

**AMERICAN WATER RESOURCES ASSOCIATION-  
WISCONSIN SECTION**

**30<sup>th</sup> ANNUAL MEETING**

**WISCONSIN'S WATER RESOURCES: CONFLICTS  
AND COLLABORATIONS**

**March 2 & 3, 2006**

**The Osthoff Resort  
Elkhart Lake, Wisconsin**

**Hosts:**

**American Water Resources Association-Wisconsin Section  
University of Wisconsin Water Resources Institute  
Wisconsin Department of Natural Resources  
Center for Watershed Science & Education, UW-Stevens Point  
Wisconsin Geological and Natural History Survey  
U.S. Geological Survey, Wisconsin District**

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# PROGRAM SUMMARY

## Wisconsin's Water Resources: Conflicts and Collaborations

### 30<sup>th</sup> Annual Meeting of the American Water Resources Association – Wisconsin Section

The Osthoff Resort, Elkhart Lake, Wisconsin

#### Thursday, March 2, 2006

- 9:00 a.m. – 2:30 p.m. Registration – Palm Garden Foyer
- 11:30 – 12:15 Welcome and Lunch – Palm Garden Ballroom A
- 12:15 – 12:45 Board Member Elections and Treasurer's Report
- 12:45 – 2:25 **Plenary Session:** Conflicts and Collaborations
- Dan Duchniak, Waukesha Water Utility  
George Kraft, Central Wisconsin Groundwater  
Center  
Sandra McLellan, Great Lakes WATER Institute
- 2:25 – 2:45 p.m. **Break**
- 2:45 – 3:55 p.m. **Concurrent Sessions 1A and 1B**
- Session 1A – Groundwater Quality Studies–**  
Villa Gottfried Room A  
Moderator: Eugene McLinn, RMT, Middleton
- 2:45 Evaluation of Natural Attenuation at Closed Wisconsin  
Leaking Underground Storage Tank Sites. Rachel M.  
Greve\*
- 3:05 Contaminant Transport and Hydraulic Control of  
DNAPL and LNAPL from a Former Industrial Site in  
Southeast Wisconsin through Low Permeability Soils  
to an Adjacent Stream.  
Christina A. Reese

3:25 Investigation of Hormone and Pharmaceutical Transport through Unsaturated and Saturated Sediments Using Laboratory Column Experiments. Jeffrey D. Wilcox\*

**Session 1B – Regional Planning and Water Resources–**

Villa Gottfried Room B

Moderator: Earl Spangenberg, UW-Stevens Point

2:45 Regional Water Supply Planning in Southeastern Wisconsin. John Jansen

3:05 Comprehensive Planning in Wisconsin: Are Communities Planning to Protect Their Groundwater? Part II. Lynn Markham

3:25 Interagency Creation of a Watershed Boundary Dataset in Wisconsin. Milo Anderson

3:45 – 4:05 p.m. **Break**

4:05 – 5:25 p.m. **Concurrent Sessions 2A and 2B**

**Session 2A – Land Use and Runoff Studies–**

Villa Gottfried Room A

Moderator: Mike Penn, UW-Platteville

4:05 Filterstrip Attenuation of Open Dairy Feedlot Effluent and its Effect on Soil Physical and Chemical Properties. Dennis L. Busch

4:25 Evaluating the Significance of Winter Runoff from Agricultural Fields in Southwest Wisconsin. Randy M. Mentz

4:45 Predicting Potential of Riparian Buffers to Attenuate Eutrophication in Wisconsin Lakes. Jeff T. Maxted

5:05 Using the SWAT Model to Link Land Management with Phosphorus Loading in the Upper Fever River, Lafayette County, Wisconsin. Adam T. Freihoefer\*

**Session 2B – Natural and Human-Induced Groundwater**

**Quality Problems**

Villa Gottfried Room B

Moderator: Katherine Grote, UW-Eau Claire

- 4:05 Fluoride Concentrations in a Crystalline Bedrock Aquifer, Marathon County, Wisconsin. David L. Ozsvath
- 4:25 Agricultural Phosphorous Enrichment: Making a Case for Rising P in Wisconsin Groundwater. Bryant A. Browne
- 4:45 Understanding the Role of Groundwater in Pollutant Export from a Northern Mississippi Valley Loess Hills Watershed. Kevin C. Masarik
- 5:05 Agriculture-Related Trends in Ground-Water Quality of the Sand and Gravel Aquifer in Central Wisconsin. David A. Saad

5:25 – 7:00 p.m. **Poster Session and Social Hour –**  
Palm Garden D, E, and F

Assessment of Microbial Contamination in Cooks and Opunohu Bays on the French Polynesian Island of Moorea. Justin M. Barrick\*

Pollutant Analysis of a Snow Pack and Underlying Soil on a Collection Site. Heidi M. Begin\*

Mercury and Lead in a Core from Turtle Creek, Shopiere, Wisconsin: Implications for Interpreting Land-use and Environmental Change. Rebecca B. Carvin\*

Baseflow Prediction in the Fox-Wolf Watershed: A Case Study for Wisconsin Act 310. Katherine A. Clancy

Groundwater/Surface Water Interactions in a Small Midwestern Wetland and Implications for Denitrification. Laura Craig\*

Distribution of Phosphorus in the Stream Sediments of the Lake Mendota Watershed. Jeremy P. Haas\*

Delineating Problem Wetlands at Chiwaukee Prairie, Pleasant Prairie, Wisconsin. Ryan S. Helgesen\*

Fluorescence Lifetime Measurements with Fiber Optic Sensor Arrays. Paul E. Henning\*

Combination of Surfactant Solubilization with Permanganate Oxidation for Groundwater Remediation – Batch, Column and Tank studies. George Li

Toward Better Simulations of Wetland Hydrology - the Need for Diverse Field Data Collection. Christopher S. Lowry\*

Removal of Chlorophenols from Water Using Polyvinyl Pyrrolidone (PVP). Stephen J. Matoska\*

Optical Sensing of Oxygen in Gas and Aqueous Phase. Veronica M. Rigo\*

Evaluating Groundwater use in Southern Wisconsin. Laura Rozumalski\*

Combining Surface Geophysical Methods to Identify Karst Hidden beneath Glacial Till. James E. Wedekind

7:00 p.m. **Dinner** – Palm Garden Ballroom A

**Speaker:** Robert Zimmerman, Senior Engineer Water Conservation Initiatives, Kohler Company

**The Kohler Company and Water Conservation– Past, Present and Future**

**Friday, March 3, 2006**

7:00 – 8:30 a.m. AWRA–Wisconsin Section Board of Directors'  
Breakfast Meeting – Boardroom

8:30 – 10:10 a.m. Concurrent Sessions 3A and 3B

**Session 3A – Hydrogeologic Investigations –**

Elkhart Lake Ballroom A  
Moderator: John Skalbeck, UW Parkside

- 8:30 Geochemical and Stratigraphic Controls on Radium Activities in the Cambrian Ordovician Aquifer, Waukesha, Wisconsin. Sue E. Friers\*
- 8:50 Groundwater Recharge through a Thick Sequence of Fine-Grained Sediment in the Fox River Valley, East-Central Wisconsin. Thomas S. Hooyer
- 9:10 Pleistocene Hydrology of the Deep Sandstone Aquifer in Southeast Wisconsin. Timothy J. Grundl
- 9:30 The Hydrogeologic Significance of Karst Features in the Prairie du Chien Group Dolomite of West-Central Wisconsin. Michael K. Cobb\*
- 9:50 Dual-Porosity and Dispersion in Silurian Dolomite near Valders, Wisconsin: The Influence of Coral Zones and Fractures on Flow and Transport. Kenneth R. Bradbury

**Session 3B – Surface Water Quality Studies –**

Elkhart Lake Ballroom B  
Moderator: Stephen Galarneau, Wisconsin DNR, Sheboygan

- 8:30 Distribution of Phosphorus in the Stream Sediments of the Lake Mendota Watershed. Ben W. Wood\*
- 8:50 Greenhouse Gases in Central Wisconsin Streams. Samuel F. Werner\*

- 9:10 a.m. Phosphorus Forms and Fate in the Lower Fox River Watershed. Paul D. Baumgart
- 9:30 Arsenic Speciation in the Kewaunee Marsh: Method Development and Analytical Results. Kristie M. Ellickson
- 9:50 Characterization of Chloride Concentrations in Northern Marshes. Stephani Miklovic
- 10:10 – 10:30 a.m. **Break**
- 10:30 – 11:50 a.m. **Concurrent Sessions 4A and 4B**
- Session 4A – Modeling and Hydrogeologic Studies –**  
Elkhart Ballroom A  
Moderator: David Saad, USGS, Middleton
- 10:30 Subsurface Precambrian Basement Topography of Southeastern Wisconsin from Coupled Modeling of Gravity and Aeromagnetic Data. John D. Skalbeck
- 10:50 Using Groundwater Models to Assess Flow to Wells in Residential Subdivisions. Madeline B. Gotkowitz
- 11:10 Impacts of Multiple Aquifer Wells on Groundwater Flow in Southeastern Wisconsin. David J. Hart
- 11:30 How Complex Do Models Need To Be? Randy J. Hunt
- 11:50 Announcement of student paper award winners
- Session 4B – Surface Water Management –**  
Elkhart Lake Ballroom B  
Moderator: Tim Asplund, Wisconsin DNR
- 10:30 Concentration Ain't Nothin' but a Number – Exposure Pathways and Bioavailability Affect Sediment Remediation Objectives. Eugene L. McLinn

