North Dakota Water Resources Research Institute
Annual Technical Report
FY 2003

Introduction

This report describes the activities of the North Dakota Water Resources Research Institute (ND WRRI) during the period March 2003 to February 2004.

The ND WRRI is one of 54 Institutes known collectively as the National Institutes for Water Resources. The Institute was founded in 1965,by authority of Congress (Water Resources Research Acts of 1964,1972, 1984 and 1990), and is administered through the United States Geological Survey. Section 104 of the Water Resources Research Act requires the North Dakota Water Resources Research Institute to apply its Federal allotment funds to:

1. Plan, conduct or otherwise arrange for competent research that fosters: (A) the entry of new research scientists into the water resources field, (B) training and education of future water resources scientists, engineers, and technicians; (C) the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena; and (D) the dissemination of research results to water managers and the public,

2. Cooperate closely with other colleges and universities in the state that have demonstrated the capability for research, information dissemination and graduate training, in order to develop a statewide program designed to resolve State and regional water and related land problems, and

3. Cooperate closely with other institutes and other organizations in the region to increase the effectiveness of the Institute and for the purpose of promoting regional cooperation.

This year, the Institute once again allocated its 104(B) resources to fund research projects that are coupled to Graduate Research Fellowships (GRFs). The upgraded GRFs program meets the requirements of Section 104 of the Water Resources Act very effectively in the following respects:

often it is junior faculty as well as graduate students who perform competent research that fosters the entry of new research scientists into the water resources field,

the modest 104b Federal allotment is focused on training and education of future water resources scientists, engineers, and technicians,

graduate student thesis and dissertation topics foster the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena,

through the Institute newsletter and website, plus student and faculty presentations and peer-reviewed publications, the dissemination of research results to water managers and the public is accomplished, the Institute cooperates closely with other colleges and universities in the state that have demonstrated the capability for research, information dissemination and graduate training by offering competitive fellowships at both research universities in North Dakota, and

the Institute cooperates closely with other institutes and other organizations in the region to increase the effectiveness of the Institute and for the purpose of promoting regional cooperation by encouraging faculty to seek in-kind and cash matching support from those institutes and organizations, and its external seminar program.

The website and the newsletter were continued to facilitate information dissemination and communication. The Institute also continued its efforts to enhance communication between the State and Federal agency personnel and university faculty and students. Advisors and fellows presented their research results to State and Federal professionals.

The Institute continued the same administrative mechanism with the Director, Dr. G. Padmanabhan, Professor of Civil Engineering, managing the Institute program with the help of an Advisory Committee consisting of three members representing the three principal water agencies: State Water Commission, State Health Department, and the USGS. In addition, the Institute also has a Technical Advisory Committee consisting of faculty from the two universities. Though the Institute has no state appropriated support currently, efforts were directed to seek state appropriation and other support sources. The North Dakota State University and the University of North Dakota administrations consider the Institutes activities important and are supportive of its efforts.

The Institute is located in the Administrative building of the College of Engineering and Architecture of North Dakota State University in Fargo, North Dakota.

Research Program

For the last several years North Dakota Water Resources Research Institute has offered competitive Fellowships to North Dakota State University (NDSU) and University of North Dakota (UND) graduate students for research on water resources topics. This use of the modest amount of allotment from the USGS Institute base grant is perceived to meet the requirements of Section 104 of the Water Resources Research Act of 1984 effectively. The Fellowships encourage entry of new research scientists into the water resources field, training and education of future water resources scientists, engineers, preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and faculty to engage in research and seek collaborative support from entities concerned with water problems.

This year again the North Dakota Water Resources Research Institute continued the Graduate Research Fellowship program and applied the bulk of the Federal allotment to it. The Fellowship program meets almost every requirement of the Section 104 of the Water Resources Research Act of 1984. The Fellowship program is administered and monitored by the Director. Applications are invited from the graduate students of the two universities of the State. A rigorous review by the advisory committee and other water professionals in the state determines the awards. Active participation of the advisors of the students in meeting matching requirements and in seeking co-funding from local, state and other sources is a positive aspect of the program. Periodical review of the progress of the students in meeting Fellowship expectations is ensured by seeking reports from the students and by encouraging them to make presentations in local and regional technical seminars and conferences.

Guidelines for the 2003-2004 Graduate Research Fellowship competition were posted on the Institute website in September, and the competition was announced in October. The following is the RFA that was published on the University of North Dakota and North Dakota State University campus newsletters, and distributed by e-mail lists:

ND WRRI Calls for Applications for Graduate Research Fellowships

The ND Water Resources Research Institute announces its 2003 Graduate Research Fellowship program. NDSU and UND Graduate students who are conducting or planning research in water resources areas may apply for fellowships varying from three summer months to a full year in duration. Stipends average $1,400 per month. The fellowship funds must be applied between March 2003 and February 2004.

Projects proposed for fellowship support should relate to water resources research issues in the state or region. Regional, state, or local collaborations or co-funding will strengthen an application.

Applications are due in the office of the director on November 15, 2002. Proposals will be reviewed by a panel of faculty and state water resources research professionals. Announcement of awards will be made by early January.

Consult the ND WRRI website, www.ce.nodak.edu/wrri for background on the program, and guidelines for preparation of applications. Fellowships have matching requirements. Applicants and advisors who are new to the program are urged to contact ND WRRI Director, G. Padmanabhan, at 231-7043, or G.Padmanabhan@ndsu.nodak.edu.

Send your applications to Dr. G. Padmanabhan, Director, ND Water Resources Research Institute, North Dakota State University, CIE 201A, Department of Civil Engineering and Construction, P.O. Box 5285, Fargo, ND 58105.

NDWRRI Graduate Research Fellowships

Seven Fellowships were selected for award in FY2003. The titles of the Fellowship projects awarded are given below and details are provided for each project under separate project sections. Two of the selected fellowships one M.S. and one Ph.D. of respectively Anthony Pothoff and Sreerama Murthy were renewals.

· Anthony Potthoff (M.S. program, Zoology, NDSU). Evaluation of Walleye to Suppress Fathead Minnow Populations in Type IV & V Wetlands; advisor, Malcolm Butler, Zoology, NDSU.

· Chris Laveau (M.S. program, Geology, UND). Hydrological Modeling of the Spatial and Temporal Variation of Prairie Potholes at the Basin Level; advisor, Phil Gerla, Geology and Geological Engineering, UND.

· Jennifer Newbrey (Ph.D. program, Zoology, NDSU). Effects of West Nile Virus Infection, Immune Function, and Age on Female Yellow-headed Blackbird; advisor, Wendy Reed, Biology, NDSU.

· Michael Newbrey (Ph.D. program, Geology, NDSU). Comparative Study of Fossil and Extant Fish Growth: Including Analyses of Mean Annual Temperature in the Geologic Record; advisor, Allan Ashworth, Geology, NDSU.

· Sreerama Murthy (Ph.D. program, Civil Engineering, NDSU). Phosphorus Transport through a Wetland Ecosystem; advisor, Wei Lin, Civil Engineering, NDSU.

· Tedros Tesfay (Ph.D. program, Geology, UND). Modeling Groundwater Denitrification by Ferrous Iron Using PHREEQC; advisor, Scott Korom, Geology, UND.

· Trent Museus (B.S. program, prospective M.S student, Civil Engineering, NDSU). A Study of Microbial Regrowth Potential of Water in Fargo, North Dakota and Moorhead, Minnesota; advisor, Eakalak Khan, Civil Engineering, NDSU.

Evaluation of walleye to suppress fathead minnow populations in Type IV & V wetlands.

Basic Information

Title:	Evaluation of walleye to suppress fathead minnow populations in Type IV & V wetlands.
Project Number:	2002ND9B
Start Date:	3/1/2003
End Date:	5/31/2003
Funding Source:	104B
Congressional District:	At large
Research Category:	Biological Sciences
Focus Category:	Wetlands, Ecology, Water Quality
Descriptors:	Fathead Minnows, Prairie Wetlands Management, Walleye stocking, Wetland water quality
Principal Investigators:	Malcolm George Butler

Publication

1. Potthoff, Anthony Joseph, August 2003,Evaluation of Walleye to Suppress Fathead Minnow Populations in Class IV and V Wetlands,M.S., Department of Biological Sciences, College of Science and Mathematics, North Dakota State University. Major Professor: Dr. Malcolm G. Butler.

Evaluation of walleye to suppress fathead minnow populations in Type IV & V wetlands

ND WRRI Graduate Research Fellowship Project
Anthony Potthoff, Fellow
Malcolm Butler, Advisor and Principal Investigator
Biological Sciences Department
North Dakota State University
Fargo, ND 58105

REGIONAL WATER PROBLEM

Changes to the landscape of the prairie pothole region over the last hundred years, primarily due to agriculture, have caused the consolidation of temporary, seasonal, semi-permanent, and permanent wetlands, creating large Type IV and V wetlands. These larger, deeper wetlands are consistently found to be in a turbid state. The increase in the depth of many prairie wetlands due to drainage and consolidation has caused a decrease in the frequency and extent of summer and winter anoxia. Historically such harsh conditions have kept fathead minnow populations in check. Fathead minnows now persist on a more permanent basis, and population densities often become very high, with repercussions throughout the food web. The high densities of fathead minnows reduce zooplankton and macroinvertebrate diversity and abundance. Reductions in zooplankton in turn directly contribute to very high abundances of algae, which are directly associated with increases in turbidity and degraded water quality. The high turbidity causes a reduction in macrophyte diversity and abundance. The overall degradation of wetlands deters waterfowl use, as many waterfowl species are dependent upon zooplankton, macroinvertebrates, and macrophytes as major food sources. Innovative, effective ways to control the distribution and abundance of fathead minnow populations in wetlands throughout the Prairie Pothole Region are needed.

LITERATURE SUMMARY

The steady increase in land use for agriculture has resulted in consolidation of smaller shallower wetlands in the Prairie Pothole Region, creating large Type IV and V wetlands (Stewart and Kantrud 1971). The lower probability of these larger and deeper wetlands producing anoxic conditions has permitted for major increases in fathead minnow (*Pimephles promelas*) populations. Fathead minnows are a native species and are the most common fish in prairie wetlands (Peterka 1989) but their distribution is limited by the harsh conditions in prairie potholes, particularly anoxia. Fathead minnows have a very dynamic life history that under favorable conditions allows populations to grow exponentially into high densities (Held and Peterka 1974; Payer and Scalet 1978; Carlson and Berry 1990; and Duffy 1998). Due to this high reproductive potential, fathead minnows in wetlands without periodic anoxia can reach very high densities very quickly. The rapid growth and high food consumption of fathead minnows cause them to have critical influences on energy flow in wetlands. Fathead minnow diets consist predominantly of crustaceans and aquatic insects (Held and Peterka 1974). Fatheads' ability to grow so quickly and to have such a profound influence on a wetland's fauna stems from their ability to consume prey with both filter-feeding and particulate feeding methods (Hambright and Hall 1992).

The extremely high densities of fathead minnows found in the larger Type IV and V wetlands results in some negative effects on those waterbodies. Reduced abundances, biomass, and species richness in common orders of invertebrates were reported by Hanson and Riggs (1995), and Zimmer et al. (2000) documented dramatic shifts in invertebrate community composition when minnows were present. Increases in nutrient levels, phytoplankton biomass, and turbidity were seen in experimental wetlands stocked with fathead minnows (Hanson et al. 1995). Zimmer et al. (2001) found that fathead minnows directly and indirectly affect the nutrient partitioning within a wetland, with wetlands that have low macrophyte abundance and high fathead minnow densities being in a turbid state. The increase in nutrient recycling provides more nutrients available to phytoplankton, allowing them to grow and increase in density. One might expect, in response to the increase in phytoplankton, an increase in zooplankton densities, but the high feeding efficiency of fathead minnows does prohibit the increase in zooplankton, resulting in an overall increase in turbidity. Also, macrophyte communities deteriorate under the highly turbid conditions. Plant abundance and species composition decrease due to increased light attenuation (Hansel-Welch et al. in press). Nutrient recycling rates are increased in part due to the increased density and the feeding efficiency of fathead minnows and the absence of macrophytes, both of which contribute to greater turbidity (Scheffer et.al. 1993; Hanson and Butler 1994).

Previous studies evaluated ways of controlling fathead minnows but no methods have had a high success rate. In one study conducted by Zimmer (2001), rotenone was applied to ten Minnesota wetlands containing fathead minnows. Only one treatment out of the ten was successful in eradicating the fathead minnow population. In another study, commercial harvesting of fatheads was applied to two South Dakota wetlands, but had little influence on the fathead minnow populations (Duffy 1998).

The application of "biomanipulation" to control fathead minnow populations is based on the concept of a top-down effect of predation causing a "trophic cascade" (Carpenter et. al. 1985; Carpenter and Kitchell 1988). The idea is that the introduction of a top predator can alter the entire trophic structure of a system. In the case of wetlands, the top predator is a piscivore (walleye), intentionally stocked to decrease and regulate the planktivores (fathead minnows), allowing the herbivores (zooplankton) to increase and flourish. The flourishing zooplankton in turn regulate the phytoplankton by grazing. This reduction of algae also slows down nutrient recycling because nutrients are retained by the zooplankton and piscivores. The net result hoped for is a shift of the system from a turbid water state to a clear water state. The clear water state will allow the resurgence of macrophytes, which in turn contribute to suppression of algae via several mechanisms (Scheffer 1998; Moss et al. 1996). The macrophytes will also decrease turbidity by not allowing the sediment to be stirred up of the bottom by wave action created by the wind.

The use of piscivorous fish to limit fathead minnow densities and improve water quality has shown some success in previous studies. A study in a South Dakota pond showed a significant decrease in fathead minnow densities during the summer growing season due to walleye (*Stizostedion vitreum*) predation (Walker and Applegate 1976). Northern pike (*Esox lucius*) and largemouth bass (*Micropterus salmoides*) have also shown promise for suppressing fathead minnow populations (Elser et. al. 2000; Spencer and King 1984). Stocking piscivorous fish in wetlands that are already fishless can have negative effects on the wetland. Reed and Parsons (1999) reported that walleye rearing in a fishless wetland did appear to reduce densities of some invertebrate orders, and recommended that walleye rearing cease in fishless ponds.

The uncertainty surrounding the effects that stocked piscivorous fish may have on a wetland ecosystem has prevented managers from using this method to control fathead minnow populations. The rising problem of deteriorating wetlands has pushed this issue to the forefront. There is as of yet no information indicating negative effects from walleye rearing in wetland ponds already containing fathead minnows. If the current evaluation of walleye stocking proves to result in improvements in wetland water quality and other ecosystem characteristics, this technique may hold benefits for the management of both wetlands and fisheries.

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OBJECTIVES OF THE PROPOSED RESEARCH

The degradation of prairie pothole wetlands as a result of fathead minnow infestations is a steadily increasing problem. Wetland managers need effective tools to deal with this problem. The purpose of this project is look at one possible tool that could be used by wetland mangers to improve conditions in degraded wetlands. The project also focuses on the effectiveness of wetlands as rearing sites for walleyes for subsequent stocking in lakes. Wetlands are already used for walleye rearing, but the net effects the walleyes may have on the wetlands themselves are not clear. With these two overall objectives in mind, the intent of the project is to test the following hypothesis:

H_1: The biomass of fathead minnow populations will decrease following the introduction of walleye.

H_2: The densities of cladocerans, amphipods, dipterans, and corixids will increase following the introduction of walleye.

H_3: Water clarity will increase in the ponds following the introduction of the walleyes.

H_4: The density of submerged aquatic plants will increase following the introduction of walleye.

METHODS, PROCEDURES, AND FACILITIES

This research is part of a collaborative effort between the Minnesota Department of Natural Resources, NDSU, and SDSU. Other participants are focusing on the fisheries aspects of the study, while I am responsible for investigating responses of water quality, invertebrate communities, and plants.

Study sites and design

Eighteen semi-permanent type IV and V wetlands with established fathead minnow populations were randomly chosen for this two-year study from forty possible wetlands in the Minnesota Prairie Pothole Region. The selected ponds are distributed from the middle of Clay County south to the southern end of Big Stone County and east to Douglas and Pope Counties. The eighteen chosen wetlands were then randomly assigned to one of three treatments, with six sites in each treatment. The three treatments are: 1) walleye fry, 2) advanced-stage walleye, and 3) control (containing only fathead minnows). In the six walleye fry stocking treatments the fry were stocked in late spring and removed in the fall of 2001, this stocking and removal will be repeated for the second season of 2002. The six advanced-stage walleye treatments were stocked in the spring of 2001. Population estimates were taken this last fall (2001) and the walleyes were left in the wetlands to be carried over for the next year (2002). The treatments in the second year will be applied to the same wetlands as in the first year.

Sampling Methods

<u>Fish communities:</u>

Brian Herwig, a fisheries biologist from the Minnesota DNR office in Glenwood is working on biomass and relative abundance of fathead minnows. Matt Ward, a graduate student at South Dakota State University, is working on walleye diet, growth, and survival.

