# Water Resources Center

# Annual Technical Report

# FY 1999

## Introduction

## Research Program

Research priorities are: groundwater quality; potential insufficiencies in water resources, including the management of water resources among competing uses; controlling pollution from nonpoint sources; recovering water-based fish and wildlife habitat; developing and evaluating means for formulating policies that are based on limited data; and emerging issues, including other innovative research topics that are not included in the five priorities above. In addition, in 1998, the Illinois Water Resources Center (IWRC) and the Illinois State Water Survey successfully competed in a national USEPA competition to establish regional centers that would provide research and other forms of technical assistance to drinking water systems in small communities, including native American communities. The Midwest Technology Assistance Center (MTAC) started in November 1998 and is a collaborative effort of the IWRC and nine other water resources research institutes in the Midwest and the Illinois Water Survey. In 1999, MTAC funded projects in four states, including the following research: (1) a survey of the technical and management needs of 200 small systems in ten states; (2) a Benchmark Economic Study to assist small systems with their financial and managerial problems and ensure they will have adequate financial resources to meet new treatment requirements; and (3) a pipe corrosion study that will help communities protect their pipe systems while complying with federal statutes that require disinfection (some disinfection processes accelerate corrosion to such an extent that lead and copper standards for drinking water are exceeded).

The IWRC base research program operates on a biennial schedule: every two years researchers at universities throughout the state are invited to submit proposals for up to two years of funding. In 1998, 19 preproposals were received by the IWRC under the Water Resources Research Institutes (WRRI) program. Based on review by the Executive Committee, 10 full proposals were invited. The full proposals were distributed for review by peers outside the state of Illinois. Based on the peer reviews and the IWRC's announced priorities, the Executive Committee selected one project for funding with available nonfederal resources and three for funding from the core federal grant. While no part of the core USGS grant was used to start up the nonfederally-funded project, the core grant does provide the capacity to administer this project and provide information transfer.

Synopses of eight individual research projects which continued in 1999 appear in the following part of this report. One project (Analysis of Water Use Trends in the United States, 1950-1995) was funded through a national WRRI competition in 1999 and several projects that continued into1999 were funded through regional WRRI competitions prior to 1999.

The Center takes a special interest in helping young scientists establish a track record in water resources research. The Water Resources Center both encourages new scientists to submit proposals and gives their proposals extra consideration. The proposals, however, must be of significant scientific merit (as determined by the reviewers and the Executive Committee) and have relevance to the total water program of Illinois to be judged worthy of

funding. Virtually all projects supported by the IWRC contribute significantly to the education of students, both graduate and undergraduate, who participate in the research projects. The Student Support table lists students supported in both the internship program with the Illinois District Office of USGS and on the individual grants to faculty researchers.

The Illinois Water Resources Center (IWRC) also helps administer the research component of the Illinois-Indiana Sea Grant College program in partnership with the National Oceanic and Atmospheric Administration (NOAA). This program was initiated in 1982 as a Marine Extension Project through the efforts of the Cooperative Extension Services at the University of Illinois and Purdue University. A small research component was added in 1984. In October 1997, following review of the program's activities and potential, Illinois-Indiana Sea Grant was designated a "college" program, the highest level a state program may attain within the National Sea Grant College Program. IWRC's involvement in this program has increased the Center's opportunities for coordinating research activities with other water-related programs in the Midwest. The Center responded to calls for proposals from NOAA and also coordinated the Illinois-Indiana research program that receives base funding from Sea Grant. In 1999, 31 preproposals were submitted for review, fourteen full proposals were requested, and seven obtained federal funding through Illinois-Indiana Sea Grant.

### Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Optimizing Control Strategies for Disinfection By-Products for Small Water Supplies Using Ozone as an Alternative Disinfection Process |
| **Project Number** | C-04 |
| **Start Date** | 09/01/1996 |
| **End Date** | 08/31/1999 |
| **Research Category** | Water Quality |
| **Focus Category #1** | Water Quality |
| **Focus Category #2** | Water Quality |
| **Focus Category #3** | Water Quality |
| **Lead Institution** | University of Illinois |

### Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Roger A. Minear | Professor | University of Illinois | 01 |

**Problem and Research Objectives**

PROBLEM DESCRIPTION:

Some years ago, the discovery that conventional disinfection of drinking water with chlorine led to the formation of chlorinated hydrocarbons, the trihalomethanes, and other disinfection by-products (DBPs) stimulated much research into the causes and means of controlling this "problem". Associated with increased knowledge of DBPs has been increasingly more stringent regulation of finished drinking water. The resulting shift to alternate disinfection processes includes ozone which is ideally suited to small systems. However, the presence of bromide in many waters (especially ground waters) leads to bromate formation when treated with ozone. Bromated is now being regulated at maximum contaminant level (MCL) of 10 ìg/L. Various control strategies that reduce bromate formation in ozone treatment lead to increased formation on brominated organic DBPs. Some of these are regulated but only a small fraction of theTOBr has been identified, much concern has been expressed about toxicity and regulation of these as yet unidentified constituents of treated, bromide containing drinking waters.

The reactions of ozone and bromide are known to operate through two distinct reaction pathways, a direct molecular ozone pathway and a more complex pathway involving hydroxyl radicals (HO$) that result from the decomposition of ozone. Natural organic matter (NOM) is ubiquitous in natural waters and not only serves as the precursor to all TOBr produced, but also appears to have an influence on which of the pathways is predominant and, consequently, the mixture of DBPs formed in a given water. Variations in treatment conditions designed to control bromate concentrations in treated water, such as lowering the pH, can actually increase the TOBr concentrations. It also appears that the properties of the NOM in a given water influences the outcome through differential influence on the reaction pathways. Previous work by the PI has demonstrated that NOM characteristics are variable from water to water. How these differences influence pathway dominance and how this in turn affects specific bromate minimization remain to be elucidated.

RESEARCH OBJECTIVES:

The objectives of the proposed research are:

- To delineate the relative dominance of the $O_3$ versus HO$ pathways in the presence of NOM, and in the formation and distribution of bromate and organo-Br compounds;
- To determine if more than one radical pathway is initiated by HO$ generation;
- To evaluate the role of other radical species including carbonate/bicarbonate radicals and NOM radical intermediates;
- To relate NOM properties and source variations to pathways dominance;
- To compare bromate and organo-Br formation through the different pathways during AOPs versus simple ozonation, and to compare the roles of HO$ formed in each;
- To characterize the risk tradeoffs between bromate minimization and potentially enhanced organo-Br formation; and
- To incorporate the role of NOM into a more comprehensive analytical model, augmented by the ability to predict organo-Br as well as bromate.

**Methodology**

The general approach will be to perform an orthogonal matrix of true batch experiments employing a

range of well characterized NOM isolates from a variety of water sources. Each isolate will be characterized by $^{13}$C NMR spectroscopy, elemental analysis, pyrolsis GC-MS, spectrophotometric properties, molecular weight distribution, and humic content. The NOM will be isolated by membrane techniques designed to maximize bulk NOM recovery and minimize salt concentration. Other experimental variables will include pH, total inorganic carbon, bromide ion, temperature, $O_3$ dose, $H_2O_2$ dose, and selected radical scavengers. Time series experiments will be conducted to generate kinetic data for various pathways and associated reaction products. Selected experiments will be conducted without ozone in order to evaluate Advanced Oxidation Process (AOP)-induced HO$ reactions, and in addition with aqueous bromine to evaluate pathways proceeding through the OBr-/HOBr intermediate. Bromate, TOBr and individual brominated organic compounds will analyzed as the end points for the experiments.

**Principal Findings and Significance**

Work with direct bromine reaction with Suwannee River Fulvic Acid (SRFA) and previously isolated NOM from a previous investigation was conducted to investigate the reaction rates of bromine product formation to assess the importance of the bromine formed from ozone reaction with raw water bromide.

It was observed that formation of TOBr and a few identifiable DBP species (i.e. bromoform, monobromoacetic acid, dibromoacetic acid, and tribromoacetic acid) was through a two-stage reaction for various NOM isolates at high initial HOBr concentration. The first-stage reaction was presumed to be first-order reaction with high rate constant. This phase of the reaction was completed in less than 2 minutes, the minimum time required to isolate and quench a sample from the experimental reactor. The second-stage reaction, was also an apparent first-order reaction with relatively low rate constants by comparison to the first stage of the reaction. For HOBr disappearance, a two stage reaction consisting of apparent first-order reactions was also observed. At low initial HOBr concentration, only the rapid first-stage reaction was observed.

The effects of water quality variables and preozonation of NOM were examined. The experimental results from true? batch reactions indicated that high pH and alkalinity addition resulted in increasing both rate and total quantities of TOBr yield and HOBr disappearance. Ozonation of NOM seemed to produce a more stable NOM structure, so aqueous bromine? NOM interaction was suppressed by preozonation. The wide differences in rates for different NOM sources was also reduced by preozonation of the sample.

The rate constants for HOBr disappearance and TOBr formation were calculated from the experimental results to obtain a better quantitative understanding of the kinetics of aqueous bromine? NOM interaction. A bromine demand determination for 3 mg C/L for SRFA yielded a value of 1000 Fg/L as Br or 333 Fg Br per mg of DOC.

Experimental results from studying TOBr molecular weight characteristics demonstrated that 37% of TOBr and 37% of TOC were contained in the molecular weight range of 500-1K daltons and 10K-30K daltons, respectively. The largest atom ratio of TOBr to TOC was 0.33 in the 500-1K dalton fraction.

For the central focus on upper mid-west waters, six water sources collected and characterized are Champaign, IL (GW), Decatur, IL (SW), Minot, ND (GW), St. Paul, MN (SW), Sioux Falls, SD (SW) and Manhattan, KS (GW). All samples are collected and size fractionation by sequential membrane filtration is complete for all six water sources, yielding 18 size-fractionated samples. Freeze drying of

those fractions is complete.

Fraction DOC characterization, elemental and spectral analysis are complete. Data from fluorescence characterization, 13C NMR and humic/fulvic fractionation by XAD-8/XAD-4 resin are gathered and final analysis is in progress.

Batch ozonation experiments on the six raw waters are complete for all the matrix variables. The experiments for the baseline conditions, pH and ozone dose are complete for the 30K and 1K fractions. The baseline condition experiments are complete for the RO fraction. The effect of the concentrated salts in this fraction has to be considered for other conditions.

Project experimental work is now essentially completed and data analysis for the final report preparation is now underway.

## Descriptors

Disinfection, Ozonation, Water Treatment, Water Chemistry, Water Quality, Trace Organics, Organic Compounds, Mathematical Models

## Articles in Refereed Scientific Journals

## Book Chapters

1. Kargalioglu, Y., B. J. McMillan, R. A. Minear, and M. J. Plewa, "A New Assessment of the Cytotoxicity and Genotoxicity of Drinking Water Disinfection By-Products," Submitted for publication in ACS Symposium, Natural Organic Matter and Disinfection By-Products: Characterization and Control, S. E. Barrett, S. W. Krasner, and G. L. Amy editors, 2000.
2. Echigo, S., R. A. Minear, and H. Yamada, "Ultra Low Bromate Detection in Drinking Water: A post Column Derivatization Method without Anion Suppressors for Bromate Analysis," Submitted for publication in ACS Symposium, Natural Organic Matter and Disinfection By-Products: Characterization and Control, S. E. Barrett, S. W. Krasner, and G. L. Amy editors, 2000.
3. Zhang, X., S. Echigo, R. A. Minear, and M. J. Plewa, "Characterization and Comparison of Disinfection By-Products from Using Four Major Disinfectants," Submitted for publication in ACS Symposium, Natural Organic Matter and Disinfection By-Products: Characterization and Control, S. E. Barrett, S. W. Krasner, and G. L. Amy editors, 2000.
4. Echigo, S., X. Zhang, R. A. Minear, and M. J. Plewa, "Differentiation of TOBr and TOCl in TOX Measurement," Submitted for publication in ACS Symposium, Natural Organic Matter and Disinfection By-Products: Characterization and Control, S. E. Barrett, S. W. Krasner, and G. L. Amy editors, 2000.

## Dissertations

1. Huang, Wei, 1997, "Kinetics of Aqueous Bromine NOM Interaction During Ozonation in Drinking Water Treatment." M.S. Thesis, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois. August, 1997.
2. Smith, Michael, 1999, "Title not yet defined." M.S. Thesis. Completion expected in October 1999.

