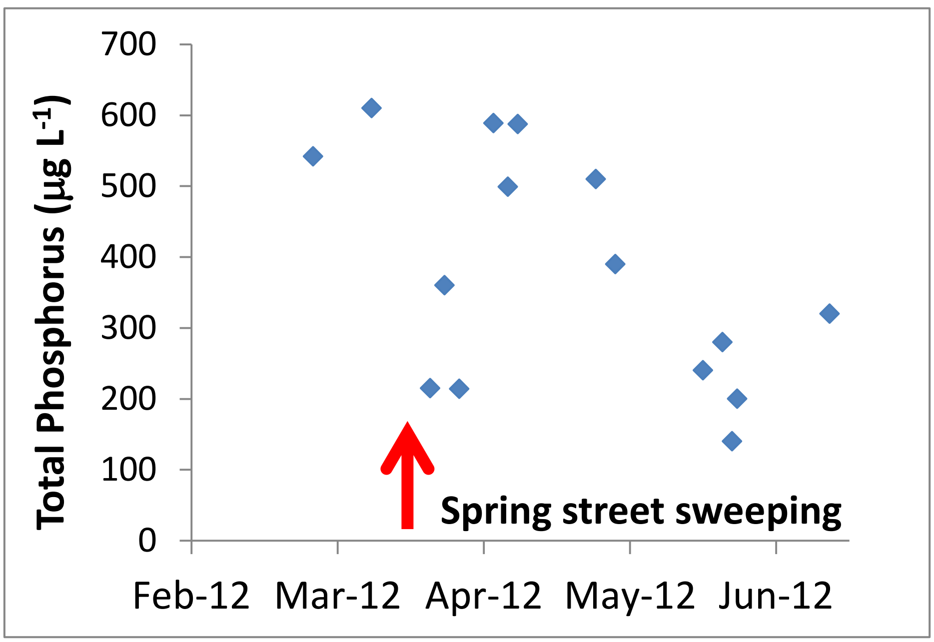

Figure 5 Stormwater total phosphorus concentrations in the AHUG watershed outlet for a series of storms prior to and after city street sweeping. TP concentrations decreased by more than 50% after sweeping but increased after two weeks to levels measured before sweeping.

During 2012 we successfully sampled stormwater runoff before and immediately after spring city sweeping. We observed a sharp decrease in stormwater TP concentrations for three rain events after sweeping, followed by an increase in TP (Figure 7). We hypothesize that this increase is related to new inputs of nutrients from surrounding vegetation during springtime. (In the fall, the extensive drought prevented useful comparisons of pre and post sweeping nutrient concentrations.) In contrast, following spring sweeping in 2013, we saw an increase in TP due to intense rainfall, and high rates of new P inputs from trees (unpublished data).

We are currently in the process of preparing several papers that are the result of support to this project.

2) PUBLICATIONS

Janke, B., J. C. Finlay, S. E. Hobbie, L. A. Baker, D. Nidzgorski, R. W. Sterner, and B. N. Wilson. 2014. Contrasting Influences of Stormflow and Baseflow Pathways on Nitrogen and Phosphorus Export from an Urban Watershed. Biogeochemistry DOI 10.1007/s10533-013-9926-1

3) STUDENT SUPPORT

Anika Bratt- Graduate student in the Ecology, Evolution and Behavior Graduate Program. One chapter of her dissertation investigates the role of winter decomposition processes in snowmelt nutrient export in a small storm drain in St. Paul.

Adam Worm- Directed undergraduate research (spring 2013). His project examined the role of litter decomposition on release of soluble nutrients to impervious surfaces, and this project is helping to support his analyses.

4) PRESENTATIONS

"Stormwater Management and Water Quality Issues in St. Paul" [class lecture] *University of St. Thomas*, Feb 13, 2013.

"Importance of Hydrologic Pathways to Urban Nutrient Loading and Implications for Current Stormwater Management Practices" *Minnesota Water Conference*, Oct 16, 2012.

"A watershed approach to understanding urban eutrophication" May, 2014 Institute on the Environment, University of Minnesota

"Our Water in a Changing World: Climate Change and the Urban Watershed" May, 2014 Presentation to the Friends of Diamond Lake

"Our Water in a Changing World: Climate Change and the Urban Watershed" February, 2014 Presentation at the Science Museum of Minnesota, sponsored by SMM and Friends of the Mississippi

"Ecosystem regulation of nutrient transport in urban landscapes" May 2014, Joint Aquatic Science Meeting, May 2014

5) AWARDS

None

6) RELATED FUNDING

Anika Bratt received a 3-year EPA STAR graduate fellowship to work on urban nutrient cycling.

References

Capitol Region Watershed District (CRWD). 2010. Capitol Region Watershed District 2010 monitoring report. April 2011. 191 pp.

Janke, B.D., Finlay, J.C., Hobbie, S.E., Baker, L.A., Sterner, R.W., Nidzgorski, D., and Wilson, B.N. 2014. Contrasting Influences of Stormflow and Baseflow Pathways on Nitrogen and Phosphorus Export from an Urban Watershed. *Biogeochemistry*, DOI 10.1007/s10533-013-9926-1

Identification of Municipal Wastewater as a Key Reservoir of Antibiotic Resistance: Itasca State Park as a Model System

Basic Information

Title:	Identification of Municipal Wastewater as a Key Reservoir of Antibiotic Resistance: Itasca State Park as a Model System
Project Number:	2012MN316B
Start Date:	3/1/2012
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	Minnesota fifth
Research Category:	Water Quality
Focus Category:	Treatment, Ecology, Wastewater
Descriptors:	None
Principal Investigators:	Timothy Michael LaPara

Publications

There are no publications.

1. Research

Identification of municipal wastewater as a key reservoir of antibiotic resistance: Itasca State Park as a Model System

Principal investigator
Timothy M. LaPara, Department of Civil Engineering, University of Minnesota

Research assistant
Kyle Sandberg, Department of Civil Engineering, University of Minnesota

Start date: 3/1/2012
End date: 2/28/2014

Research Project Title: Identification of municipal wastewater as a key reservoir of antibiotic resistance: Itasca State Park as a Model System

Abstract

Antibiotics and antibacterials are critically important drugs for the protection of public health. Historically, concerns about antibiotic resistance have been virtually disregarded, as it was assumed that new antibiotics would be discovered or that, similarly, existing drugs could be structurally modified to extend their effective lifetime. However, this assumption has been horribly wrong, as antibiotic resistance has developed at an alarming rate and the development of new antibiotics has almost completely stopped. New and complementary initiatives are therefore needed to help resolve this critically important problem.

Over the past decade or so, a new paradigm has developed with respect to the evolution and ecology of antibiotic resistance. The foundation of this theory is that antibiotic resistant bacteria are common in the environment but that pathogenic bacteria, which live inside the human body, are typically antibiotic-sensitive. Under the umbrella of this "antibiotic resistome paradigm", this research project tests the theory that municipal wastewater and its treatment are critically important in the proliferation of antibiotic resistance. Treated municipal wastewater still contains substantial quantities of antibiotic resistant bacteria and antibiotic resistant genes, which are then released to the environment where they can intermix with environmental organisms and potentially further exchange resistance genes to the detriment of public health.

The goal of the research described herein is to unequivocally identify human sewage as a statistically significant source of antibiotic resistance and antibiotic resistance genes in the environment. This goal will be achieved by determining the quantities of several antibiotic resistance genes in the wastewater treatment lagoon and four lakes within Itasca State Park. Itasca State Park provides an ideal opportunity for this research because produces a substantial quantity of domestic sewage (i.e., there are no industrial or agricultural inputs). Itasca State Park also has numerous lakes, with different levels of human use, which can serve as experimental controls (likely negative) for surface waters without an input of sewage.

Introduction

Antibiotics and antibacterials are critically important drugs for the protection of public health. These compounds target specific features of bacterial physiology (e.g., the bacterial cell wall) to suppress activity (bacteriostatic) or to kill (bacteriocidal) these organisms. Because the target site is unique to bacteria, antibiotics and antibacterials have great medical value because they can be used to treat bacterial infections without a direct effect on the patient. Unfortunately, after decades of indiscriminate antibiotic use by the medical profession as well as a host of other frivolous uses (e.g., subtherapeutic antibiotic use in agriculture), antibiotic resistant bacteria are now pervasive, threatening the efficacy of virtually all applications of antibiotic chemotherapy. Indeed, many scientists fear that the "antibiotic era" will soon end.

Historically, concerns about antibiotic resistance have been virtually disregarded, as it was assumed that new antibiotics would be discovered or that, similarly, existing drugs could be structurally modified to extend their effective lifetime. However, this assumption has been horribly wrong, as antibiotic resistance has developed at an alarming rate and the development of new antibiotics has almost completely stopped.

The primary focus of the medical community to thwart the development of antibiotic resistance is to limit inappropriate use and to improve hygiene within the hospital setting. The latter efforts are intended to limit nosocomial infections – secondary infections, which are often resistant to antibiotic treatment, that develop during hospital visits (hospitals are viewed as hotspots of antibiotic resistance). The effort to reduce inappropriate use has been much more challenging (and sadly, less effective), but includes initiatives to: (1) reduce inappropriate antibiotic prescriptions (i.e., viral infections, like the common cold, are unaffected by antibiotics), (2) eliminate antibiotic use in agriculture for growth promotion and prophylaxis (this practice continues in the USA; it has been banned in the European Union), and (3) reduce the superfluous use of antibacterial use in soaps and other personal care products (antibacterials in most of these cases are redundant and unnecessary; this practice also continues). While each of these initiatives by the medical community is an excellent idea, they are difficult to implement and they are likely to be insufficient to indefinitely extend the antibiotic era. New and complementary initiatives are therefore needed to help resolve this critically important problem.

Over the past decade or so, a new paradigm has developed with respect to the evolution and ecology of antibiotic resistance. The foundation of this theory is that antibiotic resistant bacteria are common in the environment but that pathogenic bacteria, which live inside the human body, are typically antibiotic-sensitive (D'Costa *et al.* 2007). The proliferation of antibiotic resistant bacteria, therefore, stems from the genetic exchange that inevitably occurs when these two types of organisms are intermixed as well as the selective pressure imposed by the heavy antibiotic use that has occurred since World War II. The key feature of this new paradigm – dubbed the antibiotic resistome (D'Costa *et al.* 2007) – is that environmental bacteria are critically important, as they are the most prominent source of the genes that are observed among medically-relevant pathogens (Allen *et al.* 2010).

Under the umbrella of this "antibiotic resistome paradigm", this research project tests the theory that municipal wastewater and its treatment are critically important in the proliferation of antibiotic resistance. Municipal wastewater (a.k.a., sewage) contains the fecal material of a substantial fraction of the population, which has been long been known to contain substantial quantities of antibiotic resistant bacteria. In contrast, wastewater treatment improves the water quality of the sewage such that it can be released to the environment without detrimental impact. It is critical to note that an explicit goal of municipal wastewater treatment is to merely limit <u>direct</u> exposure to pathogens such that people accidentally ingesting surface waters do not become fatally sick. Treated municipal wastewater still contains substantial quantities of antibiotic resistant bacteria and antibiotic resistant genes, which are then released to the environment where they can intermix with environmental organisms and potentially further exchange resistance genes to the detriment of public health.

The goal of the research described herein is to unequivocally identify human sewage as a statistically significant source of antibiotic resistance and antibiotic resistance genes in the environment. This goal will be achieved by determining the quantities of several antibiotic resistance genes in the wastewater treatment lagoon and four lakes within Itasca State Park. Itasca State Park provides an ideal opportunity for this research because produces a substantial quantity of domestic sewage (i.e., there are no industrial or agricultural inputs). Itasca State Park also has numerous lakes, with different levels of human use, which can serve as experimental controls (likely negative) for surface waters without an input of sewage.

Methods

<u>Sample Collection.</u>

Surface water samples (sample volume = 250 mL) are being collected from the wastewater treatment lagoon, Lake Itasca, Mary Lake, Elk Lake, and Lake Ozawindib within Itasca State Park (Fig. 1). These surface water samples are manually collected from one location within each lake (or wastewater lagoon) at a distance of 0.5 m below the water surface using sterile polystyrene bottles. As soon as possible after collection (less than 6 hours), surface water samples are passed through a 47 mm-diameter nitrocellulose filter (pore size = 0.22 μm) to concentrate microbial biomass. Filters are then immersed in 0.5 mL of lysis buffer (120 mM phosphate buffer, pH = 8.0, 5% sodium dodecyl sulfate) to preserve the sample until genomic DNA can be extracted and purified.

Similarly, triplicate sediment samples will be collected from each lake (or wastewater lagoon) using a gravity-corer (HTH Teknik; Luleå, Sweden) during one of the sample collecting trips (probably in June or July 2013). Sediment samples will be sliced into approximately 2.5 cm sub-sections to a depth of about 15 cm (i.e., about 6 sub-samples per sediment core).

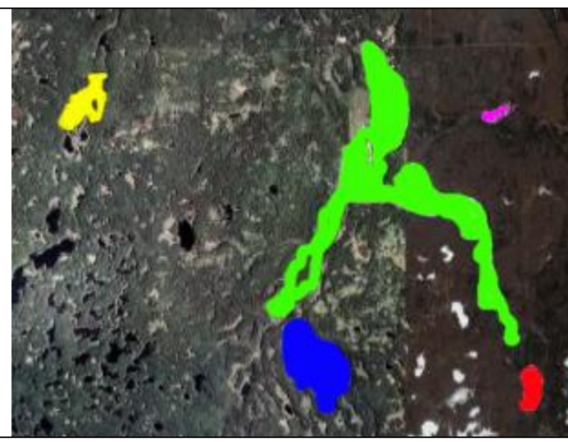

Fig.1. Map showing the relative locations of the wastewater treatment lagoon (magenta), Lake Itasca (green), Lake Ozawindib (yellow), Elk Lake (blue), and Mary Lake (red) within Itasca State Park.

Additional samples are being collected from numerous other locations to help test the hypothesis that manure and fecal material are pertinent sources of ARGs. These samples consist of numerous untreated municipal wastewaters (to date, we have collected samples from Marshfield, WI, Rochester, MN, Baxter, MN, and Brainerd, MN) as well as animal manure from various farming operations (some of these animals are grown without non-veterinary use of antibiotics, other animals are grown with substantial subtherapeutic antibiotic use).

All samples are stored on ice while they are transported to the University of Minnesota (within 1 day), after which they are stored at -20°C.

Genomic DNA extraction.

Water samples (preserved in lysis buffer) undergo three consecutive freeze-thaw cycles and an incubation of 90 minutes at 70ºC to lyse cells. Genomic DNA is then extracted and purified from these samples using the FastDNA Spin Kit (MP Biomedicals; Solon, OH) according to manufacturer's instructions. Genomic DNA is also extracted from sediment samples and manure samples (~ 500 mg of wet weight per sample) using a bead beater to lyse cells. All genomic DNA extractions are performed in triplicate and stored at -20ºC until needed.