<u>Aquatic Invertebrates:</u>

Activity traps, a vertical column sampler, and an Ekman grab are being used to sample aquatic invertebrates. The sampling season begins in May and ends in September. Two sampling crews do the sampling, one crew samples the nine northern most ponds and the second crew samples the nine southern most ponds. Ten sampling sites are used per wetland; these sites were used for the entire sampling season. There are five sampling sites in the littoral zone around the wetland, and five in the open water zone.

Selection of sampling sites involves:

1. The approximate center of wetland is located.
2. Five transects at random compass bearings are selected.

- Transects cannot be within 20^0 of each other.
- All transects can not be within 180^0.

3. Two sample sites are located along each transect, one at the interface of the open water, and emergent vegetation and the second half way between shore and the center of the wetland.
4. Sites are marked with buoys and used for the entire sampling season.

Ten activity traps are deployed in each wetland monthly, hung from the site buoys for 24-hour periods. From the activity trap catches taxon richness and relative abundance of invertebrates are being analyzed. The analysis of invertebrate and zooplankton is being done at NDSU.

A vertical column sampler is used monthly at the five open water sites in each wetland. At each site two samples are taken. Taxon richness, relative abundance, and biomass (estimated from length-weight regressions) of zooplankton are being analyzed.

Twelve Ekman grab samples are collected once at the beginning of August in each wetland. Ten of these samples are taken at the 10 previously marked sample sites, and two samples are taken directly in the center of the wetland. Taxon richness, relative abundance, and biomass of invertebrates (from length-weight regressions) are being analyzed from the samples.

Macrophytes

Aquatic plants are sampled in late July using a plant rake. Ten sample sites are used, and at each site four samples (or rake throws) are taken. The ten sample sites are along transects one, three and five. The open and emergent sites on these transects are used, plus one in between the two sites on those transects. One sample site is in the center of the wetland. Taxon richness and frequency of plant occurrence are being analyzed.

Water Quality Parameters:

Turbidity measurements are taken from the center of each wetland each month with a nephelometer. Water samples are also taken from the center of the wetland each month simultaneous with the other monthly sampling. These water samples are shipped to the Minnesota Department of Agriculture chemistry lab in St. Paul for analysis for total phosphorous, total nitrogen, Kjeldahl nitrogen, and chlorophyll *a*.

Facilities Used:

The Department of Biological Sciences at NDSU provides office and laboratory space, along with secretarial and clerical support. The laboratory provides microscopes, image analysis equipment, and computers. Chemicals (ethanol) are bought from the NDSU Chemistry Department. The majority of field equipment being used is from North Dakota State University, though the Minnesota DNR does provide some field equipment, for example a boat.

ANTICIPATED RESULTS AND BENEFITS FROM THE PROPOSED STUDY.

The expected effect of adding walleyes to type V and IV wetlands with fathead minnows is that of a “trophic cascade”. The walleyes should decrease densities of fathead minnows. The decrease in fathead minnows should allow zooplankton and invertebrate diversity and densities to increase. The increase in zooplankton, particularly *Daphnia*, should cause a decrease in alga standing stock, which will increase water clarity (or decrease in turbidity). The decrease in turbidity should allow macrophytes to increase in diversity and abundance. The decrease in turbidity and increases in zooplankton and macrophytes should also increase use of the wetlands by waterfowl. The survival and growth rates of the walleyes are expected to high.

The information gained by this study will be used by state and federal wetland managers in their management decisions. The information will also be used by area fisheries managers who must decide whether using wetlands as rearing ponds is an effective way of rearing walleyes for stocking, and what the environmental consequences of this practice may be.

RESULTS AND CONCLUSIONS

The success of biomanipulation efforts aimed at switching wetlands from a stable, turbid-water state to a stable clear water state depends on two key steps: (1) the trophic cascade, and (2) secondary responses. The first step is the triggering of a trophic cascade (Carpenter et al 1985 & 1987; Scheffer et al 2001; Hansson et al 1998). Within the trophic cascade, three key groups must change significantly for this step of a biomanipulation to work: planktivorous fish, large cladocerans, and phytoplankton. Planktivorous fish biomass must decrease; not only must the adult planktivores be suppressed, but also recruitment of young of the year (Hansson et al 1998). Large cladocerans, like *Daphnia*, must increase in response to reduction planktivore biomass. This should reduce phytoplankton biomass via increased grazing pressure and result in a relatively instantaneous increase in water clarity (McQueen et al 1986; Carpenter et al 1987; Carpenter & Kitchell 1998).

Trophic cascades were achieved in the summer of 2001 and maintained in the summer of 2002 in the walleye fry treatment wetlands, but were never developed in the advanced walleye treatment wetlands. The walleye fry treatment wetlands were successful because the walleye fry were able to suppress the fathead minnow populations by depleting both juvenile and adult fathead minnows and limiting young-of-year fathead minnows through predation and indirectly by lowering recruitment. This allowed for dramatic increases in large cladoceran populations, followed by a decrease in phytoplankton and an increase in water clarity by the second year of the study. Suppression of larval fathead minnows is key, because most adult fathead minnows perish after breeding limiting their direct effect on the wetland ecosystem to only a portion of the summer. Thus, fathead minnow populations as whole become dependent on the success of the young-of the-year. In addition, the influences of fathead minnow populations on wetland ecosystems quickly switch from the activities of fish which are a year or older, to those of young-of-the-year fish. The advanced walleye treatment was unsuccessful in initiating a trophic cascade because of the large walleye's inability to sufficiently suppress adult fathead minnows and lower the reproductive potential of the fathead minnow population overall. Further more, adult walleye do not prey heavily on larval fathead minnows. As a result fathead minnow populations continue to grow, making it even more unlikely for adult walleyes to control their populations. Thus, even when adult fathead minnow populations were low fathead minnows were still influencing wetlands through young-of-the-year fish, preempting any response by large cladocerans, phytoplankton, and water clarity.

The second step needed for a biomanipulation to be successful in creating or maintaining a stable clear water state is the establishment of secondary responses to the trophic cascade. Secondary responses include the reestablishment or increase of aquatic macrophytes, the reduction of internal loading, and the reduction of resuspended sediments (Scheffer et al 1993). The key secondary response are the reestablishment or increase in aquatic macrophytes. Once plants become dominant in a wetland, they directly and indirectly influence the other secondary responses.

The walleye fry and advanced walleye treatments did not initiate any significant change in the aquatic macrophytes, but wetlands stocked walleye fry are posed for changes in 2003 due sustained trophic cascades and improvements in water clarity throughout 2002. Water clarity started to improve in some of the walleye fry treatment wetlands at the end of summer in 2001 and significant improvements were observed in 2002. Unfortunately the macrophytes were not able to respond that quickly, but a response may develop in 2003. If a macrophyte response develops in the walleye fry treatment wetlands then other secondary responses should follow that will promote further increases in water clarity and greater stability of the clear water state. The advanced walleye treatment wetlands never succeeded in producing a trophic cascade, thus no secondary effects are expected.

At the end of the two-year study the walleye fry treatment succeeded in switching wetlands from a turbid water state to a clear water state. The stability of the clear water state is still questionable, and will remain so until there is positive improvement in macrophyte abundance. Another important positive result from the walleye fry treatment is the overall higher abundance of most macroinvertebrates resulting from the trophic cascade. One negative result from the walleye fry treatment appeared during the second year of the study. There was a trend toward decreasing abundance of benthic chironomids and Chaoborous in the second (even lower than the control treatment wetlands). The decrease is likely due to an increase in walleye fry predation upon chironomids and Chaborous during the second year because of the decline in fathead minnows, the prefferred food source for the walleye fry. A possible solution to dealing with this problem might be to stock walleye fry every other year. Overall in this study, using wetlands to rear walleye fry does not appear to have any significant negative effects on the wetland ecosystems, and in fact can be beneficial to turbid wetlands by switching them to a clear water state with higher abundance of zooplankton, macroinvertebrates, and potentially macrophytes. These documented benefits from the walleye fry treatment indicate that using rearing walleye fry can be used as a tool by wetland mangers to switch turbid wetlands to a clear water state.

The advanced walleye treatment was not successful in initiating a trophic cascade. During most of the study, the advanced walleye treatment wetlands did not deviate significantly from the control treatment wetlands in most of the parameters measured. During the first year of the study, the advanced walleye treatment had lower abundance of many of the invertebrate groups relative to control treatment wetlands, indicating a slight negative impact on these wetlands. The results from the advanced walleye treatment indicate that stocking year-plus walleyes in wetlands will not positively affect the wetlands and may even have a negative impact.

Study of Effectiveness of Northern Prairie Wetlands as a Resource to Control Nutrient (Phosphorus) Load to Receiving Water.

Basic Information

Title:	Study of Effectiveness of Northern Prairie Wetlands as a Resource to Control Nutrient (Phosphorus) Load to Receiving Water.
Project Number:	2002ND17B
Start Date:	3/1/2003
End Date:	12/31/2003
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Descriptors:	Nutrient Load, Phosphorus, Wetlands
Principal Investigators:	Wei Lin

Publication

1. Presentation: Murthy, Sreerama and Wei Lin, Sept. 23, 2003, Phosphorus Transport in Wetlands, ND WRRI Advisory Committee, Bismarck, North Dakota.

Study of effectiveness of Northern Prairie Wetlands as a Resource to Control Nutrient (Phosphorus) Load to Receiving Water

ND WRRI Graduate Research Fellowship Project
Sreerama Kasi Murthy, Fellow
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Description of the critical state or regional water problem being investigated:

Wetlands are dominant aquatic resources in the prairie pothole region (PPR), an area that spans portions of Iowa and Minnesota, the Dakotas, and three Canadian provinces. Ranging from tiny potholes to huge lacustrine complexes, prairie wetlands are among the world's most productive ecosystems.

Intense agriculture and associated drainage of wetlands, urban sprawl, and other human-induced changes over the past 100 years has had a tremendous effect on this area's natural resources. The prairie upland, almost all of the prairie wetlands, and some of the timberlands have been converted to cropland.

The conversion of wetlands into agricultural lands and intense use of fertilizers has been a source of eutrification and impairment in water quality of lakes and rivers. The conversion of the depressions into wetlands has been done with a purpose of restoring the wildlife and natural habitat of the region.

Return of agricultural lands to natural habitats and restoration of wetlands are under way in the Buffalo River Watershed in Becker County, Minnesota. This area is reach in shallow surface water and groundwater has been drained and cultivated for nearly 40 years usually with conventional tillage. Currently, drainage ditches have been closed to restore natural water levels and to return depressions back to wetlands.

It is expected that restoration of these wetlands would reduce the nutrient loads to the receiving streams and lakes. The excess growth of hybrid cattails in these restored wetlands is suspected due to the high nutrient levels in the soil/sediment and surface water. Phosphorus, the limiting nutrients in these depressions, if studied for its movement, transformation and translocation in the wetland ecosystem would enlighten better understanding on the effectiveness of wetland in controlling nutrient loading to streams and lakes and in restoring the natural habitat and wildlife of the region.

As wetland ecosystems become degraded due to human actions, restoration efforts are becoming more pronounced. Large scale wetland restoration appears to be available management practice for controlling phosphorus (P) and other non-point source pollution to the water systems. Processes affecting fluctuations in N and P are of interest because there is conflicting evidence about the ability of wetlands to act as sinks for N and P (van der Valk *et al*., 1979). Study of Phosphorus dynamics in the system will provide a better understanding of the phosphorus transport and deposition in the wetlands. This study will help in better controlling and managing Buffalo-Red river water quality.

Anticipated results and benefits from the proposed study:

The results of this study will provide a better understanding of how phosphorus moves through a wetland and influences wetland characteristic. The phosphorus retention capacity and transportation through these semi-permanent wetlands can be applied to similar systems in prairie pothole region to predict the effectiveness of wetlands in controlling the phosphorus transport to the receiving streams. This information will be of interest to federal agencies such as US EPA, the Natural Resources Conservation Services, the Bureau of Reclamation, the Army Corp of Engineers, and the US Geological Survey, as well as to the State Resources Management agencies and private agencies concerned with surface water management, water quality, and wetland habitat issues.

Scope and Objectives of the proposed research:

Phosphorus is selected as the target nutrient for this research project. We hypothesize that transformation, movement, and concentration of phosphorus compounds in the wetlands are affected by seasonal variations of water chemistry and phosphorus solubility, sediment decomposition and subsequent release of organic phosphorus, and biological assimilation and decomposition. The objectives of this research project include:

1. Studying the seasonal water quality changes in the three wetlands;
2. Determining phosphorus forms and concentrations in wetland water, plants, sediments and soil water;
3. Performing a mass balance analysis on phosphorus and developing a mathematical model to simulate the phosphorus dynamics in the wetland systems; and
4. Sampling and data collection at the wetlands and model evaluation.

1 INTRODUCTION

Wetland in prairie pothole region (PPR) is one of the dominant aquatic sources in North America. The PPR region as shown in Figure 1 spans portions of Iowa and Minnesota, the Dakotas, small region in Northern Montana, and three Canadian provinces (southwestern Manitoba, southern Saskatchewan and southeastern Alberta). These PPR wetlands are known to support diverse species of biota, regulate flooding, control water quality, and recharge ground water (Mitsch and Gosselink, 2000). Due to immense agricultural activities during past couple of centuries about 50% of these wetlands are lost (Van der valk, 1989). Various national agencies that are interested in protecting national resources have increased their efforts in reclaiming and restoring the lost wetlands.

Restoring wetlands to their original condition needs to identify the health indicators, such as nutrients, vegetation, fish and wildlife (or define presence of exotic invaders, poor water quality, altered hydrology, and human activity) in order to assess the long-term sustainability of restoration. Among nutrients, phosphorus is believed to be the limiting nutrient for biological growth (USEPA, 2000) and understanding its dynamics will allow controlling it using best management practices (BMP). Eutrophication (an excess growth of aquatic species such as algae, macrophytes, etc., due to excess supply of nutrients) of surface waters is one of the examples for phosphorus to be believed as major limiting nutrient (USEPA, 2000). The major problems associated with eutrophication are low dissolved oxygen, turbidity and inconvenience for recreational purposes in surface waters.

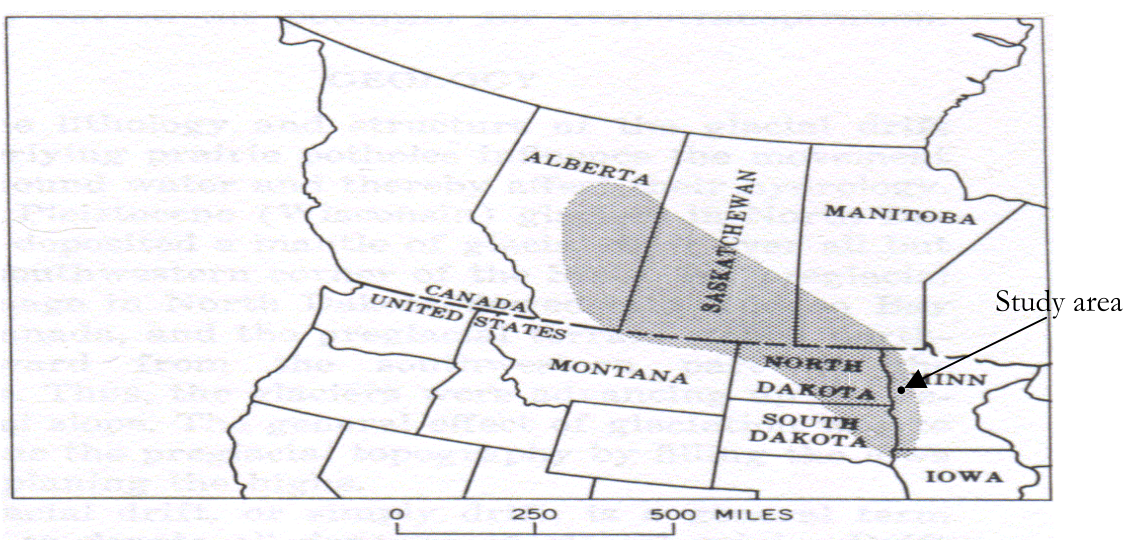


FIGURE 1: LOCATION OF THE PRAIRIE - POTHOLE REGION (SHADED)

2 SITE DESCRIPTION (PAST AND PRESENT ACTIVITIES IN THE REFUGE)

The Hamden Slough National Wildlife Refuge's wetlands (NWR) are one among the restored wetlands in the PPR. The refuge is located approximately 72 km east of Fargo, North Dakota, in the Buffalo River Watershed in western Becker County, Minnesota (48°57'50"N, 95°58'W) (Figure 1). The whole refuge spans along the