**Water Resources Research Institute Reports**

**Conference Proceedings**

1. Kim, J-H., M.A. Urban, S. Echigo, R.A. Minear, and B.J. Marinas. "Integrated Optimization of Bromate Formation and *Cryptosporidium parvum* Oocyst Control in Batch and Flow-through Ozone Contactors." Proceedings of the 1999 Water Quality Technology Conference, American Water Works Association, Tampa, FL November 1-4, 1999.
2. Plewa, M.J., Y. Kargalioglu, D. Vankerk, R.A. Minear, and E.D. Wagner. "Development of Quantitative Comparative Cytotoxicity and Genetoxicity Assays for Environmental Hazardous Chemicals." Proceedings of the 3rd IAWQ Specialized Conference on Hazard Assessment and Control of Environmental Contaminants: ECOHAZARD '99, Otsu City, Japan, December 5-8, 1999.
3. Ikeda, K., R. Arimura, S. Echigo, Y Shimizu, R. A. Minear, and S. Matsui. "The Fractionation/Concentration of Aquatic Humic Substances by the Sequential Membrane System and their Characterization with Mass Sectrometry." Proceedings of the 3rd IAWQ Specialized Conference on Hazard Assessment and Control of Environmental Contaminants: ECOHAZARD '99, Otsu City, Japan, December 5-8, 1999.

**Other Publications**

Referred Abstracts:

1. Kargalioglu Y, E.D. Wagner, S. Richardson, R.A. Minear, M.J. Plewa. 2000. Mammalian cell genotoxicity of drinking water disinfection by-products using single cell gel electrophoresis. Environ. Molecular Mutagenesis 35:35 Supp. 31.
2. Vankerk, D.D., R.A. Minear and M.J. Plewa. 2000. Comparative cytotoxicity of drinking water disinfection by-products in mammalian and bacterial cells. Environ. Molecular Mutagenesis 35:63 Supp. 31.

Extended Abstracts:

1. Echigo, S., R.A. Minear, H. Yamada, and P.E. Jackson. "Comparison Among Three Methods for Bromate and Nitrite measurements in Drinking Water." American Chemical Society, Division of Environmental Chemistry Extended Abstracts, 219th National Meeting, San Francisco, CA, March 23-27, 2000, vol. 40:1, .pp 44-46.
2. Zhang, X., and R.A. Minear. "Decomposition of Trihaloacetic Acids and Formation of the Corresponding Trihalomethanes in Water." American Chemical Society, Division of Environmental Chemistry Extended Abstracts, 219th National Meeting, San Francisco, CA, March 23-27, 2000, vol.40:1, pp 34-36.
3. Echigo, S., X. Zhang, H. Lei, R.A. Minear, and M.E. Smith. "Optimizing Control Strategies for Disinfection By-products for Small Water Supplies Using Ozone as an Alternative Disinfection Process." American Chemical Society, Division of Environmental Chemistry Extended Abstracts, 220th National Meeting, Washington, D.C., August 20-24, 2000, vol.40:2.
4. Zhang, Xiangru, S. Echigo, H. Lei, M.E. Smith, and R.A. Minear. "Effects of Temperature and Chemical Treatment on the Formation of Halogenated Disinfection By-products from Ozonation of Raw Waters." American Chemical Society, Division of Environmental Chemistry Extended Abstracts, 220th National Meeting, Washington, D.C., August 20-24, 2000, vol. 40:2.

5.  Lei, H, R.A. Minear, and B.J. Marinas. "Formation of CNBr in O3/NH2C1 Seqential Disinfection." American Chemical Society, Division of Environmental Chemistry Extended Abstracts, 220th National Meeting, Washington, D.C., August 20-24, 2000, vol. 40:2.

## Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Controlling *Cryptosporidium* in Drinking Water Supply for Small Communities |
| **Project Number** | C-02 |
| **Start Date** | 09/01/1997 |
| **End Date** | 06/30/2000 |
| **Research Category** | Water Quality |
| **Focus Category #1** | Water Quality |
| **Focus Category #2** | Treatment |
| **Focus Category #3** | Surface Water |
| **Lead Institution** | University of Illinois |

## Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Benito J. Marinas | Professor | University of Illinois | 01 |

## Problem and Research Objectives

*Cryptosporidium parvum (C. parvum)* is a protozoan parasite that is known to infect humans and many animals, both wild and domesticated. The prevalence of *C. parvum* makes this pathogen difficult to control, especially in the rural communities of the North Central Region due to the high population of domesticated farm animals that inhabit the watersheds of this area. The recent interest in *Cryptosporidium parvum* is the result of an outbreak of cryptosporidiosis that occurred in the spring of 1993 in Milwaukee, WI.1 As a result of this outbreak, more than 400,000 people became infected with cryptosporidiosis; a disease for which there is no cure.1 Although most of the people infected recovered within two weeks, a number of people died from complications stemming from other medical conditions most notably, immune system disorders which were the result of cancer, AIDS, or organ transplant therapy.

*C. parvum* has been shown to be extremely resistant to conventional disinfection processes; as much as fifty (50) times more resistant than *Giardia lamblia*, the next most resistant pathogen. Because of this resistance, inactivation of *C. parvum* is considered by the industry to be difficult. Small utilities potentially face a greater threat from *Cryptosporidium* than large utilities because of insufficient resources that are required to train and support full-time plant operators. In addition, utilities in the North Central Region may also be more at risk due to the harsh winters associated with the area. The cold temperatures result in significantly slower inactivation kinetics observed in conventional

disinfection treatment, which makes chemical disinfection much more difficult.

The main objective of this project is the development of a cost effective treatment strategy for providing safe drinking water to small communities using surface water or groundwater under the direct influence of surface water. The approaches under consideration are consistent with existing treatment systems in order to avoid high capital investment related to overall technology replacement, and to take advantage of the relative affordability of land in rural areas. The anticipated strategy is a three-step treatment process (pretreatment, holding pond, disinfection) to provide adequate disinfection of *C. parvum* oocysts.

**Methodology**

The inactivation of *C. parvum* oocysts was studied with both batch (free/combined chlorine) and semi-batch (ozone) reactors. Target disinfectant concentrations were 8 mg/L for free and combined chlorine and varied depending on temperature for ozone. Viability was determined by an *in vitro* excystation method. *C. parvum* oocysts treated by sequential disinfection were first pretreated with ozone at a CT (i.e. product of disinfectant concentration and contact time) sufficient to inactivate approximately 80% of the oocysts. The oocysts were then exposed to free or combined chlorine until the inactivation efficiency was greater than 99 percent.

**Principal Findings and Significance**

Research progress to date includes:

- Assessment of *C. parvum* oocyst inactivation with free/combined chlorine (pH 6 and 8, respectively) and temperature (1-30ºC);
- Study of the effects of varying ozone pretreatment *CT*s on the subsequent inactivation kinetics of *C. parvum* with free or combined chlorine;
- Inactivation of the synergistic effects of sequential disinfection (ozone pretreatment-free/combined chlorine disinfection) on the inactivation of *C. parvum* oocysts in the experimental temperature range of 1-30ºC.

Results obtained for the free chlorine (pH 6) disinfection experiments performed to assess the effect of temperature are presented in Figure 1. Each inactivation curve was characterized by a lag phase or shoulder region followed by pseudo-first order inactivation kinetics. Temperature had a significant effect on the resistance to *C. parvum* oocysts to free chlorine, which resulted in a longer lag phase and slower inactivation kinetics at lower temperatures. Data (not shown) indicate that the inactivation of *C. parvum* oocysts is the direct result of exposure to hypochlorous acid (HOCl) and not hypochlorite ion (OCl-).
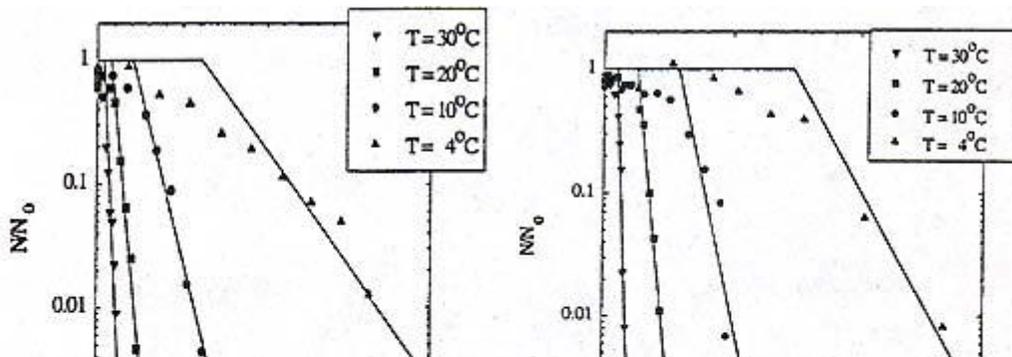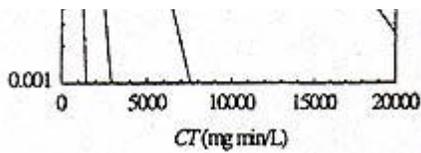
Figure 1. Effect of Temperature on the Free Chlorine Inactivation of *C. parvum* Oocysts at pH 6.
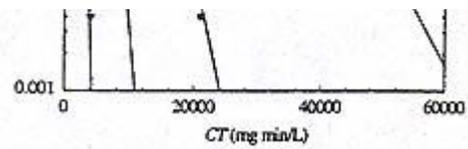
Figure 2. Effect of Temperature on the Monochloramine Inactivation of *C. parvum* Oocysts at pH 8.

Based on the results obtained for free chlorine, it was determined that *C. parvum* is resistant to this disinfectant such that impractical contact times are required to inactivate significant numbers of oocysts. A similar trend was observed for monochloramine, in which the inactivation kinetics are given by a shoulder region, followed by a first order decrease in viability. Given the *CT*s required to achieve significant inactivation, the use of monochloramine alone appears to be an impractical approach to treating water for *Cryptosporidium*.

Temperature dependence experiments, similar to those described above, were conducted with ozone (data not shown). The results of these experiments revealed that in addition to being much more effective at inactivating *C. parvum*, the lag phase region was significantly shorter. Given the shoulder for both disinfectants, it was hypothesized that if the shoulder region was removed with ozone, subsequent exposure with free or combined chlorine would result in an inactivation curve with no shoulder. This hypothesis was proven true, and an additional benefit of an increased rate of inactivation with both free and combined chlorine was observed if ozone was allowed to completely remove the shoulder region. The most beneficial aspect of this sequential effect is that the synergism increases as temperature decreases. The data given in Figure 3 depict the inactivation kinetics of C. parvum with monochloramine alone and following ozone pretreatment to levels which inactivated 80% of the oocysts (a CT exposure of 22.5 mg×min/L at 1ºC). As observed in Figure 3, a reduction in the viability of the oocysts from 0.1 to 0.01 with monochloramine alone requires a CT of 22,900 mg×min/L. The same level of inactivation with ozone pretreated oocysts requires only a CT of 1040 mg×min/L; a 22-fold increase in the rate of inactivation, as well as the complete of the lengthy shoulder region observed for monochloramine alone.