10:50 a.m. Lake Levels Got You Down? Find the Positives and Reap the Benefits. Scott M. Provost

11:10 Lake Water Levels as a Management Tool. Mark F. Sesing

11:30 The Restoration of Rush Lake, a Deep Water Marsh in Northeast Wisconsin. Timothy E. Lizotte

11:50 a.m. Announcement of student paper award winners

\*student presentation

12:15 – 2:15 p.m. Student Career Workshop  
Palm Garden Ballrooms E and F

**SESSION 1A:  
Groundwater Quality Studies  
Thursday, March 2, 2006  
2:45 – 3:55 p.m.**

**Evaluation of Natural Attenuation at Closed Wisconsin Leaking Underground Storage Tank Sites**

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Leaking underground storage tanks (LUSTs) are a major source of petroleum contamination to surficial aquifers. Approximately 20,000 LUST sites have been identified in Wisconsin since monitoring began in the 1980s, with approximately 3000 sites currently being monitored by the Wisconsin Department of Natural Resources (WDNR) and Wisconsin Department of Commerce (WDCOMM). In the past, contaminant concentrations at LUST sites were required to meet state environmental standards before closure could occur. A rule change in 1996 allowed site closure with contaminant concentrations above environmental standards under certain conditions: (1) adequate source zone control and site investigation, (2) plume shown to be stable or receding due to natural attenuation and (3) residual concentrations pose no threat to public health, safety, or the environment. Natural attenuation is defined by the EPA as the reduction of contaminant concentration and mass through physical, chemical and biological processes without human intervention. These processes include biodegradation, sorption, dilution, dispersion, volatilization, transformation, destruction, and others.

A joint WDNR/WDCOMM study is currently underway to determine whether the above conditions for site closure under natural attenuation can be adequately evaluated using current protocols. As part of this study, ground water monitoring systems were reestablished at a total of ten sites closed in 1999 and 2000 to determine changes in plume dimensions and contaminant concentrations, as well as to provide additional site characterization. These sites included four former retail gasoline stations and six other, lower-volume sites. Samples were evaluated for volatile organic compounds (VOCs) such as benzene,

ethylbenzene, toluene, and xylenes (BTEX) as well as for the gasoline additive MTBE. Seasonal variations in flow direction and water level-concentration relationships appear to be important factors in measured contaminant levels. Several parameters indicative of natural attenuation were also measured. Although these parameters suggest that natural attenuation is occurring, contamination is present at all sites. Several plumes appear to have expanded or shifted since site closure. These results indicate that, while natural attenuation is occurring at some or all sites, the five-year time interval since site closure has not been sufficient to reduce contamination levels below environmental standards, and in some cases natural attenuation is not sufficient to keep the plume from expanding.

\*Note: This is a student presentation.

## **Contaminant Transport and Hydraulic Control of DNAPL and LNAPL from a Former Industrial Site in Southeast Wisconsin through Low Permeability Soils to an Adjacent Stream**

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Koltz, Brandon J. Triad Engineering Incorporated, 325 E. Chicago Street, Milwaukee, WI 53202; [brandon.koltz@triadengineering.com](mailto:brandon.koltz@triadengineering.com)

In the mid-1990's, site investigations identified impacts to soil and groundwater at a former 32-acre stainless steel tubing manufacturer (1941 – 1984) located in southeastern Wisconsin. Impacts to soil, groundwater, surface water and sediment included chlorinated solvents, nickel, chromium, and select petroleum constituents at concentrations above regulatory standards at various locations across the site.

Site geology consists of three stratigraphic units: an upper fill unit, a second unit of intermixed native deposits and a lower native silt unit. The lower silt unit is contiguous across the site and represents a semi-confining layer. Surface water features include an adjacent stream immediately south of the site and an impoundment immediately upstream. A natural wetland is located directly south of the creek.

Migration pathways for the released chlorinated solvents include downward migration of free phase product (DNAPL) through the unsaturated upper sand unit to the water table, continued downward migration within the saturated zone until impeded by the silt unit, and dissolution and transport via groundwater. Discharge of contaminated groundwater and DNAPL to the adjacent stream and wetland to the south has been documented. Discharge of chlorinated solvents through coal cinders mobilized PAHs that have adsorbed to sediment in the stream. Water column impacts have been found to be minimal.

The presentation will identify transport pathways and rates, control technologies and contaminant removal, contaminated soil and streambank relocation for remediation onsite, and expected improvements to groundwater and the stream.

## **Investigation of Hormone and Pharmaceutical Transport through Unsaturated and Saturated Sediments Using Laboratory Column Experiments**

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Recent work has shown that municipal and domestic wastewater contains hormones, pharmaceuticals, and personal-care products (HPPCPs). In this study, we have detected several HPPCPs in samples collected from private septic systems in southeast Wisconsin and a sample collected downstream from the Nine Springs wastewater treatment plant in Madison. While the release of these compounds to the environment has been documented, little is known about their transport and fate in the subsurface. We have designed laboratory column experiments to investigate how sorption affects the mobility of selected HPPCPs through unsaturated and saturated soils.

Unsaturated columns were constructed using porous stainless-steel bases and 8-inch diameter aluminum irrigation pipes lined with Teflon contact paper. Sediment depth was 3 feet, the minimum unsaturated thickness required by Wisconsin code beneath conventional septic system leach fields. Preliminary results show that sorption of HPPCPs is significant; target hormones ( $\beta$ -estradiol, 17- $\alpha$  ethynyl estradiol, estriol, and estrone) have a particularly high propensity to sorb.

A 24-inch stainless-steel column was constructed for investigating HPPCP transport through saturated soils. Experimental breakthrough curves have been compared to theoretical curves produced using Langmuir, Freundlich, and linear sorption isotherms. Retardation factors of HPPCPs have exceeded 20 with respect to a conservative bromide tracer, although some compounds are more mobile than others.

\*Note: This is a student presentation.

**SESSION 1B:  
Regional Planning and Water Resources  
Thursday, March 2, 2006  
2:45 – 3:55 p.m.**

**Regional Water Supply Planning in Southeastern Wisconsin**

Jansen, John, P.G., Ph.D., Aquifer Science and Technology a Division of  
Ruekert/Mielke Inc.

Steven H. Schultz, P.E., Aquifer Science and Technology a Division of  
Ruekert/Mielke Inc.

The seven-county area that comprises southeast Wisconsin is a major population and economic center for Wisconsin. Decades of over use of the deep sandstone aquifer have created a large cone of depression with over 5 feet of drawdown per year and about 500 feet of drawdown from predevelopment conditions. Many of the wells in the sandstone aquifer exceed drinking water standards for radium and gross alpha and TDS levels are rising in a few wells. These water quality issues will require significant capital investment for treatment systems if the aquifer is to be continued to be used. The declining head and water quality have led many water utilities to look at alternative water sources. Attempts to expand the use of Lake Michigan are limited by laws that limit diversion across the subcontinental divide that passes through the area. Many communities are planning to significantly increase the use of the shallow aquifer system, which has raised concerns over the long-term impact on surface water

The region has slowly been moving towards a plan to determine the direction of future water supply. As part of that work, regional planning commissions, private funding agencies, and state and national government agencies have performed a number of topical studies on the resources of the region. To date, studies have been performed on the declining water levels in the area and a comprehensive MODFLOW model has been developed to help predict future situations. The Great Lakes Protection Fund has funded a study of the impacts on the regional groundwater flow system and water quality caused by prolonged over drafting of water from the deep sandstone aquifer in the area.

The Southeast Wisconsin Regional Planning Commission (SEWRPC) has received funding from the seven counties and has embarked on a study of all the issues related to the future water supply of the area. This study is reviewing not only the future use of Lake Michigan water, but also the sustainable yield of the shallow and deep aquifers in the area. Begun in mid 2005, the study will take a little over two years to complete. The first work product, due in early 2006, is a review of water management practices and technologies, such as artificial recharge, conservation, and emerging water treatment technologies that could be used as part of the plan. Subsequent work products will look at the economic and ecological implications of several water supply alternatives. The best plan will be

selected from the list of alternatives using a set of principles and objectives defined at the start of the process.

This plan is expected to comprise the first Groundwater Management Area Plan as required by the new Wisconsin High Capacity Well Law, Act 310. While the plan will be specifically designed for southeast Wisconsin, many of the concepts developed will be directly relevant to other parts of the state.

## **Comprehensive Planning in Wisconsin: Are Communities Planning to Protect Their Groundwater? Part II**

Lynn Markham, Center for Land Use Education, UW-Stevens Point College of Natural Resources, 800 Reserve St., Stevens Point, WI 54481, [lmarkham@uwsp.edu](mailto:lmarkham@uwsp.edu)

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For communities to plan effectively for the future, it is essential that both the quantity and quality of groundwater be protected. Legislation adopted in Wisconsin in 1999 requires that by January 1, 2010 all communities that make specified land use decisions base those decisions on a comprehensive plan. This study is the first to track how groundwater is being addressed in the plans.

The occurrence and types of groundwater-related data, goals, and policies were analyzed in 29 comprehensive plans. The most common groundwater data provided in plans were related to surface watersheds, soil types, and groundwater susceptibility. Generally plans contained few groundwater-related goals with an average of 1.4 groundwater goals per plan. The average number of groundwater-related policies per plan was 8.5 with *waste management* being the most common policy category to mention groundwater.

Communities in counties that have produced a groundwater protection plan and communities with municipal water systems included more groundwater data in their plan than communities without these resources. Communities with moderate or high groundwater susceptibility had higher groundwater goal scores than communities with low groundwater susceptibility. Data scores did not correlate with goal or policy scores; nor did goal scores correlate with policy scores.