Quantitative PCR

Quantitative real-time PCR (qPCR) is used to quantify 16S rRNA genes (a measure of total bacterial biomass) as well as three genes encoding tetracycline resistance (*tet*(A), *tet*(W) and *tet*(X)) and the integrase gene of class 1 integrons (*intI1*) as described previously (Diehl and LaPara, 2010). These genes will be targeted in this study because these genes encode proteins that confer tetracycline resistance via each of the three known mechanisms of resistance. Furthermore, our prior work has demonstrated that *tet*(A) and *tet*(X) are detectable when there is significant influence of wastewater; in contrast, *tet*(W) was detectable in all of our previous surface water samples. qPCR is also used to quantify the 16S rRNA genes of all members of the domain *Bacteria* as well as total and human-specific *Bacteroides* spp. as described previously (LaPara *et al.*, 2011).

The qPCR analysis is conducted using an Eppendorf Mastercycler ep *realplex* thermal cycler (Eppendorf; Westbury, NY). Each qPCR run consists of an initial denaturation for 10 min at 95°C, followed by forty cycles of denaturation at 95°C for 15 s, and anneal and extension at 60°C (most targets) or at 56°C (human-specific *Bacteroides*) for 1 min. A typical 25 µL reaction mixture contains 12.5 µL of iTaq SYBR Green Supermix with ROX (Bio-Rad; Hercules, Calif.), 25 µg bovine serum albumin (Roche Applied Science; Indianapolis, Ind.), optimized quantities of forward and reverse primers, and a specified volume of template DNA (usually 0.5 µL). The precise volume and concentration of template DNA is empirically optimized for each sample to generate the lowest detection limit while minimizing inhibition of PCR.

The quantity of target DNA in unknown samples is calculated based on a standard curve generated using known quantities of template DNA. Standards for qPCR have already been prepared by PCR amplification of genes from positive controls, followed by ligation into pGEM-T Easy (Promega; Madison, Wisc.) as described previously (Diehl and LaPara, 2010). Ten-fold serial dilutions of plasmid DNA are prepared and run on the thermal cycler to generate standard curves ($r^2 > 0.99$). Following qPCR, melting curves are generated and analyzed to verify that non-specific amplification does not occur.

Table 1. Description of target genes and PCR primers that are targeted by quantitative real-time PCR in this study. Detection limits are based on prior work and are expected to be similar in the this study.

Gene Target	PCR primer sequence (5′→3′)	Detection limit (genes/mL water)	Detection limit (gene/ g sediment)
tet(A)	GCT ACA TCC TGC TTG CCT TC CAT AGA TCG CCG TGA AGA GG	1.2×10^{1}	6.2×10^{4}
tet(W)	GAG AGC CTG CTA TAT GCC AGC GGG CGT ATC CAC AAT GTT AAC	2.0×10^{1}	2.0×10^{4}
tet(X)	AGC CTT ACC AAT GGG TGT AAA TTC TTA CCT TGG ACA TCC CG	2.6×10^{2}	1.3×10^{4}
intI1	CCT CCC GCA CGA TGA TC TCC ACG CAT CGT CAG GC	2.0×10^{2}	6.0×10^{4}
All *Bacteroides*	AAC GCT AGC TAC AGG CTT CAA TCG GAG TTC TTC GTG	1.2×10^{0}	6.0×10^{2}
Human *Bacteroides*	ATC ATG AGT TCA CAT GTC CG CCA TCG GAG TTC TTC GTG	1.2×10^{0}	6.0×10^{2}
16S rRNA	CCT ACG GGA GGC AGC AG ATT ACC GCG GCT GCT GG	3.0×10^{3}	1.6×10^{5}

The quantity of target DNA in unknown samples is calculated based on a standard curve generated using known quantities of template DNA. Standards for qPCR have already been prepared by PCR amplification of genes from positive controls, followed by ligation into pGEM-T Easy (Promega; Madison, Wisc.) as described previously (Diehl and LaPara, 2010). Ten-fold serial dilutions of plasmid DNA were prepared and run on the thermal cycler to generate standard curves ($r^2 > 0.99$). Following qPCR, melting curves will be generated and analyzed to verify that non-specific amplification does not occur.

Data Analysis

Non-metric multidimensional scaling (nMDS) will be statistically compare the qPCR profiles from each of the lake and wastewater lagoon samples. Each sample will be scored with respect to the concentration of each of the genes tested.

One way analysis of variance (ANOVA) will also be performed to compare the concentrations between lakes for all gene targets. Tukey's Honestly Significant Difference (HSD) test will be conducted for each gene target to determine the difference in mean gene concentrations between each possible pair of surface water samples sites. Pearson correlation coefficients of gene concentrations will also be calculated for all possible pairs of gene targets. An F-test will be conducted to determine if results from a surface water sample exhibited gene concentrations that are significantly different from results at the other sample locations.

Progress to Date

Sample Collection

Although this project was formally initiated on March 1, 2012, activity did not commence until late July 2012 because a research permit was needed from the Minnesota Department of Natural Resources to collect samples from within a State Park and because the graduate student working on the project did not matriculate onto the University of Minnesota campus until August 2012. Once this permit was obtained and the student arrived, numerous samples have been collected from Itasca State Park (August 2012; November 2012), from other untreated municipal wastewaters, and from various agriculturally-related animal manures. We anticipate collecting samples from Itasca State Park on two more occasions (likely May 2013; June 2013) as well as other sample locations.

Genomic DNA Extraction and quantitative real-time PCR

Genomic DNA has been extracted and preserved from all samples collected to date. No samples have been analyzed by quantitative real-time PCR because this assay is a high-throughput technique in which 96-well plates are used. We are waiting, therefore, for a sufficient number of samples before we initiative qPCR.

References

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2. Publications

None to date

3. Student Support

Kyle Sandberg, Department of Civil Engineering, University of Minnesota (Ph. D. Student; Anticipated Graduation: May 2016). Kyle was awarded a fellowship from the Department of Civil Engineering for the 2012-2013 academic year; Kyle will be supported on this project beginning in Fall 2013.

4. Presentations

None to date

5. Awards

None to date

6. Additional Funds

None to date

Predicting Erosional hotspots in North Shore streams from high-resolution spatial data

Basic Information

Title:	Predicting Erosional hotspots in North Shore streams from high-resolution spatial data
Project Number:	2012MN320B
Start Date:	5/1/2012
End Date:	6/30/2013
Funding Source:	104B
Congressional District:	MN 8
Research Category:	Water Quality
Focus Category:	Geomorphological Processes, Sediments, Surface Water
Descriptors:	None
Principal Investigators:	Karen Bobbitt Gran

Publications

1. Wick, M. J. and K. B. Gran, 2012. Identifying Riverine Erosional Hotspots Using Airborne Lidar. Abstract G23A-0897, 2012 Fall Meeting, American Geophysical Union, San Francisco, California, December 3-7, 2012.
2. Gran, K. and M. J. Wick, Duluth Flood of June 2012: Stream Visual Assessments, Living with Uncertainty: Duluth Streams in the Aftermath of the 2012 Floods. Minnesota Pollution Control Agency Offices, Duluth, Minnesota, October 31, 2012.
3. Wick, M. J. and K. B. Gran, 2012. Identifying Riverine Erosional Hotspots Using Airborne Lidar. Abstract G23A-0897, 2012 Fall Meeting, American Geophysical Union, San Francisco, California, December 3-7, 2012.
4. Gran, K. and M. J. Wick, Duluth Flood of June 2012: Stream Visual Assessments, Living with Uncertainty: Duluth Streams in the Aftermath of the 2012 Floods. Minnesota Pollution Control Agency Offices, Duluth, Minnesota, October 31, 2012.

Predicting erosional hotspots in North Shore streams from high-resolution datasets
Project Number 2012MN320B

Principal Investigator

Karen Gran, Associate Professor, UMD, Department of Geological Sciences

1) Research:

Introduction

This research focuses on predicting erosional hotspots from remote data along the North Shore of Lake Superior in Minnesota. Many of these streams are listed as impaired for turbidity according to section 303d of the U.S. Environmental Protection Agency's Clean Water Act. Although previous studies have hypothesized that land use is the central driver in water quality impairments in Lake Superior streams (Detenbeck et al., 2003, Detenbeck et al., 2004; Crouse, 2013), correlations between land use measures of sediment loading are poor (Crouse, 2013). Instead, we hypothesize that much of the fine sediment that contributes to turbidity comes from natural erosional hotspots. If erosional hotspots arise naturally due to local geomorphology and surficial geology, they should be predictable given high-resolution topography and soils data. This project focuses specifically on identifying near-channel erosional hotspots based on newly-available high-resolution remote datasets for streams along the North Shore of Lake Superior. These natural hotspots represent areas that would contribute a disproportionate volume of sediment to the channel under current conditions, and may be exacerbated by changes in land use of climate.

Both high-resolution topography and soils data were recently released for northeastern Minnesota. High-resolution lidar-derived DEMs (digital elevation models) are now available for the entire region at 3m-resolution from the Minnesota Geospatial Information Office. Lidar data were acquired May 3 - June 2, 2011, and tested to meet a vertical accuracy of 5.0 cm Root Mean Squared Error (RMSE). In addition, the high-resolution Soil Survey Geographic Database (SSURGO) dataset for St. Louis County was recently released by the Natural Resource Conservation Service (NRCS), and should be released in the near future for Lake and Cook Counties. Our original goal was to construct an erosional hotspot model using solely these two datasets as the data will be available throughout the entire North Shore. However, we found that additional information was required on the locations of bedrock outcrops. This is discussed below.

We constructed a model in ArcGIS for predicting hotspots using five main factors: stream power, bluff location, angle of impingement, soil erodibility, and bedrock exposure. We conducted these five analyses and tested our predictive model on three target watersheds: Amity Creek, the Talmadge River, and the French River (Figure 1). The lidar data have been prepped for ten additional North Shore watersheds including Lester, Sucker, Knife, Split Rock, Beaver, Baptism, Poplar, Cross, Grand Portage, and the Flute Reed. We have not run the predictive model on these streams due to a lack of reliable bedrock data. We have made the data layers available to researchers on an as needed basis and will soon be posting the data on-line.

In order to validate our erosion potential predictions, we conducted field surveys over the summer of 2012. First, we conducted modified Bank Erosion Hazard Index (BEHI) surveys at sites in the Amity, Talmadge, and French watersheds. The BEHI surveys are a pre-established protocol for assessing erosion potential, giving a rating of very low to extreme (Pfankuch, 1975). We also completed what we call Field Erosion Index surveys. The Duluth area experienced a 500-year flood event on June 19 – 20th, 2012. Areas in the region received 6 – 10 inches of rain within a 24 hour period (Huttner, 2012). Duluth streams are very flashy due to their bedrock channels, so water levels in Duluth streams rose very quickly and then fell very rapidly after the event. Many stream gages were lost during the event. The flood resulted in substantial geomorphic changes to Duluth streams, and the historic flood event offered us the opportunity to collect post-storm data and essentially compare our predicted erosion hotspots to where erosion actually occurred. We completed Field Erosion Index surveys (FEI) in which we walked the lower portions of Amity Creek and the Talmadge River in order to locate areas where extensive erosion occurred in order to assess the validity of our predictive model.

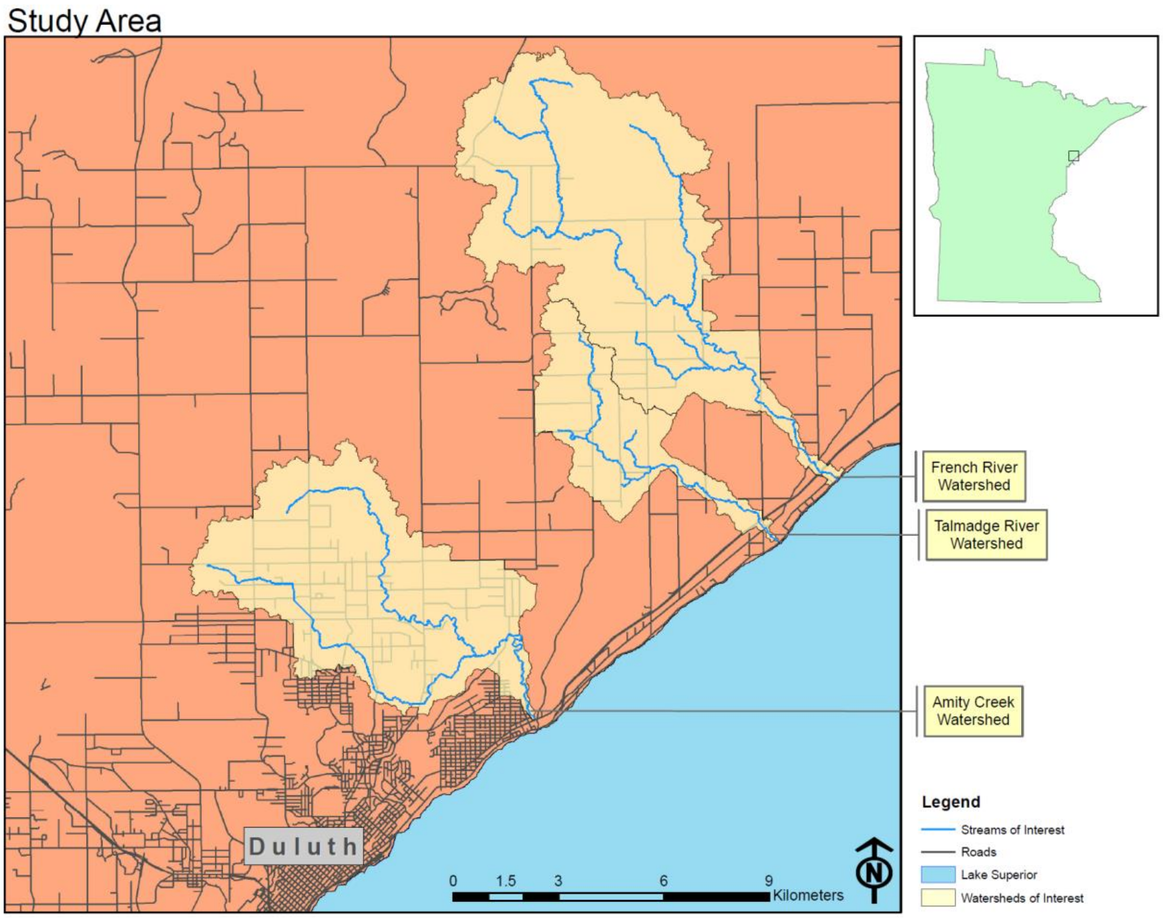


Figure 1: Map of the three watersheds focused on for development of erosion hotspot prediction model. The state map at right shows the location of study area.

Defining stream networks and delineating watersheds from lidar data

We delineated stream networks based on the lidar-derived DEMs. We used two methods, a program called GeoNet (Passalacqua et al., 2010a,b), and the Hydrology toolbox in ArcGIS to delineate Amity Creek. The benefit of GeoNet is that it is designed to deal with "data dams" that arise when trying to delineate channel networks with very high-resolution topographic data. Essentially, the data resolution is so high that road crossings become topographic barriers to flow. Geonet is an automated routine that can delineate channels across these topographic barriers. ArcGIS routines can also be used, but they require manual removal of bridges and other blockages that become topographic barriers to flow in a sometimes time-consuming iterative process.