Similar experiments were conducted using ozone/monochloramine and ozone/free chlorine sequential disinfection scenarios over the temperature range of 4 to 30ºC. A summary of the sequential disinfection experimental results is given in Figure 4.
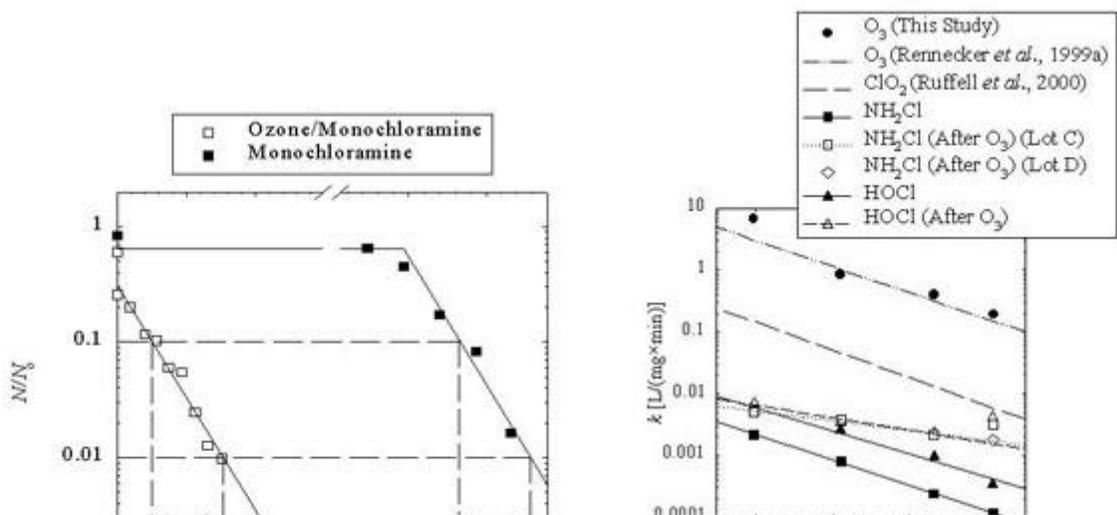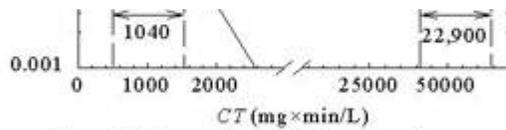
Figure 3. Comparison of Primary and Secondary Inactivation of *C. parvum* Oocysts with Monochloramine at pH 8.0 and 1°C. Ozone Pre-Treatment Conditions for the Sequential Disinfection Experiment: CT=22.5 mg×min/L, pH 7.0, and 20°C.
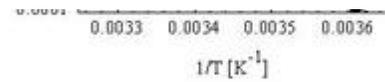
Figure 4. Arrhenius Plot of Second-Order Rate Constants for Primary Inactivation with Ozone (pH 7, This Study and Rennecker *et al.*, 1999a), Chlorine Dioxide (Ruffell *et al.*, 2000), Free Chlorine (pH 6) and Monochloramine (pH 8), and for Secondary Inactivation with Free Chlorine (pH 6) and Monochloramine (pH 8) after Ozone Pre-treatment (pH 7).

Rate constants obtained by regression the linear portion of each data set (ozone, free chlorine, monochloramine) which were subsequently plotted according to the Arrhenius expression given by equation 1:

$$k = A \exp\left(-\frac{E_a}{RT}\right)$$

where A is the frequency factor in L/(mg´min), Ea is the apparent activation energy in J/mole, R = 8.314 J/(mole´K) is the ideal gas constant, and T is absolute temperature in K. Also shown in Figure 3 is the line reported by Rennecker et al. (1999) for the ozone inactivation of rodent-source Iowa strain oocycts (A = 3.00´1014 L/(mg´min), Ea = 81,200 J/mole). As depicted in Figure 4, experimental k values obtained in this study were consistent (within 30 percent) with the temperature dependence by Rennecker et al. (1999) with exception of that at 30oC that was 2.25 times higher than expected. As given in Figure 4, the rate constants for all single step disinfection experiments obey Arrhenius law. Interestingly, the activation energies for each disinfectant are very similar, indicative of a similar mechanism of disinfection for each disinfectant studied. In addition, the rate constants obtained for sequential disinfection with ozone followed by free or combined chlorine are also plotted. As with the rate constants for single step disinfection, the rate constants obtained for sequential disinfection also follow an Arrhenius type law; however the activation energy for both ozone/free chlorine and ozone/monochloramine is significantly less. This observation results in minimal temperature dependence in the sequential inactivation scenario and greater rates of C. parvum inactivation at lower temperatures. This increased efficiency at low temperature not only translates into reduced cost for small utilities, but also helps to ensure that the people served will be drinking significantly safer water.

References:

1. Fox, K.R.; Lytle, D.A. (1996) "Milwaukee's Crypto Outbreak: Investigation and Recommendation", *Journal of the American Water Works Association*, 88(9), 87-94.
2. Ruffell, K.M.; Rennecker, J.L.; Mariñas, B.J. (2000) "Inactivation Kinetics of *Cryptosporidium parvum* Oocysts with Chlorine Dioxide," *Water Research*, 34(3), pp. 868-876.
3. Rennecker, J.L.; Mariñas, B.J.; Owens, J.H.; Rice, E.W. (1999) "Inactivation of *Cryptosporidium parvum* Oocysts with Ozone" *Water Research*, 31 (11), pp. 2481-2488.

**Descriptors**

*Cryptosporidium parvum* oocysts, disinfection, ozonation, protozoa, small communities, surface water, water quality control, water treatment

## Articles in Refereed Scientific Journals

1. K.M. Ruffell; J.L. Rennecker; B.J. Mariñas (2000) "Inactivation of *Cryptosporidium parvum* Oocysts with Chlorine Dioxide." *Water Research, 34(3)*,pp. 868-876.
2. A.M. Driedger, J.L. Rennecker, B.J. Mariñas, "Sequential Inactivation of *Cryptosporidium parvum* Oocysts with Ozone and Free Chlorine," *Water Research, 34(14)*, pp. 46-52.
3. Rennecker, J.L.; Driedger, A.M.; Rubin, S.A.; Mariñas, B.J.; "Synergy in Sequential Inactivation of *Cryptosporidium parum* with Ozone/Free Chlorine and Ozone/Monochloramine," *Water Research, 34(17)*, pp. 83-92.
4. Rennecker, J.L.; Corona-Vasquez, B.; Driedger, A.M.; Mariñas, B.J.; "Synergism in Sequential Disinfection of *C. parvum*," *Water Science and Technology*, (in press)
5. Driedger, A.M.; Rennecker, J.L.; Mariñas, B.J.; "Inactivation of *Cryptosporidium parvum* Oocysts with Ozone and Monochloramine at Low Temperature", *Water Research*, in press.
6. Corona-Vasquez, B.; Rennecker, J.L.; Mariñas, B.J.; "Sequential Inactivation of *Cryptosporidium parvum* with Chlorine Dioxide Followed by Free Chlorine or Monochloramine," *Water Research*(in preparation).
7. Rennecker, J.L.; Kim, J.H; Corona-Vasquez, B.; Driedger, A.M.; Mariñas, B.J. "Effect of pH and Disinfectant Concentration on the Inactivation of *C. parvum* with Ozone and Monochloramine," *Environmental Science & Technology*, (in preparation).

## Book Chapters

## Dissertations

1. Ruffell, Kristen M., M.S.E.E., 1999, Inactivation of *Cryptosporidium parvum* with Chlorine Dioxide and Potassium Permanganate.
2. Driedger, Amy M., M.S.E.E., 2000, "Inactivation of *Cryptosporidium parvum* Oocysts with Ozone, Free Chlorine, and Monochloramine."
3. Corona-Vasquez,Benito, M.S.E.E., 2000, "Sequential Inactivation of *Cryptosporidium parvum* with Chlorine Dioxide Followed by Free Chlorine or Monochloramine."

## Water Resources Research Institute Reports

## Conference Proceedings

1. Ruffell, K.M.; J.L. Rennecker; B.J. Mariñas (1998) "Inactivation Kinetics of *Cryptosporidium parvum* Oocysts with Chlorine Dioxide." *Proceedings of the American Water Works Association Water Quality Technology Conference*, San Diego, CA, November 1-5, 1998.
2. Rennecker,J.L.; S.A. Rubin, B.J. Mariñas "Synergistic Effects of Sequential Disinfection Schemes with Ozone/Monochloramine and Ozone/Free Chlorine,"

*Proceedings of the 1999 American Water Works Association Annual Conference*, Chicago, IL, June 20-24, 1999.

3. Driedger, A.M.; S.A. Rubin, J.L. Rennecker, B.J. Mariñas "Inactivation of *Cryptosporidium parvum* Oocysts with Free Chlorine and Monochloramine," *Proceedings of the 1999 American Water Works Association Annual Conference*, Chicago, IL, June 20-24, 1999.

4. Corona-Vasquez, B.; J.L. Rennecker, B.J. Mariñas, "Inactivation of *C. parvum* with Chlorine Dioxide/Free Chlorine and Chlorine Dioxide/Monochloramine," accepted for presentation and publication in the *Proceedings of the 1999 American Water Works Association Water Quality Technology Conference*, Tampa, Florida, October 31-November 4, 1999.

5. Driedger, A.M.; J.L. Rennecker, B.J. Mariñas, "Optimization of *C. parvum* Inactivation with Ozone/Free Chlorine and Ozone/Monochloramine," accepted for presentation and publication in the *Proceedings of the 1999 American Water Works Association Water Quality Technology Conference*, Tampa, Florida, October 31-November 4, 1999.

## Other Publications

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## Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Use of Constructed Wetlands to Improve Water Quality in Lake Bloomington |
| **Project Number** | C-05 |
| **Start Date** | 09/01/1997 |
| **End Date** | 02/28/2001 |
| **Research Category** | Water Quality |
| **Focus Category #1** | Water Quality |
| **Focus Category #2** | Wetlands |
| **Focus Category #3** | Non Point Pollution |
| **Lead Institution** | University of Illinois |

## Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| David A. Kovacic | Associate Professor | University of Illinois | 01 |
| Mark B. David | Professor | University of Illinois | 02 |
| Lowell E. Gentry | Research Associate | University of Illinois | 03 |
| Richard A. Cooke | Assistant Professor | University of Illinois | 04 |

## Problem and Research Objectives

We have shown that drainage tiles are the major source of nitrate entering the Embarras River in central Illinois, causing nitrate concentrations to repeatedly exceed the EPA's MCL (David et al., 1997). Improvements in surface water quality will require the implementation of strategies and management practices that reverse these effects by directly reducing nitrate application through fertilizer management; and, by reducing nitrate output from tile drainage systems to streams using techniques such as constructed wetlands. Constructed wetlands may prove to be a practical, economical, and effective method to reduce surface water nitrate contamination. These "wetlands" are formed by berming an area adjacent to a stream and forming a small detention basin or holding pond that intercepts tile drainage water before it enters the stream. The basin acts to reduce transport of nitrate in drainage water through plant uptake and microbial transformation and degradation. Following wetland "treatment", drainage water is slowly released to the stream, through regulated flow. Research on constructed wetlands addresses the WRRP interest areas of watershed protection, wetlands processes and management, and water quality and supply for small communities; and may provide new methodologies to resolve associated water contaminant problems.

The goal of the proposed research was to determine input/output nitrogen, and water budgets for experimental wetlands constructed in conjunction with two experimental systematically tile-drained sub-basins in the Lake Bloomington watershed. The Bloomington wetlands and their experimental watershed can serve as a valuable case study in determining the efficiency of wetlands for removal of agricultural NPS pollutants. Results from this study will allow us to determine whether or not constructed wetlands have the potential to remove NPS nitrogen from adjacent subsurface tile-drained agricultural fields before they enter the surface waters of Lake Bloomington. In a collaborative study with Illinois State University, the city of Bloomington, the McLean County Natural Resources Conservation Service, the McLean County Soil and Water Conservation Service, and the Nature Conservancy, we will establish potential wetland management criteria that will be used to reduce nitrate levels in surface waters of the Midwest. To achieve this goal, detailed studies on the effectiveness of constructed wetlands were conducted over a multi-year period.

Our overall objective was to study constructed wetlands receiving tile drainage water from two experimental tile drained watersheds (this work will be done in conjunction with the city of Bloomington, who will construct the wetlands, and researchers at Illinois State University, who are studying fertilizer nitrate losses following varied application rates).

The specific objectives of our research component were to:

1. Determine nitrogen concentrations and loads entering and leaving constructed wetlands in the Lake Bloomington watershed for a two-year period;
2. Determine potential seepage rates from the constructed wetlands;
3. Determine the potential effectiveness of constructed wetlands as a tool in reducing nitrate loading to midwestern surface waters;>

We are addressing the following hypothesis:

Constructed wetlands can remove a substantial portion of nitrate from subsurface tile drainage water before entering surface waters.