In addition to the comprehensive plan analyses, five case studies were developed describing how Wisconsin communities have implemented groundwater protection tools. Based on the plan analyses and case studies, recommendations are made for community groundwater planning.

## **Interagency Creation of a Watershed Boundary Dataset in Wisconsin**

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Since the 1970s, federal agencies have been developing a system called the hydrologic unit code (HUC) that catalogues the nation's water system. The purpose of the HUC system is to provide a nested, topographically-defined classification of surface water features. In the mid-1990s, there was an increased focus by state and federal agencies to begin to delineate watersheds using base data and methods that meet national standards (Federal Standards for Delineation of Hydrologic Unit Boundaries: Version 2.0). This developed into a goal to produce a seamless hydrologic boundary dataset for the United States called the Watershed Boundary Dataset (WBD).

The new dataset's goal is to develop two new classification levels, the Watershed (10-digit code), and the Sub-watershed (12-digit code). This permanent national standard dataset would compliment the existing HUC dataset. These later classifications will be of greater assistance with small-scale management and water issues than the current 8-digit code dataset originally developed in the 1970s. In September 2004, the project to digitally map the hydrologic units in Wisconsin began. The work relies on interagency cooperation between the Environmental Protection Agency, U.S. Geological Survey, U.S. Forest Service, National Resource Conservation Service, Wisconsin Department of Natural Resources, several local planning commissions, and state and federal agencies in the bordering states of Minnesota, Michigan, Iowa and Illinois. The coordination between agencies is vital to the goal of the production of a seamless Watershed Boundary Dataset for the state of Wisconsin by fall of 2006.

The production of the WBD for Wisconsin involves a process of first using simulated catchment boundaries derived from digital elevation models as a guide for aggregating drainage basins at a specific size range, then compare the simulated boundaries with other available catchment linework, and then finally do heads-up digitizing on USGS topo maps using all of these catchment lines as guides. The linework is then groundtruthed based on coordination with knowledgeable Federal, State, and local officials most familiar with the landscape. The result is an agreed-upon watershed GIS data layer that meets the Federal Standards for Delineation of Hydrologic Unit Boundaries.

**SESSION 2A:  
Land Use and Runoff Studies  
Thursday, March 2, 2006  
4:05 – 5:25 p.m.**

**Filterstrip Attenuation of Open Dairy Feedlot Effluent and Its Effect on Soil Physical and Chemical Properties**

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Open feedlots are a common component of Midwestern animal agriculture, providing an economical option for the feeding and raising of livestock. However, open lot effluent, if not properly treated, can contribute to environmental pollution. Filterstrips are designed to treat open lot runoff by reducing concentrations of nutrients and sediment, which mitigates potential environmental impacts. The goals of this study are to (1) determine the ability of a filterstrip to attenuate pollutants, and (2) investigate the effect 20 years of filterstrip operation has on soil physical and chemical properties.

Filterstrip treatment performance was determined by analyzing water samples entering and exiting the filterstrip. Water samples were collected and water volume determined using USGS gauging stations. Samples were analyzed for the following: total solids, suspended solids, nitrate-N, ammonium-N, total-N, organic-N, dissolved reactive phosphorus, and total phosphorus. Treatment performance was based on percent removal for each of the above constituents.

The effect of filterstrip operation on soil chemical and physical properties was investigated by collecting and analyzing soil samples from the filterstrip and adjacent soils not impacted by the open lot effluent. Soil cores (12) were collected to a depth of 1 meter and divided into 10 cm segments prior to analysis. Samples were analyzed for the following: organic matter, pH, phosphorus, potassium, total nitrogen, ammonium-N, nitrate-N, chloride, and particle size. Research was conducted at U.W.-Platteville's Pioneer Farm.

## **Evaluating the Significance of Winter Runoff from Agricultural Fields in Southwest Wisconsin**

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Non-point source pollution of surface water with sediment, nutrients, and other agrichemicals is a growing public and regulatory concern. Pollutants exported from agricultural fields are often estimated using computer models and simulated runoff experiments, rather than with actual field measurements. Pioneer Farm, a 430-acre mixed-livestock farm associated with the University of Wisconsin-Platteville is intensively instrumented with flumes and automated samplers to sample runoff at intervals throughout individual storm events. With modification, these field devices can quantify winter runoff events, which are difficult to monitor and are rarely reported in scientific literature. Our monitoring has shown that winter runoff volumes can be large, particularly during rains on frozen ground, and nutrient concentrations can be high. This presentation will describe the annual runoff monitoring from 2004 and 2005 and highlight the relative importance of winter runoff to the annual export of non-point source pollutants.

## **Predicting Potential of Riparian Buffers to Attenuate Eutrophication in Wisconsin Lakes**

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Riparian buffers have the potential to reduce phosphorus loads in streams. These reductions may also have beneficial effects on downstream oligotrophic and mesotrophic lakes. We present a model for estimating phosphorus load reduction potential at the scale of a small watershed and extend the analysis to show which lakes may benefit most from phosphorus load reductions.

Load reduction potential is the current load minus the sum of unbufferable sources. We built regression models from measured annual loads and landscape metrics to estimate current annual loads. Unbufferable sources cannot be attenuated by riparian buffers and include point sources, fine-textured soils, and meander belt erosion. We estimate the model parameters for a set of 1598 small (average 52 sq. km) watersheds in Wisconsin. We then identified 355 Wisconsin lakes that are most likely to benefit from phosphorus load reduction. This application is part of a geographic targeting scheme that seeks to invest conservation funds where eutrophication is most likely to be attenuated.

## **Using the SWAT Model to Link Land Management with Phosphorus Loading in the Upper Fever River, Lafayette County, Wisconsin**

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Maintaining water quality in an agriculturally dominated watershed requires an understanding of how nutrient application and land management influence nutrient transfer and concentrations in surface water. Within southwestern Wisconsin's Upper Fever River Watershed, phosphorus in agricultural runoff is a concern as nearly 75% of the 7.8 square kilometer watershed is managed for agriculture. In order to understand and eventually control phosphorus loading from nonpoint sources within the watershed, the Arc View Soil and Water Assessment Tool (AVSWAT) model approach was used to simulate the influence of land management on phosphorus transfer. The SWAT model is a physically based, continuous time, geographic information system (GIS) model developed by the U.S. Department of Agriculture - Agriculture Research Service (USDA-ARS) for the prediction and simulation of flow, sediment, and nutrient yields. It relies on many of the process descriptions used in previous USDA-ARS models but incorporates them within spatially distributed hydrologic response units. The Upper Fever River Watershed has been monitored for the past three years as part of the Pioneer Farm monitoring project. Runoff monitoring from individual fields at the Pioneer Farm and stream monitoring at the watershed outlet were both used to calibrate the model and determine the sensitivity of the simulations to assumptions about nutrient application and management. The results will be used to understand how SWAT can guide management decisions for future landuse within the Upper Fever River and other agricultural watersheds.

\*Note: This is a student presentation.

**SESSION 2B:**  
**Natural and Human-Induced Groundwater Quality Problems**  
**Thursday, March 2, 2006**  
**4:05 – 5:25 p.m.**

**Fluoride Concentrations in a Crystalline Bedrock Aquifer, Marathon County, Wisconsin**

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Water samples from 2,786 private water-supply wells in Marathon County, Wisconsin reveal that dissolved fluoride concentrations in the crystalline bedrock aquifer range from <0.01 to 7.6 mg/L, with 0.6 percent of the values exceeding the EPA's maximum contaminant level of 4 mg/L, and 8.6 percent exceeding the EPA's secondary maximum contaminant level of 2.0 mg/L. Roughly a quarter of the wells contain fluoride within the range that is considered optimal for human health (between 0.5 and 1.5 mg/L), whereas 63.2 percent fall below 0.5 mg/L.

Consistent with studies conducted in other regions, felsic rocks have significantly higher fluoride concentrations than do other lithochemical groups (mafic and metasedimentary rocks). Amongst the felsic rock types, syenites yield the most fluoriferous groundwaters, but the highest median concentration occurs in a biotite, sodium-plagioclase granite. A relationship between plagioclase composition and fluoride concentrations suggests that dissolved fluoride levels are controlled by fluorite solubility and that higher fluoride concentrations are generally found in soft, sodium-rich groundwater.

## **Agricultural Phosphorous Enrichment: Making a Case for Rising P in Wisconsin Groundwater**

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Agricultural phosphorous additions (manure and fertilizer) have exceeded crop removals (and losses of P in surface runoff) over several decades. This has resulted in excess soil P storage in many Wisconsin settings. Plant available P levels (soil test P) in Wisconsin agricultural fields have increased substantially since the early 1960s and now exceed levels for optimum production of most crops. If soil P enrichment increases the leaching of dissolved P to groundwater, groundwater discharge to streams and lakes may eventually add substantial new challenges to the development of effective strategies to reduce or decelerate surface water eutrophication in Wisconsin.

Groundwater P is generally hypothesized to be a negligible surface water input compared to surface runoff and erosion. However, few studies have been designed appropriately to test for or against this idea. In this paper we present new data from study sites in Wisconsin that suggest (1) groundwater P from agricultural landscapes can no longer be ignored as a future threat to surface water and (2) enhanced groundwater P mobility may not only be a P enrichment consequence but a collateral geochemical impact of agricultural N enrichment as well.