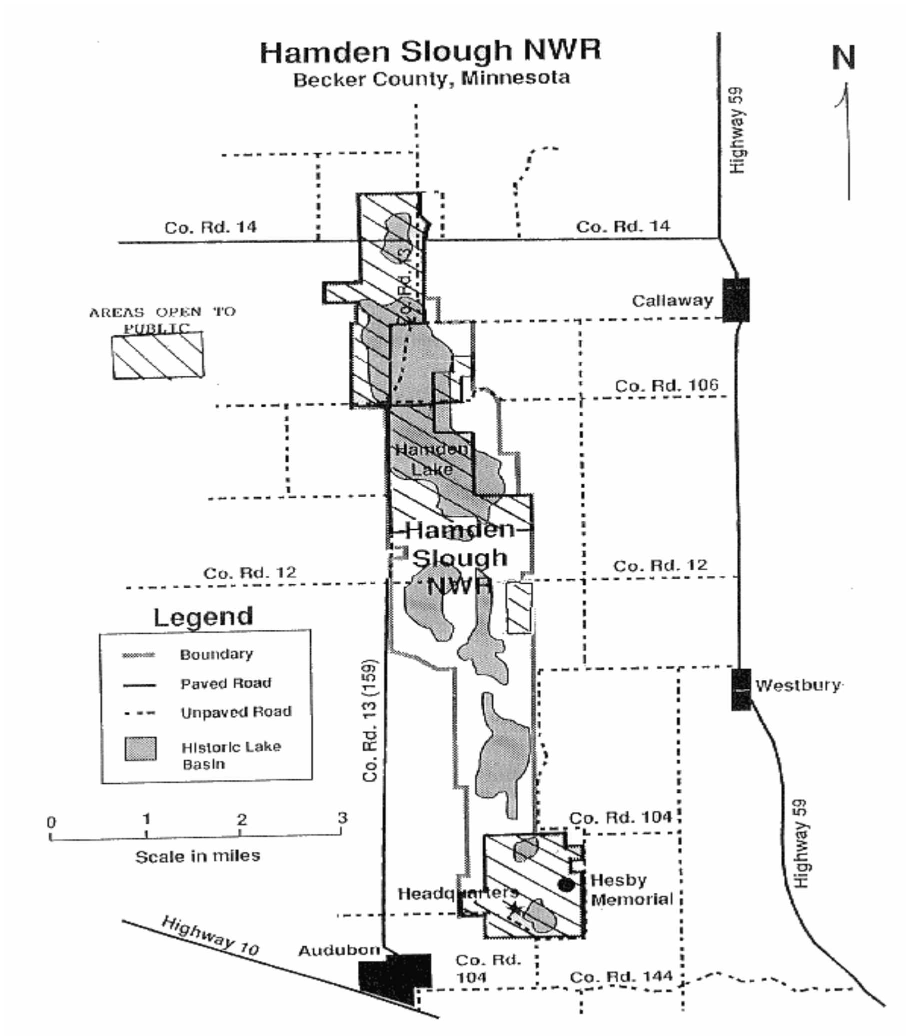


FIGURE 2: LOCATION OF HAMDEN SLOUGH NWR

County Road 13 in the Becker County (Figure 2) and the area of the refuge includes 5944 acres. The refuge is geographically located in a transitional zone between tall grass prairie on the northwest of PPR, and a rolling hardwood forest-lake region on

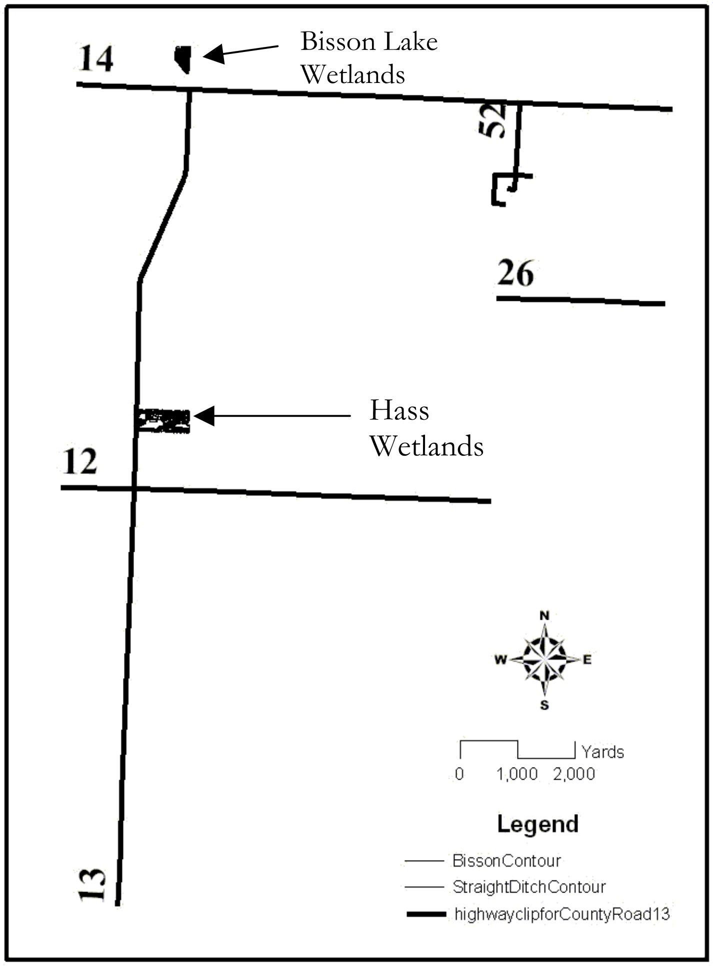


FIGURE 3: BISSON LAKE AND HASS WETLANDS LOCATED NEAR COUNTY ROAD 13 AND COUNTY ROAD 14 IN BECKER COUNTY, MINNESOTA.

the southeast of PPR. The primary economic base for the area surrounding the refuge is agriculture (Murphy 1991). The early agricultural activities in this area started in late 1890s, draining the wetlands in the refuge. Almost 100% of all wetlands in the study area have been drained. Migratory Bird Conservation Commission approved Hamden Slough NWR as 452nd refuge in 1989 to restore the lost wetlands in this region.

The objectives of NWR are to provide habitat for birds, and restore native plants and animals of PPR ecosystems (Murphy 1991). Prior restoration efforts, started in 1991, include plugging the ditches and seeding them with native grass seed mix in the restored wetlands. The majority of the wetland restorations (130 restored wetlands) surrounding Bisson Lake were completed in 1998. The NWR now choose to serve as educational model for land and water stewardship and also educate the farmers around the refuge land and implement best management practices (BMP). The reason for this is, the water from upland agricultural lands flows through Hamden Slough NWR into Buffalo River. Several water conservation agencies and wetland management districts (WMD) believe that the fertilizer application in the upland fields might contaminate the surface water in the downstream lakes and rivers. Buffalo Red-River watershed and some federal, state, and private agencies have initiated a project in educating the farmers to control manure application and sediment control (Murphy, Personal communication, 2002).

Preliminary field studies indicate high nutrient levels (phosphorus) and domination of cattail growth. Field observations also indicate that there is a lot of algae and moss on the surface of the water in the restored wetlands. One hypothesis is that the extensive growth of the cattails is also due to high phosphorus levels in these wetlands. Earlier agricultural practices such as fertilizer application might have raised the phosphorus levels.

Two wetland regions with three in one area (Bisson Lake wetlands) and six in the other (Hass wetlands) are selected to study phosphorus dynamics (Figure 3). The selection of study sites was based on ground water movement; these wetlands have little/no interference of groundwater from surrounding areas. So, the study can also be helpful in understanding the transport of the existent phosphorus loaded onto soil from past agricultural activities. Groundwater in Bisson Lake area flows from north to south into the Bisson Lake. Bisson Lake water levels are controlled and the water from Bisson Lake flows 4.8 km south through ditch 15 of the Buffalo Watershed District system to Hamden Lake, 5.6 km west to Buffalo River, and 48 km west to the Red River of the North. The other ditches nearby the Bisson Lake were plugged and vegetated spillways over the ditch plugs were constructed. The total surface acreage of Bisson Lake wetlands, including spillways, is 0.6 acres. The Hass area wetlands have a total surface acreage of 3.2 acres. Among all wetlands in NWR two were

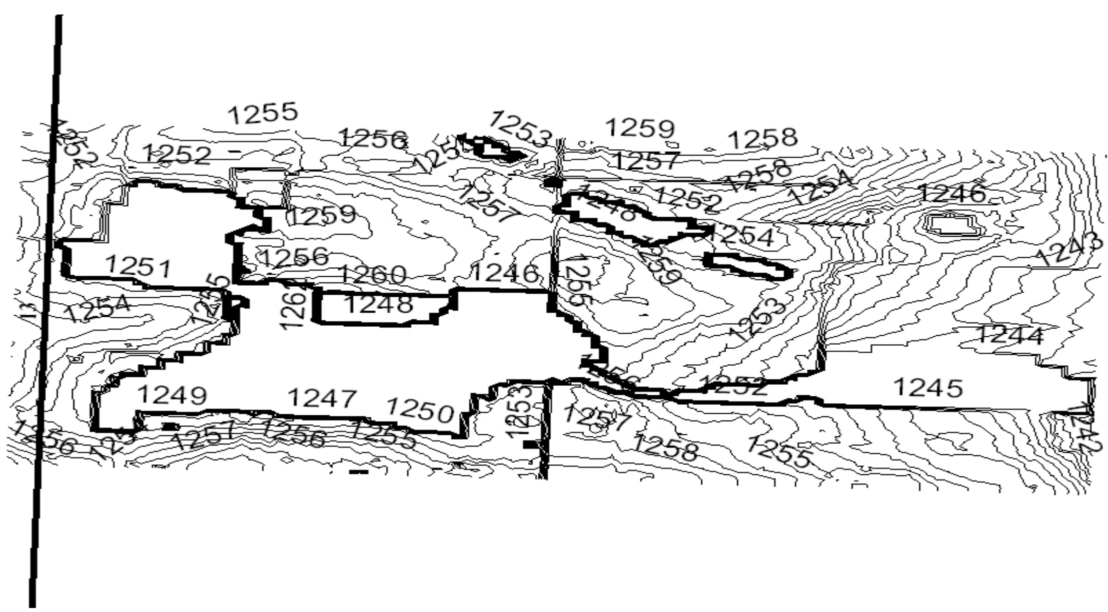


FIGURE 4: CONTOUR MAP FOR HASS AREA WETLANDS

restored and two were excavated. The topography of Hass is undulating. The survey done in this area shows (figure 4) that in overall it slopes downhill to the east. The ground water also flows west to east in these wetlands. The major plant species that are found in the whole Hamden Slough study area is cattails. The growth of these species is high in summer and they almost choke up all the wetlands leaving a little open water in the middle.

3 MODELING CONCEPTS

A model can be conceptual, or mathematical, or physical (Vollenweider, 1972). Conceptual models include a mass balance on a control volume with inputs, outputs and internal reactions. Wetland models on phosphorus, conceptually, can be classified into three categories; 1) a model that describes soil phosphorus cycle, 2) a model that describes the effects of seasonal variations on phosphorus cycle and 3) a model that describes long term (includes more than one seasonal cycle) phosphorus cycle. The first type of model is a conceptual model that illustrates the internal processes involved in phosphorus transformations. The other two models describe how the internal processes change with time. Based on the site conditions and the literature, the model for Hamden Slough Refuge wetlands will include the following internal processes:

1. Adsorption and Desorption – the Hamden slough wetlands were once used for agricultural purposes and the wetland soils have high phosphorus levels. Since most of these wetland soils are fine textured, sorption capacity can be high and desorption is also expected to occur when the influent flow has less phosphorus dissolved than the phosphorus sorbed onto soils (McGechan, 2002). The major controlling parameters for adsorption and/or desorption are soil texture and chemical composition, pH, temperature, and soil to solution (weight/volume) ratio (Barrow, 1979; Barrow, 1983).

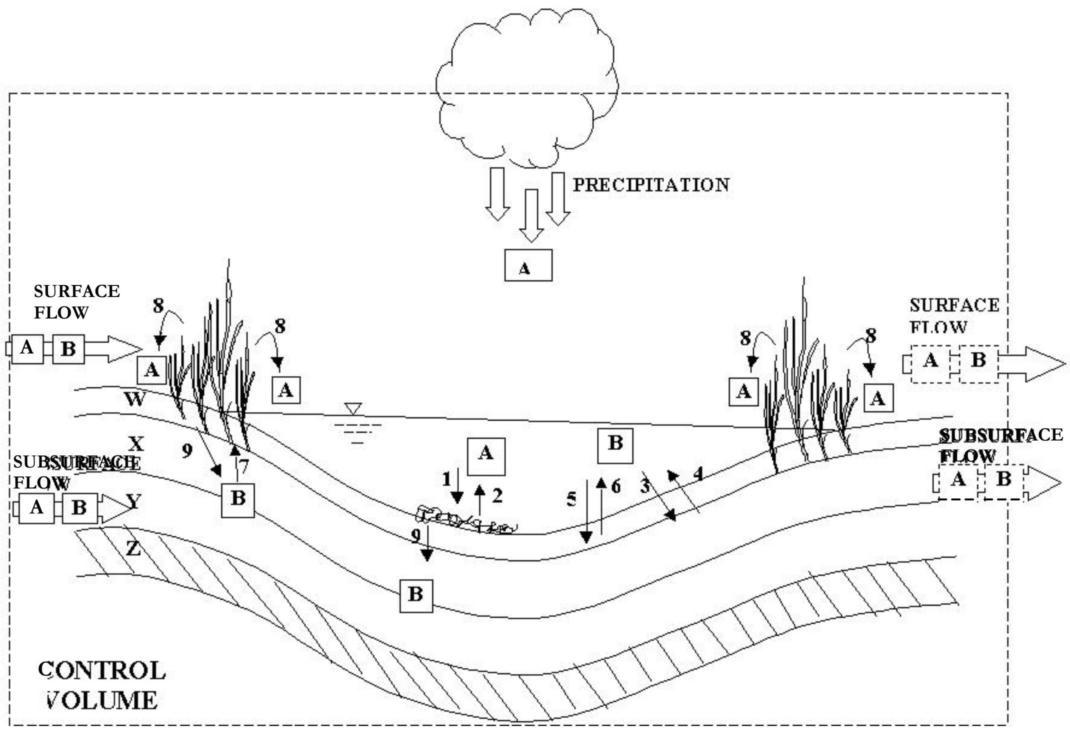
2. Dissolution and Precipitation – the surface water and ground water that flow through the surrounding agricultural fields may carry lot of dissolved phosphorus in them. Temperature variations and subsequent changes in pH can be the driving forces for precipitation and dissolution of dissolved phosphorus (Grant and Heaney, 1997). Besides temperature and pH; water depth, redox conditions and the controlling solid phase of the metal phosphate also define the rate of precipitation and dissolution (Ann et. al., 2000; Pant and Reddy, 2001).

3. Sedimentation – Lot of particulate matter (plant debris) observed in all wetlands and sedimentation can be a major sink for particulate phosphorus. Sedimentation of particulate particles is a function of velocity of flow, temperature and water depth (Prescott and Tsanis, 1997; Wang and Mitsch,

2000). Since water is deep enough (> 2 ft) at the center and has thick cattails on the perimeter of all wetlands, there is less possibility of resuspension due wind shear force and surface flow.

4. Biological uptake and release – Macrophytes, such as cattails, growth, death and decomposition create a cycle for uptake and release of phosphorus from wetland soils and water (Kadlec 1997). The rate of each process (growth, death and decomposition) in the biological cycle have an effect on amount of phosphorus in wetland in long period of time (Wang and Mitsch, 2000).

All of the above processes can be schematically described as shown in Figure 5, and the phosphorus internal cycle shown in the figure can be explained as follows. The plant uptake can be a major driving process for phosphorus movement within a wetland. When plants take up phosphorus from the soil, a concentration gradient will be created between the root vicinity and the soil surrounding the roots. The gradient causes diffusion of dissolved/particulate phosphorus from water and surrounding soil to the root vicinity zone. The dissolved/particulate



Description of letters		Description of numbers (processes)		Description of symbols	
A	Particulate Phosphorus	1	Sedimentation		Influent concentration
B	Dissolved Phosphorus	2	Resuspension		Effluent concentration
W	Top soil	3	Precipitation		Processes involved in phosphorus transformations
X	Low permeable soil	4	Dissolution		Flow
Y	Highly permeable soil	5	Sorption		
Z	Very low permeable soil	6	Desorption		
		7	Plant uptake		
		8	Plant release (die-off or leaf fall)		
		9	Mineralization		

FIGURE 5: CONCEPTUAL DIAGRAM OF PROCESSES INVOLVED IN PHOSPHORUS TRANSFORMATIONS

phosphorus will be sorbed by surface soil sediments and diffused to inner particles.

As the plants mature to die, they fall as litter and return phosphorus to water in particulate form, most of which will eventually reach soil sediments through settling process and cause accretion of litter. This litter when decomposes, releases dissolved phosphorus back into the water column through dissolution and desorption processes.

If the wetland system is assumed as closed and completely mixed system and also if there is no other process involved in the system, all the above said processes form a cycle for total phosphorus. If there is no supply of phosphorus to the system, all of the phosphorus present in the system will eventually disappear. But if there is an external supply of phosphorus from various point (sewage treatment plants, industrial discharges, etc.,) and non point sources (agricultural fertilizers, precipitation, etc.,), then the amount of total phosphorus in the system changes based on the rate of supply and rate of the internal processes. A mass balance on inputs, outputs, and the internal processes helps to understand the changes in phosphorus forms and concentrations in the wetland water column.