**Methodology**

*Wetland study area.* Two replicate wetlands were constructed on city owned land adjacent to an existing experimental agricultural tile drainage system at the edge of Lake Bloomington in McClean County, Illinois. The wetlands intercept drainage waters from experimental tile drained watersheds rather than allowing them to flow directly into Lake Bloomington. Watersheds were planted in a typical corn/soybean rotation. Wetlands were initially planted with barnyard grass to provide rapid cover and an abundant source of carbon for denitrification. Our previous research on constructed wetlands points to the need to construct experimental wetlands large enough to prevent severe rainfall events from breaching the wetland berms. Wetland sizes are approximately 0.2 ha (0.5 acre) for the 2-ha (5-acre) experimental watershed and 0.4 ha (1 acre) for the 4-ha (10-acre) watershed (a 1:10 wetland-to-watershed ratio). Weirs were constructed by the city of Bloomington for detailed chemical budget analysis, including input and output flow measurement. Automated sampling devices and data logging equipment allowed concentrations to be determined through weather events and provided information to create a detailed budget for nitrate leaving the agricultural drainage. Output from the wetland was also measured in a similar fashion to determine if constructed wetlands could reduce nitrate concentrations from drainage water.

Flow measurement (pressure transducers and V-notch weirs) and water sampling equipment (ISCO automated samplers) were installed at each site to measure the quantity and quality of both surface and tile drainage water entering from the agricultural fields. Campbell data loggers were used to record data and to control the ISCO collectors. We measured surface and subsurface flow, surface water in the wetlands, and monitored N chemistry of the subsurface waters entering and leaving the sites. These provided a constant record of water flow and nutrient fluxes into and out of the wetlands and also a record of changes occurring within each wetland.

*Laboratory analysis. Nutrient analysis.* Each solution sample was analyzed for the major forms of N (including $NO_3^-$, $NH_4^+$, $NO_2^-$, and organic N).

*Field studies. Data collection and analysis.* Pairs of PVC sampling piezometers were installed at two locations on each wetland site to measure potential wetland seepage through the berm (based on head differential) and to measure potential flow and concentrations leaving the wetlands. They were placed approximately 4 feet below the base of the berm outside the wetland, at the depth where seepage would be expected. Water depth in the wetland was monitored continuously throughout the experiment. Water samples were collected weekly at the weirs (if flowing) between precipitation events, and in the adjacent lake. More intensive sampling occurred during selected precipitation events when flow increased. Samples analyzed for nitrate concentrations along with water quantity data were used to determine nutrient budgets for the wetlands. The collected nutrient data will be used to make the following comparisons; 1) inflow versus outflow nutrient concentrations and loadings for each wetland, 2) differences between wetlands, and 3) seasonal nutrient differences for each wetland.

## Principal Findings and Significance

*Progress Report.* Preliminary results: Chemical analyses. Inlet and outlet flow and nutrient concentrations for water year 1999 have been monitored since October 1, 1998. Wetland 1 inlet concentration peaked at 17 mg L-1 on April 20, 1999, outlet concentration peaked at 12 mg L-1 on March 15, 1999. Wetland 2 inlet concentration peaked at 19 mg L-1 on May 15, 1999, outlet concentration peaked at 17 mg L-1 on April 20, 1999 Wetland 1 average inlet and outlet nitrate, ammonium and organic-N concentrations were 13.4, 0.09, 0.08 and 7.1, 0.03 and 0.40 mg L-1. Total N removal in wetland 1 during water year 1999 was 44%. Wetland 2 average inlet and outlet nitrate,

ammonium and organic-N concentrations were 14.3, 0.03, 0.28 and 10.4, 0.05 and 0.39 mg L-1. Total N removal in wetland 2 during water year 1999 was 25% (Tables 1 & 2). Removals are based on concentration data only. Problems were encountered with flow determinations. Flow corrections are now being made; when complete they will be used to determine the actual budgets for N entering and leaving the wetlands.

**Table 1. Wetland 1 average nitrate, ammonium organic N concentration for water year 1999.**

|  | Nitrate | Ammonium | Organic N | Total N |
|---|---|---|---|---|
| Inlet | 13.4 | 0.09 | 0.08 | 13.5 |
| Outlet | 7.1 | 0.03 | 0.40 | 7.6 |
| % Retained | 47 | 62 | -500 | 44 |

**Table 2. Wetland 2 average nitrate, ammonium and organic N concentrations for water year 1999.**

|  | Nitrate | Ammonium | Organic N | Total N |
|---|---|---|---|---|
| Inlet | 14.3 | 0.03 | 0.28 | 14.6 |
| Outlet | 10.4 | 0.05 | 0.39 | 10.9 |
| % Retained | 36 | -54 | -40 | 25 |

Organic N was probably a result of algal growth within the wetlands and loss through outlet flow in wetlands 1 and 2. Algae probably assimilated nitrate and ammonium resulting in a greater concentration of organic N leaving than entering the wetlands. The majority of the N retained by the wetlands was probably in the form of nitrate (36% in wetland 1 and 47 % in wetland 2) (Tables 1 & 2).

The role of plant nutrient uptake is important in understanding nutrient cycling in wetlands. In a supporting study, biomass in an existing wetland site was studied to determine the role of wetland vegetation in the overall N budget (Hoagland, 1999). Most plant growth occurred after tile input stopped, therefore plants had a small direct effect on the N budget. However, plants were an important source of carbon for microbial denitrification which was the main source of N removal from the wetland. Although aquatic vegetation did not play a role in permanent nutrient removal, it did act as a sink for N during periods of active growth. Algae, often the only plants active early in the growing season, may play a role as a sink in the early spring and during wet years when wetlands dry out much later than normal.

## Descriptors

Agriculture, Denitrification, Nitrogen, Nutrients, Pollutants, Subsurface Drainage, Water Quality, Water Quality Management, Wetlands

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

1. Hoagland, Curtis R. 1999. "MS Thesis," Natural Resources and Environmental Sciences, University ofIllinois, Urbana, Illinois, 47pp.

**Water Resources Research Institute Reports**

**Conference Proceedings**

**Other Publications**

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**Basic Project Information**

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Cost-Effective Monitoring Design for Intrinsic Bioremediation |
| **Project Number** | C-03 |
| **Start Date** | 06/01/1998 |
| **End Date** | 08/31/2000 |
| **Research Category** | Ground-water Flow and Transport |
| **Focus Category #1** | Groundwater |
| **Focus Category #2** | None |
| **Focus Category #3** | None |
| **Lead Institution** | University of Illinois |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Barbara S. Minsker | Assistant Professor | University of Illinois | 01 |
| Albert J. Valocchi | Professor | University of Illinois | 02 |

**Problem and Research Objectives**

A recent Environmental Protection Agency report (U. S. EPA, 1997) reported that over 217,000 sites in the United States currently need to be remediated under existing regulations, at a predicted cost of $186 billion. Over 70 percent of these sites have contaminated groundwater requiring remediation (U. S. EPA, 1997). During remediation, whether by natural attenuation or active remediation technologies, monitoring wells must be sampled to track the progress of remediation. Large, complex sites may have hundreds of monitoring wells that were installed for site characterization and long-term sampling from all of these wells can cost millions of dollars per year. The objective of this research is to develop a methodology for designing cost-effective long-term monitoring plans and to demonstrate the methodology's capabilities by applying it at a field site.

**Methodology**

The method developed combines three primary components: a groundwater fate-and-transport

simulation, several plume interpolation techniques, and a genetic algorithm. The fate-and-transport simulation model, RT3D, is used to predict concentrations at all existing monitoring wells in future monitoring periods. These concentrations are then used with one of several plume interpolation techniques, including inverse distance weighting, kriging, and a hybrid of both methods, to obtain a global estimate of contaminant mass remaining in the groundwater. The genetic algorithm then searches through possible sampling plans using a process analogous to natural selection to identify sampling plans that provide reasonably accurate mass estimates at the least cost.

**Principal Findings and Significance**

Progress report: The initial methodology has been completed and published in Patrick Reed's thesis (Reed, 1999), with an application to a relatively simple site from the literature. The thesis has been submitted to *Water Resources Research* for publication (Reed et al., 1999a, 1999b). In preparation for applying the methodology to Williams Air Force Base, we conducted an in-depth modeling study using RT3D to simulate the plume behavior measured at a site where petroleum products were spilled (Schmidt, 2000). Results of this study demonstrated that the available data were too sparse to be used as a rigorous case for testing the methodology. Instead, we have pursued an extension of the method to handle uncertainty. Monte Carlo simulation will be used to generate multiple possible plumes in the future monitoring period. A second objective will then be added to the model (in addition to minimizing cost), to minimize uncertainty in the global mass estimates from the selected monitoring network. A relatively new genetic algorithm method called a nondominated sorted genetic algorithm (NSGA) will be used to allow tradeoffs between the cost and uncertainty objectives to be elucidated. Recent work has focused on adding the NSGA and Monte Carlo simulation within the existing model and implementing the model in parallel to increase computational speed. Once the method is complete, it will be applied to the test site used in previous work.

References:

1. United States Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, 1997, *Cleaning Up the Nation's Waste Sites: Markets and Technology Trends*, EPA 542-R-96-005.
2. Reed, Patrick, 1999, *Cost Effective Long-term Groundwater Monitoring Design using a Genetic Algorithm and Global Mass Interpolation*, M. S. dissertation, Department of Civil and Environmental Engineering, College of Engineering, University of Illinois, Urbana, IL, 54 pages.
3. Reed, Patrick, Barbara Minsker, and Albert Valocchi, submitted 1999, Cost Effective Long-Term Groundwater Monitoring Design Using a Genetic Algorithm and Global Mass Interpolation.
4. Reed, Patrick, Barbara Minsker, and David Goldberg, submitted 1999, Designing a Competent Genetic Algorithm for Search and Optimization.
5. Schmidt, Brett, 2000, Modeling of the BTEX Natural Attenuation at the Williams Air Force Base Former Liquid Fuels Storage Area using MODFLOW and RT3D within GMS, Final Report for CEE 497, Special Project Independent Study.

**Descriptors**

Water quality monitoring, sampling plans, groundwater modeling, optimization, plume interpolation

**Articles in Refereed Scientific Journals**

1. Reed, Patrick, Barbara Minsker, and Albert Valocchi, submitted 1999, *Water Resources*

*Research*, Cost Effective Long-Term Groundwater Monitoring Design Using a Genetic Algorithm and Global Mass Interpolation.

2. Reed, Patrick, Barbara Minsker, and David Goldberg, submitted 1999, *Water Resources Research*, Designing a Competent Genetic Algorithm for Search and Optimization.

## Book Chapters

## Dissertations

1. Reed, Patrick, 1999, *Cost Effective Long-term Groundwater Monitoring Design using a Genetic Algorithm and Global Mass Interpolation*, M. S. dissertation, Department of Civil and Environmental Engineering, College of Engineering, University of Illinois, Urbana, IL, 54 pages.

## Water Resources Research Institute Reports

## Conference Proceedings

1. Reed, P. M., B. S. Minsker, and A. J. Valocchi, in press 2000, A Multiobjective Approach to Long-Term Groundwater Monitoring Design, Proceedings of the ASCE Water Resources Planning and Management and Water Resources Engineering Joint Conference, Minneapolis, MN.
2. Reed, P. M., B. S. Minsker, A. J. Valocchi, and D. E. Goldberg, in press 2000, Efficient use of a genetic algorithm for long-term groundwater monitoring design, Computational Methods in Water Resources XVIII Proceedings, Calgary, Alberta.
3. Reed, Patrick, Barbara Minsker and Albert Valocchi, 1999, Cost-Effective Long-Term Monitoring Design for Intrinsic Bioremediation, in Proceedings of the 26th Annual Water Resources Planning and Management Conference (ISBN 0-7844-0430-5), ed. Erin M. Wilson, Session 2B: Natural Attenuation Management Issues, Tempe, AZ, CD-ROM proceedings available from American Society of Civil Engineers, Washington, DC.
4. Reed, Patrick, Barbara Minsker and Albert Valocchi, 1999, Cost-Effective Long-Term Monitoring Design for Intrinsic Bioremediation, in Proceedings of the 5th International In Situ and On-site Bioremediation Symposium (Bruce C. Alleman and Andrea Leeson, eds.), San Diego, CA , pp. 301-306.

## Other Publications

Abstracts:

1. Reed, P. M., B. S. Minsker, and A. J. Valocchi, 2000, Cost-Effective Long-Term Groundwater Monitoring Design Using a Genetic Algorithm and Global Mass Interpolation, presentation at the Environmental Horizons 2000 Conference, The Environmental Council, University of Illinois, Urbana, IL, March 27-28, 2000.
2. Reed, Patrick, Barbara Minsker and Albert Valocchi, 1999, Cost-Effective Long-Term Groundwater Monitoring Design Using a Genetic Algorithm and Global Mass Interpolation, presentation at the American Geophysical Union Fall Meeting, San Francisco, CA, December 13-17,1999.

