Report for 2002ND17B: Study of Effectiveness of Northern Prairie Wetlands as a Resource to Control Nutrient (Phosphorus) Load to Receiving Water.

There are no reported publications resulting from this project.

Report Follows:

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
Wei Lin, Advisor and Principal Investigator
Civil Engineering and Construction Department
North Dakota State University
Fargo, ND 58105

Abstract

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. 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.

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.

Timeline:

The project will begin in September 1, 2002 and will be continued as the student's Ph.D project till completion. The student will work on the project supported by the ND Water Resources Research Institute Fellowship through February 28, 2003. Depending on the performance of the student in the project, the Fellowship may be continued in subsequent years.

Methods, procedures, and facilities:

Hydraulic loading: Hydraulic loading and flow pattern affects the phosphorus retention capacity of the wetland. Low flow wetlands observed high P retention capacity as compared to high flow wetlands (Mitsch *et al*., 1995). This is possibly due to high hydraulic retention time in low flow condition. Adler, 1995 observed the effect of flow pattern on P removal and wetland productivity. Also observed that nutrients removal is maximal near the inlet and controls the retention capacity of the wetland.

Wetlands get hydraulic inputs from the atmosphere, surface runoff, stream flow, ground water flow, or combination of these inputs. Hydraulic loading consideration for a wetland involves careful evaluation of all inputs which primarily affects the productivity and health of a wetland.

The surface runoff reaches a particular wetland either through sheet flow (non-point source; NPS) or collected channelized flow. Discharge from the watershed contributing these flows to the wetland may be estimated using an integrated watershed approach within GIS environment. Use of either a " modeling-within" or "linked-model" approach similar to those used in non wetland studies may be possible for estimating NPS loading to wetlands (Karen *et.al*., 1995]. This use of coupled model-GIS approach has the potential to provide a general method for estimating NPS pollution potential or loading rates to wetlands and to link such information to the spatial characteristics in a watershed. Such an approach also would allow for the consideration of many more wetlands than site-specific nutrient budget studies [Karen et al. 1995]. In the studied wetlands, change/stop in agricultural practice and land use, change in ground water table through hydraulic structures may affect the NPS pollution load from the watershed which can be better addressed by this linked model simulation.

Groundwater: Lack of a subsurface component in a model constitutes a serious limitation for use in large areas of the Midwest and eastern North America where many wetlands are groundwater discharge areas (Carter 1986). There are limited wetlands where input ground water values are possible to measure as wetlands occupy a typical position with respect to ground water. So it requires an integrated use of several different methods. Shaw et al. (1990) used Darcy's equation with data from piezometers and water table wells, major ion concentrations, and environmental isotopes (deuterium and 18O), along with a simulation model to quantify P fluxes to a Canadian lake that lacked defined drainage pattern. The model will be developed including a subsurface flow component.and simulated values may be evaluated with site measured values.

Phosphorus in Wetlands: Data on total phosphorus supply to northern prairie lakes in Canada indicate that these lakes are eutrophic but the data on total phosphorus supply to wetlands and lakes within prairie of the United states are rare. Most of the data is for concentration of soluble reactive phosphorus. Barcia (1975) determined that soluble reactive phosphorus fluctuates considerably on a seasonal basis in prairie lakes and wetlands. Even with these data, it indicates that many of the wetlands in South Dakota (Petri and Larson 1973) are eutrophic. In these studies, the concentration of soluble reactive phosphorus was greater than 0.020 mg/l, considered the lowest concentration for eutrophic condition. Phosphorus data are not available in North Dakota, however a study done by

LaBaugh *et al*. 1987 indicates that the wetlands are eutrophic. Hardly any data exists for eutrophic conditions of wetlands in Minnesota. P can be an active part in the compartments such as soil sediment, overlying water column, interstitial soil water, various types of live biomass, standing dead biomass, litter and dry deposition and its content in these compartments may be studied to incorporate into the model describing the concentration/ transport of Phosphorus in a wetland system. The kinetics of P transport in these individual compartments has got an effect on the phosphorus retaining capacity of the wetland. In addition to agricultural runoff, phosphorus fixed in the sediments may be released to the water column as a result of microbial activities in the sediments (Lin and Nustad, 2000; and Nustad 2001). The impact of temperature on CO_2 solubility results in seasonal variation of water pH in wetlands. This pH variation affects the solubility of phosphorus compounds and therefore phosphorus concentrations in wetlands (Richardson and Bigler, 1986; and Freeland *et al.,* 1999). P interaction in the wetland ecosystem may be described as follows.