Errors in delineated networks were identified by comparing the networks using both techniques to DEM and hillshade layers and to high-resolution air photos. Both networks were significantly more accurate than the existing Minnesota Department of Natural Resources stream files for most of the stream length, but both networks contained errors in the very flat upper reaches of the stream networks where topographic variability is low. Figure 2 shows an area along the East Branch of Amity Creek that illustrates the difference between the two networks. The ArcGIS network follows meanders very closely while the GeoNet network cuts off meanders. We found the ArcGIS Hydrology toolbox to be more user-friendly. GeoNet required a significant amount of computing power and time to run. Therefore we delineated all further networks using the ArcGIS hydrology toolbox, using an accumulation threshold of 10,000 m^3 to define the limits of network delineation. Errors in the network were corrected only if essential for the identification of erosion hotspots. For example, if errors were located upper reaches and wetlands where erosion potential is known to be low or where the stream is intermittent, they were disregarded. Hydrologic processing has been completed on fourteen North Shore streams (Amity, Talmadge, French, Lester, Sucker, Knife, Split Rock, Beaver, Baptism, Poplar, Cascade, Cross, Brule, and Flute Reed) and will be made available to the public through the Lake Superior Streams website (*www.lakesuperiorstreams.org*).

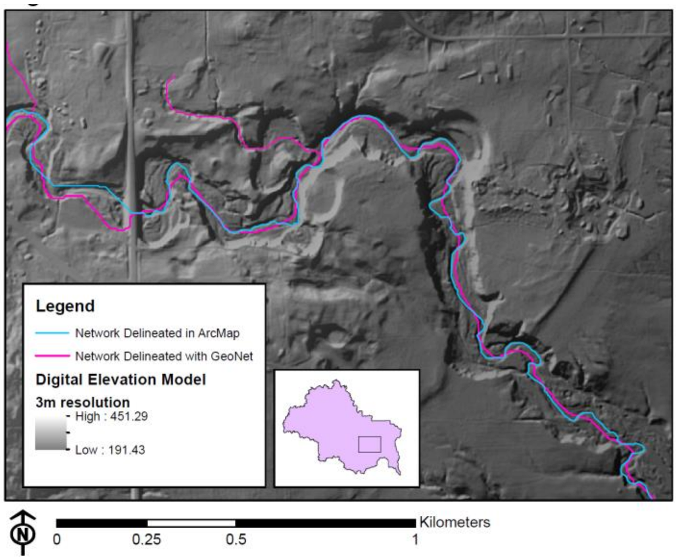


Figure 2: Comparison of the delineation of Amity Creek's stream network using two methods, GeoNet (shown in pink, Passalacqua et al., 2010a,b), and the hydrology toolbox in ArcGIS 10.0 (shown in blue).

<u>GIS Analysis Methods</u>

We used ArcGIS to analyze five potential predictor variables as described below: stream power, bluff proximity, angle of impingement, soil erodibility, and bedrock exposure. We created an addressing system with 25m reaches along which the predictor values were calculated. The erosion model we generated from these predictor variables was developed initially using data from Amity Creek, where we have the most dense field dataset for validation. It was then tested on the Talmadge and French Rivers.

Erosion potential in bedrock streams is a function of stream power. We used a stream power-based erosion index to predict the fluvial erosion potential along mainstem streams (e.g. Whipple and Tucker, 1999). Unit stream power (ω) is a function of the specific weight of water (density times gravity, or (ρ· g)), slope (S) and unit discharge (total discharge divided by channel width, or (Q/w)):

$$\omega \propto \rho g (Q/w) S \qquad (1)$$

However, channel width varies as a function of discharge, $w = c_1 Q^b$, and discharge varies as a function of area (A), $Q = c_2 A$, so we can rearrange equation 1 to form a stream power-based erosion index (SP) in terms of upstream drainage area and slope:

$$SP = kA^{(1-b)}S \quad (2)$$

where k is a coefficient accounting for the specific weight of water and the coefficients above (c_1 and c_2), which incorporate the effects of varying bedrock and substrate erodibility. Although we have both till and bedrock in these channels, we assign k a constant value here, and account for differences in erodibility separately using the SSURGO dataset and bedrock exposure mapping. The parameter b, the exponent in the width-discharge relation, was assigned a value of 0.5. Width-discharge relationships in North Shore streams are poor, but Leopold & Maddock (1953) found that 0.5 was appropriate in alluvial channels, and Montgomery & Gran (2001) found values of 0.3 – 0.5 are appropriate for bedrock channels. To calculate the stream power-based erosion index using ArcGIS, we extracted elevation data at points every 25 meters along the main stem channel and used them to calculate the slope at each point over a 100 m reach (50 meters upstream to 50 meters downstream). The upstream area at each point was extracted from the flow accumulation raster created using the Hydrology toolbox in ArcGIS.

Bluffs were delineated using topographic data to identify high bluffs along streams. Bluffs represent potential point sources of sediment, and locations where channels interact with bluffs can be erosional hotspots, particularly if those bluffs are composed of till or glaciolacustrine sediments rather than bedrock. We delineated bluffs using the focal statistics tool in ArcGIS to identify areas with relief > 2m over a 12 m by 12 m window. We also tracked areas with relief > 4 m to potentially separate out valley walls from in-valley terraces. Only bluffs adjacent to the stream were used in the erosion prediction model. Bluffs were defined as adjacent if they intersected a 14 m buffer established around the channel centerline. Most channels in Amity Creek are < 7m wide, so this analysis selects all bluffs a full channel width away from the stream on either side.

Secondary flows in rivers often drive erosion along the outside bend, with tighter bends resulting in higher shear stresses. To capture the effects of bend geometry on potential erosion, we calculated the angle of impingement for the channel centerline every 5 m. We used the Planform Statistics Toolbox (Lauer, 2006) to calculate a value for the angle of impingement every 5 m along the channel centerline. The angle of impingement here is defined as the difference between the stream direction vectors in two adjacent points along the stream centerline (5 m apart). Thus, a bend that is changing rapidly will have a higher angle of impingement than a more gradual bend.

To determine the role of substrate erodibility on erosion, we used two different approaches. The first measured soil erodibility using a “K factor”, which is the erodibility factor from the Revised Universal Soil Loss Equation. The K factor incorporates characteristics such as texture, structure, organic matter, and permeability of the soil and rates the soil based on the susceptibility of soil particles to be removed and transported away by water (Renard et al., 1991). We extracted K factor values at the prediction points every 25 m along stream networks from the SSURGO dataset, using the dominant K value for all soil horizons.

We quickly realized that there is little variability in K factors in our study area, and what is most important is the presence or absence of bedrock in the channel. Unfortunately, the SSURGO dataset does not include this information. We thus defined an additional layer that identified bedrock outcrop locations. This proved to be a challenging layer to create solely from remote data. One method we are working on uses the Feature Analyst program distributed by Overwatch Systems, LTD, to extract bedrock outcrop from air photos and lidar data. Feature Analyst is an extension for ArcGIS that allows the user to create “training polygons” which the tool then uses to identify similar polygons based on the input datasets. Input datasets included 4-band air photos (0.3m resolution, obtained from the USGS); lidar first returns (vegetation height), last returns (bare earth), and intensity (all 1m resolution) (all calculated from the lidar point cloud data, obtained from the Minnesota Geospatial Information Office); and the Normalized Difference Vegetation Index (NDVI, used to visualize green vegetation, calculated as (Band 4

- Band 3)/(Band 4 + Band 3) from the air photos). After the Feature Analyst identifies similar polygons to the training polygons, the user then inputs correctly and incorrectly identified polygons and reiterates the program, until a satisfactory map is produced.

We used a corridor of 300 meters wide to be sure to include the valley walls, and ran the program only on Amity Creek below Jean Duluth Road, as we know that bedrock outcrop interaction with the creek is very limited along the creek upstream of Jean Duluth Road. Typically, features are mapped in Feature Analyst solely based on training polygons defined by the user and based solely on visual inspection of remote data. However, because of the limits of our datasets, we used records of outcrop exposure from our field data as well as outcrop maps from the Minnesota Geological Survey to verify outcrop locations for our training polygons.

Field Surveys

Field work was completed during the summer of 2012. We completed Field Erosion Index (FEI) surveys and modified Bank Erosion Hazard Index (BEHI) surveys in order to validate our erosion potential predictions. Our initial plan was to spread surveys out across different North Shore streams. Instead, we decided to focus on a more dense data set in only a few streams. Field Erosion Index surveys were conducted on Amity Creek and the Talmadge River on a range of different channel types on approximately the lower third of the main stem channels in each watershed. BEHI surveys were along Amity, Talmadge and French River main stems throughout the stream network.

BEHI surveys utilized a pre-established protocol for assessing erosion potential, giving a rating of very low to extreme bank erosion hazard for each bank (Pfankuch, 1975). The BEHI survey is based on field observations of the near-channel zone, including bank height, material, angle, channel area, and signs of erosion. We used a modified BEHI survey, adding a component to account for stream interaction with till valley walls. We completed 28 sites on Amity's main stem, 10 sites on Talmadge's main stem, and 12 sites on French's main stem.

In the middle of the field season, Duluth experienced a very large flood event. We took advantage of this opportunity to not just predict erosion, but instead to actually measure it. The FEI surveys focused on documenting the erosion that occurred during the June 2012 flood. We assumed that the degree of erosion that occurred during this flood should be proportional to the erosion potential along the streams during a typical annual flood. A rating system was created based on field observations, from 1 (no erosion) to 7 (complete scour on both banks). A value of 0 denoted bedrock exposure and indicates erosion potential is very low. We used this rating system to create a running assessment of field erosion potential based on locations that were highly eroded compared to areas that were not eroded in the June flood on Amity Creek and the Talmadge River.

Results: Erosion Potential Predictions

We predicted erosion potential based on five predictor variables: stream power-based erosion index, bluff proximity, angle of impingement, soils, and bedrock exposure, for Amity Creek, the Talmadge River, and the French River. The results of our erosion predictors for a portion of Amity Creek are shown in Figure 3. We then compared the results of our GIS predictors to our sets of field data from Amity Creek and the Talmadge River. Here we focus on our FEI data because we have significantly more observations in that dataset (Figure 4). The last step of the analysis involved combining predictor variables to develop an erosion hotspot index. This was done using both a logistic model and a threshold-based model.

Stream power is lowest in the upper reaches of the stream network where drainage area is small and slopes are very low, with a rapid increase towards the outlet as both slope and drainage area increase. Because the erosion index assumes a constant erodibility, the stream power-based index varies only with upstream area and slope. For both streams, the correlations with stream power are very poor because we did not account for substrate variability. Bedrock exposure is restricted to areas near the outlet in these watersheds. These areas typically have high stream power values (high drainage area and steep slope) but low erodibility due to the presence of bedrock. Erosion predictability should improve when combined with soil erodibility data and information on bedrock outcrop locations.

Soil erodibility was extracted from the SSURGO soils dataset. Despite the vast improvement in resolution over the STATSGO (State Soil Geographic) database, soil K factor values along the stream network varied minimally in all three watersheds. Bedrock exposure was a much more useful parameter for determining erosion potential than mapped soil K factors. Bedrock exposure for a 300m corridor along the channel, from Jean Duluth to the outlet, was mapped using feature extraction methods for Amity Creek. Along Amity Creek, most bedrock outcrops are located along Seven Bridges Road, especially in the vicinity of the uppermost three bridges, and near the first bridge (area shown in Figures 3 and 4 and downstream). This method resulted in identification of the large obvious outcrops which were visually confirmed on the air photos, but also small polygons (~1 to 10m^2) along the creek that may be erroneous identification of bedrock. The bedrock exposure maps derived using Feature Analyst were more accurate than the Minnesota Geological Survey maps (Hobbs, 2002; Hobbs, 2009), which contain very large, generalized polygons. Unfortunately, the feature extraction method relied upon high-resolution air photos which are not available throughout the entire North Shore. We also used field notes on the locations of bedrock outcrops to help "train" the polygons prior to automating the procedure, so the results were not completely derived from remote datasets alone.

The delineation of steep bluffs adjacent to the stream is a very simple calculation that yielded the most promising results when compared to field surveys. We saw positive correlations of percent of points near bluffs with FEI surveys. On the Talmadge, r^2 values were 0.2 and 0.25 for 2m and 4m bluffs, respectively. On Amity, r^2 values were 0.9 and 0.7 for 2m and 4m bluffs, respectively. Bluff delineation may be used as a starting place to identify areas that may be actively eroding. The major limitation of this analysis is the presence of different substrate materials. If a bluff that was delineated is made of bedrock, the erosion potential is likely very low, while if the delineated bluff consists of glacial till, then erosion potential may be quite high. Therefore, this analysis is most useful with either prior knowledge of the watershed or bedrock outcrop maps.

The angle of impingement is calculated along the stream network, so by nature it is dependent on accurate network delineation. It is also highly dependent on using an applicable "ruler", or distance along which the value is calculated. We used a ruler of 5m, which captured most sharp turns, but may have been too short of a distance for large-amplitude bends along Amity Creek. Possible values for the angle of impingement range in radians from 0 to 6.28 (straight to curved), with the highest observed values for each creek equal to 1.57 rad along Amity and French Creeks, and 1.18 rad along Talmadge Creek. For Amity Creek, there is a positive correlation between angle of impingement and FEI, with an r^2 value of 0.8. However, in Talmadge Creek, we do not see a positive correlation, and we see a large spread in the data at moderate FEI values. This is likely due to the limited number of data points on Talmadge (137 points) compared to Amity (341 points).

Overall, the most useful predictor variables were bedrock exposure, bluff proximity and stream power. Stream power in the absence of information on bedrock outcrop locations was not useful, and soil K factor data were simply too low of a resolution with too little variability to be useful. The angle of impingement varied with meander wavelength and was less useful than originally hoped.

We created two different models to combine the predictor variables. A logistic model developed using the three most useful predictor variables was unsuccessful. A threshold-based model with the same variables was 70% accurate for predicting erosion hotspots along Amity Creek. Some of the variability between predicted erosional hotspots and the actual erosion that occurred in the June 2012 flood was related to local site-specific features like the location of large wood jams.