## **Understanding the Role of Groundwater in Pollutant Export from a Northern Mississippi Valley Loess Hills Watershed**

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The groundwater contribution of nitrate, pesticides, and phosphorus from agricultural landscapes to surface water systems has received little attention in the Northern Mississippi Valley Loess Hills of Southwestern Wisconsin, where more than 100 water bodies are listed as impaired on state 303(d) lists. In this region, nearly 25% of wells exceed the NO<sub>3</sub>-N standard, 11% contain atrazine residues, 32% contain alachlor residues, and 34% contain metolachlor residues.

In order to gain a better understanding of non-point pollution in agricultural landscapes, pollutant loading from the Fever River was studied. Baseflow was used to estimate the importance of groundwater in the export of pollutants compared to that of event flow caused by runoff. An extensive sampling of groundwater discharge features was also performed; groundwater samples were analyzed for nutrients, pesticides, dissolved gases, and chlorofluorocarbons.

Two years of data suggest that baseflow accounts for nearly 92% of the annual streamflow and 87% of the total nitrogen export mainly as NO<sub>3</sub>-N. While runoff represents only 8% of the annual streamflow, it accounted for 85% of the total phosphorus load, mainly in the particulate P form. Age dates of collected groundwater samples ranged from 1969 to 1989. Correlation coefficients (*r*) of age-date with NO<sub>3</sub>-N, denitrified N, and soluble reactive phosphorus were 0.72, (-0.79), and 0.80 respectively (*p*<0.001), suggesting that groundwater export of nutrients has been increasing as younger water replaces older water within the aquifer. Although no significant correlation was observed between age-date and pesticide residues; concentrations of certain pesticides were persistent and suggest groundwater export to be significant.

## **Agriculture-Related Trends in Ground-Water Quality of the Sand and Gravel Aquifer in Central Wisconsin**

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Trends in nitrate and atrazine concentrations in ground water, in an area of central Wisconsin underlain by the sand and gravel aquifer, were examined using water-quality data collected in 1994 and 2002 as part of the USGS National Water-Quality Assessment Program in the Western Lake Michigan Drainages. Ground-water recharge dates based on chlorofluorocarbons, nitrogen- and atrazine-use histories, well information, hydraulic conductivities, and other ancillary data such as climate and soils were used to help characterize the environmental setting and interpret the water chemistry results.

Statistical comparisons of the two sets of samples indicated nitrate concentrations increased significantly from 1994 to 2002 while atrazine concentrations decreased. Chlorofluorocarbon-based ground-water recharge dates enabled temporal changes in nitrate and atrazine concentrations to be related to historical chemical use and climatic conditions over a 40-year period. Comparisons with static characteristics like soils and well information also proved important for understanding ground-water concentrations. Changes in nitrate concentrations were correlated to historical fertilizer use, dissolved oxygen concentrations, precipitation, and well depth. Changes in atrazine concentrations were correlated with historical atrazine use, precipitation and soils characteristics.

**POSTER SESSION**  
**Thursday, March 2, 2006**  
**5:25 – 7:00 p.m.**

**Assessment of Microbial Contamination in Cooks and Opunohu Bays on the French Polynesian Island of Moorea**

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This project assessed the abundance of total coliform, enterococci and *Escherichia coli* in tributaries and marine waters of Cook's Bay, a developed watershed and Opunohu Bay an undeveloped watershed on the French Polynesian island of Moorea. The objectives of this study included investigation of bacterial levels with land use and population density, effects of precipitation, comparison of marine and freshwater sites and to determine if enterococci was a better indicator species than *E. coli* or total coliform of potential health hazards in the marine environment. Numerical bacterial counts in streams were highly variable and impacted by runoff events and were well above World Health Organization (WHO) standards for recreational freshwaters, and 93% were above USEPA standards. Similarly, enterococci levels placed 40% of the sites above USEPA standards for marine recreational waters. Urban land use and housing density were shown to correlate with increased bacteria densities within the watersheds. Bacteria counts from tributary streams and within Opunohu Bay were positively correlated. However, a similar comparison in Cook's Bay with tributary streams was inconclusive. Total coliform and *E. coli* bacteria in marine sites were strongly correlated with enterococci suggesting total coliform and *E. coli* counts alone may be indicative of potential microbial hazards in marine environments.

\*Note: This is a student presentation.

## **Pollutant Analysis of a Snow Pack and Underlying Soil on a Collection Site**

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Snow collection sites are frequently overlooked as a source of contamination, but the long-term accumulation of snow at these sites has the potential for contamination of soil and groundwater. This study sought to quantify the nature and extent of organic and inorganic pollution at a snow collection site and determine compounds that pose a potential problem. The snow pack and underlying soil were sampled at a site that has been used for municipal snow collection. The analysis showed detectable levels of some organic and metals compounds in the snow pack and surface soils. Contaminants were more concentrated near the soil surface and they were higher than at a nearby location not used for snow collection. The results allowed recommendations to be made for future snow collection.

\*Note: This is a student presentation.

## **Mercury and Lead in a Core from Turtle Creek, Shopiere, Wisconsin: Implications for Interpreting Land-Use and Environmental Change**

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Fine sediment in a river will gradually build up behind a dam. The sediment record, along with its associated organic matter and heavy metals, can reflect the history of local and regional land-use and environmental change. The Shopiere dam on Turtle Creek in Rock County trapped sediment for 151 years before it was demolished in winter 1999-2000. We analyzed a 58-cm core of dammed sediments at 1-cm intervals for grain size (hydrometer method) and organic carbon (loss-on-ignition method). The Plant and Soil Analysis Laboratory in Madison analyzed all samples for thirteen heavy metal concentrations; leachable mercury (stable isotope dilution-cold vapor ICP-MS method) and lead (nebulization ICP-OES method) are reported here. We have assumed that the core represents a complete record of continuous and constant deposition from 1848 through 1999 (151 years) because of (1) consistent grain size (clay to very fine sand) and organic carbon (4.3 to 6.4%) and (2) absence of obvious bioturbation throughout the core. Dating by  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  (currently being completed) will provide a check on these assumptions and facilitate interpretation of changes in heavy-metal concentrations.

Mercury increases with depth. Concentrations generally oscillate between 0.019 and 0.021 ppm in the upper 22.5 cm (i.e., since ca. 1941); increase steadily to 0.026 ppm between 22.5 and 44.5 cm (ca. 1941 to 1882); and then oscillate between 0.025 and 0.028 ppm to 58 cm. The low values in the upper part of the core probably reflect regional decreases in mercury emissions. The highest level (0.03 ppm), however, occurs at 12.5 cm (ca. 1967), in the middle of the low values; this spike in mercury could be local or global in origin.

Lead concentrations range from 5.71 ppm to 12.12 ppm and show no obvious trend with depth. If normalized to percent silt plus clay, however, values fluctuate but decrease with depth. Fluctuations may reflect local and regional inputs in lead from manufacturing, fertilizers, and leaded gas.

\*Note: This is a student presentation.

## **Baseflow Prediction in the Fox-Wolf Watershed: A Case Study for Wisconsin Act 310**

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Wisconsin's new groundwater quantity management law, 2003 Wisconsin Act 310, expands the State's authority to consider the environmental impact of high capacity wells and requires an environmental review for wells located in "groundwater protection area"- places within 1,200 feet of an outstanding resource, exceptional resource water or any class I, II, III trout stream. The review must find that an approval for a new high capacity well will not result in a significant adverse environmental impact. Implementation of Act 310 represents a formidable challenge for Wisconsin Department of Natural Resources, both in terms of complexity of making "no significant adverse environmental impact" determination, and having a sufficient information base to make the determination.

Our study site is the western Fox-Wolf watershed. We chose this region because GPAs are common in the region, and exist in close relation to present or anticipated high capacity wells. These GPAs contain about 3000 km of streams and 10 lakes. To determine baseflow we measured flows 5 times at 200 locations during baseflow periods and have installed 5 continuously stage monitoring devices in different regions within the Fox-Wolf watershed. The Fox-Wolf drainage basins are well defined due to the topography and soil type; however, the groundwater basins are significantly larger than the overall watershed region. This difference adds to the complexity of predicting baseflow in this region. The objective of this project is to predict baseflow based upon watershed area, landuse, soil type, stream length or a weighted combination of these variables.

We present data which include a multivariate analysis of discharge to watershed area, landuse, soil type, and stream length. Our hypothesis is that stream length will produce a stronger correlation with baseflow due to the difference in watershed area versus groundwater watershed area. In addition, we analyze and compare standard hydrograph separation techniques for the five continuously monitored stations. We anticipate this research to not only be of use to WDNR, but other researchers who work on baseflow estimation and hydrograph separation.

## **Groundwater/Surface Water Interactions in a Small Midwestern Wetland and Implications for Denitrification**

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The problem of eutrophication caused by nitrogen pollution in surface waters is well known, especially in marine, marine-coastal, and estuarine environments where nitrogen is often the limiting nutrient for plant growth. The source of nitrogen delivered to these ecosystems is often from surface waters contaminated by agricultural activities that may be physically remote from the affected areas. Several studies have documented significant reduction in nitrate levels within riparian wetlands receiving agricultural discharge, suggesting that wetland buffer zones can act as a control mechanism limiting nitrate contamination of surface water. Though it is clear from these results that natural nitrate removal from groundwater and surface water does occur in riparian systems, the conditions that favor denitrification are still not well understood.