Sedimentation: Mitsch *et al*., (1995) has observed that most P is retained through sedimentation with some capacity for P retention by macrophytes and a lesser amount by microbial epiphyte and planktonic communities. Low water flow through velocity in the wetland enhances sedimentation of nutrients. The P in the sediments eventually gets into the water column through resuspension. Prescott (1997) has observed about 57% of P contribution to the water column comes from resuspension. Soil sorption may provide initial removal, but this partly reversible storage eventually becomes saturated

Plant uptake: Hydrogeologic setting and chemical characteristics of water in prairie wetlands result in aquatic plant communities that are very diverse. Plant communities change in response to changes in water level (van der Valk 1981). The length of time a prairie pothole contains water and the salinity of water affect the type and composition of vegetation in prairie potholes (Stewart and Kantrud 1972). The plant uptake provides short to long term retention of P depending on rate of leaching, translocation to and from storage structures. The type of plant developed in the restored wetland depends on water level fluctuations, soil organic carbon content, soil bulk density, surface water pH, alkalinity, conductivity, ca and Mg concentration (Galatowitsch *et al.,* 1996).

Litter decomposition: Changes in water level can affect N and P concentrations in wetlands due to decomposition of macrophyte vegetation (Kadlec 1986). This is explained sometimes by the soluble reactive P (SRP) in wetlands and has got a control on the P balance in the wetlands. Losses of plant material from standing dead macrophyes occur primarily due to fragmentation of the plants in winter and springs. Additional losses of plant material results from toppling of standing dead material that decomposes when submerged in the spring. This litter material is found to release N and P between May and June. This process could add N and P to the water in the wetlands during spring.

Microbial processes: Microbial action on the phosphorus transformation is an important aspect in the P cycle in the wetland. Kinetics of such transformation may be taken into consideration for study of P dynamics in wetland. Investigation of the biological processes affecting seasonal changes in conc. of nutrients in prairie wetlands and lakes are rare (van der Valk *et al.* 1979; Davis and van der Valk 1983).

Research site:

Three wetland sites have been selected based on the land use history and age of restoration carried out at the sites. These sites are located in the Hamden Slough National Wildlife Refuge in western Minnesota. One wetland group is situated at north of Bisson Lake and discharge to the lake. The two other wetland groups (straight ditch area) are situated at central part of the refuge and flows to another lake. The north of Bisson Lake site was historically range land whereas the straight ditch site was an agricultural land and the former site was restored in 1991 and the later one recently.

The task of the study will include analysis of existing data, field sampling and water quality modeling. Water quality modeling will help simulate future scenarios of nutrient (Phosphorus) transport. We need to monitor the water flow, both surface and ground water, into and out of the wetlands.

Modeling: The flow and phosphorus transport models in these types of wetland complexes will be developed. The main model may be interfaced with submodels to account for groundwater flow and quality, non-point source pollution. These models can be interfaced with GIS and digital elevation models of the topography which I have been working with. A GIS database need to be assembled.

Water quality modeling activities for this study will include

- i) evaluation of available water quality models/softwares;
- ii) formulation of mass balance and kinetic relationships for phosphorus simulation or prediction.
- iii) collection and compiling geographical, water flow and water quality data, and other pertinent data;
- iv) model development and calibration.