A control volume is assumed around each wetland with known inputs, outputs, and processes in internal phosphorus transformations. Inputs for the control volume are surface runoff, subsurface flow and precipitation; and outputs from the control volume are surface runoff and subsurface flow. Litter fall, particulate matter settling, soil sorption and chemical precipitation are the internal phosphorus sinks; and organic matter mineralisation, resuspension of sediments, desorption from soil particles and chemical dissolution are Internal phosphorus release (or source) processes. Following are some assumptions made for mass balance on the control volume.

3.1 ASSUMPTIONS

1. Lake is completely mixed; i.e. constituents A and B are constant throughout the lake.

2. Z is an impermeable soil layer and there is no flow through this layer.

3. Surface runoff is the overland flow water from surrounding areas.

4. Phosphorus loss due evapotranspiration and evaporation is ‘0’.

5. Phosphorus is primarily consumed by macrophytes such as cattails, and periphyton such as algae and moss.

4 FIELD METHODS

Since modeling phosphorus movement needs a mass balance on the control volume defined in the previous section, a detailed description of input and output variables, soil and hydrological conditions, and environmental parameters for this control volume is needed. Defining the site conditions (such as landscape, soil profile, surface and ground water flows) with proper field survey data is also needed to make a model from more a site specific and then generalizing it to ecologically similar type of wetlands. Sampling in Hamden Slough wetlands are planned based on major processes involved and also the site conditions.

4.1 SAMPLING METHODS

Field surveying was done in summer 2001 and survey data is plugged in ArcView GIS to draw contour maps of the wetlands. Water sampling points are located based on ground water flow. One sampling point on up stream and one on down stream of each wetland is located to identify the amount of phosphorus entering and leaving the wetland. Spectrophotometer and YSI's Multiple Parameter (Figure 6) are used to measure and record water sample readings on the site. Water samples are collected in small bottles and acidified to preserve for laboratory analysis (calcium, magnesium, sodium, potassium, carbonates, bicarbonates, chlorides, and sulfides are measured in the laboratory).

FIGURE 6: SPECTROPHOTOMETE R YSI MULTIPLE PARAMETER

4.2 CONSTRUCTION OF WELLS AND PIEZOMETERS

Piezometers and wells are located next to each other (within 1 to 2 ft distance) in the wetlands. They are used to determine the direction of ground water flow and also to collect ground water samples. Piezometers have a slot (opening) only at the bottom and protected with a "well fabric" covering and a sand pack below it as shown in Figure 9. Piezometer walls are covered with an impermeable material such as bentonite clay between sand pack and soil surface level. Wells also have same diameter and length as of piezometers, but have slots (openings) all over up to the surface level (Figure 9). Well walls are covered with coarse sand packing to keep the clay and sand out of the tube and let water in. Water levels incorporated with survey elevation of wells/piezometers help to determine the direction of groundwater flow. Water level elevations in wells indicate that the ground water flows to southeast.

4.3 RESULTS

Preliminary field data collected in summer 2001 and summer 2002, suggested that phosphorus levels in water column in all wetlands and Lake Bisson are quite high (Table 1) and thus these wetlands can be classified as *hypereutrophic* (USEPA, 2000). Water sample analysis (summer 2001 and summer 2002) revealed high levels of calcium and magnesium and that a previous study in Lake Bisson done by Feigum (2000) also indicated the soils as calcareous. The pH of soil in Bisson Lake ranged between 7.5 and 8.0. Under high pH conditions apatite ($Ca_5(PO_4)_3OH$) is the solid phase that controls phosphate solubility. But apatite formation is hindered if high amounts of carbonates and magnesium are present. The other metal ions that control phosphorus availability in wetland water are iron and manganese. The wetland soils and water have high seasonal variations in oxidized/reduced conditions.

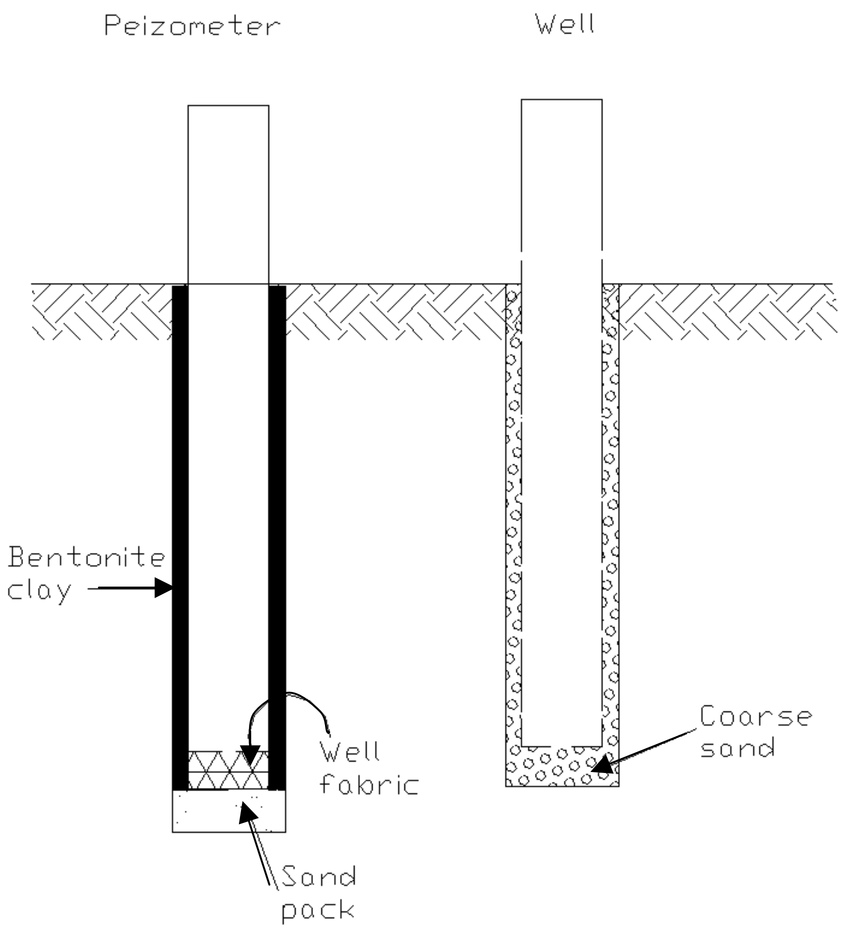


FIGURE 7: CONSTRUCTION OF WELLS AND PIEZOMETERS IN HAMDEN SLOUGH WETLANDS

Table 4.1 Summary of Chemical analysis for surface water samples for summer 2001and 2002

Wetland name	Phosphorus (mg/L)		Calcium (mg/L)		Magnesium (mg/L)	
	Summer 2001	Summer 2002	Summer 2001	Summer 2002	Summer 2001	Summer 2002
112	0.151	0.138	116	63	44	28
113	0.262	0.209	165	77	53	23
110	0.184	0.256	133	96	86	42
Bisson Lake	0.479	0.973	184	96	247	52
35	0.118	0.138	48	21	38	21
38	0.198	0.233	99	129	149	84
38a	0.112	0.209	104	99	81	62
41a	0.139	0.175	104	122	116	89
41b	0.214	0.245	136	124	135	88

The water sampling in June and July of 2003 was done to identify the iron and manganese levels in the study area. Water samples from ground water wells were analyzed for ferrous iron and manganese on the site itself (Ferrous iron and manganese (divalent) change their oxidation state quickly. So they have to be measured as soon as possible). Divalent forms of iron and manganese are found to be high in the wells. This can be correlated with redox potential values, which indicate reduced conditions in all wells. Under reduced conditions iron and manganese get reduced to divalent forms and increase the solubility of corresponding phosphates (Ann et. al., 2000; Lindsay 2001).

4.4 DISCUSSION AND FURTHER RESEARCH

The above results indicate that phosphate solubility in Bisson Lake and Hass wetlands appear to be controlled by metal (calcium, iron, and manganese) ions' solid phases. Equilibrium equations for the metal ions' solid phases will be included in the model to identify the availability of orthophosphate under varying pH and redox conditions. Defining equilibrium conditions with controlling parameters and conditions is need. For example, calcium phosphate solubility is mainly controlled by pH rather than redox. Whereas, iron and manganese phosphates solubility is controlled by redox conditions.

Calcium phosphate solubility decreases with increase in pH. But in calcareous soils, the phosphorus solubility can again increase at pH above7.9 (Lindsay 2001) due to increase in calcium carbonate formation. In calcareous soils, under reduced conditions and depending on metal oxides that control metals, most phosphate minerals can be transformed to vivianite ($Fe_3(P0_4)_2.8H_20$). Vivianite reduces the solubility of phosphate. This indicates that equilibrium equations should also include the controlling metal oxides/hydroxides that are present in the soil (due to weathering effects).

Thus, the dissolution/precipitation processes will be developed based on the equilibrium equations. These processes can indicate (or predict) the form and quantity of phosphate available under specified conditions (pH, redox and initial/current phosphorus concentration).

4.4.1 FURTHER RESEARCH

So far, chemical processes are identified as one of the internal processes controlling the availability of phosphorus in the water column. The other major processes need to be identified to complete the mass balance on the control volume. Adsorption/desorption (or simply called 'sorption') processes are expected to occur (due to high phosphorus levels found in the soil and water) and sorption equilibrium equations or kinetic equations (time-dependant) have to be developed to define the nature of the wetland soils. Laboratory tests on particle phosphorus have to be done to observe the significance of sedimentation process. Biological uptake-release mechanisms have to be studied yet and a sampling procedure and a mass balance have yet to be developed.

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Hydrological Modeling of the Spatial and Temporal Variation of Prairie Potholes at the Basin Level

Basic Information

Title:	Hydrological Modeling of the Spatial and Temporal Variation of Prairie Potholes at the Basin Level
Project Number:	2003ND21B
Start Date:	5/15/2003
End Date:	8/15/2003
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Congressional District:	At large
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Focus Category:	Wetlands, Surface Water, None
Descriptors:	Hydrologic Modeling, Prairie Potholes, Basin level modeling
Principal Investigators:	Phil Gerla, Gregory J. McCarthy

Publication

1. Chris Laveau, 2003, Using GIS and Digital Terrain Data to Model Groundwater Interaction in Prairie Wetlands, 4th Biennial ND/SD Joint EPSCoR Conference,Poster Presentation
2. Chris Laveau, 2003, Using GIS and Digital Terrain Data to Model Groundwater Interaction in Prairie Wetlands, University of North Dakota RNEST Biocomplexity Workshop, Presentation

HYDROLOGICAL MODELING OF THE SPATIAL AND TEMPORAL VARIATION OF PRAIRIE POTHOLES AT THE BASIN LEVEL

ND WRRI Graduate Research Fellowship Project
Chris Laveau, Fellow
Philip Gerla, Advisor and Principal Investigator
Geology Department
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Grand Forks, ND 58202

DESCRIPTION OF WATER PROBLEM

Water resources and aquatic ecosystems in the prairies have great economic importance for water supply, flood control, and waterfowl breeding and habitat. Previous studies related to the hydrology of these wetlands (e.g. Woo and Roswell, 1992; Winter and Rosenberry, 1998) have focused on the hydrodynamics and climatic response of prairie potholes in small areas. These studies provide valuable information on the hydrology of select high-relief areas of the prairie pothole province. Information on the general hydrodynamic conditions of the entire region, however, is often needed by wildlife and wetland managers.

This proposal forms part of a larger research project funded through NSF's Biocomplexity seed grant to UND's Department of Biology. As part of their work with host - parasite / pathogen interactions on a spatially heterogeneous and temporally dynamic landscape, our portion focuses on the hydrological modeling of grassland-wetland linkages in natural and human-dominated landscapes. Dr. Brad Rundquist and graduate student Paul Sethre of UND's Department of Geography are quantifying the dynamics of wetland and open water extent using historical remote sensing imagery. Their results will complement our research component, which will provide a conceptual framework and model that describes the spatial and temporal variation of hydrologic features at Newman's amphibian study site in eastern Nelson County, North Dakota.

OBJECTIVE

The objective of this research is to provide a conceptual framework and model that describes the spatial and temporal variation of hydrologic features within the upper Turtle River drainage basin in Grand Forks and Nelson counties, North Dakota. This characterization will be conducted at the watershed level as this is a fundamental spatial unit in which to (1) estimate groundwater and surface water budget, (2) relate all surface water channels, sub-basins, and their interconnection, and (3) recognize the relationship of soil catena to geomorphology, hydrology, and land use.

Research tasks of the study include

(1) Use existing data to map the surficial geology of the area.

(2) Make a spring and fall inventory of electrical conductivity and pH of wetlands, lakes, and ponds in the watershed study area, and, if possible, establish a correlation to the classification (Cowardin and others, 1979) used in the U.S. Fish and Wildlife Service National Wetland Inventory. (Completed for Fall 2002).

(3) Identify greater-than-annual periodicities in the precipitation record, if any exist, by computing autocorrelation for precipitation recorded for nearby weather stations. Precipitation constitutes the largest input to the prairie pothole water budget, and may therefore be the best component to use.

(4) If greater-than-annual periodicities exist, then cross-correlation techniques (Davis, 1986) will be used to characterize the relationship between precipitation and the extent of wetlands. (Work now underway by Sethre and Rundquist will quantify the temporal and spatial changes in wetland and open-water extent).

(5) Modify and apply a water budget method to model the effect of climate variability on the expansion and contraction of wetlands. Wigley and Jones (1986) used time interval, historic stream flow, precipitation, and potential evapotranspiration parameters to model changes in stream and river flow. We will test the application of a similar approach to predicting the dynamics of wetland hydrology.

(6) Use the groundwater – DEM-based surface model of Gerla (1999) to map the distribution of recharge and discharge areas in the watershed study area. Using a DEM and a map of hydraulic conductivity, the model uses raster-based water balance constraints to predict the variation of recharge and discharge across the landscape. Calibration is performed using maps of surface water and shallow groundwater (based on NWI wetlands). Soils maps, which are now being digitized, will be used to provide a spatially varying estimate of hydraulic conductivity.

Effort Planned For Summer 2003 under this Fellowship: Current funding for the Graduate Fellow, Chris Laveau ends on 30 April 2003. At this point, Chris and I have made good progress on the easier tasks, 1 – 4. Chris' thesis will focus on the methods and limitations of the spatial and temporal analysis described in tasks 5 and 6. I anticipated that the work associated with modeling would not be finished by May. To meet the goal of the biocomplexity grant, Chris and I will produce digital maps of the watershed that show how recharge, discharge, and wetlands expand and contract with observed climate variability. The data and results of Rundquist's work will be used to help calibrate and verify hydrological models.

METHODS, PROCEDURES, AND FACILITIES

The research will be conducted in an environment combining geographical information systems (ArcView 3.2), hydrological software, and field observations. Thirty-meter digital elevation models (DEMs) will be processed using flow accumulation methods developed by Jensen and Domingue (1988) to delineate a watershed that completely contains the basin and associated till plains of the upper Turtle River.

To develop an understanding of the area all available data on geology, soils, groundwater, and wetlands for the watershed have been complied as a GIS project. The data was acquired from North Dakota's Digital Data Clearinghouse, National Wetlands Inventory (NWI), Soil Conservation Services, and North Dakota Geological Survey's county studies. A spring and fall inventory of electrical conductivity and pH of randomly selected wetlands, lakes, and ponds in the watershed will be conducted and, if possible, a correlation established to the classification (Cowardin et al., 1979) used in the U.S. Fish and Wildlife Service National Wetlands Inventory.

To place our model in the largest possible context, historical records on precipitation and the Palmer Drought Severity Index (PDSI) (Palmer, 1965) will be statistically analyzed using autocorrelation techniques as presented in Davis (1986). Precipitation constitutes the largest input to the prairie pothole water budget and therefore is the most important component of the model. The PDSI is an index based on precipitation, evapotranspiration, and soil moisture that was found to have a strong relationship to wetland extent (Winter and Rosenberry, 1998). If cyclicity is found to exist, then cross-correlation techniques (Davis, 1986) will be used to characterize the relationship between precipitation, PDSI, and the extent of wetlands based on aerial photos.

A water budget model that takes into account the effect of climate variability on the expansion and contraction of wetlands will be applied. Wigley and Jones (1986) used time interval, historic streamflow, precipitation, and potential evapotranspiration parameters to model changes in stream and river flow; these methods may also work with wetland dynamics by using wetland extent as a surrogate for stream flow. Groundwater recharge and discharge areas in the watershed will be accessed using the groundwater-surface water model of Gerla (1999). Soil maps, conductivity measurements, and NWI maps of the area will be used to corroborate the results.

