# Water Resources Institute
# Annual Technical Report
# FY 2007

# Introduction

The University of Wisconsin Water Resources Institute (WRI) is based at UW−Madison as an academic unit of the university's Graduate School and works with its Office of Research &Sponsored Programs to ensure compliance with university, state and federal guidelines. WRI is housed in the UW−Madison Aquatic Sciences Center (ACS), the administrative home of both WRI and the UW Sea Grant Institute. The staff at ACS provides support for WRI administration, research and outreach activities. The WRI also supports a library containing more than 26,000 volumes covering all major water topics.

With nearly 65% of its current base budget targeted for research, the WRI supports a total of 24 individual research projects that address a wide range of water−related issues and problems. Research projects fall into the following four thematic areas: groundwater, surface water, groundwater/surface water interactions and drinking water initiatives. Participants in WRI−supported projects include faculty, staff and students at UW System campuses at Madison, Milwaukee, Stevens Point, Green Bay; UW−Extension; Wisconsin Geological and Natural History Survey; Beloit College, Wisconsin Department of Natural Resources, U.S. Geological Survey, and individuals in private industry.

In May 1984, Comprehensive Groundwater Protection legislation for Wisconsin (1983 Act 410, Wisconsin Statutes) was signed into law. One of the provisions of the bill was to establish a state Groundwater Coordinating Council (GCC) appointed by the legislature and the governor. Advisory to the GCC is the Groundwater Advisory Council (GRAC), which is appointed by the UW−Madison Chancellor. Because groundwater protection is deemed a priority issue by the WRI, the GRAC serves as an important advisory committee for the WRI. Composed of a diversity of representatives with a great deal of scientific, political and administrative experience, the GRAC has helped the WRI identify current and anticipated water problems and issues and establish priorities for initiating research projects.

Since July 1989, the state has provided line item funding for groundwater research to the UW System. This Groundwater Research Program, administered by the WRI, currently funds 18 projects that provide a balanced program of laboratory, field, and computer−modeling studies and applications designed to preserve or improve groundwater quality. Charged with the primary mission to plan, develop and coordinate research programs that address present and emerging water−related and land−related issues, the WRI has developed a broadly−based statewide program of basic and applied research that has effectively confronted a spectrum of societal concerns.

Institute staff; UW System faculty, staff and students; state administrators and other public officials; industry, and the public have come to rely on the WRI for objective, timely scientific information about water resources issues. The WRI ensures that this information reaches these individuals through its strong information dissemination/technology transfer program. An integral part of the WRIs total program is the training of students. Research projects have provided support and training for graduate and undergraduate students pursuing degrees in a wide range of disciplines.

# Research Program Introduction

As established by Wisconsin's Groundwater Law of 1984, the state provides $300,000 annually to the UW System to support groundwater research and monitoring. In 1989, the WRI became the UW System's lead institution for coordinating the calls for proposals and peer reviews for distribution of the funds. To avoid duplication and better target groundwater research funding, several other state agencies (the departments of Commerce, Natural Resources, and Agriculture, Trade and Consumer Protection) agreed to partner with the WRI to establish an annual Joint Solicitation for Groundwater Research and Monitoring. This annual solicitation has funded more than 300 groundwater research and monitoring projects since its inception and has helped establish Wisconsin as a leader in groundwater research.

The results of the Wisconsin Groundwater Research and Monitoring Program (WGRMP) are recognized internationally, and WRI plays an important role in coordinating project reporting and making all technical reports available though our institute's library and website. Given the limited funding available through the annual 104(B) allocation, the Wisconsin WRI has decided to use its funds to participate in the WGRMP by supplementing this funding source and providing additional opportunities for groundwater research in the UW System.

Our priorities for research are established annually by the Wisconsin Groundwater Research Advisory Council (GRAC), and the priorities are included as part of the Joint Solicitation. The GRAC is our institute's advisory council and also convenes to make project funding decisions. All proposals submitted to the Joint Solicitation receive a rigorous external peer review (coordinated by the WRI) and a thorough relevancy review by the Research Subcommittee of the state's Groundwater Coordinating Council. We believe that partnership with other state agencies provides us with the ability to fund highly relevant research and allows our limited funds for 104(B) to be leveraged to the fullest extent.

***In FY2007, funding from the State of Wisconsin allowed the WRI to support an additional 16 projects and 21 students (7 undergrads, 4 Masters, 8 PhDs, and 2 Post−Docs) over and above the 15 reported elsewhere in this document (see the Student Support Table).*** This partnership between the UW system and the State is made possible because the WRI provides a mechanism to accept and distribute groundwater research funds. Without NIWR base support to maintain the WRI, this opportunity to leverage State funds would be lost. During this reporting period, the following projects were supported by WRI with State funds:

PROJECTS ENDING JUNE 30, 2007

Arsenic Species (III,V) Distribution in Wisconsin Groundwaters: Field Measurements and Prediction Using Multivariate Analysis of Geochemical Data Prediction Using Multivariate Analysis of Geochemical Data. Martin Shafer: University of Wisconsin – Madison (2005WI155O)