Flow monitoring: Both surface and subsurface flow contribute to the wetland complex under study. We need to measure or estimate the surface inflow and outflow. There is a shallow aquifer system beneath the wetland area and considerable leakage from this aquifer into the wetlands takes place. We need well piezometer monitoring system to estimate it. From May 2002 to October 2002, two measurements will be taken each month. The water monitoring data will be evaluated to determine surface water and groundwater flow rates, relationship between groundwater and surface water, and variations of water flows. The water flow and water level monitoring events will be arranged to coincide with water quality sampling to provide data for water quality modeling.

Water and Sediment sampling: Surface water and sediment samples will be carried out in the selected wetlands. Water samples will be taken at upstream and downstream of each wetland, and over some transects. Water samples will be taken twice a month from May 2002 till Oct., 2002. During each sampling event, water temperature, DO, pH, turbidity, and electrical conductivity will be monitored on site. Water samples will be preserved and taken back to NDSU for analysis of plant available phosphorus, total phosphorus, total and inorganic carbon, particle sizes, total and volatile suspended solids, and chlorophyll *a*. During the frozen season, water samples will be taken below ice level.

Two sediment samples from each wetland will be collected in May 2002. These samples will be analyzed for total phosphorus, plant available phosphorus, and calcium carbon equivalent. Since no sediment characteristic change is expected during the one-year sampling period, sediments will be sampled only once. Groundwater phosphorus concentration will be estimated through the mass balance analysis of phosphorus and model simulations.

Plant sampling: Potential biotic pools of wetland phosphorus include macrophytes, algae (phytoplankton, and metaphyton), invertebrates and vertebrates (fish and amphibians). Zimmer et al.

(in press) found wetland macrophytes to contain large quantities of phosphorus assimilated from the sediments, while other biotic pools were small. Monthly during the summer of 2001, macrophytes biomass will be quantified at two stations in each of the three wetland sites by cutting, drying, and weighing all above-sediment plant material inside 3 random, 0.25 m^2 quadrants (Filbin and Barko 1985). One station will be in the center of each wetland to sample submergent macrophytes in open water (if present); the other will be within the zone of emergent vegetation. Dried plant materials will be analyzed for phosphorus content to determine grams of phosphorus per m^2.

Research underway:

Soil (core and bag) samples are taken for determining the profile of phosphorus concentration and other compounds along transects of the wetland. The soil samples are being analyzed in Soil Science Laboratory, NDSU. The soil sampling completed at one site (wetlands north of Lake Bisson) and is underway at other two sites.

Preliminary water sampling completed and analyzed for basic water quality parameter including phosphorus. Further sampling and data acquisition will be done after the model development for Phosphorus.

The area was surveyed using GPS and level for preparing topographic map which will be used to asses the non-point source flow to these wetlands.

Literature review and evaluation of existing models are in progress. The model development for studying the phosphorus transport in these types of semi-permanent wetlands needs more attention as there are not many developed for this type of systems and is being formulated.

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Summary of Results:

Wetlands are valuable as sources, sinks, and transformers of a multitude of chemical, biological, and genetic materials (Mitsch & Gosselink, 2000). Prairie pothole marshes in North Dakota, South Dakota and eastern Minnesota are considered as one of the dominant areas of freshwater marshes in the United States. The Prairie upland, almost all of the prairie wetlands, and some of the timberlands have been converted into croplands. Wetland restoration efforts and return of the agricultural lands to natural habitats are increasing in this particular region. Phosphorus is believed to be the biggest problem in returning the reclaimed wetlands to a healthy condition. Enormous application of fertilizers has caused high phosphorus levels in soil, and water in this wetland region. These phosphorus levels can be a serious problem in causing imbalance in plant species growth and thereby a problem to water levels and also to some wildlife. This research is mainly concentrated on phosphorus transport in wetlands ecosystem.

Current status of project:

1. Key literature reviewed

Phosphorus is selected as target compound for this research project. Phosphorus compounds transportation, movement, and concentrations in wetlands are hypothesized as being affected by seasonal variations of water chemistry and phosphorus solubility, sediment decomposition and subsequent releasing of organic phosphorus, and biological assimilation and decomposition (Mitsch & Gosselink 2000).