ANTICIPATED RESULTS AND BENEFITS

Modeling water budgets and recharge-discharge on a landscape scale constitutes a challenging problem in hydrology. The work described in this proposal will assess the ability of Gerla's (1999) model to simulate the groundwater flow in a region of low topographic relief and poorly integrated drainage. The estimation of model parameters using readily available data offers a practical method for providing the data required for meaningful hydrological analysis by wetland and wildlife managers.

Current wetland classification systems that depend on qualitative descriptions, based on fauna and physical parameters of wetlands, limit their range of applicability and validity. As noted by Brinson (1993), wetland classification schemes are useful for aggregating wetlands with similar hydrology, but they generally cannot be used to compare hydrologic variations among wetlands or to evaluate temporal and spatial variations within individual wetlands.

A numerical representation of hydrodynamics in prairie wetlands also has application in understanding the role potholes play modifying peak flow. Land drainage has been implicated as cause for the increase in streamflow over time on the tributaries of the Red River in North Dakota (Brun et al. 1981). The interaction of wetlands with adjacent ground-water and surface water systems determines its water budget components and its effect on downgradient water quantity. The role of wetlands in mitigating floods would be better understood if wetland managers could take into account hydrologic dynamics within an entire watershed.

RESULTS AND CONCLUSIONS

Prairie potholes are water-holding depressions of glacial origin in the northern portion of the Great Plains. They are significant hydrologic features because of the role they play in flood control, water supply, and biological activity of prairie communities. This role is often a function of the existing water balance within the wetland.

Hydrologic investigations (e.g. Shjeflo, 1968; Woo and Roswell, 1992) found that direct precipitation and spring runoff from snowmelt were the major sources of water supply for prairie potholes, while evapotranspiration was the major cause of water loss. Their results indicated that northern prairie potholes have a negative water balance with respect to the atmosphere.

With more water leaving than entering from the atmosphere the persistence of a prairie pothole in the landscape is directly related to its groundwater budget (Sloan, 1972). An understanding of groundwater dynamics has important applications in predicting the spatial and temporal distribution of wetlands. The thesis work is focused on working with spatial datasets and groundwater modeling (Gerla, 1999) to explain the distribution and persistence of wetlands within the upper Turtle River drainage basin in Grand Forks and Nelson counties, North Dakota.

Gerla (1999) used a method of integrating digital terrain data with groundwater modeling to estimate the local configuration of the water table. The estimation technique combines the use of digital elevation models (DEMs) with numerical modeling to solve the groundwater equation for transient, unconfined flow. The thesis is taking the next steps with this initial research. The model has been redesigned to incorporate the heterogeneity of hydraulic conductivity. The model output on groundwater conditions is being quantitatively compared to field data using a statistical program. The current goal is to incorporate the statistical program into the groundwater model. The result will be a groundwater model with input parameters derived from readily available spatial datasets and output that is immediately and quantitatively compared to field data.

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Effects of West Nile Virus Infection, Immune Function, and Age on Female Yellow-headed Blackbird (Xanthocephalus xanthocephalus) Reproduction

Basic Information

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Publication

1. Jennifer Newbrey and Wendy Reed, 2003,DETECTING WEST NILE VIRUS ANITBODIES IN CENTRAL NORTH DAKOTA YELLOW-HEADED BLACKBIRDS, Entomological Society of Manitoba meeting,Winnipeg, Manitoba, Canada.
2. Presentation: Jennifer Newbrey, Sept. 23, 2003, Effects of West Nile Virus Infection, Immune Function, and Age on Female Yellow-headed Blackbird (Xanthocephalus xanthocephalus) Reproduction,ND WRRI Advisory Committee Meeting, Bismarck, North Dakota.

EFFECTS OF WEST NILE VIRUS INFECTION, IMMUNE FUNCTION, AND AGE ON FEMALE YELLOW-HEADED BLACKBIRD (*XANTHOCEPHALUS XANTHOCEPHALUS*) REPRODUCTION

ND WRRI Graduate Research Fellowship Project
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DESCRIPTION OF THE CRITICAL WATER PROBLEM

Recent high water levels and canalization of water resources (i.e., Garrison diversion) in North Dakota have resulted in an increase of aquatic habitats for many wildlife species. Current water conditions correspond with increased numbers of wetland breeding birds and increased habitat for breeding mosquitoes. Because birds often serve as intermediate hosts for mosquito borne diseases, increased populations of bird and mosquitoes could impact the ecology, rate of emergence, and persistence of diseases in humans and wildlife. The recent spread of WNV into the state has produced a need for research to study the influence of the virus on North Dakota wildlife.

The North Dakota Department of Health reported the first cases of WNV in the state in the summer of 2002. The first bird to test positive for WNV was a crow found on July 14th, and the first positive human cases were reported on August 28th. Because stagnant water in wetlands is ideal breeding habitat for mosquitoes, wildlife associated with these habitats may suffer high rates of WNV infection. The recent arrival of WNV into the state necessitates a study of the prevalence and immunological impact of WNV on native North Dakota wetland species. Most research on the virus has focused on using carcasses of birds as a surveillance system for detecting the spread of WNV across North America. No published research has been conducted on a living population of free-ranging birds. Failure of biologists to adequately address disease emergence in free-ranging wildlife may lead to diminished geographic distributions and populations declines (Friend et al. 2001).

The prairie couteau region of central North Dakota has many small prairie wetlands, which provide essential foraging and breeding habitat for many species of birds. Yellow-headed blackbirds are an ideal species to study WNV infection because they breed in high-density wetland colonies, which insures a large sample size. Establishing rates of WNV infection in yellow-headed blackbirds is necessary to determine the vulnerability of this wetland dwelling species. Information gathered on WNV for this study can also be used to model and predict potential impacts of the virus on other species of wetland birds.

KEY LITERATURE

West Nile virus is a mosquito-borne virus that was first diagnosed in North America in 1999 (Rappole et al. 2000). Since that time, the virus has spread across the United States and into Canada. Because the virus can cause fatal meningitis, it has become a national health concern for human populations, an economic concern for domestic animal losses, and a concern for the status of free-living bird populations (Campbell et al. 2002). Birds are one of the principal hosts of WNV (Rappole et al. 2000), with more than 111 species of wild birds diagnosed with the virus in the United States since 1999 (CDC unpub. data). Most of the information we have on the prevalence and distribution of the virus is based on information from symptomatic birds (i.e., sick or dead), which can bias estimates of potential outbreaks if asymptomatic birds have survived infection or act as carriers of the virus. By testing for the presence of antibodies to WNV in yellow-headed blackbirds, I will be able to assess the degree to which a free-living population has been exposed to the virus, the degree to which the population can avoid an epidemic, and the potential for blackbirds to serve as carriers for WNV.

When a bird suffers immune system stress, resources are allocated away from nonessential processes, such as growth and reproduction, and are reallocated to activities directly related to survival (Lochmiller and Deerenberg 2000). For example, depressed female immunity is known to decrease the diversity and concentration of carotenoids in egg yolks (Saino et al. 2002). Carotenoids are biologically active, lipid-soluble pigments synthesized by plants and photosynthetic microorganisms, which animals must obtain from their diet (Blount et al. 2000). In developing avian embryos, carotenoids in the yolk protect vulnerable tissues against damage caused by free radicals, by-products of normal metabolism and immune defense, which can cause extensive DNA, protein, and lipid damage (Surai et al. 2001). Because carotenoids are derived solely from the female, they reflect the quality of the maternal diet prior to egg laying.

As powerful antioxidants and immunostimulants, carotenoids are also incorporated into the sexual signals of many animals and are thought to indicate individual health (Blount et al. 2000). Yellow-headed blackbirds depend on carotenoids for their brightly colored yellow plumage. Second year (SY) female yellow-headed blackbirds can be distinguished from older, after second year (ASY) females because they have smaller patches of yellow feathers and are paler in their head, neck and breast regions (Crawford and Hohman 1978). These differences in plumage may reflect a female's ability to obtain carotenoids from surrounding habitats and therefore reflect her ability to deposit carotenoids into her eggs (Royle et al. 2001). Female age could also have substantial impacts on resource allocation and immune function. Young females may allocate more physiological resources to growth than mature females, and therefore allocate less to reproduction and immunity.

Maternal tradeoffs exist between the use of carotenoids for physiological functions, the expression of sexual signals, and investment into eggs (Saino et al. 2002). Yellow-headed blackbirds are an ideal species to study maternal tradeoffs between reproduction and self-maintenance, because females can easily be separated into 2 age classes and they allocate carotenoids both to plumage and eggs. Also, the high density of conspicuous, easily accessible nests in small North Dakota wetlands makes yellow-headed blackbirds an ideal species for study of WNV infection, immune response, and carotenoid concentrations in breeding females and their offspring.

SCOPE AND OBJECTIVES

The overall objective of this project is to determine the effects of female age and infection with West Nile virus on yellow-headed blackbird (*Xanthocephalus xanthocephalus*) maternal investment into eggs. The specific objectives of this project are to identify the prevalence of WNV in a free-living population of yellow-headed blackbirds, to quantify variation in immune function of female blackbirds, and to measure the relationship between female immune function and age on carotenoid allocation to eggs. These objectives will allow us to evaluate potential relations between wetland bird WNV infection and increased aquatic habitat for breeding mosquitoes in North Dakota.

METHODS, PROCEDURES, AND FACILITIES

Female yellow-headed blackbirds will be captured using mist-nets in order to collect blood samples to assess WNV antibody production and to measure variation in immune function using non-lethal immune challenges. Blood serum will be tested for WNV antibodies using competitive enzyme-linked immunoabsorbent assay (ELISA). We will follow protocol specifically designed to detect WNV antibodies in blood serum from avian species (Dr. Barry Beaty, Colorado State University, pers. comm.). We will quantify variation in female immune function at both the cell-mediated (i.e., white blood cell) and humoral (i.e., antibody production) levels using the methods described in Casto et al (2001). To assess cell-mediated immunity, we will measure differential-cutaneous swelling between wings of 30 females injected with a harmless plant protein (phytohemaglutinin - PHA) in the right wing and saline solution in the left. We will assess variation in humoral immune response by quantifying the antibody production of 30 females injected with sheep red blood cells (a novel, non-lethal antigen). Prior to release, each female will be categorized as either SY or ASY and will be banded with a standard Fish and Wildlife Service aluminum band along with a unique color-band combination for individual field identification.

We will locate and monitor nests of marked females to assess maternally allocated carotenoids in eggs and offspring survival and growth. The third-laid egg will be removed from each nest for carotenoid analysis, which insures the detection of differences among females and not variation in carotenoid allocation due to egg laying order. Yolks will be separated from the egg and the carotenoids will be extracted from the yolk using the methods described in Surai and Speake (1998). We will analyze carotenoids with High Performance Liquid Chromatography (HPLC) using a reverse-phase column. We will assess the concentration of carotenoids by comparing my samples to a calibration curve obtained from known concentrations of carotenoids. After sampling the third egg, we will monitor each nest at 3-day intervals to determine hatching success and nestling growth rates (i.e., body mass, tarsus length, and wing length).

This study will be conducted on several wetlands located within a 20 square mile area of the prairie couteau region of central North Dakota (Stutsman County). Central North Dakota has one of the highest concentrations of yellow-headed blackbirds in North America (Twedt and

Crawford 1995). In addition, Stutsman County has one of the highest numbers of positive avian West Nile Virus cases in North Dakota (CDC unpub. data). Conducting this study in a high-density population of yellow-headed blackbirds with known exposure to WNV insures a large enough sample size for all analyses.

Dr. Wendy Reed will provide field facilities in Stutsman County for all field data collection. Lab analysis of WNV antibodies and carotenoid concentrations will be conducted at NSDU.

ANTICIPATED RESULTS AND DELIVERABLES

This study will provide essential information on the prevalence and immunological impact of WNV on a North American avian species. Infection with the virus can be lethal, however, the degree to which birds are adversely affected varies across species and even between individuals within a species (Rappole et al. 2000). By testing for the presence of antibodies to WNV in yellow-headed blackbirds, we will be able to assess the vulnerability and degree of virus exposure in a free-living population of wetland dwelling birds. We will also be able to evaluate potential influences of current high-water conditions on breeding populations of mosquitoes and avian WNV infection rates.

Many wildlife pathogens cause non-lethal physiological and reproductive effects that remain poorly understood. This study will quantify the immunological costs and maternal tradeoffs associated with exposure to a non-lethal antigen. Because female birds allocate essential resources to eggs, exposure to pathogens can shift maternal resources away from reproduction. This seemingly small, non-lethal effect influences the survival of offspring and can therefore cause population level effects in the next generation.

The research conducted for this study will comprise a Ph.D. dissertation. Results will be presented at an American Ornithologist Union conference and will ultimately be submitted for publication to a prestigious peer-reviewed journal.

RESULTS AND CONCLUSIONS

This study is being conducted on several wetlands located within a 5 square mile area of the Missouri coteau region of central North Dakota. The general area is marked with a yellow dot on this slide. Central North Dakota has one of the highest concentrations of yellow-headed blackbirds in North America, as you can see from this distribution map. In addition, the study area has one of the highest numbers of positive avian WNV cases in central North Dakota.

Yellow-headed blackbirds are an ideal species to study maternal tradeoffs between reproduction, self-maintenance, and the influence of WNV for 3 reasons:

The first is that female yellow-heads allocate carotenoids both to their yellow plumage and egg yolks, which will allow me to study carotenoid allocation tradeoffs. Yellow-heads are also a good species because they nest in high-density colonies and have conspicuous, easily accessible nests. And the third reason is that yellow-headed blackbirds nest in stagnant-water wetlands, which are ideal breeding habitats for mosquitoes, making yellow-heads at high risk of WNV exposure.

Yellow-headed blackbird exposure to WNV is being detected by the presence of antibodies specific to the virus in the blood of free-living individuals. A small blood sample is collected from the brachial vein of captured birds for lab analysis. Blood has also been collected from 3 other species in the Icteridae family including: red-winged blackbirds, common grackles, and Western meadowlarks.

To determine differences in carotenoid concentrations in female yellow-headed blackbirds, we will measure carotenoid levels in eggs and feathers of each female. Three yellow feathers will be collected from the breast of each captured female and the third-laid egg will be collected from each study nest. Carotenoids will be extracted from feather and yolk samples in the lab and will be analyzed using chromatography techniques.

Prior to release each female is weighed, measured, and banded with a standard aluminum band and a unique color combination for individual field identification.

We will monitor nests of each female to determine nest success and nestling performance and how differences in WNV exposure and carotenoid levels influences their reproductive output.

In the lab, we are using a blocking ELISA to detect WNV antibodies.

Thus far, we have tested 38 yellow-headed blackbirds, 15 grackles, 2 red-winged blackbirds, and 1 Western meadowlark for WNV antibodies. Only 2 birds were positive, 1 red-winged blackbird and a Western meadowlark.

We were surprised that we did not find WNV antibodies in yellow-headed blackbirds and common grackles. The virus was definitely present in our study area because we were able to detect WNV antibodies in 2 other Icterid species.

We have 2 working hypotheses on what may be occurring:

The first is that WNV is lethal in free-living yellow-headed blackbirds and common grackles. In a recent study by Komar et al., experimentally infected common grackles were shown to have a 33% death rate within 4.5 days of being infected with WNV. Perhaps death rates are closer to 100% in less hospitable natural conditions and that is why we were unable to detect individuals with antibodies. We did not observe large numbers of dead birds, but perhaps infected individuals avoid the breeding colonies where most of our effort has been focused.

Our second hypothesis is that WNV infection rates are low in yellow-headed blackbirds and common grackles. If infection rates are low, perhaps we did not have a large enough sample size to detect WNV infected individuals. This seems unlikely since 1 out of 2 red-winged blackbirds and the only western meadowlark sampled had WNV antibodies. Since all sampled birds were collected within a 5 square mile area, it would seem infection rates were actually high in our study area.

In their study, Komar et al. did not observe any deaths in experimentally infected red-winged blackbirds, indicating that the species is able to survive WNV infection by producing antibodies.

We hope to experimentally infect yellow-headed blackbirds with WNV in captivity to better understand how the species responds to infection. We have collected eggs and feathers from 20 female yellow-heads to study carotenoids, but since they were not infected with WNV we will be unable to study non-lethal WNV effects. If WNV infection is lethal in yellow-headed blackbirds, we may include red-winged blackbirds in our carotenoid research to study non-lethal effects of the virus.

This research is very important because it will provide information on the impact of WNV infection on North American Icterids. No published research has been conducted on a living population of free-ranging birds. North American avian species may experience virus related populations declines if biologists do not act quickly to learn more about the virus. You can see from this slide that yellow-headed blackbird populations in our study area increased by greater than 1.5 percent per year from 1966 to 1996. We have a poor understanding of how WNV will influence future population trends in this and other Icterid species.

The loss of large numbers of yellow-headed blackbirds and common grackles due to WNV infection would have ecological ramifications in the food-web dynamics of the prairie wetlands of North Dakota. Eggs, young, and adult birds of both species are an invaluable food source to predatory birds and mammals.