This study is investigating the factors and processes that control denitrification in a small midwestern wetland, particularly regarding the control of nitrogen released from groundwater discharge. We seek to identify recharge areas for groundwater flow paths terminating in the wetland, and areas with high rates of denitrification in the aquifer, hyporheic zone and surface water. We will also identify and quantify spatial and temporal heterogeneity in groundwater discharge rates, nitrogen discharge rates, and denitrification rates throughout the wetland. The results of this work will lead to improved wetland management techniques and maximization of potential wetland services with an eye to reduced nitrogen loading downstream.

\*Note: This is a student presentation.

## **Distribution of Phosphorus in the Stream Sediments of the Lake Mendota Watershed**

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This study focuses on the distribution and potential transport of particulate phosphorus (P) in the stream sediment of the Lake Mendota watershed. Sediment cores were collected at more than forty sampling sites along the 9 km length of Dorn Creek. Cores were sliced to determine physical and chemical characteristics as a function of depth. Each sample was analyzed for total P, particle size, organic content, and water content. The stream slope, width and sediment depth was recorded at each site. Phosphorus levels were correlated with site and sediment characteristics. These relationships and additional sampling were utilized to determine estimates of the P content of the sediment in other Lake Mendota tributaries. Horizontal and vertical sediment P distributions among sites contribute to the understanding of sediment transport dynamics.

\*Note: This is a student presentation.

## **Delineating Problem Wetlands at Chiwaukee Prairie, Pleasant Prairie, Wisconsin**

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This study characterized vegetation, soils, and water-table hydrology of two problem coastal wetland types (low prairie and sedge meadow) in the Lake Michigan Basin. Additionally a quantitative groundwater flow model was constructed to assess sources of water and wetland vulnerability. A total of 66 species from three low prairie sites and 74 species from three sedge meadow sites were recorded and eight species are determined to be major dominants. These six seasonal wetlands are dominated by hydrophytic vegetation based upon percent cover values and each site exhibits a positive FAC-neutral test, which is a secondary hydrology indicator. The most common NRCS hydric soil indicators were identified as surface accumulation of organic matter (A10: 2 cm muck) and reduction/oxidation of sandy mineral soils (TS5: Chroma 3 sandy redox).

Water levels from pressure transducers in six water-table wells and hand measurements in the three piezometers were documented from April 2003 to November 2005. Large magnitude short-term fluctuations of water levels for the six water-table wells indicates these wetland sites respond rapidly to precipitation. Summary statistics evaluated the contiguous periods of time where the water level was in the root zone. Fitted lognormal distributions do not closely match the residence time data suggesting that these sites are primarily precipitation-dominated wetlands where climatic noise adds to the signal. The groundwater model identifies recharge areas that are water sources to the wetlands and sand shows the connection between possible future land-use changes and wetland water levels.

\*Note: This is a student presentation.

## **Fluorescence Lifetime Measurements with Fiber Optic Sensor Arrays.**

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Optical fibers can deliver light to sensing regions and capture the modulated signal from a sensing event. Sensor molecules can be placed outside of the fiber core and interact with light through the evanescent fields. Optical fibers are flexible, immune to electromagnetic interference, and allow for remote sensing in harsh environments.

Fluorescence is one technique for measuring parameters such as pH or the concentration of an analyte species of interest (e.g. toxins). Although this technique has high sensitivity, the measurement is based on light intensity and requires frequent calibration. Alternatively, the fluorescence lifetime, or the decay rate of intensity, is relatively independent of source intensity. The fluorescence lifetime may reflect changes in pH or quenching by a chemical species.

In previous work, an array of 100 fiber optic sensing regions was built within a six centimeter square with spatially-resolved readout. Fluorescence lifetimes can also be used with fiber arrays since time resolved measurements are taken. Here, pH dependent fluorescence lifetimes were investigated with a similar array.

\*Note: This is a student presentation.

## Combination of Surfactant Solubilization with Permanganate Oxidation for Groundwater Remediation – Batch, Column and Tank studies

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The central goal of this research is to test the feasibility of using surfactant to significantly increase the solubility of chlorinated solvents while using permanganate to degrade solubilized chlorinated solvents. The objectives are to investigate the effects of types of surfactants, concentration of surfactants and of permanganate on oxidation of different types of chlorinated solvents in batch, column as well as 3-dimensional tank scales. Batch results showed that chloride production, an indication of TCE degradation, followed a pseudo-first-order reaction kinetics with respect to  $\text{KMnO}_4$  in the presence of free phase TCE. A higher chloride production rate was seen when anionic surfactant, particularly sodium dodecyl sulfate (SDS), was present. When the surfactant concentration was less than its critical micelle concentration (CMC), the TCE reduction rate constant  $k_{obs}$  increased by a factor of three while the TCE half-life  $t_{1/2}$  decreased by three folds. With the surfactant concentration greater than the CMC, further increase in  $k_{obs}$  and decrease in  $t_{1/2}$  was seen. The reaction rates also increased when ninate 411 and Calfax, both anionic surfactants, were present in the system at concentrations of 0.1, 0.3 and 1.0%. Contrast to the much greater enhancement for TCE oxidation, no significant increase in PCE oxidation by  $\text{KMnO}_4$  in the presence of SDS was found. Column experiments on well sorted coarse Ottawa sand showed increase in effluent TCE concentration during earlier stage of flushing. TCE concentration decreased much faster in the presence of SDS. For example, after 1 mL of TCE was placed in the columns, the effluent TCE concentration for the columns fed with SDS and permanganate was below 5 mg/L after 1740 to 1870 minutes. While for columns fed with permanganate only, it took 2200 and 4400 minutes before the effluent concentration reached 5 mg/L or below. For the columns fed with SDS and permanganate, The highest effluent TCE concentration was about 1700 mg/L when SDS was present contrast to less than 300 mg/L when SDS was absent, indicating enhanced solubilization. In addition,  $\text{MnO}_4$  breakthrough occurred after 21-25 hour injection when SDS was present. Without SDS,  $\text{MnO}_4$  breakthrough occurred 45-70 hours later. The earlier  $\text{MnO}_4$  breakthrough indicates exhaustion of dissolved TCE during the flushing stage. Chloride analysis revealed a slightly high chloride concentration in the earlier stage of the column experiment and chloride concentration decreased quickly once permanganate is seen in the effluent. Mass balance of TCE eluted plus chloride generated showed that only 25-50 % of the input TCE was either eluted or degraded, the rest may be entrapped within the sand, possibly due to the formation of  $\text{MnO}_2$  zone, or being transformed into other intermediates which were not monitored. The 3-dimensional tank test further confirmed the results from column study, i.e. with the presence of surfactant SDS a higher amount of TCE was removed within given time. Furthermore, visualization showed that a  $\text{MnO}_2$  precipitation front was formed much quickly when 1% SDS was present.

The research shows that anionic surfactants, such as SDS, are able to increase the chloride production in batch test. In column tests, the removal of TCE in the presence of SDS is faster, particularly when the volume of free phase TCE was large. Although no clogging was found when coarse Ottawa sand was used in the column study, the decrease in hydraulic conductivity when fine beach sand was used imposes a limitation to the method.

## **Toward Better Simulations of Wetland Hydrology— the Need for Diverse Field Data Collection**

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A common problem in simulating groundwater flow in wetlands stems from the lack of flux targets, which creates non-unique simulations resulting from calibration on hydraulic head alone. Moreover, the wide range of hydraulic properties and highly transient nature of these systems can make characterization with models difficult. To overcome these issues, a diverse data set has been collected and incorporated to produce a more representative model. Our approach incorporates a range of instrumentation installed in a fen/stream complex in the Allequash wetland, Trout Lake basin in Vilas county, northern Wisconsin. The instruments collect a diverse data set that will be used to simulate transient groundwater characteristics important to wetland functioning and ecology. The fen/stream complex covers 32 hectares comprised predominately of peat of varying thickness. A geophysical survey using 50 MHz ground penetrating radar (GPR) successfully delineated the boundary between peat and sand along two transects. Additionally, two transects bisecting the wetland were instrumented with nested piezometers in order to monitor variations in temperature and water levels. Measurements of temperature are useful in estimating groundwater flux and in constraining estimates of hydraulic parameters, such as hydraulic conductivity of peat, which is particularly difficult to determine. Real time data, including water levels, air and soil temperature, soil moisture data, stream discharge, and precipitation are collected at four locations within the wetland. A nine-point thermocouple array grid was installed in and around one of the seeps along the stream to monitor temperature fluctuations and infer groundwater flow regimes. These data, in combination with a parameter estimation and heat transport and groundwater flow code, were used to simulate transient flowpaths and residence times within the fen/stream complex. The diverse data were successful in identifying a unique solution that could not be obtained by head data alone.

\*Note: This is a student presentation.

## **Removal of Chlorophenols from Water Using Polyvinyl Pyrrolidone (PVP)**

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Chlorophenols belong to a type of organic contaminants whose solubility and sorptive properties on different substrates vary with solution pH. Under low pH they are present in water as protonated species such as chlorophenols. As the pH of water is higher than their  $Pk_a$  values they form deprotonated species such as chlorophenolates. Their toxicity generally increases with the degree of chlorination. Use of cross-linked polyvinyl pyrrolidone (PVP) polymers as the anti-leaching agents to selectively retain pesticides was patented by International Specialty Products (ISP). In this study we focused on testing the feasibility and applicability of using PVP to sorb and remove chlorophenols from water. Kinetic studies reveal that the sorption of chlorophenols on PVP is instantaneous. Equilibrium sorption studies showed that the sorption of protonated species followed a linear sorption isotherm, indicating a partitioning mechanism. As the solution pH increases, the contaminant distribution coefficients decreases, revealing that deprotonated species have a weaker affinity onto the PVP surfaces. In addition, the sorption increases as the degree of chlorination increases.