Project Reports:

1. Schmidt, Brett, 2000, Modeling of the BTEX Natural Attenuation at the Williams Air Force Base Former Liquid Fuels Storage Area using MODFLOW and RT3D within GMS, Final Report for CEE 497, Special Project Independent Study.

## Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Genetic Algorithms for the Control of Sedimentation in River-Reservoir Networks |
| **Project Number** | B-02 |
| **Start Date** | 05/16/1999 |
| **End Date** | 05/15/2001 |
| **Research Category** | Water Quality |
| **Focus Category #1** | Sediments |
| **Focus Category #2** | Management and Planning |
| **Focus Category #3** | Methods |
| **Lead Institution** | Southern Illinois University at Carbondale |

## Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| John W. Nicklow | Assistant Professor | Southern Illinois University at Carbondale | 01 |

## Problem and Research Objectives

Sediment transport is a natural dynamic of an alluvial river-reservoir system. If left uncontrolled, however, excess scour of a streambed induces major shifts in geometry and threatens stability of bridges, hydraulic control structures, and underground utilities. Similarly, continued deposition of bed material reduces conveyance capacity of a channel and can lead to chronic inundation of adjacent property. In reservoirs, deposition reduces storage capacity and diminishes benefits associated with activities such as hydropower generation, navigation and water supply.[1] Though difficult to quantify on a worldwide basis, a 1987 study estimated that reservoirs globally are losing storage capacity at an average rate of 1% per year and that the associated annual cost of sediment accumulation has grown to more than $6 billion.[2] A more recent 1998 study estimated that annual depleted storage costs in the U.S. alone have exceeded $2 billion.[3]

In Illinois rivers and streams, excess sedimentation is recognized as the most critical surface water pollution problem.[4,5] More than 1,700 drainage districts in the state require periodic maintenance to remove significant amounts of silt, and many of Illinois' commercially navigable rivers require frequent

dredging so that barge traffic remains uninterrupted and profitable.[6,7] Sedimentation has also caused significant loss of reservoir capacity in more than 100 Illinois instream and side-channel impoundments.[7] Consider as examples that Lake Decatur and Lake Springfield have lost capacity at a rate of 0.3 to 0.5% per year and that, as of 1985, Peoria Lake had lost 68% of its original capacity due to sedimentation.[7] In addition, the regional scientific community has supported the notion that sediment has been destructive to the aquatic component of riverine ecosystems.[7]

While restoration efforts such as dredging, flushing and filling have been effective in many cases, sediment is difficult and very costly to remove from or restore to drainageways.[8] As a result, focus should be directed towards control methods that prevent excessive scour and deposition and thus sustain the benefits that these regional water resources are capable of providing. Since channel discharges, or reservoir releases, are the most important controllable factor that affects channel morphology, control techniques can be based on a discharge approach. This approach is designed to evaluate short- or long-term, optimal reservoir-operating plans that limit the rate and occurrence of bed material movement for forecasted storms.

The objective of this research project is to develop a methodology and computational model for determining reservoir releases that minimize sedimentation in multiple-reservoir river networks. The methodology is based upon a unique discrete-time optimal control approach that interfaces a sediment transport simulation model with a probabilistic optimization method called genetic algorithms. The methodology will also incorporate uncertainties on sediment characteristics and hydrologic parameters. The distinct advantages of the interfacing approach are a reduced size of the overall control problem and the elimination of simplifying assumptions about the physics of the actual problem in order to reach an optimal solution. The approach goes far beyond sediment transport prediction and has practical utility at the water resources managerial level to limit the adverse effects of sedimentation.

**Methodology**

The sediment control problem has been formulated as follows:

Minimize $\Rightarrow$ The maximum change in bed elevation occurring over any discrete time interval and at any predefined river or reservoir cross section for a simulated storm event.

Subject To $\Rightarrow$ (1) Physical laws governing hydraulic and sediment transport dynamics; (2) operating bounds on reservoir releases, and; (3) bounds on reservoir storage levels.

A sediment transport simulation model has been interfaced with a hybrid genetic algorithm within the framework of discrete-time optimal control. The simulator is used to solve the governing hydraulic and sediment constraints, thus revealing the behavior of a network in response to an imposed reservoir operating policy. Constraints on storage levels are accommodated using a bracket penalty function, while bounds on decision variables are handled implicitly by the optimization module. The genetic algorithm is used to solve the overall problem, thus yielding an optimal release schedule that satisfies the formulation.

**Principal Findings and Significance**

Research progress to date consists of:

- Mathematical formulation of the sedimentation control problem as described in the previous section
- Development of a hybrid genetic algorithm and associated computer software module
- Evaluation of suitable sediment transport simulators for inclusion in the overall model
- Selection and modification of the U.S. Army Corps of Engineer's *HEC-6* source code
- Construction of the computational interface between *HEC-6* and the genetic algorithm
- Testing and evaluation of parameter sensitivity through application to a hypothetical system
- Partial collection of existing data from the Illinois State Water Survey and U.S. Army Corps of Engineers for future application to the Kaskaskia River, Illinois

The genetic algorithm developed in this research is a real-valued algorithm in which each gene represents a release at a particular reservoir and discrete time interval and each chromosome represents a particular multi-reservoir release schedule. Briefly, within each generation of the algorithm, the computational module sorts a chromosome population according to resulting objective function values, selects those for subsequent mating, conducts a blending crossover operation, and mutates chromosomes according to a user specified frequency. The objective of the algorithm is to encourage the generation of new policies that preserve the best genetic material from two parent release policies.

Although other models could be used, the *HEC-6* simulation model was selected for incorporation into the optimal control model based upon the wide availability of its documentation; its continued technical support by the Hydrologic Engineering Center; a long history of use in engineering practice; its flexibility in offering 10 different transport functions for application, and; its familiarity to reviewing authorities. Modifications made to the original source code allow for the transfer of data between the genetic algorithm and simulation modules and limit the production of output until the final generation of the genetic algorithm.

Preliminary tests have been conducted using a hypothetical, 3-reservoir network. This system has been used previously by Nicklow[1] to investigate the applicability of an SALQR gradient-based optimization algorithm to the sedimentation problem and is designed to transport large amounts of sediment in response to a storm event. Testing was used to evaluate the effects of parameter values including mutation frequency, population size, and number of generations. One application indicated that the genetic algorithm was capable of minimizing the objective function value to 4.25 ft. Figure 1 shows a convergence plot of this solution and illustrates that a near-optimal objective function, with penalties included, is reached within the first 1,000 generations. This solution improved upon that provided by Nicklow[1] by 4% and required a reduced computational time. These tests confirm that the solution methodology can be a useful tool in preventing excess sediment scour and deposition.



Figure 1. Convergence Characteristics
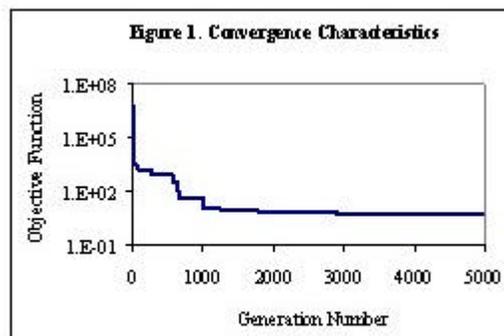
References:

1. Nicklow, J.W. and L.W. Mays (2000). "Optimization of Multiple Reservoir Networks for Sedimentation Control." *J. of Hydraulic Engrg.*, ASCE, 126(4), 232-242.
2. Mahmood, K. (1987). "Reservoir Sedimentation: Impact, Extent, Mitigation." World Bank Technical Paper No. 71, Washington, D.C.
3. Osterkamp, W.R., P. Heilman, and L.J. Lane (1998). "Economic Considerations of a Continental Sediment Monitoring Program." *Int. J. of Sediment Research*, 13(4), 12-24.
4. Bhowmik, N.G., J.R. Adams, A.P. Bonini, A.M. Klock, and M. Demissie (1986). "Sediment Loads of Illinois Streams & Rivers." Illinois State Water Survey Report of Investigation 106, Champaign, IL.
5. Illinois State Water Plan Task Force (1984). Illinois State Water Plan: Critical Issues, Cross-Cutting Topics, Operating Issues. Illinois Department of Transportation, Division of Water Resources (1988). Directory of Lake & River Terminals in IL.
6. Illinois Department of Energy and Natural Resources (1994). The Changing Illinois Environment: Critical Trends. Technical Report of the Critical Trends Assessment Project Vol. 2: Water Res., Springfield, IL.
7. Fitzpatrick, W.P., W.C. Bogner, and N.G. Bhowmik (1987). "Sedimentation and Hydrologic Processes in Lake Decatur and Its Watershed." Illinois State Water Survey Report of Investigation 107, Champaign, IL.

Work Planned for Next Period: Based on promising results to date, future research will include the incorporation of uncertainty of sediment and hydrologic parameters using a chance constrained formulation; further testing using the hypothetical network; the compilation of remaining Kaskaskia River data; the application of the optimal control model to the Kaskaskia River, including Lake Shelbyville and Carlyle Lake, in central Illinois; and a final assessment of the model and its applications.

## Descriptors

Sedimentation, optimization, water resources planning, decision models, discrete-time optimal control, reservoir management, genetic algorithms, sediment transport simulation.

## Articles in Refereed Scientific Journals

1. Nicklow, J.W. (2000). "Discrete-Time Optimal Control for Water Resources Engineering and Management." *Water International*, Int. Water Res. Assoc., 25(1), 89-95 (Project IL-99-2).
2. Nicklow, J.W. and Ozkurt, O. (2001). "Application of Genetic Algorithms for the Control of Scour and Deposition in Multi-Reservoir River Networks." *Water Resources Management*, Kluwer (In Preparation; Project IL-99-2).

## Book Chapters

## Dissertations

## Water Resources Research Institute Reports

## Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Relative Scales of Hydrodynamic and Geomorphologic Influence on the Hydrologic Response in the Illinois River Basin |
| **Project Number** | B-04 |
| **Start Date** | 06/01/1999 |
| **End Date** | 05/31/2001 |
| **Research Category** | Climate and Hydrologic Processes |
| **Focus Category #1** | Geomorpological and Geochemical Processes |
| **Focus Category #2** | Hydrology |
| **Focus Category #3** | Floods |
| **Lead Institution** | University of Illinois |

## Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Praveen Kumar | Assistant Professor | University of Illinois | 01 |
| Bruce Rhoads | Associate Professor | University of Illinois | 02 |
| Ben Yen | Professor | University of Illinois | 03 |

## Problem and Research Objectives

The objective of the proposed work is to determine the relative effects of geomorphological dispersion and hydrodynamic dispersion on the hydrological response of the Illinois River system as scale increases. The specific hypothesis to be tested is that as basin size increases, the river network structure, as compared to channel hydrodynamic properties, plays an increasingly dominant role in determining the hydrological response. The research will also explore the effects of two human actions - modification of network structure via land drainage activities and construction of dams - on contemporary hydrological conditions. Whereas dams have undoubtedly had an important influence on hydrodynamic dispersion, the exact nature of this influence at different scales remains unknown. Moreover, the addition of

headwater tributaries through land drainage activity in the late 1800s has undoubtedly greatly modified geomorphological dispersion, but the influence of this activity is also unknown. The results will provide important information and predictive capabilities for assessing the influence of future management scenarios on the hydrology of the Illinois River.

The geomorphologic dispersion coefficient, DG, is a measure of the geomorphologic dispersion, or the tendency of a disturbance to be dispersed by the river network structure. This concept incorporates the idea that raindrops falling on different areas at the same time will not reach the outlet at the same time (Rinaldo et al. 1991). The theory of hydrodynamic dispersion has been around since the 1960s and the hydrodynamic diffusion coefficient, DL, is a measure of the tendency of a disturbance to disperse longitudinally as it travels downstream. This dispersion is caused by the turbulence induced by the shearing effect of channel boundaries (Henderson, 1966; Mesa and Mifflin, 1986; Rinaldo et al., 1991).

## Methodology

**Task 1.** Estimation of flow path characteristics from DEM and GIS data on the topological structure of the drainage net of the Illinois River system.

The research uses DEM data to estimate the properties of the stream network. The aim of this task is to assess the reliability of the DEM extracted information. The following activities were performed under this task:
1) Obtained two different stream networks for the Illinois River Basin from ISWS and ISGS, one from the IEPA's Reach files (RF3a) and one from digitized USGS quad maps, respectively.