Nitrate and Pesticide Penetration into a Northern Mississippi Valley Loess Hills Aquifer. George Kraft: University of Wisconsin – Stevens Point (2005WI158O)

Climate Signals in Groundwater and Surface Water System: Spectral Analysis of Hydrologic Processes. Hector Bravo: University of Wisconsin – Milwuakee (2005WI005O)

Evaluation of On−Site Wastewater Treatment as a Source of Antibiotic Resistance Genes in Groundwater. Katherine McMahon, University of Wisconsin – Madison (2005WI161O)

Transient Functioning of a Groundwater Wetland Complex, Allequash basin, Wisconsin. Mary Anderson: University of Wisconsin – Madison (2005WI159O)

Validation of Transport of VOCs from Composite Liners Tuncer Edil, Craig Benson &Christopher Carlsen: University of Wisconsin – Madison, Wisconsin Department of Natural Resources (2005WI154O)

Application of LSQR to Calibration of a Regional MODFLOW Model: Trout Lake Basin, Wisconsin. Mary Anderson, Haiijang Zhang: University of Wisconsin – Madison (2006WI189O)

PROJECTS CONTINUING

Multi−Parameter, Remote Groundwater Monitoring with Referencing Using Crossed Optical Fiber Fluorescent Sensor Arrays. Peter Geissinger: University of Wisconsin – Milwuakee (2006WI190O)

PROJECTS BEGINNING JULY 1, 2007 (summarized together as project 2007WI201O)

Transport and Survival of Pathogenic Bacteria Associated With Dairy Manure in Soil and Groundwater. Jin Li, Ching−Hong Yang: University of Wisconsin – Milwuakee

Is Phosphorus−Enriched Groundwater Entering Wisconsin Streams? Bryant Browne: University of Wisconsin – Stevens Point

Occurrence and Generation of Nitrite in Ground and Surface Waters in an Agricultural Watershed. Emily Stanley: University of Wisconsin – Madison

Geochemical Characterization of Sulfide Mineralization in Eastern Wisconsin Carbonate Rocks. John Luczaj, Michael McIntire: University of Wisconsin – Green Bay

A Thermal Remote Sensing Tool for Mapping Spring and Diffuse Groundwater Discharge to Streams. Steven Loheide: University of Wisconsin – Madison

Monitoring Septic Effluent Transport and Attenuation using Geophysical Methods. Dante Fratta, David Hart, Kevin Masarik: University of Wisconsin – Madison, Wisconsin Geological and Natural History Survey, University of Wisconsin – Stevens Point

Influence of Wetland Hydrodynamics on Subsurface Microbial Redox Transformations of Nitrate and Iron. Jean Bahr, Eric Roden: University of Wisconsin – Madison

Controls on Methylation of Groundwater Hg(II) in Hyporheic Zones of Wetlands. Martin Shafer, Christopher Babiarz, David Armstrong &Eric Roden: University of Wisconsin – Madison

# Climate Signals in Groundwater and Surface Water System: Spectral Analysis of Hydrologic Processes

## Basic Information

| | |
|---|---|
| **Title:** | Climate Signals in Groundwater and Surface Water System: Spectral Analysis of Hydrologic Processes |
| **Project Number:** | 2005WI005O |
| **Start Date:** | 7/1/2005 |
| **End Date:** | 6/30/2007 |
| **Funding Source:** | Other |
| **Congressional District:** | |
| **Research Category:** | Not Applicable |
| **Focus Category:** | None, None, None |
| **Descriptors:** | |
| **Principal Investigators:** | Hector Ramon Bravo |

## Publication


1. Namdar Ghanbari, R., H.R. Bravo, J.J. Magnuson, R.J. Hunt, D.T. Feinstein, W.G. Hyzer. 2007. Trend and oscillations in the ice cover duration of Lake Mendota, Wisconsin. 32nd Congress of IAHR, the International Association of hydraulic Engineering and Research
2. Namdar Ghanbari, R and HR Bravo. 2005. Identification of Groundwater Discharge and Recharge Sites through Temperature Time Series. Hydrological Science and Technology 21, 1−4.
3. Namdar Ghanbari, R, H.R. Bravo, J.J. Magnuson, A.A. Tsonis, R.J. Hunt, D.T. Feinstein, W.G. Hyzer and B.J. Benson. 2007. Coherence between large scale climate signals, local climate, and ice cover duration of Lake Mendota, Wisconsin. Journal of Hydrology. In Press.
4. Namdar Ghanbari, R. and H.R. Bravo. 2007. Coherence between large scale climate signals, regional climate, and Great Lakes water levels. Advances in Water Resources. In review.
6. Namdar−Ghanbari, R. and Bravo, H.R., 2008. Coherence between teleconnections, regional climate and Great Lakes levels, Advances in Water Resources, doi: 10.1016/j.advwatres.2008.05.002.
7. Namdar Ghanbari, R., Bravo, H.R, Magnuson, J.J., Hyzer, W.G. and Benson, B.J., 2008. Coherence between lake ice cover, local climate and teleconnections (Lake Mendota, Wisconsin), submitted to Journal of Hydrology.