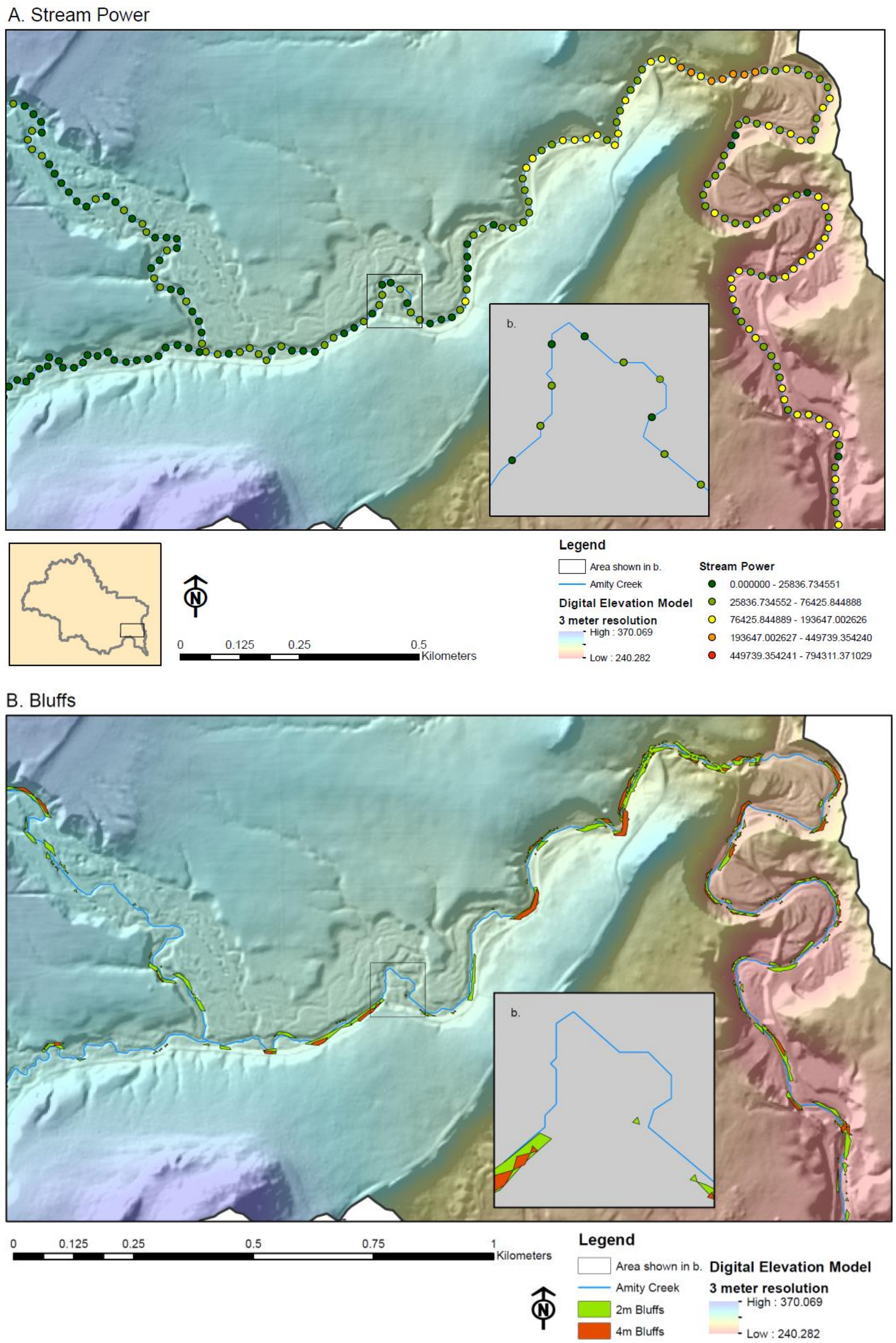
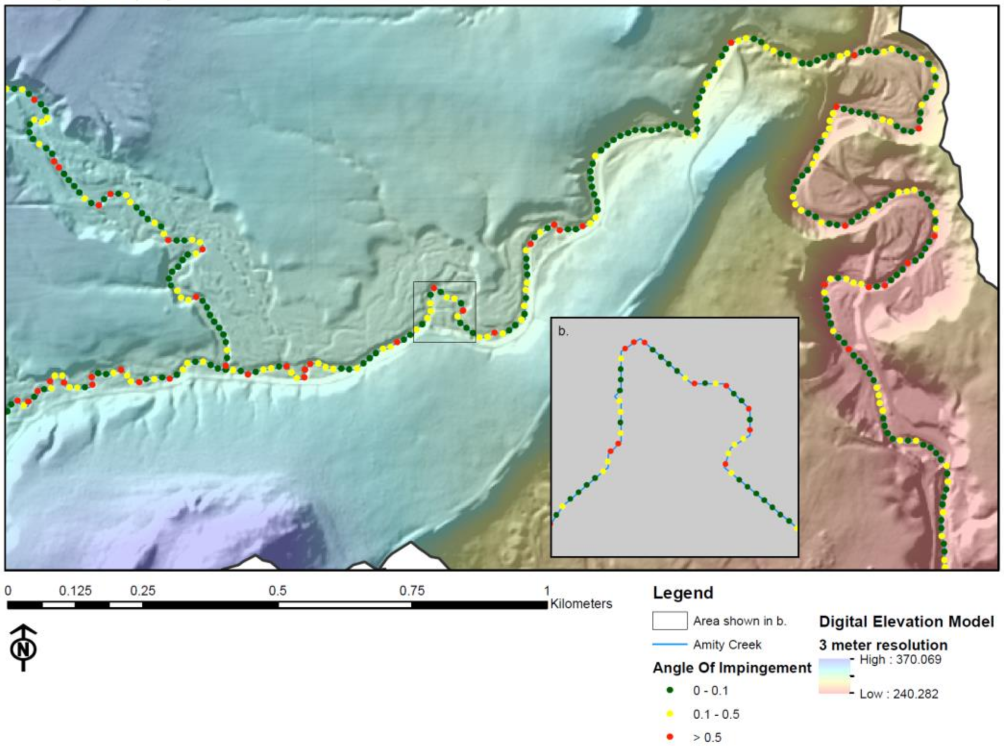


Figure 3: Results from erosion predictor analyses. The portion of the watershed shown in all tiles is outlined in the watershed map in A. Tile A shows stream power. Tile B shows delineated bluffs, with >2 meter bluffs in green and >4 meter bluffs in orange.

C. Angle of Impingement



D. Bedrock Exposure

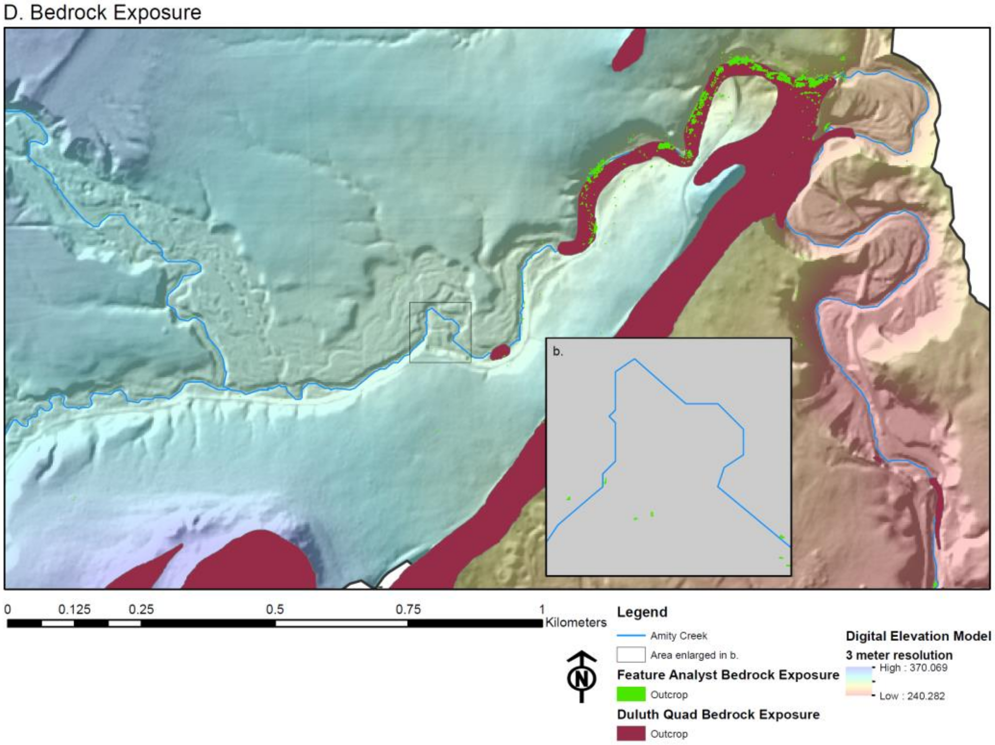


Figure 3 ctd: Results from erosion predictor analyses. The portion of the watershed shown in all tiles is outlined in the watershed map in tile A. Tile C shows angle of impingement. Tile D shows bedrock exposure, with the Feature Analyst map shown in green (mapped only in 300-meter corridor along channel), and the MGS bedrock exposure maps (for entire watershed) shown in purple.

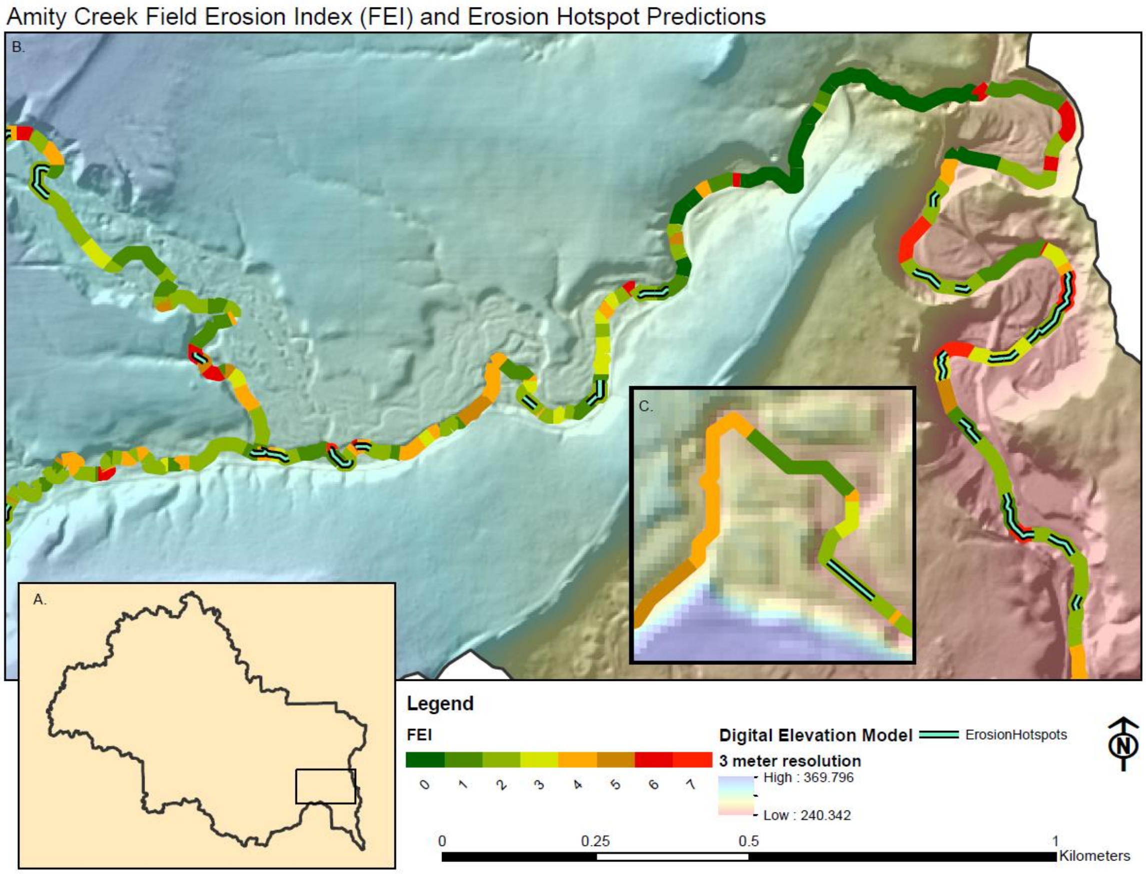


Figure 4: Results from the Field Erosion Index surveys. Area shown is the same area shown in Figure 3.

Conclusions and Project Status

We have completed hydrologic conditioning and stream network delineations on the following streams: Amity, Talmadge, French, Lester, Sucker, Knife, Split Rock, Beaver, Baptism, Poplar, Cross, Grand Portage, and the Flute Reed. These stream network delineations have been delivered to the Natural Resources Research Institute which maintains the *www.LakeSuperiorStreams.org* website where the data will be hosted. The primary predictor variables of bluff proximity and stream power have been mapped and calculated. Because bedrock exposure maps are not available for the entire North Shore, and mapping them remotely is outside the scope of this project, we will be unable to produce final erosion hotspot predictions for all watersheds. The individual predictor layers will be made available on the Lake Superior Streams website, but not the final erosion hotspot maps because their utility is limited without prior knowledge of bedrock outcrop locations.

The lack of high-resolution bedrock exposure data is a major limitation of completing this analysis on other North Shore watersheds. We had hoped to use the SSURGO data to get information on erodibility at high-resolution. Unfortunately, SSURGO soil erodibility data are still not high enough resolution to help this project, and they lack data on bedrock exposure. For Amity Creek, we were able to use prior knowledge of the watershed along with air photos and lidar data to produce a bedrock exposure map, but this may be difficult in other North Shore watersheds due to a lack of data availability and computing power limitations.

Other limitations of this approach involve temporal and spatial scales of erosion. Erosion in a single event is dependent upon fine-scale features like vegetation, large woody debris, or even culverts or other infrastructure. Although in the long-term, erosion rates may be greater in areas with erodible substrates, tight bends, high cliffs, and high stream power, in a single event it is more difficult to predict the exact locations where erosion will occur. Thus, our comparisons between erosion in the June event and predicted erosional hotspots is challenged by our inability to use remote data to predict fine-scale variation of vegetation and large woody debris that may actually dictate erosion in a single event. These fine-scale variations may account for the poor regressions between our predictors and our field datasets. In addition, the 500-year event that our FEI dataset is based on may introduce additional uncertainty due to the magnitude of the event compared to a typical bankfull flood event. Erosion in a typical bankfull flood would be more limited spatially.

Even with these limitations, these analyses may be helpful as a screening tool to locate potential field sites or sites for management or protection. However, background knowledge of the watershed characteristics such as vegetation patterns, land use, and surficial geology will be very helpful in order to use this beneficially.

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2) Publications:

Wick, M.J., 2013, Identifying erosional hotspots in streams along the North Shore of Lake Superior Minnesota using high-resolution elevation and soils data. M.S. Thesis: University of Minnesota Duluth, 99 p.

Wick, M. J. and Gran, K.B., 2012. Identifying Riverine Erosional Hotspots Using Airborne Lidar. Abstract G23A-0897 presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec.

3) Student Support:

This project provided summer RA support for one M.S. student, Molly Wick, during summer 2013. She defended her thesis in June 2013.

This project also provided support for Ryan Peterson, an undergraduate geological sciences student who assisted Molly Wick with GIS and field work. He was not paid on this grant during the March 2013 – February 2014 time period.

4) Presentations:

We gave two presentations specifically on the erosion model and results during this reporting period:

Wick, M.J., Gran, K.B., 2014, Identifying erosional hotspots in North Shore streams using airborne LiDAR, presented at the 2014 Minnesota Lake Superior Watershed Stream Science conference, Duluth, MN, 7-8 January.

Karen Gran gave a presentation on this research to the Minnesota Pollution Control Agency's Northeast Watershed Unit meeting on September 24, 2013.