\*Note: This is a student presentation.

## Optical Sensing of Oxygen in Gas and Aqueous Phase

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Fiber-optic sensors for measuring concentrations of oxygen dissolved in water are undergoing development. The proposed sensor is based on fluorescence quenching of a ruthenium (II) complex, embedded in a photo-polymerized hydrogel matrix made from poly (ethylene glycol) diacrylate, and is covalently attached to the surface-modified fiber core. The optical evaluations of this sensor are carried out in a crossed-fiber configuration placed in a flow cell. The excitation optical fiber carries the light ( $\lambda = 465$  nm) to the thin film coating at the probe region. Fluorescence generated at the probe is picked up by the detection fiber and sent to the detector. When oxygen in the gas or liquid sample diffuses into the thin film coating, it quenches the fluorescence. The degree of quenching correlates to the oxygen concentration. In the first step of development of this sensor it was tested in a gas phase environment. Response of the sensor towards oxygen gas was described in terms of fluorescence spectra, repeatability and reproducibility. Results obtained showed that the fluorescence intensity decreased upon exposure to oxygen gas, indicating that the ruthenium complex was responsive to the presence of the oxygen gas and the sensor response was found to be regenerable by flushing it with nitrogen gas.

\*Note: This is a student presentation.

## Evaluating Groundwater Use in Southern Wisconsin

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Groundwater resources are relatively abundant across Wisconsin, and 95 percent of municipalities in the state use groundwater for their water supply. However, the continuing decline of groundwater levels and documented reductions in baseflow in several regions of the state have heightened concern about groundwater withdrawals. To investigate changes in groundwater use over time, our project compares water-use trends in predominantly rural Sauk County to rapidly developing Waukesha County. The Public Service Commission of Wisconsin (PSC) collects a consistent set of pumping records from municipal wells. However, water-use data for non-municipal high capacity wells are not widely available and are difficult to estimate.

On the basis of PSC data, total pumping from municipal wells increased 32 percent in Waukesha County and 67 percent in Sauk County from 1988 to 2003. However, the population in areas served by these municipal systems increased at a lower rate, roughly 27 percent, over the same time period. In Waukesha County, municipally-supplied groundwater to industries decreased by 48 percent; commercial groundwater use increased by 53 percent. In Sauk County, the municipally-supplied industrial and commercial sectors increased their groundwater use, by 63 and 115 percent, respectively. In both counties, total municipally-supplied residential water use increased proportionally to population growth.

On the basis of information from high-capacity-well permits, withdrawals by non-municipal wells may exceed those of municipal wells in the two counties. However, we have found large discrepancies between permitted and actual pumping rates for some non-municipal wells, and we are surveying well owners to document actual water use from these wells.

\*Note: This is a student presentation.

## **Combining Surface Geophysical Methods to Identify Karst Hidden beneath Glacial Till**

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A Wisconsin-based electric cooperative identified an 800-acre site proposed for a coal-fired electric generating facility. Concerns arose over the possibility of karst conditions that could impact facility design and construction. To minimize the amount of drilling required, an investigation using high-resolution surface geophysical techniques to focus a limited exploratory drilling program was proposed.

Surface geophysical techniques included using a differential global positioning system to produce a digital terrain model (DTM) that would identify and locate low relief topographical depressions. A high-resolution electromagnetic (EM) conductivity survey was conducted simultaneously to identify areas of higher moisture content that may indicate areas of incipient karst. The results of these surveys were used to identify anomalies that were then surveyed using ground penetrating radar (GPR) to identify specific features to drill geotechnical borings. Finally, a shallow seismic survey that utilized Multichannel Analysis of Surface Waves (MASW) was conducted after drilling to provide better definition of shallow solutional features.

Results of the investigation suggest that combining DTM and EM are effective tools for rapid identification of bedrock surface and soil compositional anomalies. As a result of signal loss from the clayey till, these techniques could not identify the location of deeper bedrock voids. GPR penetration was also limited in areas of clayey till. However, the GPR successfully detected soil surface anomalies where subsequent drilling discovered silt-filled grikes. MASW identified the configuration of the bedrock surface, and identified the location of a sediment-filled grike.

**SESSION 3A**  
**Hydrogeologic Investigations**  
**Friday, March 3, 2006**  
**8:30 – 10:10 a.m.**

**Geochemical and Stratigraphic Controls on Radium Activities in the Cambrian Ordovician Aquifer, Waukesha, Wisconsin**

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A study of the Cambrian-Ordovician aquifer in Waukesha County was conducted to determine geochemical and stratigraphic controls on observed radium activities. Radium data collected from the Wisconsin DNR drinking water database was used to create maps depicting the spatial variability of the two radium isotopes in the deep sandstone aquifer. Radium-226 activities appear to remain relatively constant while radium-228 activities vary dramatically throughout the county. Radium-228 activities also generally increase with aquifer depth, while no such trend is apparent for radium-226. Geochemical speciation modeling was used to determine that radium co-precipitation into two sulfate minerals, barite and celestite, controls radium activities in the aquifer.

\*Note: This is a student presentation.

## **Groundwater Recharge through a Thick Sequence of Fine-Grained Sediment in the Fox River Valley, East-Central Wisconsin**

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The Fox River Valley in east-central Wisconsin is experiencing considerable population growth and development, thereby increasing demand for groundwater resources. To manage this demand, a better understanding of the groundwater flow system is needed. Recent geological mapping has identified a regional aquitard consisting of thick glacial deposits that include fine-grained till and clayey lake sediment that was deposited in a large proglacial lake during the most recent glaciation. This aquitard covers large parts of nine counties and is up to 150 m thick, thus limiting surface-water infiltration and recharge to underlying aquifers that are the primary source of drinking water to residential and municipal wells. Because of the limited recharge to these glacial and bedrock aquifers, many of these wells may be withdrawing relatively old groundwater from storage.

To gain a better understanding of groundwater movement through this aquitard, sediment samples were collected at regular intervals from a series of boreholes so pore water could be extracted for stable isotope analyses, including oxygen ( $^{18}\text{O}$ ). Analyses of the pore water from one borehole show lighter values ( $-15 \delta^{18}\text{O}$ ) near the middle of the aquitard and heavier values near the top and bottom of the aquitard that correspond with modern day values ( $-9 \delta^{18}\text{O}$ ). Such a bow-shaped curve is typical of chemical diffusion, with limited advection caused by differences in hydraulic head. The decrease in oxygen isotope values suggests diffusive mixing of glacially derived water with younger water across the aquitard. On the basis of these results, the thick lake sediments may represent a laterally extensive aquitard limiting surface-water recharge to important aquifers in the region.

## **Pleistocene Hydrology of the Deep Sandstone Aquifer in Southeast Wisconsin**

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Stable isotope records, noble gas thermometry, and excess air content provide hints about the hydrology of the deep sandstone aquifer in southeast Wisconsin. These data record the last advance and retreat of Pleistocene glaciation in the area. Groundwater in Milwaukee county and eastern Waukesha county pre-date the last glacial advance and show evidence of being recharged as pressurized glacial meltwater. Younger waters were recharged as rainfall in equilibrium with the existing temperature at the time of recharge. Limited  $^{14}\text{C}$  data gleaned from the literature is consistent with this interpretation.

## **The Hydrogeologic Significance of Karst Features in the Prairie du Chien Group Dolomite of West-Central Wisconsin**

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Though west-central Wisconsin is not commonly considered a karst terrain, evidence of solution weathering in the Prairie du Chien Group (PdC) dolomite raises significant questions about the mechanics of groundwater flow in the region. Here the traditional geomorphological signs of karst are often ambiguous, and are greatly complicated by a nearly continuous cover of glacial sediment. Yet sinkholes exist, significant cave systems have been identified, and water wells frequently encounter solution voids of decimeter to meter scale. As an aquifer, the PdC forms the principal residential water supply for the upland region in Pierce and St. Croix Counties, an area undergoing intense development as outlier suburbs of the Twin-Cities. All of the current regulations for protection and development of this water resource are based on porous media assumptions of homogeneity and continuity. The validity of this approach depends on the hydrogeologic significance of karst features in the PdC.

To examine the validity of a porous media approach, we are developing a hydrostratigraphic conceptual model for the PdC in Pierce and St. Croix Counties that focuses on the role of karst. We have assembled and synthesized an array of existing data sources. Data from contaminated site investigations, well-constructor reports, spring surveys, cave studies and other sources all help constrain the variety and extent of karst features in the region. We are developing a regional down-hole geophysical dataset to help establish correlations between lithostratigraphy and patterns of solution weathering. At several locations we are combining borehole logging with intensive hydraulic gauging to better characterize the roles of intergranular porosity, fractures and karst conduits in groundwater movement. Preliminary data suggest that solution-enlarged fractures pervade the PdC in Pierce and St. Croix counties, and that it is this macro porosity that dominates groundwater flow through the unit.

\*Note: This is a student presentation.

## **Dual Porosity and Dispersion in Silurian Dolomite near Valders, Wisconsin: The Influence of Coral Zones and Fractures on Flow and Transport**

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Field and laboratory investigations of groundwater flow through fractured dolomite at a contaminated site in eastern Wisconsin show the influence of both matrix porosity and fracture porosity on groundwater flow and contaminant fate. At the Lemberger site, near Valders, WI, a plume of dissolved chlorinated volatile organic compounds (CVOCs) originates in an area where waste liquids containing spent solvents were reportedly placed in drums and buried and/or dumped directly into trenches immediately on top of bedrock. The areal distribution of dissolved CVOC contamination at the site shows a regular, persistent pattern that is characteristic of matrix storage (significant decreases in concentrations over short distances, and consistent concentrations over time).