| | |
|---|---|
| **Title:** | **Climate signals in groundwater and surface water systems: Spectral analysis of hydrologic processes** |
| **Project I.D.:** | **WR05R005** |
| **Investigator(s):** | **Hector R. Bravo, Associate Professor, Department of Civil Engineering and Mechanics, University of Wisconsin-Milwaukee, PI; Reza Namdar-Ghanbari, Research Assistant, Department of Civil Engineering and Mechanics, University of Wisconsin-Milwaukee** |
| **Period of Contract:** | **07/01/2005 – 06/30/2007** |

## TABLE OF CONTENTS

PROJECT SUMMARY ..... 1
INTRODUCTION – ..... 3
PROCEDURES AND METHODS –..... 4
RESULTS AND DISCUSSION – ..... 6
CONCLUSIONS AND RECOMMENDATIONS – ..... 9
REFERENCES – ..... 10

## LIST OF FIGURES

Figure 1. Normalized time series of a-d) SOI, PDO, NAO and NP; e, I, m, q) Lake Superior water level, precipitation, evaporation and temperature; f, j, n, r) Lake Michigan water level, precipitation, evaporation and temperature; g, k, o, s) Lake Erie water level, precipitation, evaporation and temperature; h, l, p, t) Lake Ontario water level, precipitation, evaporation and temperature. ..... 5
Figure 2. Groundwater sites and precipitation stations nearest to each site used in coherency analysis. ..... 6
Figure 3. Trout Lake Basin (after Dripps 2003) ..... 7
Figure 4. Squared coherencies of (teleconnections, Great Lakes water level) pairs..... 9
Figure 5. Time series used in coherency analysis: a) quarterly precipitation time series at Minocqua Dam; b) Quarterly groundwater level time series in the whole well network; c) Quarterly groundwater level time series at well # K2; d) Quarterly Big Muskellunge Lake water level time series..... 10
Figure 6. Coherency analysis results: a) squared coherency between precipitation and groundwater level; b) squared coherency between precipitation and lake level; c) squared coherency between groundwater level and lake level..... 11

## LIST OF TABLES

Table 1. Large scale climate signals and Great Lake water levels: squared coherencies at or above the 95% confidence level and corresponding frequencies. ..... 8
Table 2. Squared coherency and significant frequency bands between precipitation, groundwater level and lake level in Trout Lake basin ..... 11

## PROJECT SUMMARY

| | |
|---|---|
| **Title:** | **Climate signals in groundwater and surface water systems: Spectral analysis of hydrologic processes** |
| **Project I.D.:** | **WR05R005** |
| **Investigator(s):** | **Hector R. Bravo, Associate Professor, Department of Civil Engineering and Mechanics, University of Wisconsin-Milwaukee, PI;**<br>**Reza Namdar-Ghanbari, Research Assistant, Department of Civil Engineering and Mechanics, University of Wisconsin-Milwaukee** |
| **Period of Contract:** | **07/01/2005 – 06/30/2007** |

**Background/Need:**

A number of studies in the US and throughout the world have shown existing relations between variability in water resources and climate variability. However, the effect of climate variability on water resources has been largely neglected. Climate variability affects all hydrologic processes to a certain degree, directly or indirectly through other hydrologic or meteorological processes.

This study explores the effect of climate variability on hydrologic processes such as precipitation, streamflow, groundwater level, lake levels, and lake ice-cover duration at the regional (Wisconsin and Great Lakes Region), watershed (Trout Lake Basin) and local scales. Coherence analysis is applied to compute the squared coherency between four teleconnections and several climate and hydrologic time series. The teleconnections considered are the Southern Oscillation Index (SOI), Pacific Decadal Oscillation (PDO), Northern Atlantic Oscillation (NAO) and Northern Pacific index (NP).

**Objectives:**

The main objectives of this research were:

1. To identify periodic forcing in existing time series of precipitation, stream flow discharge, lake levels, groundwater level, collected in Wisconsin and in the Trout Lake Basin in particular. We explored the existence of a climate-related fingerprint in the mentioned time series, and in related data series on Great Lakes levels and lake ice cover duration.
2. To investigate the coherency between large scale climate signals, regional climate, local climate, regional hydrologic time series, and local hydrologic time series.
3. To investigate the phase lag between precipitation and groundwater level, for high frequencies.

**Methods:**

The methods of analysis used included trend analysis, estimation of coherency, estimation of cross correlations, spectral estimation, and singular spectrum analysis (SSA). The statistical significance of trends was determined using the nonparametric Mann-Kendall test. Hydrologic time series are decomposed into their principal components, trend and noise using Singular Spectrum Analysis (SSA) and Multi-Taper Method (MTM) of spectral estimation. The percentage of variance explained by each component and the related frequency are computed using SSA.

**Results and Discussion:**

The results of coherence analysis showed the frequency bands where large-scale signals, climate and hydrologic time series have similar behavior in terms of oscillatory components.