Three additional presentations were given that focused more generally on erosion in Duluth-area streams during this reporting period:

Molly Wick presented “Unique Aspects of how North Shore Streams Flow and Respond to Storms." at Lake Superior Watershed Ditch and Culvert Design Workshop, EPA Mid Continent Ecology Division, Duluth, MN, March 6, 2013.

Karen Gran presented “Geologic history of western Lake Superior streams” at the Minnesota Lake Superior Stream Science Symposium, January 7-8, 2014, Duluth, MN.

Karen Gran presented a talk entitled “Duluth stream geomorphology and the solstice flood of 2012” at the Sip of Science series at the Aster café in Minneapolis, MN on November 13, 2013.

Previous presentations (earlier reporting periods):

Wick, M.J., Gran, K.B., 2012, Identifying Riverine Erosional Hotspots Using Airborne Lidar, presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec.

Karen Gran and Molly Wick presented "Duluth Flood of June 2012: Stream Visual Assessments" at Living with Uncertainty: Duluth Streams in the Aftermath of the 2012 Floods, Minnesota Pollution Control Agency Offices, Duluth, MN. Wednesday, October 31, 2012.

Faith Fitzpatrick gave a talk in which Molly Wick and Karen Gran assisted with slides and were co-authors: Fitzpatrick, F. A., Gran, K. B., Wick, M. J., and Czuba C. R., Influence of Drainage-Network Position and Geologic Setting on Channel Responses to Floods for Duluth-Area Streams. St. Louis River Estuary Summit, Superior, Wisconsin, February 2013.

5) Awards:

None

6) Related Funding:

K. Gran (PI) received an internal grant from the University of Minnesota’s Center for Urban and Regional Affairs (CURA)’s Faculty Interactive Research Program for a project entitled “Identifying and mitigating impacts from expanding urbanization to Duluth-area streams” ($37,220). This project also involves hydrologic conditioning and analyses of lidar data in Duluth-area streams, using many techniques developed as a result of WRRI funds. Project period: 3/13-6/14.

K. Gran (PI) received an extension of funds from the Water Resources Center to fund salary for a Water Resources Science M.S. student, Tiffany Sprague, to expand this project into more Duluth-area streams. Ms. Sprague is just starting her work on this now. This grant is for $22,500. Project period: 3/14 – 2/16.

Improving treatment: Understanding the effect of organic carbon on the biodegradation of two endocrine disrupting compounds

Basic Information

Title:	Improving treatment: Understanding the effect of organic carbon on the biodegradation of two endocrine disrupting compounds
Project Number:	2012MN322B
Start Date:	3/1/2012
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	5th
Research Category:	Water Quality
Focus Category:	Water Quality, Wastewater, Treatment
Descriptors:	None
Principal Investigators:	Paige J Novak

Publications

1. Tan, D.T., W. A. Arnold, and P. J. Novak, 2012. Impact of Organic Carbon on the Biodegradation of Estrone in Mixed Culture Systems. Submitted to Water Research, under review.
2. Tan, D.T., W.A. Arnold, and P.J. Novak, 2012. The Impact of Organic Carbon on the Biodegradation of Steroid Estrogens: Competition and Community. Poster presented at the Minnesota Conference on the Environment.
3. Tan, D.T., W.A. Arnold, and P.J. Novak, 2012. The Impact of Organic Carbon on the Biodegradation of Steroid Estrogens: Competition and Community. Poster presented at the Gordon Research Seminar, Environmental Sciences: Water, June 24-29, 2012, Holderness, New Hampshire.
4. Tan, D.T., W. A. Arnold, and P. J. Novak, 2012. Impact of Organic Carbon on the Biodegradation of Estrone in Mixed Culture Systems. Submitted to Water Research, under review.
5. Tan, D.T., W.A. Arnold, and P.J. Novak, 2012. The Impact of Organic Carbon on the Biodegradation of Steroid Estrogens: Competition and Community. Poster presented at the Minnesota Conference on the Environment.
6. Tan, D.T., W.A. Arnold, and P.J. Novak, 2012. The Impact of Organic Carbon on the Biodegradation of Steroid Estrogens: Competition and Community. Poster presented at the Gordon Research Seminar, Environmental Sciences: Water, June 24-29, 2012, Holderness, New Hampshire.

Improving treatment: Understanding the effect of organic carbon on the biodegradation of two endocrine disrupting compounds

Research

This research project examines the impact of organic carbon on the degradation of estrone (E1), an important endocrine disruptor frequently present in treated municipal wastewater. The project consists of three major objectives: (1) determining if and how organic carbon concentrations and loads affect estrone degradation in mixed cultures and identifying possible mechanisms; (2) studying the impact of E1 and organic carbon exposure patterns on E1 degradation; and (3) elucidating organic carbon characteristics that improve E1 degradation through microbial community selection.

The first objective of the project has been completed and was published as "Impact of Organic Carbon on the Biodegradation of Estrone in Mixed Culture Systems." Two experiments presented in this publication were conducted during the reporting period. One experiment examined the impact of substrate conditions on E1-degrading capacity by comparing batch reactors under starvation and feast-famine conditions, with the hypothesis that low organic carbon conditions would select for E1 degraders. The other experiment examined whether it would be possible to select for E1 degraders by changing the quantity of organic carbon present in the influent using a membrane bioreactor (MBR) setup.

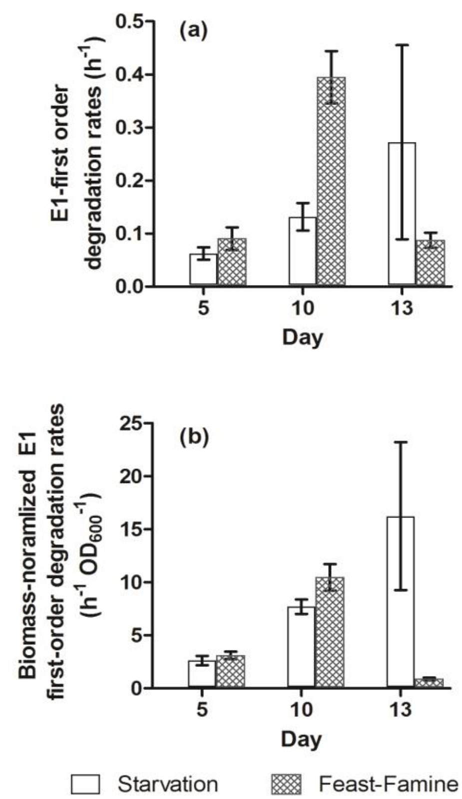

Figure 1. Overall (a) and biomass normalized (b) first order degradation rates for E1 in starvation and feast-famine reactors. Error bars represent standard deviations for triplicate reactors

In the first experiment (results shown in Figure 1), cultures from wastewater were grown in batch reactors for an initial 5-day period and were exposed to E1 during initial seeding. Subsequently, reactors were operated under feast-famine conditions (daily synthetic wastewater amendments, increasing reactor COD by 50 mg/L) or starvation conditions (no additional wastewater). E1 degradation was monitored on Days 5, 10, and 13, when E1 was added to the reactors (10 µg/L). Reactor liquor was collected, acidified, and processed via solid phase extraction and silica gel cleanup prior to LC-MS analysis. DNA samples were also collected from these reactors for community analysis via automated ribosomal intergenic spacer analysis (ARISA). A previous experiment showed that the presence of organic carbon does not inhibit E1 degradation; therefore, no short-term effects as a result of the feast-famine cycles were expected.

Results in Figure 1 show that initial operation (Day 5-10) of the feast-famine reactors did not affect biomass-normalized E1 degradation rates, which remained statistically similar to starvation reactors. However, the higher abundance of biomass in these reactors resulted in higher E1 removal. Subsequently, E1 degradation in the feast-famine reactors decreased despite a continued increase in biomass, while E1 degradation in the starvation reactors continued to improve. This suggests that the bacteria responsible for E1 degradation are outcompeted when organic carbon is abundant over an extended period of time.

In the second experiment, cultures from wastewater were grown in MBRs operating with a solids retention time (SRT) of 10 days and a hydraulic retention time (HRT) of 8 hours over a 30-day period. MBRs received a synthetic wastewater containing 20, 75, or 375 mg/L COD and 2 µg/L E1. A control reactor was also run to assess loss of E1 as a result of sorption to the membrane (sorptive loss not observed after 16 days). Reactor effluent was sampled twice weekly for E1, pH, ammonia, and COD to determine reactor performance and stability. All monitored conditions except for E1 were similar across the reactors. DNA samples were also collected for microbial community analysis.

Results in Figure 2 show that the highest E1 effluent concentrations were observed at the lowest COD load (P = 0.018). Reactor performance could not be correlated with overall microbial community structure, as the communities receiving 20 mg/L COD and 75 mg/L COD respectively tended to converge over time while the communities receiving 375 mg/L COD were distinct. Microbial diversity and the presence or absence of individual operational taxonomic units could not be correlated to E1 degradation either. These results suggest that low biomass resulting from low organic loading in continuous flow systems may be detrimental to E1 degradation. Combined with the previous experiment, the data

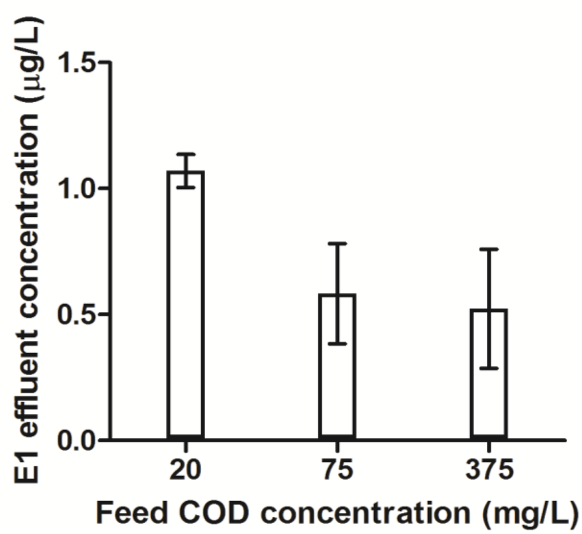

Figure 2. Average E1 effluent concentration from MBRs at varying influent feed strengths. Error bars represent standard deviations for triplicate reactors.

shows that high organic carbon concentrations in reactor liquor, but not high organic carbon loading rates in the influent, are detrimental to E1 degradation as a result of community selection over time.

The second objective of the project, determining the impact of E1 and organic carbon exposure patterns on E1 degradation, is currently ongoing. The first experiment that has been completed examined if exposure to E1 was necessary for, or improved, the E1 degradation performance of a mixed culture. A second set of experiments examined if altering the period of feast-famine cycles could affect E1 degradation rates.

In the first experiment, paired MBRs were operated at an SRT of 10 days and a HRT of 8 hours over a 30-day period. The reactors were fed a synthetic wastewater with a COD of 100 mg/L. The influent feed either contained E1 10 µg/L or no E1. After a 30-day period (3 SRTs), the biomass from the reactors was separated from the liquor by centrifugation. The biomass was then resuspended in batch reactors using filtered reactor effluent previously collected from the matching MBR. E1 was then added to the reactors at 10 µg/L and degradation was monitored over a 22-hour period.

Results in Figure 3 show that both the microbial communities with and without previous exposure to E1 were capable of degrading the compound, though a lag phase of 6 hours was observed for biomass without prior E1 exposure. This shows that (1) bacteria that do not require E1 for growth are important in E1 degradation, and (2) E1 is utilized as a carbon or energy source rather than being degraded fortuitously through cometabolism. Degradation was faster in biomass previously exposed to E1 (P = 0.05), suggesting that the ability to degrade E1 provided some competitive advantage in the MBR system. Together, these results point toward the importance of multiple substrate utilizing organisms in the removal of E1 in wastewater treatment.

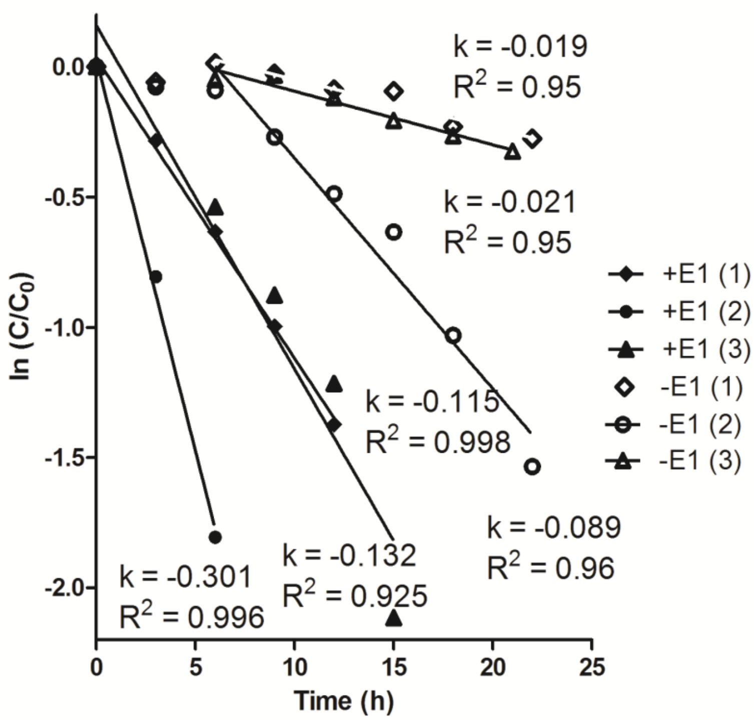

Figure 3. First-order degradation of E1 by biomass previously exposed to E1 (+E1) or not previously exposed to E1 (-E1)

In the second set of experiments, reactors were operated on feast-famine cycles to determine if the interval between cycles and the organic load during the feast period would affect E1 degradation. Batch reactors were seeded from a mother reactor in which biomass was grown on synthetic wastewater for 5 days. The batch reactors were then operated on feast-famine cycles of 1, 3, or 6 days respectively. Each set of reactors received the same quantity of food over a 6-day period, and two levels of feeding were studied (30 mg COD/L/d and 100 mg COD/L/d). Reactors received E1 on days 0, 6, and 12. E1 degradation rates were monitored on days 6 and 12 (feast periods). Results from the feast-famine reactors receiving 30 mg COD/L/d suggested that as the feeding period increased from every day to every 6 days, the rate of E1 degradation increased. Sample analysis at the higher feed rate is ongoing.

The third objective of the project, elucidating organic carbon characteristics that improve E1 degradation through microbial community selection, is currently ongoing. One set of experiments examines if the quality of organic matter affects E1 degradation over the long term through community selection.

In the first set of experiments, a biological reactor with synthetic wastewater was seeded with activated sludge. The synthetic wastewater was filter-sterilized at Day 0, 2, and 8 in order to generate organic carbon sources of different qualities and different degrees of "weathering". The resulting liquor was characterized by pH, ammonia concentration, dissolved organic carbon (DOC), and excitation-emission spectrums (EEMs). To study the effect on microbial community, a small amount of biomass was added to each reactor (1 mg/L wet weight) and grown, with exposure to E1 at 10 µg/L over a 5-day period prior to the kinetic study.