In addition, WNV induced yellow-headed blackbird population crashes could result in a population explosion of red-winged blackbirds. As the most abundant songbird in North America, red-winged blackbirds cause extensive crop damage in North Dakota annually. Yellow-heads help to control red-winged blackbird numbers by excluding red-wing breeding pairs from their colonies and competing for natural food sources.

WNV induced lethality in different bird species can also influence human health. Those bird species that suffer high death rates associated with WNV have been found to have high viremia levels circulating in their blood streams. They also have the highest probability of passing the virus to a mosquito vector. We believe WNV could be lethal in yellow-headed blackbirds and common grackles because we were unable to detect WNV antibodies in the individuals that we sampled. If the virus is lethal infected individuals may also have high virema levels and act as virus reservoirs. Therefore, further study is needed to test for WNV antibodies and how the virus impacts these 2 species, wetland ecology, and human health. We are very intrigued by our findings and will continue to collect more information on the effects of WNV infection on the Icterids in our study area.

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Comparative Study of Fossil and Extant Fish Growth: Including Analyses of Mean Annual Temperature in the Geologic Record

Basic Information

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Principal Investigators:	Allan Ashworth, G. Padmanabhan

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2. Newbrey, M.G. and M.A. Bozek. 2002. Growth of Esox tiemani of the Paleocene Sentinel Butte Formation of North Dakota with evidence to estimate mean annual temperature. Society of Vertebrate Paleontology 62nd Annual Meeting. Vol. 22.
3. Newbrey, M.G. and A.C. Ashworth. 2003. Fish community dynamics, growth of yellow perch, and correlations with climate and fire in an early Holocene lake in North Dakota. Society of Vertebrate Paleontology 63nd Annual Meeting. Vol. 23.
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6. Presentation: Michael Newbrey, Sept. 23, 2003, Comparative Study of Fossil and Extant Fish Growth: Including Analyses of Mean Annual Temperature in the Geologic Record, ND WRRI Advisory Committee Meeting, Bismarck, North Dakota.

COMPARATIVE STUDY OF FOSSIL AND EXTANT FISH GROWTH: INCLUDING ANALYSES OF MEAN ANNUAL TEMPERATURE IN THE GEOLOGIC RECORD

ND WRRI Graduate Research Fellowship Project
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DESCRIPTION OF THE REGIONAL WATER PROBLEM

It is important to consider the implications of climatic change on surface water resources in light of potential consequences of global warming. North Dakota boasts some of the best long-term data sets in the form of a fossil record to measure the effect of climatic warming on a single population of fish. A fossil lake bed near Jamestown, ND will provide perhaps thousands of years of continuous data of fish growth during a warming climate. This research will provide insight for fishery biologists and wetland ecologists concerning the long-term response of contemporary fish growth in North Dakota given potential climatic changes.

LITERATURE SUMMARY AND PRIOR WORK

Population dynamics have rarely been studied from ancient ecosystems. However, fossils can provide information about growth, mortality, and numerous other ecological processes that have been examined in extant systems (Ricker, 1975). A recent study which detailed the ageing of *Joffrichthys triangulpterus* (Newbrey and Bozek, 2000) scales and the subsequent modeling of their growth provided insight into the population dynamics of an extinct osteoglossid fish (Newbrey and Bozek, In Press). However, there are no contemporary species within the genus *Joffrichthys* to use as a reference for a comparative growth analysis. More recently, I have conducted research with an extinct form of pike (*Esox tiemani*) (Wilson, 1980) and compared its growth to living forms of *Esox* (i.e., northern pike and muskellunge). The research was presented at the 2002 Society of Vertebrate Paleontology meetings and will be submitted to the journal Palaeogeography, Palaeoclimatology, Palaeoecology for publication. The manuscript details a correlation between growth and mean annual temperature and introduces a new procedure to estimate mean annual temperature in the fossil record. Much of the methodology presented in this proposal is derived from my research of pike growth.

Climatological processes strongly influence growth rates of fish. For example, growth can vary depending on aquatic and ambient mean annual temperatures (Gillooly et al. 2002). Air temperature strongly influences surface water temperature (McCombie, 1959; Livingstone and Lotter, 1998) and therefore fish growth. Temperature has a strong influence on metabolic rate (Q_{10} relationship) and growth on ectothermic taxa; a temperature increase of 10°C increases the metabolic rate two to three fold and reaction rates increase 100-200% (Cossins and Bowler, 1987). Our pike research indicates that temperature is correlated with latitude. The pike grow more slowly in the northerly latitudes because of cooler and shorter growing seasons and more quickly in the warmer-longer growing seasons of southern latitudes.

The Fellowship research will focus on a comparative growth of several groups of fish. Specifically, we will contrast growth of fish in the fossil record to that of living fish to determine mean annual temperature change in the geologic record. The analyses are important for fishery biologists and ecologists in North Dakota who are interested in the implications of climatic change on surface water resources and fish. For example, we will study a fossil glacial lake site in North Dakota that has produced fossil specimens of contemporary species of fish. The environment of the fossil lake changed from a cool wet climate with tamarack, black spruce, birch and aspen to a contemporary prairie-pothole region. The change occurred over a period of thousands of years thus giving us insight into ecological processes that are affected by current climate changes.

A site of particular interest in North Dakota represents a glacial, 10,000 year old fossil lake bed containing extremely well preserved fish (yellow perch, *Perca flavescens*), which are still living in ND today. Some of the best preserved Late Wisconsinan/Early Holocene fossils ever reported, come from a 10,000 year-old site (Seibold site) underlying an ephemeral wetland on the Missouri Coteau, near Buchanan, North Dakota. Cvancara et al. (1971) described the geology and paleolimnology of one lake deposit called the Seibold site (SW¼ NW¼ Sec. 21, T141N, R67W), Stutsman County, North Dakota. The Seibold site represents the remains of a small basin (100m in diameter), which was probably part of large lake complex during the Late Wisconsinan/Early Holocene. The site has excellent preservation of terrestrial and aquatic plants and animals, which permits taxonomic assignments of the fossil remains to the generic and specific levels. Study of plant specimens have revealed that the lake was initially surrounded by a spruce-dominated assemblage that was replaced by a mixed assemblage of deciduous trees, shrub, herbs, and grasses (Cvancara et al., 1971). Animals recovered from the site include five species of fish, frogs, muskrat, and evidence of beaver (Cvancara et al., 1971)(see fossils http://www.ndsu.nodak.edu/instruct/ashworth/SEIBOLD.pdf).

The changes in pollen indicate this site is ideal for a long-term study of fish growth in a North Dakota lake, where all data can be gathered in one excavation. During the period of lake sediment deposition, while the climate was warming and the glacier was retreating to Canada, the botanical environment around the lake changed (Cvancara et al., 1971). Fossil pollen indicates that the plant community changed from a forest to prairie ecosystem around 7,500 years ago. As the lake warmed over a few thousand years, measurable change in patterns of growth should be detectable for yellow perch. Numerous studies have modeled growth of individual populations of yellow perch (i.e., Scott and Crossman, 1973; Becker, 1983; etc.) and, in all publications combined, from a variety of latitudes and ambient mean annual temperatures providing a spectrum of growth curves to assemble and analyze. The combined growth curves will provide a correlation between growth and mean annual temperature and thus provide an index to estimate mean annual temperature change in the fossil record. This study site and others in this research will provide insight to fishery biologists and surface water ecologists about the effects of temperature change on fish populations in North Dakota and other areas.

SCOPE AND OBJECTIVES

The overall objective of this Fellowship research is to describe changes in the paleoclimate and fossil fish growth by comparing fossil specimens to extant fish populations. For example, some site-specific objectives include: 1.) to conduct an excavation at the Seibold site near Jamestown, ND to collect fossil yellow perch; 2.) to describe growth of fossil yellow perch; 3.) to compile and analyze contemporary yellow perch growth data in order to contrast growth in relation to the fossils; and 4.) to analyze contemporary yellow perch growth in relation to ambient mean annual temperature in order to calculate a chronological series of estimates of ambient mean annual temperature.

These objectives will be repeated for numerous other localities, represented in museum collections, and containing the following taxa: bowfin, *Amia calva*; the mooneyes and goldeyes of *Hiodon*; and the members of the pikes, *Esox*. These genera are represented in the present North American fish assemblage, in the fossil record from the Cretaceous to the present, and in museum collections.

METHODS, PROCEDURES, AND FACILITIES

Numerous publications contain the information needed to locate specimens (e.g., Grande, 1984; Grande and Bemis, 1998; Grande, 1999; Li et al., 1997; Wilson, 1980, 1981, 1984; etc.) suitable for data. Typically, hard structures (i.e., scales, otoliths, cleithra, fin rays, spines, and vertebrae) from captured fish are aged and growth is calculated using the relation between growth of these structures and fish total length (Van Oosten, 1941; Carlander, 1969). Total length is the distance from the anterior-most tip of the head to the vertical plane of the posterior caudal fin tips. For this study, fossil scales and vertebrae will be aged in the lab and from museum collections by counting annulus marks or light and dark pairs of bands on bones. Fishery biologists use Von Bertalanffy growth curves (Von Bertalanffy, 1938) to assess growth rates. The curve is fit to the maximum total lengths for each age class:

$$TL_t = L_\infty[1-e^{-K(t-t_0)}]$$

where:

TL_t = Total length (cm) at t (age in years);
L_∞ = maximum total length;
K = the Brody growth coefficient;
t = time (i.e., age in years);
t_0 = time at age zero (time at theoretical zero length).

Yellow perch growth data will be taken from Scott and Crossman (1973), Becker (1983), and a list of other sources to contrast extant growth curves. Because male and female yellow perch have different growth rates and life spans all data from extant populations will be combined for both sexes. This is done to standardize error to match that of the fossil material. Site specific mean annual temperature (MAT) data rounded to the nearest 0.1°C will be taken from the WorldClimate© web site and when possible checked for accuracy with Northern Oceanic and Atmospheric Administration (NOAA) data. Ambient MAT will be used in a linear regression analysis and regressed to the natural log transformed total lengths (cm) of age three of yellow perch to obtain a correlation between MAT and growth:

$$\mathrm{Ln}\left(TL_{\mathrm{Age\,3}}\right) = m \times \sqrt{\mathrm{MAT}_E + 10°\mathrm{C}} + b$$

where:

$\mathrm{Ln}(TL_{\mathrm{Age\,6}})$ = natural log transformed total length (TL cm) at 3 years of age;
m = slope parameter of linear regression;
MAT_E = mean annual temperature (MAT) at sites of extant (*E*) populations;
b = intercept parameter of linear regression.

Von Bertalanffy total length will be used because it includes the growth parameters and describes more variation in growth than individual equation parameters alone. Age three total lengths will be used for analysis because this age represents a stable portion of the curve where the effects of the parameters L_∞ and t_0 are reduced while still providing a range of sizes to contrast prior to asymptotic length. To estimate the ambient MAT of the fossil site, the linear regression equation was algebraically rearranged:

$$\mathrm{MAT}_F = \left(\frac{\mathrm{Ln}(TL_{\mathrm{Age\,3}}) - b}{m}\right)^2 - 10°\mathrm{C}$$

where:

MAT_F = mean annual temperature (MAT) of the fossil (*F*) site;
$\mathrm{Ln}(TL_{\mathrm{Age\,3}})$ = natural log transformed total length (TL cm) at age three;

b = intercept parameter of linear regression;
m = slope parameter of linear regression.

ANTICIPATED RESULTS

As the glacial lake matured to a modern pothole wetland and as the climate changed from a cool moist environment to a dry warmer environment there were quantifiable changes occurring in fish growth. Because there is a correlation between ambient air temperature and water temperature within the first meter of depth (McCombie 1959; Livingstone and Lotter 1998), we hypothesize that growth of fossil yellow perch will initially be slow in the cool climate and then increase as the climate warmed. Mean annual temperature change will be modeled from contemporary fish growth by a mathematical relation to temperature. The correlation will then be used to predict mean annual temperature change over a few thousand years. This information will provide a better understanding of evolution of natural processes to biologists studying the pothole region in North Dakota. New climatic information will be of interest to researchers studying changes in temperature and wet/dry cycles. The information and analyses obtained from the glacial lake will be presented at a scientific meeting and will ultimately be submitted to a peer-reviewed journal for publication. The procedures will be repeated for the other taxa of fish being examined in my dissertation in order to better understand relations between changes in MAT and fish growth.

RESULTS AND CONCLUSIONS

We show 1) drought was occurring during the late Pleistocene when other studies have only shown this to be a relatively stable / wet period, 2) during the late Pleistocene and early Holocene fish abundance was negatively responding to drought, 3) fish abundance was described by nutrient levels that also respond to the intensity of drought, and 4) the pattern of post-glacial fish colonization of the Missouri Coteau in ND can be better understood from the description of a warming climate and the life-history characteristics of the fishes. This research provides peer-reviewed analyses and interpretation that will be used in a proposal to the National Science Foundation for further research at the site.

I have been aging yellow perch from the Seibold site to estimate more post-glacial paleotemperatures. However, most of the specimens in the UND collection have degraded or lack substrate depth data to be useful for a fish growth in relation to climate change analysis. A growth analysis will only take place if further funding can be procured for an excavation. I have also identified three additional fish from the site since the original research report in 1970: *Stizostedian*, *Catostomus*, and *Phoxinus neogaesus*. All three taxa are still found in North Dakota today.

This research also addresses the trends in fish movement across latitude and through time. I have constructed the largest fossil fish database to date, which is nearly double the size of previous fish reviews published in 1981 and 1986 and consists of nearly 400 taxonomic entries. Preliminary results are very interesting and suggest that fish dispersal is tracking with climate.

I have completed the datasets and analyses for seven of eight of my 'extant' dissertation taxa. These analyses include the growth of five taxa significantly responding to mean annual temperature. Two taxa do not have enough published data available to analyze. Three of the four species of pikes and yellow perch and goldeye growth significantly respond to temperature. Manuscripts are in progress describing the results at a variety of degrees of completion.

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Modeling Groundwater Denitrification by Ferrous Iron Using PHREEQC

Basic Information

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Principal Investigators:	Scott Korom

Publication

1. Presentation: Tesfay, Tedros and Scott Korom, Sept. 23, 2003,Network of in-situ Mesocosms for Monitoring Denitrification in Selected Aquifers of Minnesota and North dakota, ND WRRI Advisory Committee, Bismarck, North Dakota.
2. Poster Presentation: Tesfay, Tedros and Scott Korom, 2004, Regional Network of in-situ Mesocosms for Monitoring Denitrification Part I: Improving Aquifer Nitrate Vulnerability Assessments, South Dakota 16th Annual Environmental and Groundwater Quality Conference, Pierre, South Dakota.

MODELING GROUNDWATER DENTRIFICATION BY FERROUS IRON USING PHREEQC

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PROBLEM DESCRIPTION

Nitrate is one of the most common groundwater contaminants (Freeze and Cherry, 1979). Nitrate concentrations may be reduced by denitrification, which is a natural process that converts nitrate irreversibly into harmless nitrogen gas (Korom, 1992). Denitrification requires an anaerobic environment, denitrifying bacteria, and sufficient and reactive electron donating species (Firestone, 1982). Korom (1992) indicated that the three common electron donors for denitrification in aquifers are organic carbon, sulfide (usually as pyrite), and ferrous iron. Numerous researchers show that the availability of electron donors within aquifer sediments limits the denitrification potential of aquifers (e.g., Trudell et al., 1986; Robertson et al., 1996). Efforts by members of the UND denitrification research team show organic carbon and sulfide are active electron donors for denitrification in aquifers in North Dakota and Minnesota. We also believe ferrous iron is an active electron donor; however, the geochemical evidence for ferrous iron is more difficult to interpret. To do so requires advanced computational techniques, such as incorporated in the computer code PHREEQC (Parkhurst and Appelo, 1999) produced by the U.S. Geological Survey.

SCOPE AND OBJECTIVES

Denitrification in aquifers involves numerous hydrogeochemical processes with both the water and sediment phases. Theses include dilution, ion exchange, dissolution, precipitation, and oxidation-reduction reactions (Tesoriero et al., 2000). Knowledge of the above reactions will enable us to decipher the denitrification capacity of aquifers, particularly when ferrous iron minerals are involved. Therefore, our objective is to use PHREEQC in order to gain a more comprehensive understanding of the hydrogeochemical environment that governs denitrification by ferrous iron and associated aquifer reactions.

KEY LITERATURE AND PRIOR WORK

Figure 1 shows the seven sites in North Dakota and Minnesota currently being studied by the UND Denitrification Research Team. At each site stainless

Figure 1. The seven in situ denitrification sites (indicated by stars) in North Dakota and Minnesota.

steel chambers partially isolate a portion of saturated aquifer sediments, thereby forming in situ mesocosms (ISMs) of the sediments. Tracer tests are performed in the ISMs and the resulting changes in the groundwater geochemistry provide evidence for denitrification rates and the electron donors involved. Schlag (1999) described how these sites are installed and how the tracer tests are performed. Results from the first tracer test done at the Larimore site (Schlag, 1999) illustrate how results from an ISM tracer test are interpreted.