2) Overlaid the IEPA network with our 1-km and 90-m DEMs by:
a) Importing the 1-km and 90-m DEMs into ArcInfo
b) Changing the projection of the DEMs so as to match the Lambert-Azimuthal projection of the IEPA network
c) Overlaying the DEM and the IEPA network in ArcInfo
**d) The IEPA network adhered to the DEM well**

3) Overlaid the drainage basin boundaries derived from the 1-km DEM to see how the IEPA stream network fit by:
a) Importing the drainage basin boundaries into ArcInfo
b) Changing the projection of the boundaries to Lambert-Azimuthal
c) Overlaying the IEPA network and the boundaries in ArcInfo
**d) The IEPA network fit the boundaries well**

4) Compared the stream network derived from the 90-m DEM to the IEPA network by:
a) Extracting the stream network for the Mackinaw Basin from the 90-m DEM using ArcInfo
b) Creating a vector coverage
c) Overlaying the IEPA stream network with the derived network in ArcInfo
**d) The derived network corresponds to the IEPA network well**

5) Compared the stream network derived using RiverTools (this software package provides an excellent interface to obtain qualitative measures for our research) to the IEPA network to determine the Horton-Strahler order threshold of the IEPA network so that the network obtained from the DEM data corresponds to the IEPA network. This was accomplished by:
a) Extracting only the Mackinaw Basin in RiverTools

b) Comparing plots of the IEPA network and the RiverTools extracted network for the Mackinaw Basin at approximately the same scale.

**c) The IEPA network seems to begin with fourth or fifth order streams of a space filling network obtained using the DEM data**

**Task 2.** Estimation of hydrodynamic properties

Stall and Fok (1969) presented empirical equations developed from discharge data that describe the velocity and normal depth of various Illinois streams as a function of the Horton order of the stream and the frequency of the rain event. The drainage area is related to the order of the stream through constants p and q as follows:

$$\ln A_d = p + qU$$

where: $A_d$ = drainage area
p and q = empirical constants
U = Horton-Starhler order

Data from the extracted river network is used to determine p and q for eight of the major watersheds in the Illinois River Basin (Fox, Des Plaines, Kankakee, Vermilion, Mackinaw, Spoon, La Moine, and Sangamon), and the coefficients of the velocity and normal depth equations are adjusted accordingly. The velocities and normal depths of each order stream are calculated and the slope of each order stream are derived from the DEMs to determine the hydrodynamic dispersion coefficient, DL, as follows:

$$D_L \cong \frac{\langle u \rangle y_o}{3S_o}$$

where: $\langle u \rangle = \alpha \bar{v} \cong 1.58 \ \bar{v}$ = mean kinematic celerity of traveling wave
$\alpha$ = empirical constant dependent upon the channel geometry (typically 3/2 for a triangular channel and 5/3 for a rectangular channel)
$\bar{v}$ = mean velocity
$y_o$ = mean normal depth
$S_o$ = mean slope

Using data extracted from the DEMs, the geomorphological dispersion coefficient, DG, is determined for each of the eight basins and each stream order using the following equation:

$$D_G = \frac{\langle u \rangle}{2\bar{L}(\Omega)} \left( \sum_{\gamma \in \Gamma} p(\gamma)[L(\gamma)]^2 - \left[ \sum_{\gamma \in \Gamma} p(\gamma)L(\gamma) \right]^2 \right)$$

where:

$\bar{L}(\Omega) = \sum_{\gamma:\Gamma} p(\gamma)\bar{L}(\gamma)$ = mean length of highest order stream

$L(\gamma) = \sum_{i:\gamma} L_i$ = mean path length

$p(\gamma) = \pi_\omega P_{\omega,\omega+1} \cdots P_{\omega+i,\omega+r} \cdots P_{\Omega-1,\Omega}$ = path probability

$\pi_\omega = \frac{N_\omega}{A_\Omega} \left( \bar{A}_\omega - \sum_{j=1}^{\omega-1} \bar{A}_j \frac{N_j P_{j,\omega}}{N_\omega} \right)$ = initial probability

$P_{\omega,\omega+1} = \frac{N_{\omega,\omega+1}}{N_\omega}$ = transitional probability

$\bar{A}_\omega$ = mean area of subbasins of order $\omega$

$\Omega$ = order of the basin
$\omega$ = order of the subbasin
$\gamma$ = specific path that water flows through
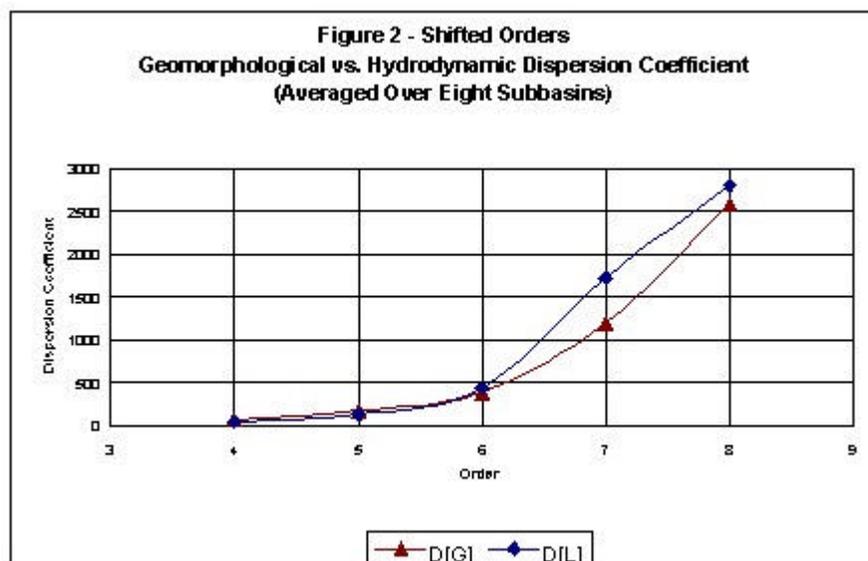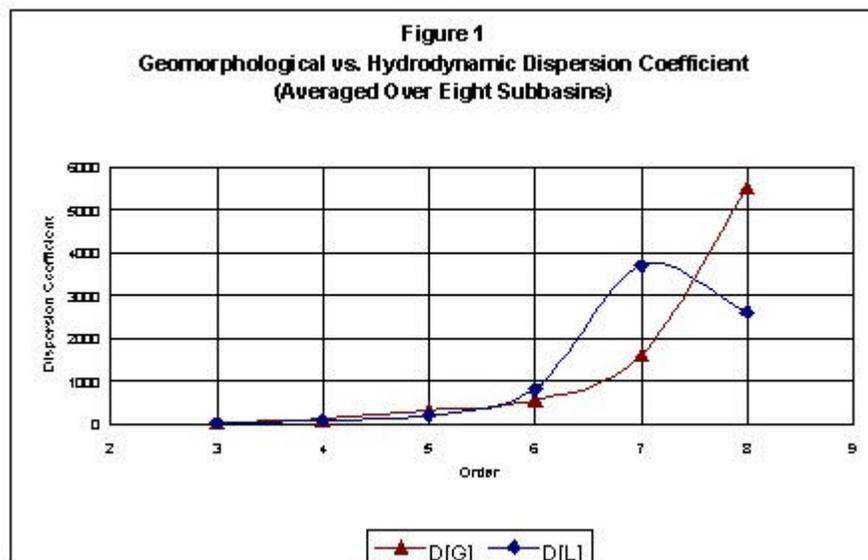$\Gamma$ = total number of paths
$N_{\omega,\omega+1}$ = number of streams of order $\omega$ draining into stream of order $\omega+1$
$N_\omega$ = number of streams of order $\omega$
$A_\Omega$ = total area of the basin

**Principal Findings and Significance**

The averages of the dispersion coefficients, DG and DL, over the eight basins studied were plotted as a function of the Horton-Strahler order. As can be seen in Figure 1, DG seems to increase exponentially, whereas DL peaks for seventh order streams, then decreases for eighth order streams. These results are in accordance with Rinaldo's assertion, however, the average dispersion coefficients retrieved for eighth order streams are not as reliable as the values for other orders. This is true for two central reasons: the lack of data, for only two basins of the eight studied had eighth order streams, and the uncertainty as to where the stream actually begins. Therefore, the stream orders of the basins were shifted so as to avoid these problems, and instead of beginning with a first order stream, the basins were initiated with second order streams. This caused changes in the distributions of the average DG and DL, as portrayed in Figures 2, and the results show that the two distributions seem to follow similar forms.

**Figure 1**
**Geomorphological vs. Hydrodynamic Dispersion Coefficient**
**(Averaged Over Eight Subbasins)**

**Figure 2 - Shifted Orders**
**Geomorphological vs. Hydrodynamic Dispersion Coefficient**
**(Averaged Over Eight Subbasins)**

References:

1. Henderson, F. M., 1966: <u>Open Channel Flow</u>, Macmillan, New York.
2. Mesa, O. J., and E. R. Mifflin, 1986: On the relative role of hillslope and network geometry in hydrologic response. <u>Scale Problems in Hydrology</u>, edited by V. K. Gupta, I. Rodríguez-Iturbe, and E. R. Wood, D. Reidel, Normwell, Massachusetts, pp 1-17.
3. Rinaldo, Andrea, Alessandro Marani, and Riccardo Rigon, April 1991: Geomorphological dispersion. *Water Resources Research*, Vol. 27, No. 4, pp 513-525.
4. Stall, John B. and Yu-si Fok, July 1968: Hydraulic geometry of Illinois streams. *University of Illinois Water Resources Center Research Report No. 15*,Illinois State Water Survey, Urbana, Illinois.

*Proposed Work for Year 2:*

Research listed under Tasks 2 and 3 of the original proposal will be conducted during the second year. These include:

1. Simulation studies to assess the relative roles of hydrodynamic and geomorphologic controls at different scales.
2. Evaluation of changes in network structure on the hydrological response of the Illinois River system.

## Descriptors

Geomorphology, channels, watershed management, hydologic models

## Articles in Refereed Scientific Journals

## Book Chapters

## Dissertations

## Water Resources Research Institute Reports

## Conference Proceedings

## Other Publications

Papers for publication are under preparation.

## Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Denitrification rates and controls in sediments of Illinois surface waters |
| **Project Number** | B-03 |
| **Start Date** | 07/01/1999 |
| **End Date** | 06/30/2001 |
| **Research Category** | Water Quality |

| | |
|---|---|
| Research Category | Water Quality |
| Focus Category #1 | Water Quality |
| Focus Category #2 | Sediments |
| Focus Category #3 | Non Point Pollution |
| Lead Institution | University of Illinois |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| Name | Title During Project Period | Affiliated Organization | Order |
| Mark B. David | Professor | University of Illinois | 01 |
| Jennifer L. Tank | Assistant Professor | University of Illinois | 02 |

**Problem and Research Objectives**

Recent estimates have shown that agriculture dominates the N budget of Illinois. The budget is unbalanced, however, with a large surplus of N estimated each year (about 650,000 Mg N), primarily due to larger inputs of N compared to crop uptake and export. Some of this surplus N is transported to rivers and exported from the state (~200,000 Mg N y-1 for 1994 to 1996), ending up in the Mississippi River. Studies in Illinois have clearly linked agricultural practices, subsurface tile drainage, and river nitrate concentrations (David et al., 1997; Gentry et al., 1998). Many Illinois surface waters, which are often used as drinking water supplies, have nitrate concentrations greater than the EPA standard of 10 mg N L-1. Due to concern about the hypoxic zone in the Gulf of Mexico and possible linkages to N in the Mississippi River, along with drinking water problems, we need to fully understand the N budget of Illinois and controls on river N concentrations and export.

In 1996, the difference between N inputs and outputs was estimated at 650,000 Mg N, and approximately 188,000 Mg of this N was exported from Illinois by the major river systems. Yet, a large amount of N (461,000 Mg N) was still unaccounted for after subtracting the export by rivers, and determining its fate is critical to better understand what is happening to this large N surplus. Denitrification in surface waters could account for much of the fate of this missing N, implying larger losses from agricultural fields than would be estimated solely by river N fluxes. Therefore, denitrification could be a major process in reducing the export of N from Illinois rivers. Estimates of in-stream denitrification rates would help resolve the linkage between agricultural losses of N to surface water export from the state. We also recognize, however, that a large amount of the surplus N estimated each year in Illinois may also be lost through field denitrification, and never reach surface waters. By providing initial estimates of denitrification rates in Illinois surface waters in this study, we will help to put bounds on possible field loss rates of N as well.