Results are shown in Figure 4. The biomass grown on the synthetic septage aged for 2 days did not degrade E1 significantly. However, the biomass grown on the synthetic septage aged for 8 days had a higher E1 degradation rate than the biomass grown on fresh synthetic septage ($P = 0.033$), even though the biomass concentrations were two orders of magnitude lower (as measured by 16S gene copies). EEM results showed that both the aged synthetic septage mixtures consisted of more recalcitrant and oxidized organic matter than the fresh synthetic septage; however, we are unable to distinguish between the 2 day old and 8 day old

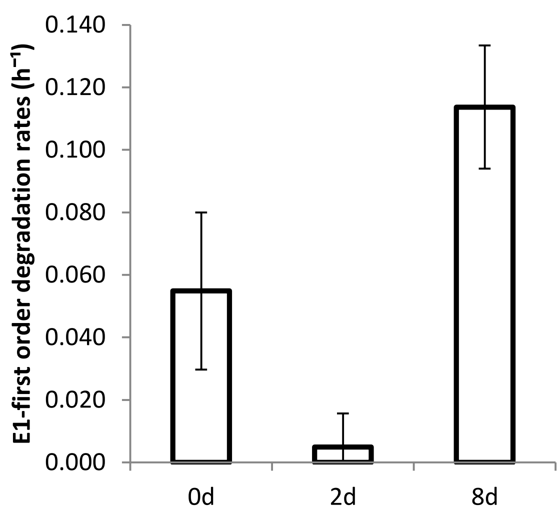

Figure 4. First-order degradation rates for E1 in reactors receiving synthetic septage aged for 0, 2, and 8 days respectively. Error bars represent standard deviations for triplicate reactors

synthetic septage via the characterization methods used. We hypothesize that the 8 day old synthetic septage contained products from cell lysis that may have stimulated the growth of E1 degrading multiple substrate utilizers, while the 2 day old synthetic septage did not have sufficient degradable organic matter to enable the growth of biomass.

In the second set of experiments, the effect of organic carbon quality on microbial community and E1 degradation was further examined by culturing biomass in four different water sources: treated wastewater, treatment wetland, river, and lake. Water samples were filter-sterilized and characterized for pH, ammonia, nitrate, nitrite, DOC, and EEMs. Biomass was grown in batch reactors with the different water samples for a 5-day period, followed by a kinetic study of E1 degradation. Samples from this study are undergoing analysis.

Summary of Key Findings

As a whole, these experiments point toward the importance of multiple substrate utilizers in E1 degradation. These microbes do not subsist solely on E1, but utilize E1 as a carbon or energy source, providing a competitive advantage. While capable of utilizing general organic carbon, these microbes appear to be outcompeted, likely by faster growing microbes, when repeatedly exposed to high organic carbon concentrations. Growth of these microbes may be stimulated by recalcitrant organic carbon, including the products of cell lysis.

Publications

Tan, DT; Arnold, WA; Novak, PJ. Impact of Organic Carbon on the Biodegradation of Estrone in Mixed Culture Systems. *Environ. Sci. Technol.* **2013**, 47(21) 12359-12365.

Student Support

1 PhD student (David Tan)

Presentations

Tan, DT, Arnold, WA, Novak, PJ. Manipulating Organic Carbon to Enhance Estrone Degradation. Poster Presentation at the 2013 Association of Environmental Engineers Scientists and Professors (AEESP) Conference, Golden Colorado, July 14-16.

Awards

Academic Excellence Award (Central States Water Environmental Association), to David Tan

Moos Fellowship (University of Minnesota), to David Tan

Sara Evans Faculty Woman Scholar/Leader Award (the Office for Faculty and Academic Affairs and the Women's Center, the University of Minnesota), to Paige Novak

Bill Boyle Educator of the Year Award (Central States Water Environment Association), to Paige Novak

Related Funding

"Wastewater estrogen: removal options, fish abundance, and cost" funded by the Legislative and Citizens' Commission on Minnesota Resources, 7/2014-6/2017, $500,000.

Understanding Pesticide Photolysis in Prairie Potholes for Water Management Strategies

Basic Information

Title:	Understanding Pesticide Photolysis in Prairie Potholes for Water Management Strategies
Project Number:	2012MN344G
Start Date:	9/1/2012
End Date:	8/31/2014
Funding Source:	104G
Congressional District:	MN05
Research Category:	Water Quality
Focus Category:	Surface Water, Non Point Pollution, Hydrology
Descriptors:	None
Principal Investigators:	William Alan Arnold

Publications

There are no publications.

Understanding Pesticide Photolysis in Prairie Potholes for Water Management Strategies
Project Number 2012MN344G

Principal Investigator
William Arnold, Department of Civil Engineering, University of Minnesota

September 1, 2012-August 31, 2014

1) Research: The primary goal of this research is to quantify the importance of pesticide photolysis processes in prairie pothole lakes/wetlands (PPLs) such that appropriate, adaptive water management strategies can be developed to handle agricultural runoff and drainage. This includes both the design of constructed wetlands and the optimization of transient drainage features. PPLs have unique water chemistry (e.g., high levels of dissolved sulfate and natural organic matter (NOM)) and shallow depths, suggesting direct and indirect photolysis processes may be active in degrading pesticides in PPLs. The central hypothesis is that the high levels of photosensitizers present in such systems will increase the importance of indirect photolysis as a pesticide loss process in PPLs. Using probe and quencher experiments, we will determine the steady state concentrations of a suite of photochemically produced reactive intermediates (PPRIs; triplet organic matter, ^3OM, singlet oxygen $^1O_2$, and hydroxyl radical ·OH) in PPL waters. Photolysis experiments with target pesticides (atrazine, *s*-metolachlor, mesotrione, bentazon, and diuron) will be used to determine the relative importance of different photolysis processes. By comparing permanent, drained, and reconstructed PPLs in North Dakota and Minnesota/Iowa, we will be able to compare varying drainage strategies and water chemistries and how they affect the fate of pesticides and potential impacts on the wetlands, surface waters, and groundwater that interact with PPLs.

Over the past six months, we have located all necessary sampling sites, obtained permission to collect samples, and have begun collecting surface water samples from each site. These sites include the Cottonwood Lakes Study Area near Jamestown, ND, Glacial Ridge National Wildlife Refuge near Crookston, MN, and a private farm in Tracy, MN. The sampling locations include one native/temporary wetland, two native/permanent wetlands, and one reconstructed wetland that is not directly affected by cropland runoff. The impacted sampling sites include a native, permanent wetland, a drained wetland, and a reconstructed wetland that each receives direct runoff from cropland. Surface and porewater samples from the PPLs will be collected seasonally (spring, summer, and fall until summer 2014). At the time of collection, temperature, pH, and dissolved oxygen are recorded for each wetland. Nitrate, dissolve organic matter, and sulfate/sulfide concentrations are measured in the laboratory.

The proposed sampling regimen will allow study of both categorical and seasonal variations in pesticide degradation among PPLs. Understanding these variations will be integral for future reconstruction of drained and agriculturally affected PPLs. It is expected that the characteristics of DOM will change as land use surrounding PPLs changes (i.e. from active crop land to reconstructed wetland).

Preliminary tests measuring the steady state concentrations of photochemically produced reactive intermediates have been performed. In the coming months, filter-sterilized surface waters will be modified with environmentally appropriate concentrations of pesticides (atrazine, *s*-metolachlor, mesotrione, bentazon, diuron) and the time required to achieve acceptable pesticide concentrations will be recorded. Reactions will be conducted both outdoors and indoors. Parent pesticide compounds and degradation products will be quantified by gas chromatography/mass spectrometry (GC/MS). Reactive intermediate quenchers will be used to quantify the contributions of direct and indirect photolysis: isopropanol and methanol for ·OH, sodium azide for $^1O_2$, and isoprene for $^3DOM^*$. Because dissolved oxygen acts as a $^3DOM^*$ quencher, samples will be sparged with nitrogen gas to examine the effect of deoxygenation on pesticide degradation. Dark controls will be incorporated to confirm that sunlight is required for significant pesticide degradation. Blank controls will be used to ensure no cross-contamination between samples.

2) Publications: None to date.

3) Student Support: One MS/Ph.D. student, Mr. Andrew McCabe, has been supported by the project.

4) Presentations: Invited Seminar, William A. Arnold, *Abiotic Transformations of Pesticides in Prairie Potholes*, University of Colorado-Boulder, November 30, 2012.

5) Awards: None to date.

6) Related Funding: None to date.

Building sustainable governance frameworks to sustainably manage Minnesota's Water Resources

Basic Information

Title:	Building sustainable governance frameworks to sustainably manage Minnesota's Water Resources
Project Number:	2013MN352B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	MN4th
Research Category:	Social Sciences
Focus Category:	Law, Institutions, and Policy, Water Quality, Water Quantity
Descriptors:	
Principal Investigators:	Sherry Anne Enzler, Mae A. Davenport

Publications

There are no publications.

BUILDING A SUSTAINABLE GOVERNANCE FRAMEWORK TO SUSTAINABLY MANAGE MINNESOTA'S WATER RESOURCES

Annual Program Report

by

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May 23, 2014

Research Synopsis

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STUDY BACKGROUND

This report describes the findings of a series of key informant interviews with decision makers in Cannon River watershed, Minnesota. The study was conducted by the Department of Forest Resources at the University of Minnesota. The goal of the study is to provide a deeper understanding of water governance systems and how systems affect users, stakeholders and Minnesota's water resource.

The U.S. Environmental Protection Agency (http://water.epa.gov/type/watersheds/approach.cfm) defines a "watershed approach" to addressing water resource problems as having three primary characteristics. It (1) is hydrologically defined—as opposed to politically defined, (2) involves all stakeholders including public, private and community sectors, and (3) strategically addresses priority water resource goals. Practically speaking, a watershed approach means planning and management of people, the built environment, and the natural environment happens at hydrologically defined rather than politically defined boundaries. This report presents findings associated with the advantages and disadvantages of a watershed approach for managing water resources in Minnesota from the perspectives of a range of state and local level decision makers with influence in the Cannon River Watershed.

STUDY DESIGN AND METHODS

Study data were gathered through key informant interviews with a sample of decision makers in the Spring/Rice Creek and Whitewater/Waterville Creek watersheds, subwatersheds of the Cannon River Watershed. The Cannon River watershed, a subwatershed of the Mississippi River watershed, stretches across Dakota, Le Sueur, Goodhue, Waseca, Steele and Rice counties (see Appendix E). Fourteen interviews were conducted from November 2013 through January 2014.

This study used a qualitative research approach for study design, data collection and data analysis. Qualitative research is well-suited for gathering rich and detailed information on complex issues and is grounded in participants' experiences, values, beliefs and attitudes. A qualitative approach such as this preserves richness and detail in the descriptions and beliefs of those interviewed but does not attempt to be statistically representative of the opinions of a broader population. Thus, the sampling technique used was non-probabilistic, purposive sampling with the goal of maximum variation. We aimed for a broad range and diversity of perspectives.

Participants were identified using publically available information on the Internet and through consultation with CRWP staff. The sample pool consisted of public officials and staff at LGUs including municipal, township and county government entities, local non-government organizations, and state level agency staff, who have an influence on water resource management either directly (e.g., water resource related education or outreach) or indirectly (e.g., land use planning). A $50 reimbursement was offered to participants for their time. Individuals were contacted via telephone using a recruitment script (Appendix A). Twenty-five individuals were contacted in total. Despite multiple attempts, we were unable to reach five individuals. Another six individuals declined participation.

The majority of interviews were conducted in participants' workplaces and lasted one to two hours. Before each interview, participants were asked to read and sign an informed consent form (Appendix B). Participation was voluntary and identities of individual participants remain confidential and are not linked to interview data in any publications. Interview questioning was semi-structured, meaning an interview guide (Appendix C & E) was followed with predetermined open-ended questions. However, interviewees had the freedom to respond to questions from their own points of view. The interviewer also had the freedom to ask probing questions for further clarity or explanation. After the interview, participants completed a background information form that inquired about individual sociodemographic information and organizational characteristics (Appendix D).

Interviews were audio-recorded and transcribed verbatim using Olympus DSS Player Standard Transcription Module Version 1.0.2.0. Interview transcripts were analyzed using standard thematic qualitative analysis techniques (Charmaz, 2006; Corbin & Strauss, 2008) for identifying themes, patterns and relationships within the data. Qualitative data were coded and organized using QSR NVivo 10.0. A range of themes including convergent and divergent themes were identified and are reported in the study findings below.

STUDY FINDINGS

Study findings focus on participants' perceptions of a watershed scale approach to planning and managing resources. Several participants characterized a watershed approach as a "complex issue" and one that is very controversial among local governmental units (LGUs). One participant explained, "Politically I think keywords pop up and then things change and I don't think people fully understand the complexity of it to be quite honest so shifting it again and again- I guess it maybe can't hurt to try, but I think there's very large issues that ultimately don't get addressed."

A few participants distinguished between a watershed approach to *planning* and a watershed approach to *management*. For instance, one participant was supportive of planning but noted concern among county decision makers as to management and governance at the watershed scale:

> There's two things: planning on the watershed scale and then actual management and governance on the watershed scale. So planning I think would definitely be good to do on the watershed scale. Although I know for some of the counties that have land in multiple watersheds, they're a little bit concerned about how are we going to do that. Although, I would argue that right now with the local water plans, they still have to address the three watersheds they're within, in one plan. So this [watershed scale plan] is sort of flipping that around.

Another participant favored allowing LGUs some time to work together on other issues and to identify common needs:

> So at this point the notion of an entire watershed district- I haven't heard yet of any indication that it would serve to focus on solving the problems that the folks in my community experience, and it seems like it's a big leap from where we are just crawling right now it terms of different local governments working with each other. It seems like we need to become accustomed to working with each other and identifying where our own local issues are and become experienced in working through those issues, before we'd ever consider something like that."

I. Perceived Advantages of a Watershed Scale Approach

Participants were asked, "What do you see as some advantages of a watershed scale approach to planning and managing water resources?" Participants' discussions of the advantages converged along three primary categories (Table 1). A watershed approach was believed to add consistency and clarity, to promote cooperation, and to be ecologically appropriate.
For example, one participant noted that resources are not evenly distributed across the watershed:

> Both from a water planning perspective…and the technical perspective, [some counties] have pretty small, limited staff. Waseca doesn't even really have an SWCD. I mean technically, they're still there, but I haven't talked to them in a while. I think they're still staff-less. So that's a situation where if this was more of

> a shared situation, maybe they're would be a way to help backfill that a little bit better.

Another participant believed one plan would reduce redundancy: "There are lots of plans that kind of overlap. It would be nice to have one plan that takes care of all of them." For some participants, a watershed approach forces counties to work together and be "good neighbors." A participant explained,

> [A joint watershed approach] makes a lot of sense. If you're one of the upper parts of the watershed like Steele County, all the water's flowing out of your county, but if you're Rice County there's a lot of water flowing in from other places; so, you've got Le Sueur and Waseca Counties that are basically delivering water to you. So the more downstream you are, I think the more it behooves you to try to collaborate upstream, because you know no matter how hard you work, if those upstream people aren't working too to make some improvements, there's only so much you can do.