Figure 2 shows the trends of several major anions during the first tracer test at the Larimore site. Note that the nitrate concentrations decreased at a faster rate than the bromide concentrations. The latter decreased due to dilution with native groundwater during the tracer test. Only the nitrate lost beyond that explained by dilution of bromide is attributed to denitrification. The steep increase in sulfate indicates that sulfide was an electron donor for denitrification. Schlag (1999) showed that about 60% of the denitrification could be explained by the oxidation of sulfide (as pyrite).

□

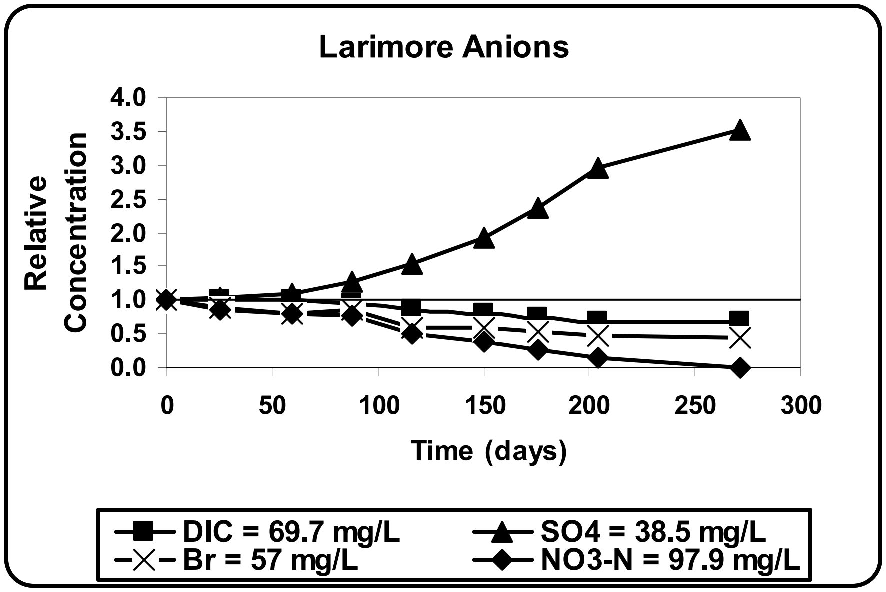

Figure 2. Anion concentrations during the first tracer test at the Larimore site. Initial concentrations are given in the box at the bottom of the figure.

Schlag (1999) also showed that organic carbon was likely responsible for most of the remaining denitrification observed. This process is illustrated by noting the decreasing dissolved inorganic carbon (DIC) concentrations in Figure 2 and the steep loss of calcium and magnesium in Figure 3.

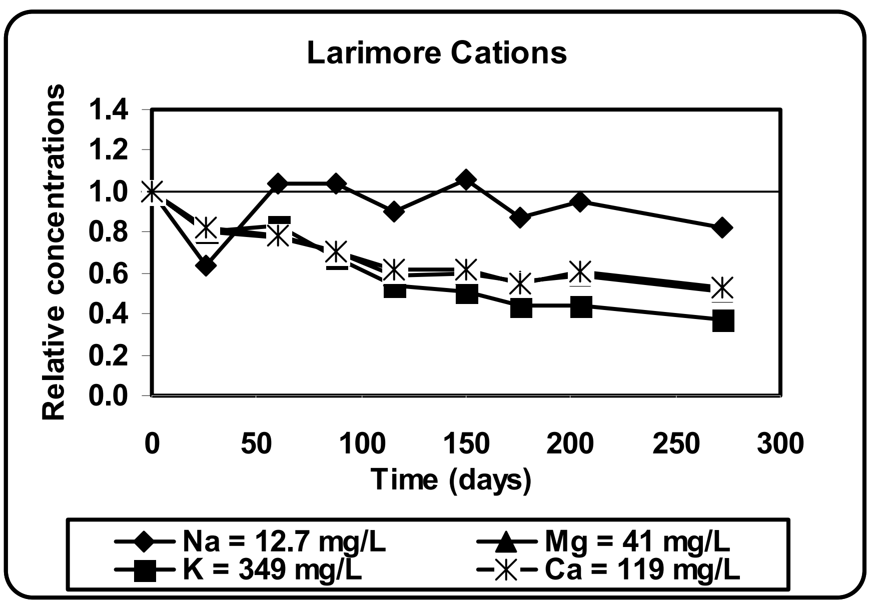

Figure 3. Cation concentrations during the first tracer test at the Larimore site. Initial concentrations are given in the box at the bottom of the figure.

The calcium and magnesium concentrations in Figure 3 should have behaved like the sodium concentrations, that is, they should have stayed near a relative concentration of 1. However, calcium and magnesium dropped much like potassium. The latter should have dropped because the nitrate and bromide added to the groundwater for the tracer test were added as potassium species, so the potassium should have decreased by dilution, as did the nitrate and bromide concentrations. Some other process is responsible for the loss of calcium and magnesium.

Denitrification by organic carbon produces inorganic carbon. We expected DIC to increase in Figure 2. It would have, except the increase in inorganic carbon was masked by the precipitation of a magnesium-rich calcite ($CaCO_3$). Therefore, we have these two patterns for denitrification by organic carbon:

1. an increase in DIC, or
2. a decrease in divalent cations (calcium or calcium and magnesium) and a decrease in DIC.

Previously, we showed that denitrification by sulfide causes an increase in sulfate.

We see these patterns at five of the seven ISM sites. Therefore, organic carbon and inorganic sulfides play a major role in the denitrification at these sites. However, these electron donors do not account for all the nitrate lost at some of the five sites. Furthermore, the reaction products for denitrification at the remaining two sites (Robinson, ND and Akeley, MN) do not reflect the involvement of organic carbon and sulfides at all. Our hypothesis is that ferrous iron is the major electron donor causing reduction of nitrates in the latter two aquifers and may also be involved to a lesser extent at some of the other five sites, as well.

METHODS, PROCEDURES AND FACILITIES

Dentrification reactions may involve many complex geochemical processes. Interpreting and understanding the processes may require computer models that incorporate multiple parameters for the participating processes and are able to solve the resulting nonlinear equations (Appelo and Postma, 1996). PHREEQC (Parkhurst and Appelo, 1999), which is one of the most advanced geochemical computer codes, will be used for the research. This code calculates the composition of a water sample at thermodynamic equilibrium by solving the mass balance and mass action equations.

To understand the controlling geochemical reactions that account for the observed denitrification results, batch-reactions that incorporate both equilibrium and kinetic reactions and inverse modeling will be invoked. Input files for the modeling will incorporate geochemical data of the native groundwater and the amended water from the tracer tests, as well as mineralogical data of the aquifers. Fortunately, substantial amounts of aqueous geochemical data for the tracer test have already been collected. These include major anions, major cations, pH, temperature, dissolved organic and inorganic carbon concentrations, and many tracer elements. Sediment data collected include inorganic sulfide and organic carbon concentrations. Additional water and sediment analyses are planned, particularly to quantify ferrous iron contents of the sediments. Analytical instruments at the UND Water Resources Research Laboratory and the x-ray diffraction machine in Geology & Geological Engineering will be used for the analyses. Finally, modeling output will be compared with the field and laboratory results in order to validate both the numerical procedures as well as the hydrogeochemical reaction schemes.

RESULTS AND CONCLUSIONS

This research will provide insights into denitrification by ferrous iron. It is expected that the modeling results will support our hypothesis that ferrous iron is the major electron donor for denitrification at the Robinson and Akeley sites. We also expect to show that ferrous iron is also involved to lesser extents at some of the other ISM sites where sulfide and organic carbon are known to be the major electron donors for denitrification.

Funding has been secured to repeat the tracer tests at the ND sites. A proposal is in review to repeat the tracer tests in the MN ISMs. In total, over $500,000 in funding and in-kind match has already been provided for our denitrification research. All data will be available to us for further investigation. Preliminary interpretations of all the completed tracer tests have been done. In addition, PHREEQC has been shown to be effective in interpreting the denitrification reactions in the ISMs during the tracer tests

NO_3^- lost unaccounted by the common e- donors, OC and IS, range from ~ 40 to 95 %.
Data collected already include:
- Analytical data of all the sites (from previous studies)
- Texture analyses of some of the samples
- TOC analyses of some of the samples
- IS analyses of some of the samples

.
Data to be analyzed in the near future
- Ferrous and total iron analyses
- Mineralogy (XRD) and CEC measurements of aquifer sediments

Fe (II) that participates in the reduction of NO_3^- is Fe (II) dissolved and ion-exchangeable (*digested in 1 M neutral salt, $CaCl_2$*)
Fe (II) in amorphous form (*digested in 0.5 M HCl*)
Fe (II) in crystalline forms (*digested in hot 5 M HCl*)
Fe (II) and total iron will be analyzed in Hach DR2010 spectrophotometer using the required reagents

Finally, modeling output will be compared with the mineralogical data (XRD) and analytical results in order to verify both the numerical procedures as well as the hydrogeochemical reaction schemes.

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A Study of Microbial Regrowth Potential of Water in Fargo, North Dakota and Moorhead, Minnesota

Basic Information

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Principal Investigators:	Khan Eakalak

Publication

1. Poster Presentation: Museus, T. and Khan, E.,April 27-29, 2004, Microbial Regrowth Potential of Water in Fargo, North Dakota, and Moorhead, Minnesota, Surface Water Treatment Workshop, Moorhead, MN,sponsored by MNAWWA, NDAWWA, SDAWWA, and Moorehead Public Service. Won first prize poster competition.

A STUDY OF MICROBIAL REGROWTH POTENTIAL OF WATER IN FARGO, NORTH DAKOTA AND MOORHEAD, MINNESOTA

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Fargo, ND 58105

BACKGROUND

In recent years, water quality scientists and engineers have emphasized on the biodegradability of dissolved organic matter in both raw and treated waters. This is because the biodegradable organic matter (BOM) in treated water can induce the growth or regrowth of microorganisms in the distribution system of drinking water. Residual BOM is usually the most important limiting factor responsible for bacterial regrowth in the water distribution system (Rittmann and Snoeyink, 1984). One of the most effective methods in controlling the bacterial growth in the distribution system is to limit the amount of BOM required for the growth of heterotrophic bacteria in treated water (Servais *et al.*, 1993). Water containing BOM less than a minimum concentration that supports the bacterial growth is usually biologically stable.

BDOC has been used as one of the parameters for quantifying the amount of BOM in water. Servais *et al*. (1989) defined BDOC as the fraction of dissolved organic carbon (DOC) which can be metabolized by bacteria within a period of time. The BDOC test measures the reduction of DOC in a water sample, which is exposed to microorganisms in a period of time (Servais *et al.*, 1987 and 1989). The first BDOC measurement was introduced by Servais *et al*. (1987). It was developed as a batch procedure. A mixed microbial culture from the same environment as the sample was used as an inoculum. Incubation occurred in the dark at 20 ± 0.5°C for a period of 10 to 30 days, and the BDOC was determined by the difference between the initial and final DOCs.

The first BDOC procedure was used specifically for testing the quality of raw water and for designing and monitoring, and optimizing operating conditions of biological activated carbon (ozonation + granular activated carbon) systems. Occasionally, it was used to examine the BDOC removal of other treatment processes such as coagulation and filtration. Interest in BDOC of finished water started to grow when BDOC was linked to the microbial proliferation in the distribution systems. As a result, BDOC is a widely used parameter in the drinking water field.

An alternative to the BDOC procedure called AOC, was invented by van der Kooij *et al*. (1982). AOC is the portion of the organic carbon that can be synthesized to cellular material by a single bacterial strain. In the AOC determination method, a preheated water sample is seeded with a pure strain of *Pseudomonas fluorescens* P17. The sample is incubated at 15°C, and bacterial growth is monitored daily by colony counts (spread plate techniques) until the maximum growth is reached. The incubation period (the number of days to reach the maximum yield) can be from 3 to 30 days depending on the type of the water sample. By concurrently determining the growth yield of bacteria in solutions of known acetate concentration, the maximum growth can be converted into AOC and expressed as μg of acetate-C equivalents/L.

van der Kooij (1987) and van der Kooij *et al*. (1989) included a *Spirillum* strain, NOX, into the procedure as an alternative seed or a dual strain seed due to the inability of *Pseudomonas fluorescens* P17 to metabolize oxalic acid, which is one of the products frequently formed during ozonation. Unlike BDOC, AOC only accounts for the organic carbon used for cell synthesis. Since the AOC test measures cell growth of a single or dual strain, the test does not guarantee that all the assimilable carbon is measured. The inoculum may not be capable of metabolizing all contaminants. Therefore, the reported AOC value is normally less than the reported BDOC value for the same sample. The AOC method has been widely adopted when the regrowth is a concern.

BDOC has also been related to the regrowth of microorganisms. High BDOC in finished water indicates poor quality and a potential of microbial multiplication. Maintaining a free chlorine residual to prevent the regrowth along the distribution system is a common solution; however, a large amount of chlorine is required. Also, chlorine residual cannot completely inactivate fixed bacteria (Le Chevallier *et al.*, 1988). Controlling microbial dynamics by limiting available substrate (BDOC) is a new and interesting approach (Rittmann and Snoeyink, 1984, Huck, 1990, and Servais *et al*., 1993). Biologically stable water should contain less than 0.15 mg of BDOC/L. At this threshold level, microbial growth is very limited (Servais *et al.*, 1993).

In order minimize AOC and BDOC in finished water, some water treatment plants employ biological filtration in their treatment trains. The biological filtration usually consists of ozonation and filtration. The purpose of ozonation is to destruct complex organic to simpler molecules which can be used by microorganisms in the filter. For some treatment plants, the ozonation portion of the biological filtration also serves as primary disinfection, and taste and odor control. Increases in BDOC and AOC after ozonation have been well documented (Janssens *et al.*, 1984, Servais *et al.,* 1987, and Volk *et al.*, 1993). The BDOC and AOC increases during ozonation are removed in the filter which contains media (activated carbon or sand) covered by attached microorganisms (biofilm).

DESCRIPTION OF THE CRITICAL STATE OR REGIONAL WATER PROBLEM

BDOC and AOC have been used to examine the regrowth potential of water throughout the world. Furthermore, AOC is included in the latest *Standard Methods* (1998). However, the regrowth potential of water in Fargo, North Dakota and Moorhead, Minnesota has never been evaluated; BDOC and AOC values of water in Fargo and Moorhead have not been reported. The ultimate goal is to minimize the concentrations of these two parameters in treated water provided by the Fargo and Moorhead water treatment plants which in turn will benefit public health by limiting the number of microorganisms in tap water. Collecting BDOC and AOC data is a first step to achieve the ultimate goal. The data will also indicate the degree of susceptibility of drinking water of Fargo and Moorhead to microbial proliferation.

It is crucial that BDOC and AOC of water in Fargo and Moorhead are studied because of the nature of high total organic concentrations in the influent and effluent and the use of ozonation at both treatment plants (Figure 1). BDOC and AOC tend to be high with these two conditions. The influent (from the Red River for the Fargo plant and the Red River blended with groundwater at 85%:15% for the Moorhead plant) and effluent total organic carbon (TOC) concentrations at both plants are sometimes as high as 8 to 10 mg/L and 1 to 2 mg/L, respectively. BDOC is a portion of total organic concentrations. Although water with high total organic concentrations does not necessarily contain large amounts of BDOC, positive linear relationships have been frequently observed between the two parameters (Servais *et al.*, 1987 and Khan *et al*. 1998b). As stated previously, ozonation of water with organics results in BDOC and AOC increases and their removal relies on the performance of subsequent treatment which normally is filtration. Currently, BDOC and AOC removal abilities of the filtration units at the Fargo and Moorhead plants are not known because the two parameters have not been measured.