Large-scale climate signals affect Great Lakes levels. The effect is verified by significant coherence between teleconnections and lake level time series, between teleconnections and over lake precipitation and lake evaporation series, and between precipitation and evaporation and lake levels series. The relations are clear for the upstream lakes, and more complex for the downstream lakes, where lake levels are affected by stream flow from the upstream lakes and their contributing watersheds.

Teleconnections affect groundwater level in Wisconsin. The effect is verified by significant coherence between teleconnections and groundwater level time series, between teleconnections and precipitation series, and between precipitation and groundwater level series. The relations are clear for the forested area of Wisconsin and more complex for the agricultural area of the State.

At the watershed scale (Trout Lake watershed), there is significant coherence between precipitation and groundwater level at high frequencies (of the order of days) and low frequencies (of the order of years), between precipitation and lake levels (at low frequencies), and between groundwater level and lake levels (at low frequencies). The use of spectral methods in the Trout Lake watershed showed that there are significant low frequency oscillations (of the order of 10 years) in lake levels, and significant oscillations in streamflow. These identified oscillations can help to improve groundwater- lake level modeling.

Teleconnections affect the ice cover duration in Lake Mendota, Wisconsin. The effect is verified by significant coherence between teleconnections and ice cover variables (ice cover duration, ice-on and ice-off dates), between teleconnections and local climate (air temperature, snowfall and snow depth), and between local climate and ice duration variables.

**Conclusions/Implications/Recommendations:**

The results obtained through the three techniques show significant links between large scale climate signals and hydrologic processes. The study estimated time scales of the principal components of important hydrologic time series and the relative importance of the components in explaining the variance of the time series.

The estimated time scales and their relative importance in the time series overall variance can be used to provide more meaningful inputs to groundwater or surface water models. For example, the recharge rate in groundwater models can be simulated more accurately using knowledge of its important oscillatory components, instead of using overall averages.

**Related Publications:**

Namdar-Ghanbari, R, 2007. Climate signals in groundwater and surface water systems: Spectral analysis of hydrologic processes, PhD Dissertation, University of Wisconsin-Milwaukee.

Namdar-Ghanbari, R. and Bravo, H.R., 2008. Coherence between teleconnections, regional climate and Great Lakes levels, Advances in Water Resources, doi: 10.1016/j.advwatres.2008.05.002.

Namdar G. R., Bravo H. R., 2007. Trend and Oscillations in the Ice Cover Duration of Lake Mendota, Wisconsin, presented at the 32nd Congress of the International Association of Hydraulic Engineering and Research, IAHR, Venice, Italy.

**Key Words:** Teleconnections; time series analysis; surface hydrology; subsurface hydrology

**Funding:** UWS Project WR05R005.

## INTRODUCTION –

Numerous investigations in the area of climate variability effects on water resources indicate that the water resources sustainability in the United States is related to climate change (i.e., Hanson et al., 2004). Hydrologists have frequently constructed groundwater models with time frames of 1 to 10 years, using a recharge rate as an input or boundary condition that is based on a long-term average for each zone defined in the model domain. Depending on the simulation period and the presence of climate extremes, we could find large errors in the results predicted by groundwater simulation models.

Groundwater level data has been collected at a Groundwater Observation Well (GWOW) network in Wisconsin for a long period of time; the US Geological Survey collects data nationwide. However, this valuable data set has not yet played a role in critical decisions on water resources planning and management in Wisconsin because the bridge necessary to convey the hydrologic information to decision makers in a usable format is missing. In addition, a remarkable data set hydrologic time series, longer than a decade for some variables, has been collected in the Trout Lake Basin in Northern Wisconsin; within the framework of the Northern Temperate Lakes "Water, Energy, and Biogeochemical Budget" (WEBB) and Long Term Ecological Research (LTER) projects supported by the US Geological Survey and the National Science Foundation (NSF), respectively. These two existing data sets give a unique opportunity to evaluate groundwater system dynamics, and its interaction with surface water. Other existing, long-term data sets provide the opportunity to explore the relations between climate and hydrologic processes at different scales. These include records related to the Great Lakes water level and water budget, and ice cover duration in Midwest lakes.

The transience of the hydrologic processes and the climate variability effects were not fully quantified in the previous investigations, at least in a way appropriate to address the problems associated with groundwater management and modeling that originate in the different time scales of the hydrologic processes and the climate variability effects on water resources. The present study is expected to help in bridging the research gap addressed above. Existing frequencies embedded in hydrologic series such as groundwater level, precipitation, stream flow discharge rate, precipitation, lake levels and ice cover duration are extracted, and relations between different time series in regional scale (Wisconsin), watershed scale (Trout Lake Basin), and local scales are explored. The relations between each hydrologic time series and well-known climatic signals such as El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO) and Northern Pacific (NP) index are explored. The effects of climate variability on the Great Lakes water levels and Lake Mendota ice cover duration were investigated to improve our understanding of effects at the regional and local scale.