Finally, a watershed approach was praised for being ecologically appropriate. One participant recalled, "as the old saying goes, water knows no political boundaries."

Table 1. Perceived advantages of a watershed approach to water resource management

Categories	**subcategories**
Adds consistency and clarity	across multiple plans
	across LGUs in resource capacity and engagement
	in jurisdictions and authority
Promotes cooperation	across communities
	problem focus versus geographic focus
	pooling resources and expertise across LGUs
Ecologically appropriate	upstream uses have downstream impacts
	supports systems thinking
	includes surface water and groundwater interactions

II. Perceived Disadvantages of a Watershed Scale Approach

Participants were asked, "What do you see as some disadvantages or challenges of a watershed scale approach to planning and managing water resources?" Participants identified several disadvantages or challenges. Altogether, perspectives converged along five broad categories (Table 2). Participants believed a watershed approach would add complexity and redundancy would fuel conflict, has limited citizen or resident support, would increase geographic constraints, and would diminish a community focus.

Adding “another layer of government” seemed to be a primary concern among several participants. One participant questioned the fairness of taxation at the watershed scale and expressed uncertainty that his township’s needs would get addressed:

> Based on my experience with multiple governmental entities, it doesn’t sound like a great idea. It sounds like we’d be paying taxes for some other office and somebody to sit in and do administration in yet another office and that the problems that I have in my township and the pain that the folks who live in my township are feeling would probably not get addressed.

Another participant noted that watershed approaches have had limited success in other communities because of conflicts over land uses: “I’ve seen it proposed in the past in other states where I’ve worked and with limited success. As long as people can keep sight of some common interests, maybe we’ll get some place but when self-interest takes over, then all bets are off.”

Table 2. Perceived disadvantages of a watershed approach to water resource management

Categories	**subcategories**
Adds complexity and redundancy	increased taxes more bureaucracy
Fuels conflict	urban versus agricultural interests inter-county conflict
Limited citizen/resident support	general support lacking upstream support lacking relationships across boundaries are weak
Increases geographic constraints	added travel time and resource needs
Diminishes community focus	rural areas lack representation large-scale plans lack community relevance and value large-scale plans lack individual relevance and value

A few participants acknowledged geographic constraints and increased costs for watershed level administration. Finally, several participants questioned the promise of stakeholder inclusivity in a watershed approach. A few were concerned that rural communities would not have fair representation. One participant described the complexity of decision making at a watershed scale:

> It is an interesting thing, because I always still think about who should be at the table, right? When you are really doing a watershed the size of the Cannon,

who's at the table and what kind of voice do they have at the table? We certainly have what I'd call some medium-sized rural communities in here and each one is located in a slightly different lobe with a slight different land characteristic they're trying to manage.

DISCUSSION AND CONCLUSION

Preliminary data analysis reveals several advantages and disadvantages of a watershed approach to water resource planning and management from water resource and community decision makers in two subwatersheds of the Cannon River Watershed, Minnesota. Though a watershed approach would compel LGUs to work together to address problems and may increase opportunities for resource pooling, many decision makers we interviewed feared that centralization of power would result in inequalities in terms of relevance and value of decisions and actions to small communities or individuals within those communities.

Future research should continue to examine horizontal and vertical governance networks and their impacts on sustainable water management (Ostrom, 2009; Ostrom, 2007) through paired watershed case studies.

LITERATURE CITED

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Ostrom, Elinor. 2009. A General Framework for Analyzing Sustainability of Social –Ecological Systems. Science 325:419-422.

Ostrom, Elinor. 2007. Sustainable Social-Ecological Systems: An Impossibility? Proceedings of the National Academy of Sciences of the United States of America [on line] URL: http://www.indiana.edu/~workshop/publications/materials/conference_papers/W07-2_Ostrom_DLC.pdf

APPENDICES

APPENDIX A: RECRUITMENT SCRIPT

Water Resource Governance Study
Contact Script (updated 11/15/13)

"Hello, my name is Amanda Sames. I am a graduate student conducting research on watershed management with Mae Davenport and John Nieber at the University of Minnesota. This study involves water resource professionals and decision makers the Cannon River Watershed. The goal of this study is to better understand diverse perspectives on water resource decision making and governance. To do this, I will be conducting interviews with resource professionals and decision makers in the Cannon River Watershed. I am hoping you would be able to assist me by participating in the study and sharing your perspectives with me. The interview takes about one hour. Would you be able to participate?"
If **yes**: "Thank you. I am available on ______ (days of week, times, have alternates ready) is there a time that would work best for you? [Set date, time, location (get directions)]. I look forward to meeting you. Please feel free to contact me at ________ if you have any questions or concerns.
If **no**: "Ok, thank you for your time. Good bye."
If they seem **unsure**: "Just to be clear, participation is completely voluntary and if you decide not to participate you can withdraw at any time. Your identity will remain confidential and we won't include any information that would make it possible for others to identify you in the final report. We're only talking to a limited number of key representatives, so capturing your perspective is important. Can I ask what your concerns about participating are?" [Try to address their concerns]
If they want more information about the **goals of this study**: We are developing a water resource decision making framework that represents the perspectives of water resource professionals on water governance. The framework will also identify key capacities and constraints for sustainable watershed management across varying units of government. We will be developing a report
If they are curious about **who is sponsoring** the study: The researchers conducting this study are: Mae Davenport and John Nieber. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact Mae at address: 115 Green Hall 1530 Cleveland Ave. North, St. Paul, MN 55108-6112. Mae Davenport's phone: 612-624-2721, email: mdaven@umn.edu.
Funding: This study is funded through the UMN Water Resources Center Competitive Grants Program by the US Geological Survey's State Water Resources Research Institute Program.

APPENDIX B: CONSENT FORM

Sustainable Water Resource Governance Study
Consent Form
Updated 11/15/13

You are invited to participate in a research study of water resource decision making and governance in the Cannon River Watershed. You were selected as a possible participant because of your role as a resource professional or decision maker in the watershed. We ask that you read this form and ask any questions you may have before agreeing to be in the study. This study is being conducted by: Mae Davenport, Department of Forest Resources, and John Nieber, Department of Bioproducts and Biosystems Engineering, at the University of Minnesota.

Background Information
The purpose of this study is to better understand diverse perspectives on water resource decision making and governance in the Cannon River Watershed.

Procedures:
If you agree to be in this study, we would ask you to do the following things:
Participate in an interview lasting approximately 60 minutes. The interview will be audio recorded and transcribed.

Risks and Benefits of being in the Study
Risks associated with this study are minimal; responses are confidential and participants' names will not be linked to any information in any publications. There is no direct benefit to subjects who participate in this study. Indirect benefits of participation may include increased awareness of water resource decision making and governance. Study results will be made available to the public and all participants will have access to them.

Confidentiality:
The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a subject. Research records will be stored securely and only researchers will have access to the records. Your responses to the interview questions will be audio-recorded, transcribed and kept for three years in a locked office. Afterward, these recordings will be destroyed. Only those directly involved with the project will have access to the audio recording or the interview notes.

Voluntary Nature of the Study:
Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:
The lead researcher conducting this study is: Mae Davenport. You may ask any questions you have now. If you have questions later, you are encouraged to contact her at address: 115 Green Hall 1530 Cleveland Ave. North, St. Paul, MN 55108-6112, phone: 612-624-2721, email: mdaven@umn.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher, you are encouraged to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612) 625-1650.

You will be given a copy of this information to keep for your records.

Statement of Consent:
I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

"I agree______ I disagree______ to have my responses recorded on audio tape"

"I agree______ I disagree______ that Mae Davenport may quote me anonymously in her papers"

Signature:____ Date: __________________

Signature of Investigator:____ Date: __________________

APPENDIX C: INTERVIEW GUIDE

Sustainable Water Resource Governance Study

Interview Guide (updated 11/18/13)

First, I'd like to begin by asking about you and your organization and your work in water-resource related issues.

1. **Tell me about your role with [organization/gov't unit]?**
    a. In what ways are you involved in water resource-related issues?
    b. Approximately what percentage of your time is spent on water resource issues?
    c. Approximately what percentage of your time is spent on water resource issues within the CRW?

2. **How would you describe your [organization's/gov't unit's] role in water resource decision making and governance in the [Whitewater/Waterville Creek, (*point to map*)] subwatershed? Please describe.**
    a. Could you describe for me an exemplary program or project within your organization related to water resources in this subwatershed?

3. Does your [organization/gov't unit] have agreed upon goals related to water resources?

4. Does your [organization/gov't unit] have agreed upon strategies for water resource management?

5. **Do you partner with other organizations/gov't units in water resource-related work? Please explain**
    a. (*If yes*) Are these partnerships effective? Please explain what makes them effective/ineffective.
    b. Does your organization receive support in water resource management? Please explain.

6. **Are there aspects of your [organization/gov't unit] work that address water resource-related issues at a regional or watershed scale (i.e., across jurisdictional boundaries)?** Please describe.
    a. (*If yes*) How were those initiatives started? OR What's driving those initiatives?
    b. (*If no*) Has there been discussion within your [organization/gov't unit] about working across boundaries on any issues?

7. **Could your organization do more in water-resource related issues?**
    a. (*If yes*) What would that be?
    b. What has constrained your organization in doing these things?

Next, I have a few questions about water resource-related problems or issues.

8. **What do you see as the primary water resource-related problems or issues in the [Whitewater/Waterville Creek, subwatershed today?**

a. What do you see as some of the causes of these problems?
b. **How concerned are you about these problems/issues?** Please explain.
c. **Is your organization addressing these problems/issues in any way?**
d. **How successful have you been?** Please explain what makes you successful/unsuccessful.

9. **As you may know, water resources within the <u>[Whitewater/Waterville Creek, (*point to map)*] subwatershed</u> have been identified as impaired for various uses including drinking water, recreation, or aquatic habitat. Is your organization addressing these problems/issues? If yes, please describe.**
    a. How successful have you been? Please explain what makes you successful/unsuccessful.
    b. **Have you partnered with other organizations or governmental units to address these problems? Please explain.**
    c. (If yes) Are these partnerships effective? Please explain what makes them effective/ineffective.

Finally, I have some questions about water resource governance at a watershed scale.

10. **Some communities in Minnesota have partnered to establish a joint watershed plan for managing water resources across jurisdictional boundaries. What do you see as some advantages of a watershed scale approach to planning and managing water resources?**

11. **What do you see as some disadvantages or challenges of a watershed scale approach to planning and managing water resources?**

12. **What would you think about establishing a joint watershed plan for the entire Cannon River Watershed?**
    a. **What would some advantages of a joint watershed plan be?**
    b. **What would some disadvantages or challenges of a joint watershed plan be?**
    c. How might a joint watershed plan in the CRW affect the water resource problems you identified earlier? Please explain.
    d. How about establishing separate plans for each of the four lobes of the watershed?

13. **If a joint watershed plan for the CRW was established,**
    a. **Who do you think should be responsible for setting water resource goals?**
    b. **Who do you think should be responsible for developing water resource strategies?**
    c. **Who should be responsible for implementing the plan?**
    d. **Who should be responsible for monitoring effectiveness?**

14. **What role do you see for local citizens and residents in joint watershed planning and management?**

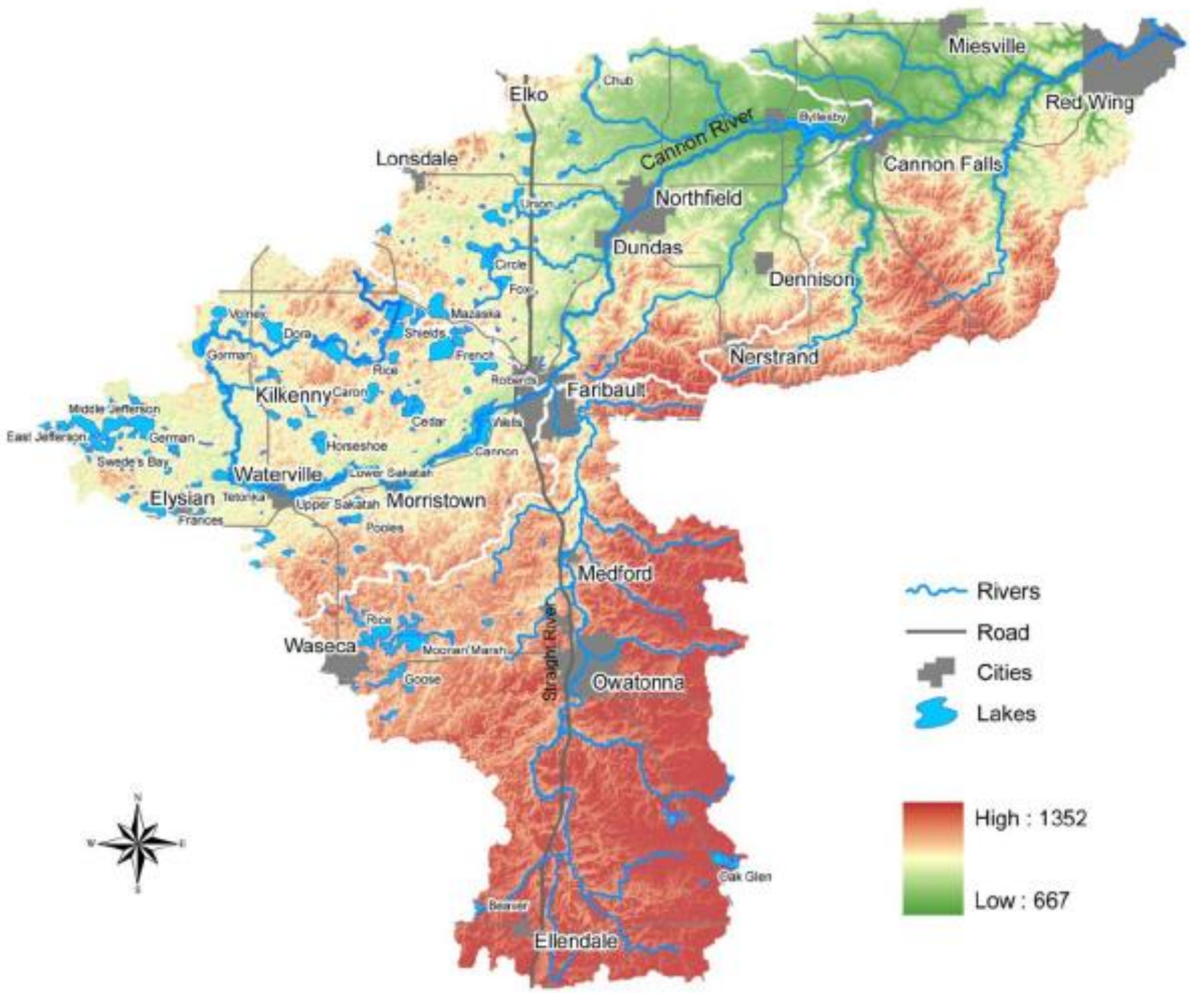
15. **What role do you see for your organization/government unit in joint watershed planning and management?**
    a. How might a joint watershed plan affect your organization?

16. **Are there other approaches to water resource governance in the CRW that you believe would be more effective than a joint watershed plan? Please explain.**

17. Is there anything you would like to add about water resource decision making and governance in the Cannon River Watershed?