Although phosphorus doesn't get altered directly by changes in redox potential as other nutrients do, it gets affected indirectly in soils and sediments by its association with several elements, such as iron, aluminum, zinc, and manganese (Mitsch and Gosselink 2000). Research has shown that flooding of organic soils has a great impact on P flux in water column (Reddy and Pant, 2001). Draining and subsequent reflooding of organic soils increases P flux into the water column. This may be due to mineralization of organic P, and subsequent adsorption and precipitation of mineralized P by cations including Ca and Mg. Soil conditions also (such as freely drained soils, or poorly drained soils) affect the availability of total and organic phosphorus. Studies show that organic phosphorus is less stable in poorly drained soils (Walker and Syers, 1976).

Losses and transformations of phosphorus can be better understood by P-fractionation in soils (Walker and Syers 1976). Total phosphorus can be separated into fractions: non occluded P, occluded P, organic P and acid-extractable P (apatite) (Williams et al., 1967). Redox potential and pH influence the phosphorus availability in soils (Walker and Syers 1976). The solubility of apatite decreases with the increase in pH and availability of organic phosphorus decreases with induction of anaerobic conditions.

Microbial activity also has a considerable impact on phosphorus availability in wetlands. Phosphate mineralization by microbes can be greatly affected by the water levels in wetlands (H.K.Pant and K.R.Reddy 2001).

2. Prior work

To quantify the impact of the above factors on phosphorus levels soil sampling has been done at three different locations in the study area. Testing of samples has been done for total phosphorus, available phosphorus, pH, electrical conductivity and also for some metal ions that are expected to have some influence on phosphorus availability.

3. Site Location

Three wetland/lake areas will be selected for sampling. These are located in the Hamden Slough National Wildlife Refuge in western Minnesota near the Lake Bisson. To study the phosphorus dynamics in wetlands, it is important to identify the major phosphorus sources and sinks (ex. Plant uptake).

4. Flow monitoring

Both surface and subsurface flow contribute to phosphorus transport through wetland ecosystem. We need to measure or estimate the surface inflow and outflow. There is a shallow aquifer system beneath the wetland area and considerable leakage from this aquifer into the wetlands takes place. Flow monitoring has been done using piezometer monitoring system and measurements were taken each month starting from May 2002 to October 2002. The monitoring data will be analyzed to determine surface water and groundwater flow rates, relationship between groundwater and surface water, and variations of water flows. The water flow and water level monitoring events will be arranged to coincide with water quality sampling to provide data for water quality modeling.

5. Water and sediment sampling

Phosphorus fixed in the sediments may be released to water column due to microbial activity (H.K.Pant and K.R.Reddy 2001). Changes in water level also affect the phosphorus availability in water (H.K.Pant and K.R.Reddy 2001). Surface water and sediment samples will be carried out in the three-selected wetland areas in the study area. During sampling, water temperature, DO, pH, turbidity, and electrical conductivity will be monitored in the field. Water samples will be analyzed for available phosphorus, total phosphorus, total and inorganic carbon, particle sizes and volatile suspended solids, and chlorophyll *a*. Sediment samples will be analyzed for total phosphorus, plant available phosphorus, and calcium carbon equivalent.

6. Progress to date

The analysis of existing data and field sampling will help determining the current status. Water and sediment sampling and testing will help study the phosphorus dynamics in wetlands. A water quality model will be used to analyze phosphorus inflow and outflow due to point and non-point sources.

Soil samples taken for determining the profile of phosphorus concentration and other compounds along transects of the wetland. The results from soil sample testing will be analyzed for available phosphorus and total phosphorus. Preliminary water sampling completed and analyzed for basic water quality parameter including phosphorus. The area was surveyed using GPS and level for preparing topographic map, which will be used to assess the non-point source flow to these wetlands.

Literature review of phosphorus dynamics in wetlands and review and evaluation of existing phosphorus models is under progress.

7. Funding agencies for the project

North Dakota Water Resources Research Institute
Department of Civil & Environmental Engineering