The main objectives of this research were:

4. To identify periodic forcing in existing time series of precipitation, stream flow discharge, lake levels, groundwater level, collected in Wisconsin and in the Trout Lake Basin in particular. I explored the existence of a climate-related fingerprint in the mentioned time series, and in related data series on Great Lakes levels and lake ice cover duration.
5. To investigate the coherency between large scale climate signals, regional climate, local climate, regional hydrologic time series, and local hydrologic time series.
6. To investigate the phase lag between precipitation and groundwater level, for high frequency components (of the order of days). This objective required the estimation of coherency and phase functions between several pairs of data series.

The main questions that this study attempted to answer using spectral analysis are:

1. Are there measurable effects of large scale climate signals on hydrologic processes such as precipitation, streamflow, lake levels, groundwater level and ice cover duration in Wisconsin and the region?

2. If there measurable effects, how are different hydrologic processes affected?
3. How do the impacts of large scale climate signals on hydrologic processes vary at the regional, watershed and local scales?

## PROCEDURES AND METHODS –

The methods of analysis used included trend analysis, estimation of coherency, estimation of cross correlations, spectral estimation, and singular spectrum analysis (SSA). The statistical significance of trends was determined using the nonparametric Mann-Kendall test (Press et al., 1988). We used coherence analysis between time series (Jenkins and Watts 1968; Bloomfield 1976) to evaluate trends and oscillations and to quantify the relations between hydrologic variables and teleconnections.

Coherence analysis, or cross-spectral analysis, may be used to identify variations that have similar spectral properties (high power in the same spectral frequency bands). This method can be thought of splitting the time series into two components: high (H) and low (L) frequencies: $x_t = x_t(H) + x_t(L)$, and $y_t = y_t(H) + y_t(L)$. We may want to know whether the slow components of x and y vary together in some way. Coherency analysis is applied to regional, watershed and local scale to find the coherency between large scale climate signals, regional or local climate variables, and hydrologic time series . The results are given in frequency bands where a pair of time series is significantly coherent. A 95% confidence limit is also built upon the coherency computations using the F test, which is based on F distribution and is explained in detail later in this chapter.

The Singular Spectrum Analysis technique (Vautard et al., 1992) along with other spectral estimation methods and coherency analysis, included in the Singular Spectrum Analysis-Multi-taper Method (SSA-MTM) toolkit (Dettinger et al., 1995), the MATLAB Signal Processing Toolbox (The Math Works, 2004) and Numerical Algorithm (NAG) Routines (1999) were applied to carry out the time series analysis in the frequency domain.

The data sets to be analyzed include 4 large scale climate signals and hydrologic variables that can be classified into three different scales: regional, watershed and local scales. The source and definition of the 4 large climate signals used in the analysis are the following:

The SOI is defined as the normalized pressure difference between Tahiti and Darwin, Ropelewski and Jones (1987). The data was obtained from the website http://jisao.washington.edu/pacs/additional_analyses/soi.html. The PDO Index (Mantua and Hare, 2002), derived as the leading PC of monthly SST anomalies in the North Pacific Ocean, pole ward of 20N, was obtained from the website http://jisao.washington.edu/pdo/PDO.latest. The NAO index is based on the difference of normalized sea level pressure (SLP) between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland since 1864. The NAO Index was obtained from the website http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html#naostatmon. The NP Index is the area-weighted sea level pressure over the region 30N-65N, 160E-140W, available since 1899, and was obtained form the website http://www.cgd.ucar.edu/cas/jhurrell/npindex.html.

Regional scale studies covered the State of Wisconsin and Great Lakes Region and the following hydrologic time series were considered in the analysis:

a. Great Lakes water level data, evaporation from Great Lakes, precipitation over Great Lakes and air temperature over Great Lakes, totaling 16 data sets (Figure 1).