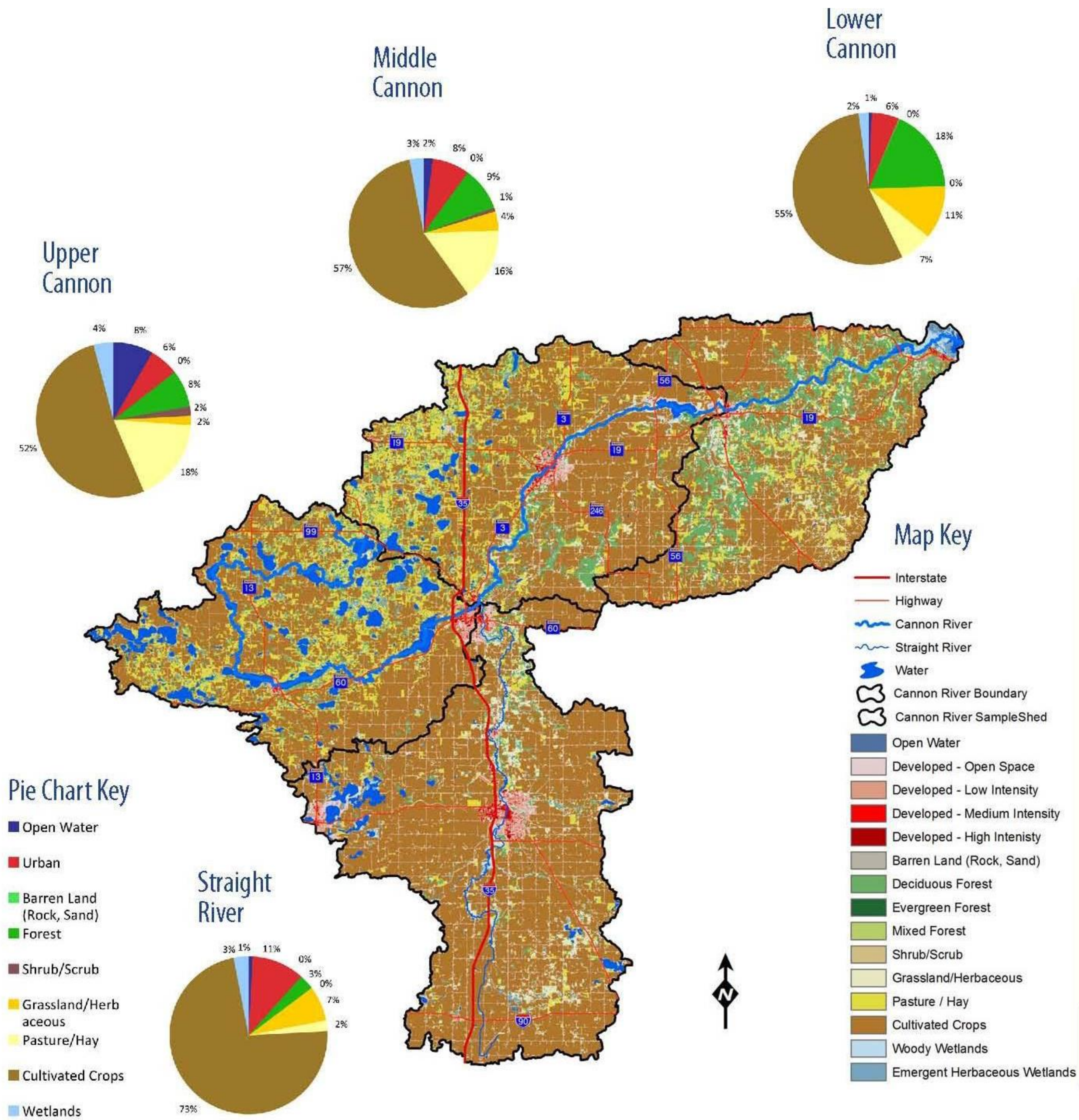
APPENDIX D: CANNON RIVER WATERSHED MAPS

Cannon River Watershed



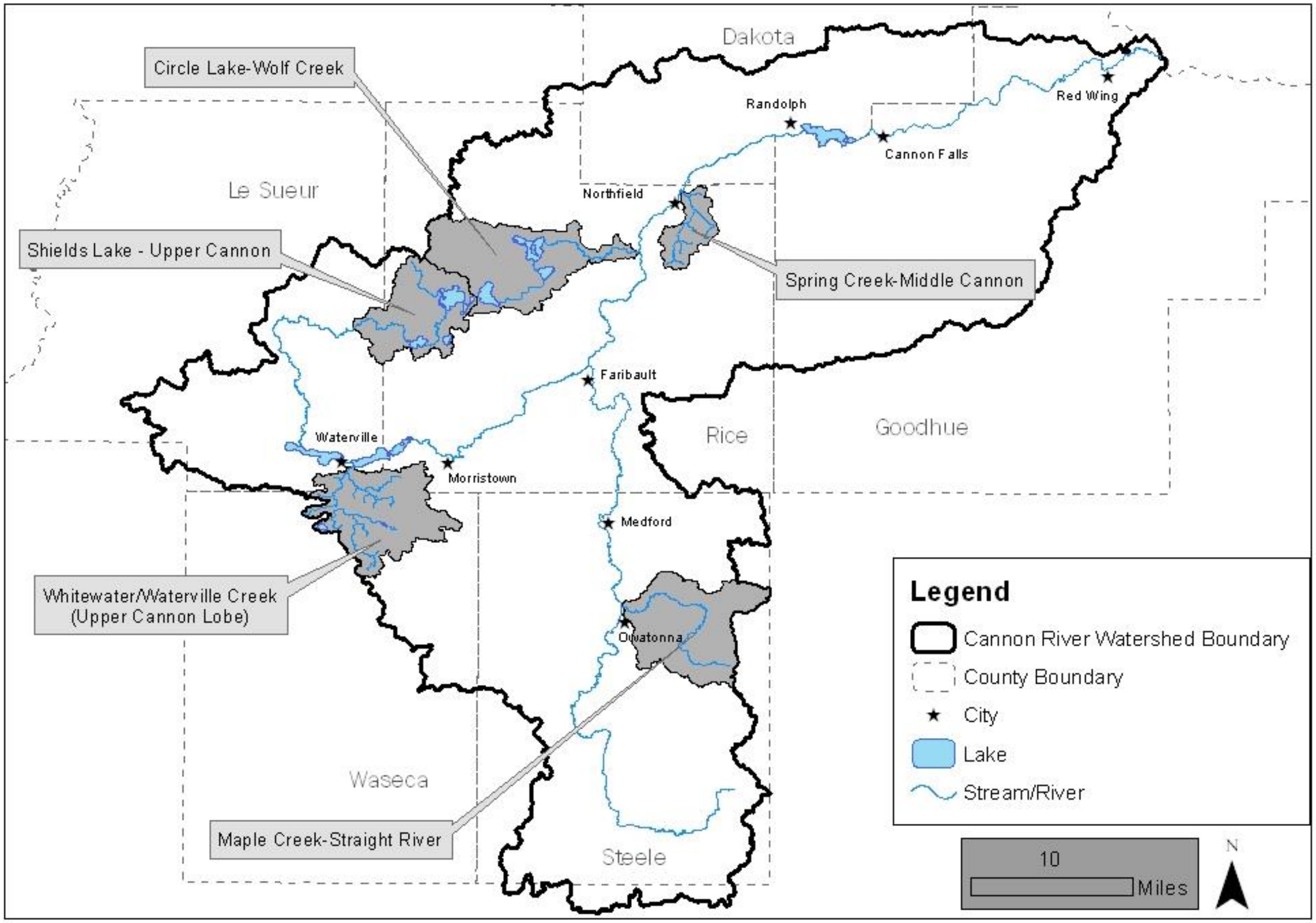
Cannon River Watershed map showing the course of the Cannon and Straight Rivers, major cities and elevation (source: Cannon River Watershed Management Strategy).

Cannon River Watershed Lobes



Cannon River Watershed map showing land use by lobe (source: Cannon River Watershed Management Strategy).

Cannon River Watershed



APPENDIX E: PARTICIPANT PROFILE

Table 1: Participants' age (n=13) and gender (n=14)

Age		
Min		24
Max		63
Mean		46
Median		44
Gender	N	Percent
Female	5	36
Male	9	64
Total	14	100

Table 2: Participants' residency/employment characteristics (n=10)

	Total
Years lived in community (n=12)	
Min	1
Max	57
Mean	19
Median	17
Years with current organization (n=9)	
Min	0.7
Max	35
Mean	11
Median	7
Years in current position (n=12)	
Min	0.7
Max	35
Mean	9
Median	4

Table 3: Participants' highest level of formal education (n=10)

Response	**N**	**Percent**
Did not finish high school	0	0
Completed high school	0	0
Some college but no degree	0	0
Associate degree or vocational degree	1	7
Completed bachelor's degree	6	43
Some graduate work	0	0
Completed graduate degree (Masters or PhD)	7	50
Total	14	100

Publications

Davenport, M.A. (2013). *Social measures monitoring system overview. Report prepared for the Clean Water Fund Tracking Framework*. St. Paul, MN: Department of Forest Resources, University of Minnesota. 31 pp.

Davenport, M.A. (2013). *Change over time in individual capacity to engage in water resource protection and restoration*. Report prepared for the Clean Water Fund Tracking Framework. St. Paul, MN: Department of Forest Resources, University of Minnesota. 17 pp.

Davenport, M.A. (2013). *Change over time in relational capacity to engage in water resource protection and restoration*. Report prepared for the Clean Water Fund Tracking Framework. St. Paul, MN: Department of Forest Resources, University of Minnesota. 11 pp.

Davenport, M.A. (2013). *Change over time in organizational capacity to engage in water resource protection and restoration*. Report prepared for the Clean Water Fund Tracking Framework. St. Paul, MN: Department of Forest Resources, University of Minnesota. 14 pp.

Davenport, M.A. (2013). *Change over time in programmatic capacity to engage in water resource protection and restoration*. Report prepared for the Clean Water Fund Tracking Framework. St. Paul, MN: Department of Forest Resources, University of Minnesota. 11 pp.

Student Support

1 M.S. student, Amanda Sames

Presentations

Seekamp, E., Davenport, M.A., Smith, J. (2014). An integrated, interdisciplinary and multi-method process for building climate readiness in coastal communities. Social Coast Forum, February 19, 2014, Charleston, SC.

Davenport, M.A. & Nelson, P. (2013). Learning and adapting: Using a community capacity model for watershed program assessment. *Minnesota Water Resources Conference*, October 15-16, 2013, St. Paul, MN.

Awards

Davenport, M.A., Received Richard C. Newman Community Impact Award, 2013

Related Funding

Freshwater Society. An Assessment of FarmWise and Its Impacts on Agricultural Practices: Phase II. M. Davenport, $10,000, 10/01/2014-7/31/2014.

US Geological Survey National Institute for Water Resources. Research Assistantship in Water Resources. M. Davenport. $22,500, 3/1/14-2/28/16.

Minnesota Sea Grant. Building Climate Readiness in Nature-Based Tourism-Dependent Coastal Communities. M. Davenport, Enzler, S., Neiber, J. & Wilson, B. $162,192, 2/15/14-2/14/16.

Ramsey-Washington Metro Watershed District, Capitol Region Watershed District, & Mississippi Watershed Management Organization. A Community Capacity Assessment for Stormwater Management in the Twin Cities Metro Area. M. Davenport, $153,440, 8/15/13-8/14/15.

Information Transfer Program Introduction

We did not fund any information transfer projects with our WRRI funds.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	3	0	1	0	4
Ph.D.	2	0	1	0	3
Post-Doc.	0	0	0	0	0
Total	7	0	2	0	9

Notable Awards and Achievements

Bill Arnold- Faculty- 24th Leonard A. Ford Lectureship, MSU-Mankato, Department of Chemistry

Bill Arnold- Faculty- Super Reviewer Award from the journal, Environmental Science and Technology

Valerie Brady –Faculty- 2013-14. Thunder Bay Coastal Wetland Habitat Surveys. From Environment Canada for $24,500. Lead PI.

Erik Brown-Faculty-Selected to be Resident Fellow at the Institute on the Environment at the University of Minnesota in 2014

Kimberly Hill – Faculty- "Bonestroo, Rosene, Anderlik and Associate Under-graduate Faculty Award from Department of Civil Engineering- May 2013"

Lucinda Johnson- Faculty- Distinguished Service Award by the Society for Fresh-water Science in May 2013

Lucinda Johnson- Faculty- Appointed to the International Joint Commission's Advisory Board, Science Policy Committee

Lucinda Johnson- Faculty- Appointed to serve on EPA Science Advisory Board Panel to review the report on Connectivity of Down-Stream Waters

Nathan Johnson –Faculty- Received $68K from the Minnesota Pollution Control Agency in June 2013 to study the bioavailability of mercury in the St. Louis River Estuary in the context of habitat restoration efforts

Thomas Johnson – Faculty- Made a Fellow of the American Association for the Advancement of Science in February 2014

Euan Reavie –Faculty- Promotion to Assistant Director of the Center for Water and the Environment

Euan Reavie –Faculty- $106K – Sea Grant award to study the paleolimnology of the St. Louis River Estuary

Euan Reavie –Faculty- $300K – MPCA award to support delisting of the St. Louis River Area of Concern

Euan Reavie –Faculty- $200K – amendment from Northeast Midwest Institute to study ballast water treatments

Robert Sterner –Faculty- Selected to be Resident Fellow at the University of Minnesota’s Institute on the Environment in 2014

Deb Swackhamer –faculty- has been named to the National Academy of Science/National Research Council Committee on Strengthening the U.S. Environmental Protection Agency Laboratory Enterprise, which begins work in September.

Alana Bartolai – Student- Received the 'Outstanding Graduate Teaching Assistant Award through the earth science department in spring 2013. Included $500 cash prize

Virginia Batts –Student- WRS summer Research Assistant

Ryan Birkmeier –Student- WRS Travel Grant in spring 2014- $500

Cheryl Haines – Student – WRS summer Research Assistant

Scott Kronholm –student-was awarded The Doctoral Dissertation Fellowship Grant which provides $600 plus conference registration fee for Doctoral Dissertation fellows to present his work at one national or international conference during tenure on the fellowship.

Brittany Kruger- student- was named a winner of the Elsevier Research Scholarship. The scholarship was launched in 2012 and is intended to encourage exchange of ideas, expertise and techniques and cultivate the scientific dialogue which Elsevier, Organic Geochemistry and European Association of Organic Geochemistry (EAOG) believe to be fundamental to the advancement of research.

Hongyu Li –Student- WRS Travel Grant in spring 2014 $500

Jiying Li – Student- WRS Travel Grant in spring 2014 $500

Jane Mazack – Student- WRS summer Research Assistant

Mike Sorensen – Student WRS summer Research Assistant

Chakong Thao –Student WRS summer Research Assistant

Mohd Zakaria- Student- WRS Travel Grant in spring 2014 $500

Xiaowei Zhao – Student- WRS Travel Grant in spring 2014 $500