Our objectives are to:

1. Measure denitrification rates in sediments sampled from a range of surface waters in east-central Illinois.
2. Conduct detailed studies to determine denitrification rates seasonally at selected representative sites and make estimates of N loss through denitrification, comparing the loss to estimated inputs and river export.
3. Examine the factors believed to limit denitrification rates, such as temperature and the availability

of dissolved organic carbon.

**Methodology**

We are making estimates denitrification in stream sediments using the technique of acetylene inhibition of N2O reductase (Balderston et al., 1976; Yoshinari et al., 1976). Sediment cores (0 –5 cm in depth) are collected from the center and the right and left margins of the channel from a representative transect of the stream and brought to the laboratory. The denitrification assay follows the modified procedure of García-Ruiz et al. (1998). Samples are incubated at the field temperature of the sediment. The amount of N2O is quantified by gas chromatography using an electron-capture detector. We recognize certain limitations of the acetylene inhibition technique (e.g., Seitzinger et al., 1993), but feel it provides the critical preliminary data needed to better understand denitrification rates in a streams of east-central Illinois. Additionally, samples from the water column just above each sediment sample are being collected and analyzed for nitrate (ion chromatograph (IC)), ammonium (colorimetric, auto-analyzer), phosphate (colorimetric, manual), sulfate (IC), and DOC (persulfate oxidation and UV detection, Dohrmann DC-80) using standard methods (APHA, 1995).

**Principal Findings and Significance**

To date, denitrification rates have been measured in six streams in east-central Illinois. At four of these sites, denitrification rates have been measured 2 – 3 times and will continue to be measured routinely. Stream discharge and nitrate concentrations also are being monitored at these four sites. Eventually, the denitrification, discharge, and in-stream nitrate concentrations will be analyzed together to provide a comprehensive assessment of the impact denitrification has on nitrate loads (i.e., quantify how much of the nitrate load is lost via denitrification). Detailed studies are underway at one of the sites to examine the effect on denitrification rates of augmenting dissolved organic carbon, a potentially limiting substrate. Additional experiments are planned to examine rates of denitrification under a range of thermal conditions.

The measurements collect thus far indicate that denitrification in the nitrate-rich streams of east-central Illinois are 1 – 3 orders of magnitude greater than values reported in the literature for streams with lower nitrate loads. An example of the type of data being collected is presented below for one of the sites being routinely monitored. Denitrification is expressed as the cumulative mass of nitrous oxide (N2O) produced over time by a gram of sediment ash-free dry mass (AFDM).



Tributary (1st order) to the Embarras River
April 17, 2000
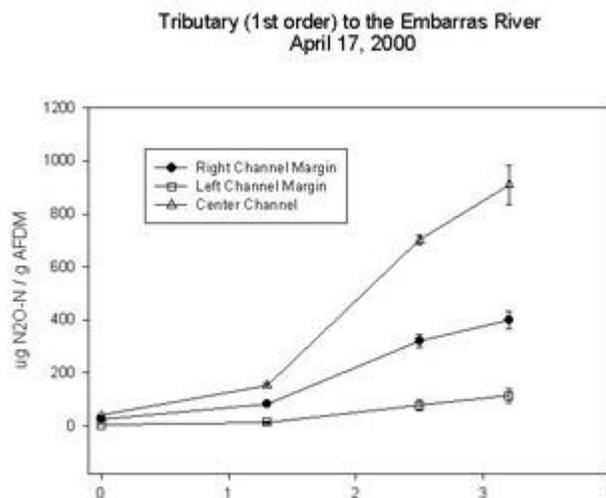
Another result illustrated by the above figure is the spatially variability in denitrification rates even within a stream. The spatial variability is most likely due to the patchy distribution of anoxic habitats within the streambed. This type of spatial variability has been observed at all sites examined to date and will provide an additional level of complexity to our conclusions regarding the role of denitrification in the surface waters of east-central Illinois.

<u>References:</u>

1. APHA. 1995. Stand Methods for the Examination of Water and Wastewater, 18th ed., Am. Public Health Assoc., Washington, D.C.
2. Balderston, W.L., B. Sherr and W.J. Payne. 1976. Blockage by acetylene of nitrous oxide reduction in *Pseudomonas perfectomarinus*. Appl. Environ. Microbiol. 31:504-508.
3. David, M.B., L.E. Gentry, D.A. Kovacic and K.M. Smith. 1997. Nitrogen balance in and export from an agricultural watershed. J. Environ. Qual. 26: 1038-1048.
4. García-Ruiz, R., S.N. Pattinson and B.A. Whitton. 1998. Denitrification in river sediments: relationship between process rate and properties of water and sediment. Freshwater Biol. 39:467-476.
5. Gentry, L.E., M.B. David, K.M. Smith, and D.A. Kovacic. 1998. Nitrogen cycling and tile drainage nitrate loss in a corn/soybean watershed. Agric. Ecosys. Environ. 68: 85-97.
6. Seitzinger, S.P., L.P. Nielsen, J. Caffrey and P.B. Christensen. 1993. Denitrification measurements in aquatic sediments: a comparison of three methods. Biogeochemistry 23:147-167.
7. Yoshinari, T. and R. Knowles. 1976. Acetylene inhibition and nitrous oxide reduction by denitrifying bacteria. Biochem. Biophys. Commun. 69:705-710.

## Descriptors

Agriculture, Denitrification, Nitrogen, Water Quality, Streams

## Articles in Refereed Scientific Journals

## Book Chapters

## Dissertations

## Water Resources Research Institute Reports

## Conference Proceedings

## Other Publications

**Basic Project Information**

| Basic Project Information | |
|--:|:--|
| **Category** | **Data** |
| **Title** | Analysis of Water Use Trends in the United States, 1950-1995 |
| **Project Number** | C-06 |
| **Start Date** | 09/01/1999 |
| **End Date** | 08/31/2001 |
| **Research Category** | Not Applicable |
| **Focus Category #1** | Water Use |
| **Focus Category #2** | Conservation |
| **Focus Category #3** | Models |
| **Lead Institution** | Southern Illinois University at Carbondale |

**Principal Investigators**

| Principal Investigators | | | |
|:--|:--:|:--|:--:|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Ben Dziegielewski | Professor | Southern Illinois University at Carbondale | 01 |
| Subhash Sharma | Professor | Southern Illinois University at Carbondale | 02 |

**Problem and Research Objectives**

Improved information about water withdrawals and uses in specific geographical regions and a basic understanding of the factors that influence water use, are a necessary requirement for sound water resources management. The USGS National Water-Use Information Program (NWUIP) has collected and published an extensive inventory of water use information since 1950. This information has provided a basis for the development and evaluation of national water policies as well as regional and local plans for the development and use of water resources. It also offers an excellent opportunity for examining and explaining historical trends in water use, and to improve our understanding of the factors that influence water use.

The research objectives are: (1) to provide important insights into the effects of individual factors that have influenced historical water withdrawals, and uses by various sectors, (2) to estimate the quantitative impact of various efforts aimed at improving the efficiency of water use, and (3) to provide the state coordinators with improved water use models for estimating water use in "nonreporting" categories or counties and verifying the reported data based on values of demographic, economic, and other data, which determine water use.

**Methodology**

One of the major purposes of this project is to develop a methodology for estimating water use based on routinely collected governmental data on demographic and economic activities within geographical areas. The aggregate analysis of this project is a new approach to modeling sectoral water demands.

The important methodological aspects of this research include 1) predictive accuracy of models at multiple levels of sectoral and spatial aggregation of water use, and 2) parsimony of statistical models, in terms of the number of explanatory variables.

### Principal Findings and Significance

The results that have been generated indicate that improved predictive models can be obtained by separating all states into two or more groups of states with similar patterns of water use. This procedure would avoid the potential biases of herteroskedasticity (non-constant error variances) of the estimated statistical models. Similar grouping may be necessary for the county-level data. The properties of the preliminary estimated models are very promising in terms of meeting the major objectives of the study.

### Descriptors

Water Demand, Water Use Data, Statistical Models, Data Sources

### Articles in Refereed Scientific Journals

### Book Chapters

### Dissertations

### Water Resources Research Institute Reports

### Conference Proceedings

### Other Publications

The completion of Task 1 of the project resulted in approximately 50 one-to-two page annotations of previous studies of water demand. These annotations together with theoretical introduction will be published as a separate volume entitled *Models of Water Demand: Analytical Bibliography*. This volume will be ready for the fall of 2000.

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# Information Transfer Program

The major functions of the Illinois Water Resources Center are to oversee a research program and convey the results of research and development within the water resources field to specialists and the interested public. Information transfer is accomplished through workshops, conferences, published proceedings, a web site, and maintenance of a lending library of Illinois Water Resources Center reports and videotapes. In addition, the Center Director and staff serve on state advisory committees and consult with government agencies. These and other activities are discussed below.

WATERSHED MANAGEMENT: A top-down regulatory approach has worked in the control of pollution from point sources (industrial and municipal sources). The same cannot be said of problems originating from nonpoint sources (excessive nutrients, pesticides, excessive sediment, water flow extremes), partly because of the diffuse nature of the sources and complexity of the problems and partly because of socio-political concerns about retaining local control and protecting private property rights. Watershed management addresses the complexity issue and

watershed partnerships provide a bottom-up, collaborative alternative to top-down control. However, the partnerships will not succeed and water quality will not improve unless some degree of technical competence and organizational skill can be transferred to the local partnerships. Connections must be made between the partnerships, delivery systems (e.g., extension), and the expanding knowledge base in both nonpoint pollution control and local governance. A Watershed Academy developed by the Illinois Water Resources Center provides those connections.

A curriculum in Basic Watershed Science was developed with a Planning Team consisting of Water Center and University of Illinois faculty and staff, staff from the Illinois Environmental Protection Agency and Illinois Department of Natural Resources, and representatives from two mature and effective watershed partnerships. A 300-page loose-leaf workbook was prepared and the first workshop on Basic Watershed Hydrology was held 24-26 February 2000 in Champaign-Urbana. Other workshops and curricular materials will be developed over the next three years, in collaboration with the University of Illinois, the state management and regulatory agencies, and the watershed partnerships themselves.

PUBLIC SEMINAR SERIES ON NUTRIENT ENRICHMENT IN THE MISSISSIPPI RIVER BASIN AND HYPOXIA IN THE GULF OF MEXICO: The severity of the hypoxia problem in the Gulf of Mexico, the links to nitrogen losses in the Corn Belt, and the policy options for reducing nitrogen loading very controversial. The Illinois Water Resources Center co-sponsored a seminar series in the Fall of 1999 that brought to the campus four of the six chairs of committees that wrote the problem assessment and policy documents for the National Hypoxia Assessment, plus one of the chief critics of the National Assessment, who had an opportunity to debate two of the scientists who have worked on the hypoxia problem. The seminar series provided an opportunity for technical experts and stakeholders to hear the scientific evidence, weigh the uncertainties, and debate the costs and benefits of alternative policy proposals.

ILLINOIS RIVER ACTIVITIES: The Illinois River, a major recreational and economic resource for Illinois (more than 90 percent of the state's population lives in this basin of 30,000 square miles), has deteriorated. The Center has played an important role in efforts to reverse this deterioration. The Center Director served on the Lt. Governor's Team that developed a consensus-based Integrated Management Plan for the Illinois River in 1997. The Plan led to a joint state-USDA initiative of $429 million to restore and preserve the watershed, including measures to reduce soil erosion and sedimentation, improve water quality, and enhance wildlife habitat. At the suggestion of the Illinois Water Resources Center, a Science Advisory Committee (SAC) was created in 1998 to assist in the implementation of the Plan and in the assessment of progress, and the Center Director was invited to serve on the SAC. Both the Director and the Editor served on the planning committee for the 1999 Governor's Conference on the Management of the Illinois River System, which was held 5-9 October 1999 in Peoria, Illinois. The Center set up a display in the exhibition that was part of the Governor's Conference, and the Center Editor produced the Conference program, abstracts, and proceedings

MIDWEST TECHNOLOGY ASSISTANCE CENTER (MTAC): MTAC is a cooperative effort of the ten states of the Midwest (congruent with USEPA regions 5 and 7), led by the Illinois State Water Survey and the Illinois Water Resources Center. The participation of each state in MTAC is led by the Director of their Water Resources Institute. Following a national competition, the Midwest Technology Assistance Center (MTAC) was established 1 October 1 1998 to provide assistance to small public water systems throughout the Midwest with funding from the United States Environmental Protection Agency (USEPA) under the 1996 amendments to the Safe Drinking Water Act.