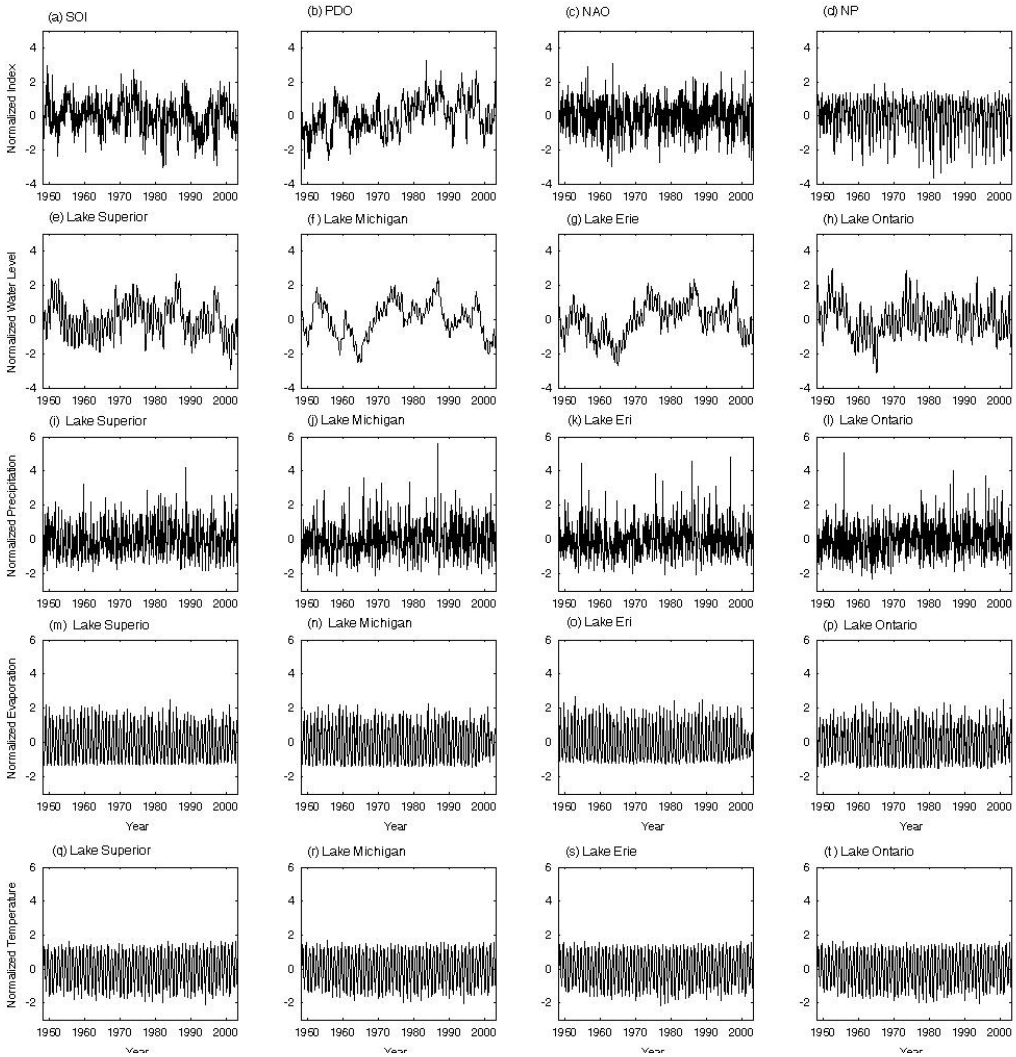



**Figure 1.** Normalized time series of a-d) SOI, PDO, NAO and NP; e, I, m, q) Lake Superior water level, precipitation, evaporation and temperature; f, j, n, r) Lake Michigan water level, precipitation, evaporation and temperature; g, k, o, s) Lake Erie water level, precipitation, evaporation and temperature; h, l, p, t) Lake Ontario water level, precipitation, evaporation and temperature.

b. Groundwater level and precipitation in 3 geographic areas, namely Agricultural, Forested and Drift-less areas in Wisconsin. Three groundwater sites and 3 precipitation station are selected in each area, i.e., collectively 18 data sets (Figure 2).

At the watershed scale the focus was on the Trout Lake Basin (Figure 3). The Trout Lake Basin is a part of Northern Highland Region with abundant surface water areas. There are approximately 3000 lakes ranging from 0.1 to 1500 hectares as well as streams, wetlands caused by coarse surficial deposits and relatively flat topography. Trout Lake Basin consists of 4 sub-watersheds as follows: Stevenson Creek Basin, Allequash Creek Basin, North Creek Basin, Mann Creek Basin.

In local scale the ice cover duration data from Lake Mendota located in Madison area is used in coherency analysis. The coherency analysis is done in 3 levels including: 1) Coherency between large scale climate signals and ice duration, ice-on and ice-off dates. 2) Coherency between large scale climate

signals and local climate time series such as local air temperature, snow fall and snow depth. 3) Coherency between 3 local climate time series and ice duration, ice-off and ice-on dates.

**Figure 2.** Groundwater sites and precipitation stations nearest to each site used in coherency analysis.

## RESULTS AND DISCUSSION –

We investigated the frequency domain relationships between four large-scale climate signals (SOI, PDO, NAO, and NP), regional climate, and Great Lakes water level from 1948 to 2002 to quantify the coherence between these three levels. The mean and standard deviation of each time series were used to normalize the series. Figure 1 shows the normalized series. Three-tiered coherence analysis provides evidence that Great Lakes levels and the large-scale signals are significantly correlated at several inter-annual and a few inter-decadal frequencies. The results also show that significant coherence is transmitted through physical mechanisms linking the large-scale signals with lake levels, namely precipitation, evaporation and air temperature. The transmission of coherence through climate is especially clear for the SOI and PDO signals. The link through the climate variables seems less clear for Lake Ontario because precipitation over and evaporation from this lake are much smaller than the flows

in connecting channels, and the latter depend on the cumulative effect of upstream lakes and their watersheds.