Although the bedrock consists of Silurian dolomite containing numerous fractures, vugs, and solutionally-enlarged voids, water quality and hydraulic head data are more consistent with a well-integrated porous medium and a broad source zone than with a system dominated by migration through a few fractures or conduits. The bedrock also contains visible but discontinuous matrix porosity, particularly in fossil-rich horizons and coral beds. Hydraulic conductivity ranges over five orders of magnitude at borehole and laboratory scales. Matrix porosity, measured on core samples, ranges over 7-14% total porosity and 2-7% effective porosity. Fracture porosity, estimated from optical borehole images, ranges from 0 to 6%. Large voids and fractures occur at or just above the water table in several borings, and borehole flow meter results indicate significant vertical hydraulic gradients within the dolomite, in downgradient locations. These observations lead to a conceptual model comprised of both rapid flow through fractures and solution features and slower flow through and storage in porous parts of the matrix. These systems appear well-integrated with each other, and there is no indication of preferential pathways of contaminant migration at the site scale.

**SESSION 3B**  
**Surface Water Quality Studies**  
**Friday, March 3, 2006**  
**8:30 – 10:10 a.m.**

**Distribution of Phosphorus in the Stream Sediments of the Lake Mendota Watershed**

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This study focuses on the distribution and potential transport of particulate phosphorus (P) in the stream sediment of the Lake Mendota watershed. Sediment cores were collected at more than forty sampling sites along the 9 km length of Dorn Creek. Cores were sliced to determine physical and chemical characteristics as a function of depth. Each sample was analyzed for total P, particle size, organic content, and water content. The stream slope, width and sediment depth was recorded at each site. Phosphorus levels were correlated with site and sediment characteristics. These relationships and additional sampling were utilized to determine estimates of the P content of the sediment in other Lake Mendota tributaries. Horizontal and vertical sediment P distributions among sites contribute to the understanding of sediment transport dynamics.

\*Note: This is a student presentation.

## **Greenhouse Gases in Central Wisconsin Streams**

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Carbon dioxide, methane, and nitrous oxide are greenhouse gases of interest to global warming concerns. More information is needed on the contribution to the global budget of these gases from stream emissions. Streams in central Wisconsin flow in three different geological settings: the sand plain, glacial drift, and drift crystalline rock provinces. The behavior of streams in these provinces as atmospheric sources and sinks for global warming gases is unknown.

In this study we examined carbon dioxide, methane, and nitrous oxide from first to fourth order streams in each of the three geological provinces. Dissolved gas samples were collected in the field by pumping induced ebullition and emission measurements were performed using a chamber approach. Dissolved gases provided insight into the physical connection between streams and landscapes (e.g. helped us distinguish between gaining and losing sections) in the three geological settings. We will describe these findings and present a further analysis of the concentrations and movement of these gases in and out of the stream system related to their global warming potential.

\*Note: This is a student presentation.

## Phosphorus Forms and Fate in the Lower Fox River Watershed

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The effectiveness of phosphorus reduction strategies may depend on whether phosphorus (P) is in the dissolved (DP) or particulate phase as it leaves the source area. Recent analysis of historical monitoring data has shown that mean concentrations of DP range from 40 to 75% of total P (TP) in rural streams within the Lower Fox River sub-basin. This study was initiated to better understand the form in which P leaves source areas and is transported by streams through tracking DP, TP and TSS from different source areas and at different scales in the Apple Creek watershed.

Sampling was conducted at eleven rural source area sites (0.25 to 2.5 km<sup>2</sup>) and four integrator sites (12 to 85 km<sup>2</sup>) during runoff events in 2004-05. Continuous discharge and intensive sampling data was also collected on the main stem of Apple Creek (117 km<sup>2</sup>), which served as the final integrator site. Excluding 2005 data, mean TP was 0.61 mg/L from source areas, 0.43 mg/L from integrator sites, and 0.58 mg/L at the main stem. DP concentrations at two sites were significantly lower than most sites. Mean DP percentage was 41% from source areas, 44% from integrator sites and 36% from the main stem. Significant differences were detected between source areas for TP, DP, and percent DP. No significant difference was detected between events for DP. Land use, management practices and site characteristics will be examined to determine which factors best explain our monitoring results.

## **Arsenic Speciation in the Kewaunee Marsh: Method Development and Analytical Results**

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Arsenic is a soluble and, therefore, potentially mobile element in the aquatic environment. It is of concern for humans due to its toxicity, and has been specifically associated with skin and bladder cancers. Arsenic is found in natural waters in two main forms: arsenic acid (As V) and arsenous acid (As III). Speciation drives environmental fate, remediation measures and toxicity.

In the 1940s, a train derailment is presumed to have caused sodium arsenate contamination of 3 acres of sediments and ground and surface waters in the Kewaunee Marsh area. The Kewaunee Marsh is located in northeastern Wisconsin, and the spill area is currently being investigated to determine the degree and extent of contamination and to develop a cleanup strategy.

Four of the major arsenic species (arsenic acid, arsenous acid, monomethyl arsenic acid and dimethyl arsenic acid) were measured in ground and surface waters. This investigation was concurrent with a larger study overseen by the Wisconsin DNR and the Railroad where total arsenic and water geochemical measurements were made.

Arsenate concentrations ranged from  $0.03 \mu\text{g L}^{-1}$  (or below detection) to  $1738 \mu\text{g L}^{-1}$ , and arsenite concentrations were found to range from  $0.02 \mu\text{g L}^{-1}$  (or below detection) to  $832 \mu\text{g L}^{-1}$ . One sample was very highly contaminated and had an arsenate concentration of  $206432 \mu\text{g L}^{-1}$  and an arsenite concentration of  $844710 \mu\text{g L}^{-1}$ . The organic forms of arsenic were so low, compared to the inorganic forms, that they could not be quantified. The concentrations of inorganic arsenic were compared to geochemical measurements for statistical associations.

## **Characterization of Chloride Concentrations in Northern Marshes**

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Road salt is a deicing agent applied in substantial amounts to ice- and snow-covered roads in cold climate regions. Wetlands are likely susceptible to road salt contamination because of their low-dilution environments. To understand the extent of road salt contamination in wetlands, this study explored chloride concentrations in marshes adjacent to and isolated from roads in the Minneapolis-St. Paul Metropolitan Area, Minnesota. Samples were collected from the water column and sediment porewater from April through October 2001. Chloride concentrations in roadside marshes were  $45 \text{ mg}\cdot\text{L}^{-1}$  greater than in isolated marshes. Concentrations reached  $101 \text{ mg}\cdot\text{L}^{-1}$  in the water column and  $300 \text{ mg}\cdot\text{L}^{-1}$  in porewater. Roadside marshes had chloride gradients across the marsh of  $60 \text{ mg}\cdot\text{L}^{-1}$  in the water column and  $150 \text{ mg}\cdot\text{L}^{-1}$  in porewater; these gradients indicate that certain areas of the marshes were more at-risk to chloride contamination. Chloride concentrations were highest in the spring and fall, and showed temporal variation similar to that exhibited by natural saline wetlands. These results indicate that road salt runoff may significantly influence chemical dynamics in wetlands; therefore, the extent of roadsalt contamination should be assessed during impact assessment and prior to wetland creation or restoration.

**SESSION 4A**  
**Modeling and Hydrogeologic Studies**  
**Friday, March 3, 2006**  
**10:30 – 11:50 a.m.**

**Subsurface Precambrian Basement Topography of Southeastern Wisconsin from Coupled Modeling of Gravity and Aeromagnetic Data**

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Coupled modeling of gravity and aeromagnetic data was performed to estimate subsurface structure along eight NE-SW profiles and one N-S profile in southeastern Wisconsin near the Waukesha Fault. Because of normal vertical displacement along the fault, the depth to Precambrian crystalline basement rock southeast of the Waukesha Fault (down-thrown block) exceeds the total depth of water wells with one exception (USGS test well in Zion, IL). Well log data constrains basement elevations northwest of the fault on the up-thrown block and Cambrian Mount Simon Formation top elevations on the down-thrown block. The southern most profile was used to calibrate density and magnetic susceptibility values for the study area since it contains the only data to constrain the basement elevations on the down-thrown block. A 3D representation of the Precambrian basement surface was created from the profile models and well logs elevations and shows a complex undulating surface on both sides of the fault. Comparison of the Precambrian basement surface from this study with a surface based on well log data alone nicely illustrates the benefit of incorporating data from potential fields modeling for the delineation of subsurface structure. The Waukesha Fault was modeled in this study as a high angle normal fault dipping to the southeast and model results suggest maximum vertical displacement of 560 m for the Precambrian basement. Results also suggest that the fault could be modeled with a more shallow dip angle.

## **Using Groundwater Models to Assess Flow to Wells in Residential Subdivisions**

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Although site-specific hydrogeologic studies are often conducted to determine the capture zone of municipal wells, wells proposed for rural, residential subdivisions do not receive the same level of scrutiny. We have compared results from two independent modeling projects to assess the capture zones of these residential wells.