The mission of MTAC is to assist small community water systems and Native American community water systems in the assessment, evaluation, and implementation of technological solutions to their drinking water problems. In 1999, MTAC conducted a survey of the technical and management needs of 200 small systems in ten states and

identified the most critical needs: infrastructure maintenance (piping and other parts of the water delivery system), financial management, and meeting the new USEPA and state regulatory requirements. MTAC funded technical workshops for Native American water supply systems, with the cooperation and participation of the Native American community, to ensure the workshops are tailored to their needs. In addition, MTAC developed a CD-ROM and interactive, web-based version of an Emergency Planning Guide for small systems, so small communities anywhere in the nation can handle droughts, power outages, and other emergencies that threaten water supplies. The Midwest Technology Assistance Center and the Missouri Technology Center co-sponsored the first workshop for small public water systems on 29 February 2000 in St. Louis Missouri. In addition to the workshop, MTAC has a web site to disseminate information to the small systems. The MTAC site is linked to the IWRC web page.

WATER 2000: The Center continued planning the second statewide biennial conference on water issues (Water 2000) to be held in November 2000. The conference will address science, technology, and policy developments in water resources and engage citizens, researchers, and groups interested in water issues. Specific issues to be addressed are water conservation and drought preparedness, non-point source pollution, water education, inland lakes, and urban stormwater.

IWRC DISPLAY: The display which describes the activities of the Center is used at conferences (including the Illinois River Conference mentioned above) and other public events to highlight the Center's accomplishments.

IWRC ON THE WEB: The IWRC is on the World Wide Web. The page may be accessed at the following Internet address: (http://www.environ.uiuc.edu/iwrc/index.htm). It provides links to other information through the national Institutes for Water Resources (http://wrri.nmsu.edu/niwr/index.html). Among the resources available from the NIWR page are all 54 State Water Research Institute's home pages, the Universities Council on Water Resources' database of experts (UWIN), and the National Oceanic and Atmospheric Association's home page (http://www.noaa.gov/). The Illinois-Indiana Sea Grant home page at (http://ag.ansc.purdue.edu/il-in-sg/) can be accessed from IWRC's page.

**Publications from core funds during 1999-2000:**

*1999 Governor's Conference on the Management of the Illinois River System.* Proceedings of the Seventh Biennial Conference, October 5-7, 1999, Peoria, Illinois, Alesia Strawn, Editor. Illinois Water Resources Center, Special Report No. 25.

Illinois Water Resources Center, University of Illinois, Illinois Department of Natural Resources, and Illinois Environmental Protection Agency. 1999. Basic Watershed Science for Effective Watershed Management: Workbook. 300 p.

Videotapes from a public seminar series on Nutrient Enrichment in the Mississippi River Basin and Hypoxia in the Gulf of Mexico, Illinois Water Resources Center, University of Illinois, Fall 1999.

- "The National Hypoxia Assessment: What Did it Really Say, and Where Do we Go from Here?" by Otto Doering.
- "Science and Public Policy: A Case Study of Hypoxia" by Derek Winstanley.
- "Gulf of Mexico Hypoxia: Linkages with the Mississippi River" by Nancy N. Rabalais; "Suspended Sediment, C, N, P, and Si Yields from the Mississippi River Basin" by R. Eugene Turner; and follow-up discussion with Rabalais, Turner, and Derek Winstanley.

**Basic Project Information**

<table>
<tr><td colspan="2" align="center"><strong>Basic Project Information</strong></td></tr>
<tr><td align="center"><strong>Category</strong></td><td align="center"><strong>Data</strong></td></tr>
<tr><td align="right"><strong>Title</strong></td><td>Midwest Technology Assistance Center (MTAC)</td></tr>
<tr><td align="right"><strong>Description</strong></td><td>MTAC is a cooperative effort of Water Resources Institutes in ten statesin the Midwest to provide assistance to small public water systems (USE funded).</td></tr>
<tr><td align="right"><strong>Start Date</strong></td><td>03/01/1998</td></tr>
<tr><td align="right"><strong>End Date</strong></td><td>12/31/2000</td></tr>
<tr><td align="right"><strong>Type</strong></td><td>Conferences</td></tr>
<tr><td align="right"><strong>Lead Institution</strong></td><td>Illinois Water Resources Center</td></tr>
</table>

**Principal Investigators**

**Problem and Research Objectives**

**Methodology**

**Principal Findings and Significance**

Assists small community water systems and Native American community water systems in ten states in the assessment, evaluation, and implementation of technological solutions to their drinking water problems.

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

**Water Resources Research Institute Reports**

**Conference Proceedings**

**Other Publications**

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**Basic Project Information**

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Watershed Management |
| **Description** | A workshop for leaders from watershed planning groups was held on February 24-26, 2000. |
| **Start Date** | 03/01/1999 |
| **End Date** | 12/31/2000 |
| **Type** | Conferences |
| **Lead Institution** | Illinois Water Resources Center |

## Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Richard E. Sparks | Professor | Illinois Water Resources Center | 01 |
| Chris Johns | Professional Staff | Illinois Water Resources Center | 02 |

## Problem and Research Objectives

## Methodology

## Principal Findings and Significance

A Watershed Academy was established to provide technical assistance to leaders in more than 100 watershed partnerships that now exist in Illinois. The curricula and workshops developed by the Academy should facilitate local planning and implementation of nonpoint source management and ultimately help improve the quality of rivers and streams throughout the state.

## Articles in Refereed Scientific Journals

## Book Chapters

## Dissertations

## Water Resources Research Institute Reports

## Conference Proceedings

## Other Publications

Illinois Water Resources Center, University of Illinois, Illinois Department of Natural Resources, and Illinois Environmental Protection Agency. 1999. Basic Watershed Science for Effective Watershed Management: Workbook. 300

**Basic Project Information**

| Basic Project Information | |
|---|---|
| Category | Data |
| Title | Public Seminar Series on Nutrient Enrichment in the Mississippi River Basin and Hypoxia in the Gulf of Mexico |
| Description | |
| Start Date | 03/01/1999 |
| End Date | 02/29/2000 |
| Type | Conferences |
| Lead Institution | Illinois Water Resources Center |

**Principal Investigators**

**Problem and Research Objectives**

**Methodology**

**Principal Findings and Significance**

The seminar series provided an opportunity for technical experts and stakeholders to hear the scientific evidence, weigh the uncertainties, and debate the costs and benefits of alternative policy proposals for reducing nutrient losses from agricultural areas.

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

**Water Resources Research Institute Reports**

**Conference Proceedings**

**Other Publications**

Videotapes from a public seminar series on Nutrient Enrichment in the Mississippi River Basin and Hypoxia in the Gulf of Mexico, Illinois Water Resources Center, University of Illinois, Fall 1999.

- "The National Hypoxia Assessment: What Did it Really Say, and Where Do we Go from Here?" by Otto Doering.
- "Science and Public Policy: A Case Study of Hypoxia" by Derek Winstanley.
- "Gulf of Mexico Hypoxia: Linkages with the Mississippi River" by Nancy N. Rabalais; "Suspended Sediment, C, N, P, and Si Yields from the Mississippi River Basin" by R. Eugene

Turner; and follow-up discussion with Rabalais, Turner, and Derek Winstanley.

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## Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Illinois River Activities |
| **Description** | Scientific Advisory Committee to the Coordinating Council that Implements the Integrated Master Plan for the Illinois River |
| **Start Date** | 03/01/1999 |
| **End Date** | 02/29/2000 |
| **Type** | Conferences |
| **Lead Institution** | Illinois Water Resources Center |

## Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Richard E. Sparks | Professor | Illinois Water Resources Center | 01 |

## Problem and Research Objectives

## Methodology

## Principal Findings and Significance

Committee provides scientific advice on restoration of the Illinois River, whose basin of 30,000 squares miles is home to 90% of the state's population.

## Articles in Refereed Scientific Journals

## Book Chapters

## Dissertations

## Water Resources Research Institute Reports

## Conference Proceedings

## Other Publications

**Basic Project Information**

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Water 2000 |
| **Description** | Statewide biennial conference on water issues |
| **Start Date** | 12/01/1999 |
| **End Date** | 11/30/2000 |
| **Type** | Conferences |
| **Lead Institution** | Illinois Water Resources Center |

**Principal Investigators**

**Problem and Research Objectives**

**Methodology**

**Principal Findings and Significance**

The conference will address science, technology, and policy developments in water resources and engage citizens, researchers, and groups interested in water issues.

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

**Water Resources Research Institute Reports**

**Conference Proceedings**

**Other Publications**

# USGS Internship Program

# Student Support

| | Student Support | | | | |
|---|---|---|---|---|---|
| Category | Section 104 Base Grant | Section 104 RCGP Award | NIWR-USGS Internship | Supplemental Awards | Total |
| Undergraduate | N/A | N/A | 11 | 5 | 16 |
| Masters | 2 | 9 | N/A | N/A | 11 |
| Ph.D. | 1 | 7 | N/A | 2 | 10 |
| Post-Doc. | N/A | N/A | N/A | 1 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| **Total** | 3 | 16 | 11 | 8 | 38 |

# Awards & Achievements

Project C-03. *Cost-Effective Monitoring Design for Intrinsic Bioremediation.* The methodology developed in this project has the potential to produce substantial cost savings at numerous sites in the U.S. Researches Barbara S. Minsker and Albert J. Valocchi presented the work at several professional conferences and interest in the method has been substantial. The University of Illinois issued a press release on the method and several articles have been written in popular environmental industry journals such as *Pollution Engineering*. Patrick Reed received an EPA STAR Fellowship to continue this research for his Ph.D.

Project B-02. *Genetic Algorithms for the Control of Sedimentation in River-Reservoir Networks* by John W. Nicklow. The newly developed interface between a genetic algorithm and a sediment transport simulation model constitutes a new solution methodology to control the adverse effects of sedimentation. Use of the method in operating protocols for dams could reduce waterway rehabilitation costs and improve sustainability of rivers and reservoirs.

The Illinois Water Resources Center and the Illinois Water Survey established the Midwest Technology Assistance Center, with funding from USEPA. Technical assistance for drinking water systems in small communities and native American communities is developed and disseminated using the network of Water Resources Institutes in the ten states of the Midwest. Projects in 1999 included: a Benchmark Economic Study to assist small systems with their financial and managerial problems; a survey of the technical and management needs of 200 small systems in ten states; technical workshops for Native American water supply systems; a CD-ROM and interactive, web-based version of an Emergency Planning Guide for small systems, so small communities anywhere in the nation can handle droughts, power outages, and other emergencies that threaten water supplies; and a workshop for small public water systems on 29 February 2000 in St. Louis Missouri.

# Publications from Prior Projects

### Articles in Refereed Scientific Journals

1. Benkstein, K.D.; J.T. Hupp, C.L. Stern, 1998, "Molecular Rectangles Based Upon Rhenium (I) Coordination Chemistry" *J.Am. Chem. Soc.* (120) 12982-12983.
2. Slone, Robert V.; K.D. Benkstein, S. Belanger, J.T. Hupp, I.A. Guzei, A.L. Rheingold, "Luminescent Transtition-metal-containing Cyclophanes ("Molecular Squares"): Covalent Self-assembly, Host--guest Studies and Preliminary Nanoporous Materials Applications" *Coor. Chem. Rev.* 1998, 171:221-243.
3. Belanger, S.; M.H. Keefe, J.L. Welch, J.T. Hupp, "Rapid Derivatization of Mesoporous Thin-Film Materials Based on Re(I) Zinc-Porphyrin "Molecular Squares": Selective Modification of Mesoporous Size and Shape by Binding of Aromatic Nitrogen Donor Ligands" *Coor. Chem. Rev.* 1999, in press.

### Book Chapters

### Dissertations

### Water Resources Research Institute Reports

**Conference Proceedings**

**Other Publications**