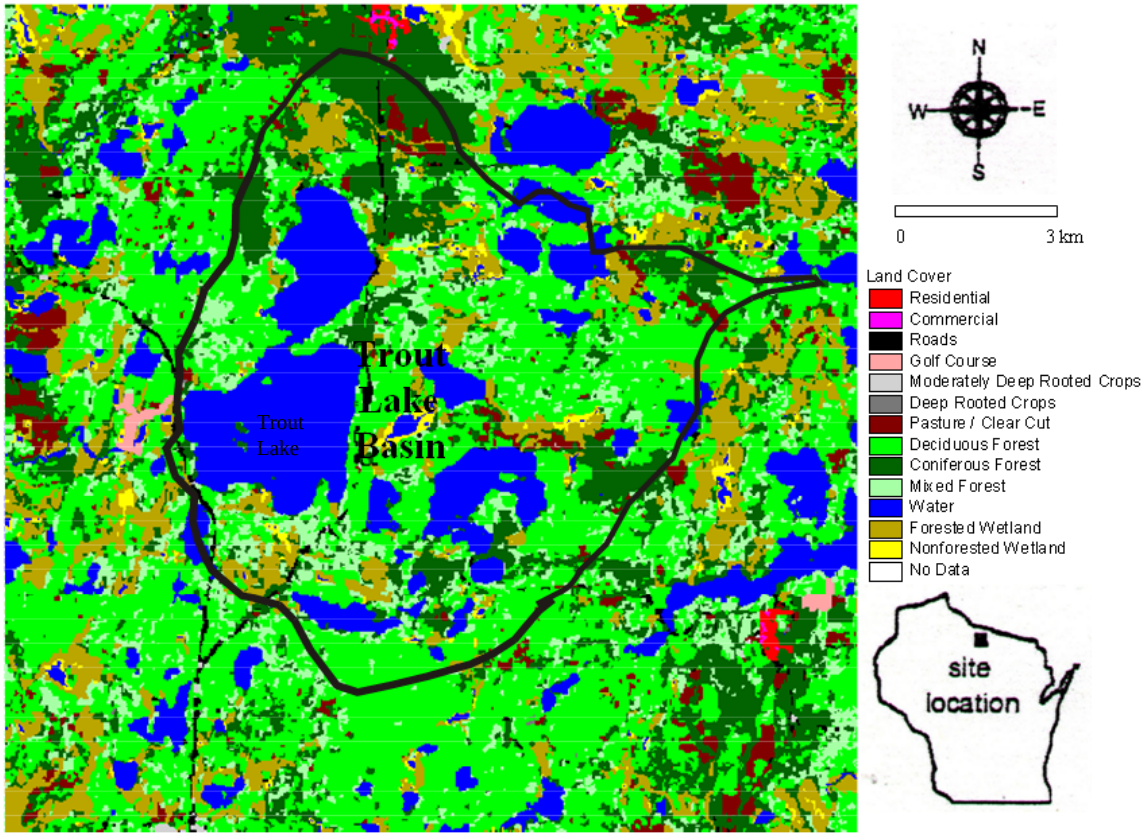



**Figure 3.** Trout Lake Basin (after Dripps 2003)

Table 1 and Figure 4 summarize some results of the coherency analysis. The values of frequencies are shown in terms of its inverse, the return period, i.e., $\omega = T^{-1}$, and the horizontal line in Figure 4 indicates the 95% confidence level. The entries in Table 1 indicate the frequency bands where coherence in a given pair of variables is statistically significant at the 95% level. It should be read as pairs of values (frequency, square coherency). Frequency is given as a range (cycles year$^{-1}$) and squared coherency is given by the maximum value in the frequency range.

Figure 4 and Table 1 show 4 x 4= 16 possible pairs that summarize the direct effect of each large scale climate signal (SOI, PDO, NAO, and NP) on each Great Lake water level fluctuation. Further analysis thereof showed the following results regarding the direct effect of large-scale signals on two or more lakes.

SOI directly affects all lake levels in the $(8.1\text{-}8.5)^{-1}$ cycles year$^{-1}$ frequency band, and directly affects levels on Lakes Superior, Erie and Ontario at $(2.3)^{-1}$ cycles year$^{-1}$ frequency. PDO directly affects levels in Lakes Michigan, Erie and Ontario at $(12.2)^{-1}$ cycles year$^{-1}$ frequency, affects levels in Lakes Superior, Michigan and Erie (western lakes) at $(7.7)^{-1}$ cycles year$^{-1}$ frequency, and affects levels in Lakes Michigan and Ontario at $(2.1)^{-1}$ cycles year$^{-1}$ frequency. NAO directly affects levels in Lakes Michigan, Erie and Ontario (eastern lakes) in the $(6.6\text{-}7.4)^{-1}$ and $(2.4\text{-}2.6)^{-1}$ cycles year$^{-1}$ frequency ranges, and Lakes Superior and Michigan in the $(3.6\text{-}4.0)^{-1}$ cycles yea$^{r-1}$ frequency range. NP directly affects levels in all lakes in the $(>20)^{-1}$ frequency range, and Lakes Michigan, Erie and Ontario at $(2.1^{)-1}$ cycles year$^{-1}$ frequency.