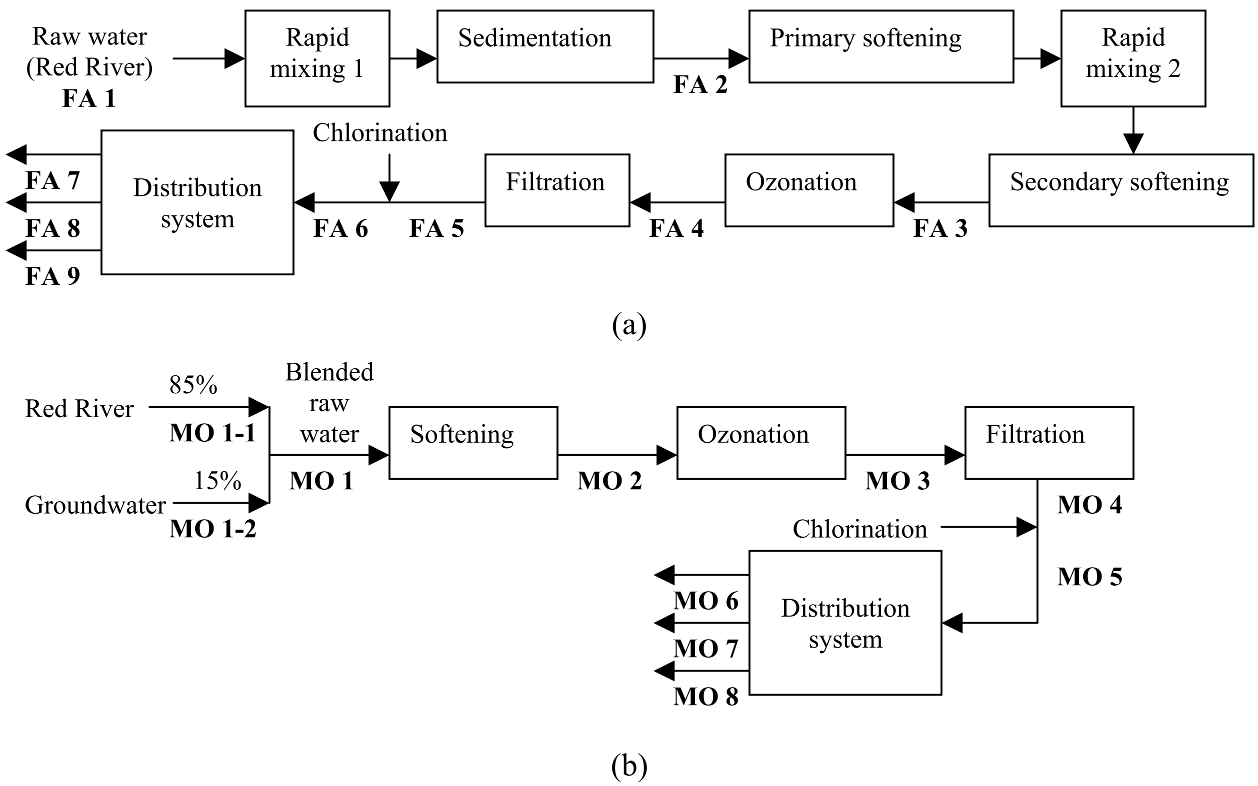


Figure 1 Simplified schematic diagrams for (a) the Fargo Water Treatment Plant and (b) the Moorhead Water Treatment Plant.

SCOPE OF STUDY AND OBJECTIVES

The main scope of this study is to collect BDOC and AOC data of water in Fargo and Moorhead in order to achieve the following objectives:

1) To evaluate the microbial regrowth potential of water especially finished water and tap water,
2) To predict the regrowth occurrence in the distribution systems by comparing AOC and BDOC in finished water and those in tap water, and

3) To compare BDOC and AOC removal of the Fargo and Moorhead plants which are different mainly in the presence and absence of the rapid mixing-sedimentation process.

METHODOLOGY

Sampling programs

From March 1, 2003 to February 28, 2004, one set of water samples will be collected weekly from each of the treatment and distribution systems of Fargo and Moorhead. The one full year sampling program is designed to observe the possible effect of season on the regrowth potential. Each set will consist of samples from different locations starting from raw water to tap water. The tap water samples from each plant will be collected from three locations that are different in distribution distances (short, medium, and long). Table 1 shows sample identification and collection locations for both water systems. The collection locations are also listed in Figure 1.

Parameter tested

Each sample will be analyzed for pH, ultraviolet absorbance at 254 nm (UV_{254}), TOC, DOC, BDOC, and AOC. UV_{254} is used to relatively measure the amount of organic compounds that are aromatic in structure or have conjugated unsaturated bonds. It is known that a decrease in UV_{254} indicates less refractory organics (more BDOC).

Table 1 Sample identification and collection locations.

Fargo water systems		Moorhead water systems	
Sample no.	Sampling location	Sample no.	Sampling location
FA 1	Raw water (Red River)	MO 1	Blended raw water
FA 2	After sedimentation	MO 1-1	Raw water (Red River)
FA 3	After secondary softening	MO 1-2	Raw water (Groundwater)
FA 4	After ozonation	MO 2	After softening
FA 5	After filtration	MO 3	After ozonation
FA 6	After chlorination (treated water)	MO 4	After filtration
FA 7	Tap water 1	MO 5	After chlorination (treated water)
FA 8	Tap water 2	MO 6	Tap water 1
FA 9	Tap water 3	MO 7	Tap water 2
		MO 8	Tap water 3

Analyses

pH will be measured using a pH meter (Orion model SA520). UV_{254} will be determined following the procedure listed in *Standard Methods* (1998), using a spectrophotometer (Thermo

Spectronics model Genesys 10 UV Scanning). TOC and DOC will be analyzed according to the procedure described in *Standard Methods* (1998), using a TOC analyzer (Tekmar-Dohrmann model Phoenix 8000). For DOC analysis, the sample will be filtered through a glass fiber filter (Whatman, GF/F) prior to TOC determination. BDOC will be evaluated in accordance with a modified protocol by Khan *et al.* (1998a) which is simpler and more accurate than the original method (Servais *et al*., 1987). AOC will be determined according to *Standard Methods* (1998).

FACILITIES, EQUIPMENT AND INSTRUMENTS

Facilities

This research will be conducted mainly in the Environmental Engineering laboratory facilities of the Department of Civil Engineering and Construction, North Dakota State University. The main laboratory facility occupies about 2,650 square feet of the second floor of the Civil and Industrial Engineering Building. An additional laboratory with an approximate area of 240 square feet is located on the first floor of the Engineering Technology Building. These two facilities have general apparatus (glassware) basic support services (gas, water, air, fume hoods, distilled and deionized water). Included in the main facility are offices for research assistants and storage spaces.

Laboratory equipment and instruments

The facilities contain most basic instruments and are well-equipped for conducting the proposed research. Examples of the basic instruments available are turbidimeters, pH meters, dissolved oxygen (DO) meters, ozone generators, a respirometer, phase contrast microscopes, conductivity meters, ion selective probes, vacuum pumps, ovens, furnaces, incubators, an autoclave, centrifuges, balances, refrigerators, water baths, cooling units, distillation and digestion systems for chemical oxygen demand (COD), nitrogen, and phosphorus analyses. Available major instruments in the main facility include a purge and trap gas chromatograph, with a mass selective detector (GC/MSD), two scanning UV-VIS spectrophotometers, and a TOC analyzer.

RESULTS AND CONCLUSIONS

The scope of the research is to monitor biodegradable dissolved organic carbon (BDOC) and assimilable organic carbon (AOC) for the Fargo and Moorhead water treatment plants and the distribution system associated with each plant. The plants are sampled once every other week for one year. The samples are taken from all of the process of each plant from raw water to finished water and three points along the distribution system. The points along the distribution system are selected based upon the estimated amount of hydraulic residence time that the water is in the system. BDOC and AOC are important because are they represent the amount of natural organic matter (NOM) that can be utilized for microbial growth. The growth of microorganisms in the water supply system can have many negative effects, such as taste and odor problems, reduced hydraulic capacity, pipe corrosion, and adverse human health impact. The unique aspect of the research is that the effect of seasonal variations on the parameters has not been investigated for the type of climate that the cities of Fargo and Moorhead experience.

This research will greatly benefit the water treatment facilities and public health because it will indicate how biologically stable the water in Fargo and Moorhead is. If the finished water produced by the Fargo and Moorhead plants has high regrowth potential (containing high BDOC and AOC), first it has to be known and then studied in more detail on strategies to minimize BDOC and AOC which will help to protect water consumers more from possible microbial contact that may cause adverse health effects. Furthermore, the results of this research will indicate whether blending the Red river water with groundwater as practiced at the Moorhead plant and the rapid mixing-sedimentation process used by the Fargo plant have any effect on BDOC and AOC in finished water.

Literature reviews have been performed to learn background information about the topic. The background information that has been reviewed assisted in the experiment design and processes that need to be followed. Preliminary testing has been performed and results of the BDOC analysis can be seen in Figures 1 and 2 below. The preliminary AOC data are not available due to problems with the test method. The test method for AOC is very meticulous and leaves a lot or room for error and contamination. The problems that occurred have been corrected and I am confident that the results will be correct in the near future. The data shown in Figure 1 suggest that there is an increase in BDOC through the treatment processes. Looking specifically at the values for the clear well and the Holiday Inn a decrease in BDOC concentration is noticed. The decrease in the BDOC concentration suggests that regrowth is occurring in the distribution system between the treatment plant and the Holiday Inn. The airport and NDSU samples show that no regrowth is occurring in this portion of the distribution system. Figure 2 shows the BDOC values for the treatment process at the Moorhead water treatment plant. The BDOC increases sharply after ozonation, which is expected. The degradation of large molecular weight compounds into smaller, more readily degradable compounds occurs increasing the amount of BDOC in the water. The BDOC values decrease after filtration because when the samples were taken the filters were still biologically active; therefore the microorganisms on the filter utilized some of the BDOC as substrate. Distribution system samples results are not available for the Moorhead distribution system due to an error with the data collection and file saving on the TOC machine. The data was lost.

Figure 1: BDOC, Fargo Water Treatment Facility

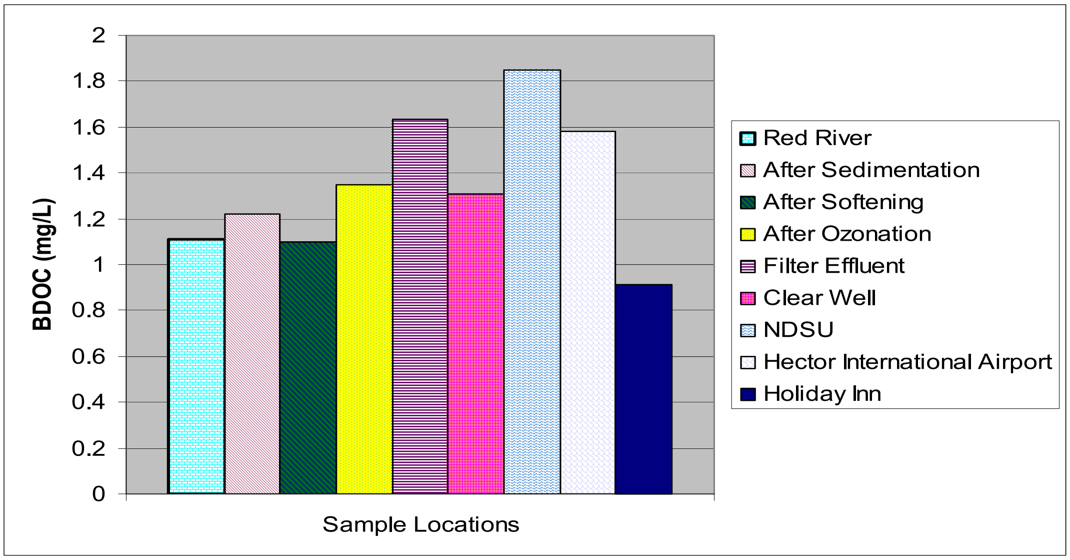
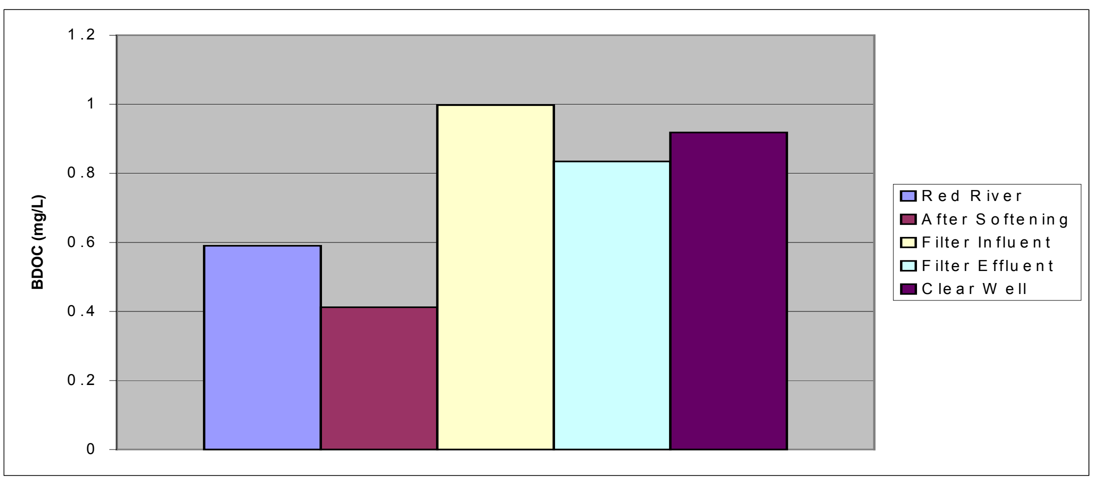


Figure 2: BDOC, Moorhead Water Treatment Facility



APPENDIX

RAW DATA FOR FARGO WATER TREATMENT PLANT AND DISTRIBUTION SYSTEM.

Fargo Water Treatment Plant **Date:11/9**

Sample Locations	DOC_i	DOC_f	BDOC	Average BDOC (mg/L)	TOC (mg/L)	UV adsorbtion	pH
Blank	0.0489	1.718	N.A.		N.A		
Clear Well	4.7655	5.1633	1.2713		4.6959	0.058	9.03
Clear Well	4.7092	5.0292	1.3491	1.3102	4.6979	0.06	9.03
Airport	4.7474	4.867	1.5495		4.557	0.058	9.39
Airport	4.9099	4.9707	1.6083	1.5789	4.5637	0.058	9.39
NDSU	N.A	N.A	N.A.		4.4621	0.051	9.13
NDSU	5.0957	4.9164	1.8484	1.8484	4.3287	0.05	9.13
Holiday Inn	4.7826	5.6654	0.7863		4.6157	0.061	9.35
Holiday Inn	4.7468	5.3717	1.0442	0.91525	4.5923	0.061	9.35
Filter Effluent	4.7599	4.9121	1.5169		4.5141	0.044	9.54
Filter Effluent	5.0096	4.925	1.7537	1.6353	4.4926	0.044	9.54
Filter Influent	4.8427	4.9996	1.5122		4.4709	0.043	9.71
Filter Influent	4.5906	5.0784	1.1813	1.34675	4.4755	0.046	9.71
After Softening	4.998	5.4924	1.1747		4.9018	0.07	9.87
After Softening	4.9153	5.5666	1.0178	1.09625	4.9116	0.072	9.87
Sedimentation	7.8424	7.9938	1.5177		7.8144	0.156	8.93
Sedimentation	7.8065	8.5546	0.921	1.21935	7.8798	0.162	8.93
Red River	7.9415	8.3056	1.305		7.7737	0.158	8.88
Red River	7.7617	8.5099	0.9209	1.11295	7.7554	0.153	8.88

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Information Transfer Program

Information transfer is done through an annual newsletter initiated in 1992, a website initiated in 1999, and presentations and publications by grant and fellowship recipients. The Institute's website address is www.ce.ndsu.nodak.edu/wrri. The newsletter is usually issued in the month of December of each year. Copies of past newsletters can be obtained by writing to the Director. Again this year, the institute continued its modest support of the Biotic Resources Seminar Series at North Dakota State University. Also it co-sponsored a regional conference with a non-profit organization, Red River Basin Institute, located at NDSU campus. Brief descriptions of both are given below:

NDWRRI continues to help support the NDSU Biotic Resources Seminar program, which has brought 66 biologically-oriented speakers to campus since 1987. Under this multi-disciplinary program, visiting scientists are invited and hosted by faculty and graduate students from several departments in the Colleges of Agriculture and Science and Mathematics. Seminar topics range widely, with the common thread being organismal/environmental biology in the broadest sense. Examples in this period include 'Flood Plains Dynamics in a River Continuum' and 'Life in a Dynamic Floodplain River: The Tagliamento River, NE Italy',and 'Damselfliesand Water Mites: Investigation of Host-Parasite Interactions in aquatic Ecosystems.' NDWRRI seed money had helped to leverage other support for this program from the NDSU Cooperative Sponsorship Committee, ND EPSCoR, and the colleges and departments of the hosts. Students, staff, and faculty from across campus attend these seminars and the associated informal gatherings. The program thus stimulates networking within campus in addition to informing NDSU researchers about studies conducted by colleagues from other institutions.

A new initiative on the part of the NDWRRI started this year in terms of information transfer was to work closely with the Red River Basin Institute, Fargo in developing water research agenda and information dissemination projects.

NDWRRI co-sponsored a conference, First Red River Basin International Conference on Water, April 23-24, 2003, Fargo, ND with the main sponsor, the Red River Basin Institute, Fargo, ND. More than sixty papers were presented from Canada and the United States on the Red River basin water issues. About 350 participants from Minnesota and North Dakota; and from Manitoba, Canada attended the conference. Next conference is scheduled for January 2005.

Among other projects, ND WRRI also worked with the Red River Basin Institute to co-sponsor an information network on the World Wide Web titled "RED RIVER BASIN DECISION INFORMATION NETWORK (RRBDIN)" at NDSU campus.

http://www.rrbdin.org/

Another initiative is to work with the Energy and Environmental Research Center (EERC) of University of North Dakota. THe Director of the ND WRRI is currently serving in the advisory team of one of the major water projects the EERC is working on called Waffle project.

Student Support

None

Notable Awards and Achievements

Publications from Prior Projects