In the first case, we calibrated a three-dimensional, subdivision-scale model using detailed, site-specific hydrogeologic data to simulate groundwater flow near Sun Prairie, Wisconsin. The simulated capture zones extend as far as 1000 feet upgradient from residential wells, and groundwater travel times from the recharge area to the wells range from less than 2 years to approximately 30 years. In the second case, we refined a two-dimensional, regional-scale flow model of northwestern Sauk County. Backward particle tracking from residential wells to the water table delineated capture zones about 150 feet upgradient of these wells, with a simulated time of travel from the water table to the wells of about two years. A casing depth of 55 feet below the water table results in capture of groundwater recharged upgradient of the subdivision boundary.

These models demonstrate that a relatively simple assessment of hydrogeologic conditions can yield practical guidelines for well construction at a specific development. The models show that pumping from residential wells has little effect on groundwater levels and flow directions because of low rates of groundwater use (several hundred gallons per day per home). Well casing depths on the order of 100 feet may result in wells with improved water quality because of increased travel times from recharge areas. In each case, a community well that serves the entire subdivision would have a larger capture zone, but that capture zone may be more easily protected by controlling land-use activities.

## **Impacts of Multiple Aquifer Wells on Groundwater Flow in Southeastern Wisconsin**

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A multiple aquifer well, defined as a well that is open to more than one aquifer across an aquitard, will allow flow of water from one aquifer to another. The aquitard is “short-circuited” by flow that under natural conditions would have to flow through the aquitard. The quantity of groundwater flow through multiple aquifer wells can dominate the natural flow that moves through an aquitard. The groundwater flow system in southeastern Wisconsin is an example of the impacts of multiple aquifer wells to groundwater flow.

A simplified hydrostratigraphy of the flow system in southeastern Wisconsin consists of a shallow aquifer of glacial material and Silurian dolomite over an aquitard, the Maquoketa shale, which in turn, is over a deeper Cambrian sandstone aquifer. In the late 1800s, an upward hydraulic gradient existed over much of the area from the deeper sandstone aquifer to the shallow aquifer. Since then, extensive pumping in southeastern Wisconsin has reversed that gradient so that now groundwater moves vertically downward across the Maquoketa shale.

A computer simulation of groundwater flow in southeastern Wisconsin suggests that much of the flow across this regional aquitard is through the more than 100 multiple aquifer wells that are currently present in southeastern Wisconsin. If these wells are abandoned, the water levels in the deep sandstone aquifer will decrease even more rapidly than they are currently. However, the wells may introduce oxygenated water into the deep aquifer and thus alter the geochemistry of the deep aquifer potentially releasing arsenic and radium.

## How Complex Do Models Need To Be?

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Models are a simplification of reality, but all parameters that relate a stress to system response need to be included to accurately predict the response to a future stress. These parameters are often included in the simplification process and limited funding makes it difficult to decide how efforts should be divided between model construction and collecting additional data. Modeling reports commonly conclude with a desire for more data and calibration; how well the model can simulate future stress, and how worthwhile the modeling effort is to decision makers, is often uncertain.

A method for assessing the effect of including model complexity is proposed that uses regularized inversion and single-value decomposition of Tonkin and Doherty (2005). In contrast to typical modeling that requires the modeler to make decisions on parsimony upfront, this approach allows the modeler to include high degrees of complexity (i.e., hundreds of parameters) and still maintain a well-posed problem. As a result, the model more closely reflects the underlying detail of the system and uncaptured detail is minimized. In addition, single-value decomposition facilitates pre-calibration analyses that can evaluate the estimated prediction uncertainty and benefits of the calibration before model calibration is started. A case study from the USGS North Temperate Lakes Water, Energy and Biogeochemical Budgets (WEBB) site in northern Wisconsin is presented to illustrate the approach.

Tonkin M. J., and Doherty, J., 2005. A hybrid regularized inversion methodology for highly parameterized environmental models, *Water Resources Research* 41, W10412, doi:10.1029/2005WR003995.

**SESSION 4B**  
**Surface Water Management**  
**Friday, March 3, 2006**  
**10:30 – 11:50 a.m.**

**Concentration Ain't Nothin' but a Number – Exposure Pathways and Bioavailability Affect Sediment Remediation Objectives**

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We evaluated the human health and ecological risk associated with exposure to MGP-related tar in ten acres of shallow sediment in a high-energy, tidal river. To assess remedial options, we divided the tar deposit into three areas, roughly equal in size, based on the characteristics of the tar and the potential for human exposure. In Area 1, the tarry sediment is up to 4 m thick, and total PAH concentrations in the central portion are sometimes greater than 20,000 mg/kg. Portions of Area 1 of the tar deposit are exposed at low tide. Physical and chemical assessment of samples from Area 1 indicate that the tar is relatively unweathered. The anaerobic degradation of organic matter in the sediment causes methane gas bubbles to evolve from the sediment at low tide, when water depths are less than 6 m in this area. Tar blebs become entrained with the rising bubbles, and occasionally trap small pockets of gas, so that the gas/tar mixture migrates from sediment and floats to the river surface. NAPL sheens containing high concentrations of PAHs disperse from the tar blebs on the surface. Area 1 had the greatest potential for human and ecological risk because of the nature of the tarry sediment and the shallow water depth.

In Area 2, up to 1 m of tarry sediment is present, and total PAH concentrations are still very high (often more than 10,000 mg/kg). However, a hardened tar layer is commonly present at the surface of the tar deposit in this area. The hardened tar appears to be a product of chemical weathering of the sediment, and of dilution of the tar with sandy and gravelly sediment. The water depth over this part of the tar deposit is typically 5 m or greater at low tide, and so the hydrostatic pressure is too great for ebullition over the tide cycle. The hardened tar layer and greater water depth in Area 2 significantly reduce the potential for migration of, and exposure to, tarry sediment from this portion of the tar deposit. As a result, the modeled human health and ecological risks in Area 2 are much less than those from Area 1.

Farther downstream, in Area 3, up to 1 m of tarry sediment was found in isolated areas, and the tarry sediment is commonly dispersed in a matrix of cleaner sediment. The observed total PAH concentrations in Area 3 were generally lower than in first two areas, but in some samples were still up to 6,000 mg/kg. In addition, the water depth in Area 3 is greater than 5 m at low tide, and no tar migration or bubbling has been observed here. The tarry sediment in Area 3 is much more physically and chemically weathered than the tarry sediment in the other areas. In support of this hypothesis, sediment toxicity testing showed that the threshold value for an observed adverse effect was higher in Area 3 than for the other portions of the tar deposit. Because of the lack of potentially completed human exposure pathways and the higher degree of weathering, the human and ecological risk is less in Area 3 than in the other portions of the tar deposit. Even though the total PAH concentrations in the tar deposit are comparable in all three portions of the tar deposit, the human health and ecological risks are disproportionately associated with Area 1, where the greater bioavailability and the potential for migration exacerbate the potential ecological and human health risks.

## **Lake Levels Got You Down? Find the Positives and Reap the Benefits**

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Natural fluctuation of water levels on lakes and rivers has been occurring since lakes were formed. Thousands of generations of aquatic organisms have evolved to live around this and need periods of low levels. Many aquatic plants, and the fish and animals that depend on those plants, need these times of low water levels to repopulate, reclaim, and essential restore the lake ecosystem. The process of fluctuating water levels is as natural as the lake itself.

When it is possible to control levels on flowages, fluctuating water levels is a viable tool to lake management. Fluctuating water levels have been used to achieve a variety of goals from creating habitat to managing exotic species. We will explore the positive side to lower water levels and what role they play in the dynamics of a lake's ecosystem. We will show a real world example in Wisconsin where lake level management has proven to be effective in exotic control and how that the droughty summer of 2003 can be viewed as a good time for our lakes.

## **Lake Water Levels as a Management Tool**

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Lake level management on Wisconsin lakes has trended toward providing user access and recreation with generally negative consequences for water clarity, macrophytes and shoreline stability. This conflict has been challenging to resolve as users demand higher water depths to satisfy their desires. Lake managers and lake communities with water level options have the opportunity to adopt water level protocols that can benefit habitat, water clarity, and shoreline stability while continuing to serve major recreational demands. Water level scenarios incorporating ecologically sensitive timing, duration, and magnitude considerations can be powerful tools for lake restoration and protection. Water level approaches can be customized for specific outcomes like sediment consolidation, bulrush enhancement, and riparian wetland stabilization.

Aerial photo images from Wisconsin lakes, experience from Wisconsin projects, and graphic representations of water level concepts will be presented in a power point format.

## **The Restoration of Rush Lake, a Deep Water Marsh in Northeast Wisconsin**

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Rush Lake is a 3,000-acre prairie pothole marsh lying between two low hills in southwestern Winnebago County, Wisconsin. Its size makes it the largest prairie pothole east of the Mississippi River. Historically, Rush Lake had extensive stands of native aquatic vegetation and was home to a multitude of wetland birds, including several threatened and endangered species.

The past 30 years witnessed a dramatic decline in the lake's aquatic vegetation, water quality, and wildlife populations. Research has attributed these declines to artificially stable and high water levels, carp infestation, and nutrient/sediment runoff.

While the Lake's decline was recognized in the 1980's, public resistance to water level management and mistrust of government agencies precluded any restoration attempts. To overcome these issues, a steering committee was formed in 1999 with government representatives, citizens, and user groups to develop a lake restoration plan. The 15-member committee conducted monthly meetings from 1999-2005 and completed an extensive citizen involvement process. The group formulated a plan that addressed all the significant problems facing the lake and had strong public support garnered through citizen participation.

The main restoration strategy is to conduct a two-year drawdown of the lake beginning in 2006. Additionally, a new, improved dam was installed to allow future water levels to be managed in the best interest of the Lake.

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