| | | Superior | Michigan | Erie | Ontario |
|---|---|---|---|---|---|
| SOI | Frequency, cycles year$^{-1}$ | (8.1-11.4)$^{-1}$<br>(2.6-4.0)$^{-1}$<br>(2.2-2.3)$^{-1}$ | (6.1-10.7)$^{-1}$<br>(3.0-3.9)$^{-1}$ | (6.9-10.7)$^{-1}$<br>(3.0-3.9)$^{-1}$<br>(2.3-2.7)$^{-1}$ | (6.8-8.5)$^{-1}$<br>(2.3-2.8)$^{-1}$ |
| | Squared coherency | 0.53<br>0.87<br>0.44 | 0.8<br>0.98 | 0.69<br>0.87<br>0.61 | 0.57<br>0.78 |
| PDO | Frequency, cycles year$^{-1}$ | (7.4-7.7)$^{-1}$<br>(2.2-2.5)$^{-1}$ | (>12.2)$^{-1}$<br>(6.5-8.5)$^{-1}$<br>(2.1)$^{-1}$ | (>11.4)$^{-1}$<br>(7.7)$^{-1}$ | (>6.8)$^{-1}$<br>(2.1)$^{-1}$ |
| | Squared coherency | 0.41<br>0.82 | 0.91<br>0.58<br>0.77 | 0.82<br>0.4 | 0.0.69<br>0.82 |
| NAO | Frequency, cycles year$^{-1}$ | (3.2-4.3)$^{-1}$ | (5.9-7.4)$^{-1}$<br>(3.5-4.0)$^{-1}$<br>(2.3-2.6)$^{-1}$ | (6.3-7.7)$^{-1}$<br>(2.2-2.9)$^{-1}$ | (6.6-9.0)$^{-1}$<br>(2.3-2.9)$^{-1}$ |
| | Squared coherency | 0.63 | 0.68<br>0.61<br>0.44 | 0.60<br>0.90 | 0.63<br>0.76 |
| NP | Frequency, cycles year$^{-1}$ | (>21.3)$^{-1}$<br>(3.3-4.0)$^{-1}$<br>(2.3-2.8)$^{-1}$ | (>17.1)$^{-1}$<br>(7.1-8.1)$^{-1}$<br>(2.1)$^{-1}$ | (>15.5)$^{-1}$<br>(2.1)$^{-1}$ | (>21.3)$^{-1}$<br>(6.8-9.0)$^{-1}$<br>(2.1)$^{-1}$ |
| | Squared coherency | 0.60<br>0.51<br>0.56 | 0.75<br>0.46<br>0.86 | 0.75<br>0.77 | 0.76<br>0.56<br>0.94 |

**Table 1.** Large scale climate signals and Great Lake water levels: squared coherencies at or above the 95% confidence level and corresponding frequencies.

In watershed scale four types of time series (groundwater level, precipitation, streamflow and lake levels in Trout Lake Basin) are analyzed in the frequency domain using coherency and phase analysis techniques, Singular Spectrum Analysis (SSA), and Multi-Taper Method of spectral estimation. The results for these analyses are given in Namdar-Ghanbari (2007) in three sections. The first section is a (high-frequencies) coherence analysis between precipitation and groundwater level, the second section is a (low-frequencies) coherence analysis between precipitation, groundwater levels and lake levels, and the third section is an analysis of low frequency oscillations in streamflow and lake levels.

Long term data sets in Trout Lake Basin were used to explore the low frequency bands of significant coherency between precipitation, groundwater level and lake levels. The data sets include quarterly data collected from 1985 to 2003, i.e., 19 years in total. Precipitation data collected at Minocqua Dam precipitation station serves as precipitation data in this analysis (Figure 5-a). There is a network of 12 wells in the area with long term records, and all of them have the same oscillatory behavior in terms of water level fluctuations over the time (Figure 5-b). Therefore one well (well # K2) is selected to represent the groundwater level fluctuation in the area around Big Muskellunge Lake (Figure 5-c). The lake level time series used in the analysis is the Big Muskellunge Lake water level (Figure 5-d). The results of the analysis are given below.

Figure 6-a and the first 2 rows of Table 2 shows the results from coherence analysis between precipitation and groundwater level. As it is seen in the figure and the numerical values in the table, precipitation and groundwater level are significantly coherent in the frequency bands of (2-8)$^{-1}$ cycles year$^{-1}$, (1.4-1.6)$^{-1}$ cycles year$^{-1}$, (0.9-1.1)$^{-1}$ cycles year$^{-1}$, and (0.67-0.7)$^{-1}$ cycles year$^{-1}$. Figure 6-b and the third and fourth

rows of Table 2 shows the results from coherence analysis between precipitation and lake level. As it is seen in the figure and the numerical values in the table, precipitation and lake level are significantly coherent in the frequency bands of $(2.2\text{-}8)^{-1}$ cycles yea$^{r-1}$, $(1.3\text{-}1.6)^{-1}$ cycles year$^{-1}$, $(0.9\text{-}1.0)^{-1}$ cycles year$^{-1}$, and $(0.6\text{-}0.7)^{-1}$ cycles year$^{-1}$. Figure 6-c and the last two rows of Table 2 shows the results from coherence analysis between groundwater level and lake levels. As it is seen both in the figure and the table, the groundwater level and lake levels are significantly coherent in the frequency bands of $(>2.4)^{-1}$ cycles year$^{-1}$, and $(0.9\text{-}1.3)^{-1}$ cycles year$^{-1}$.

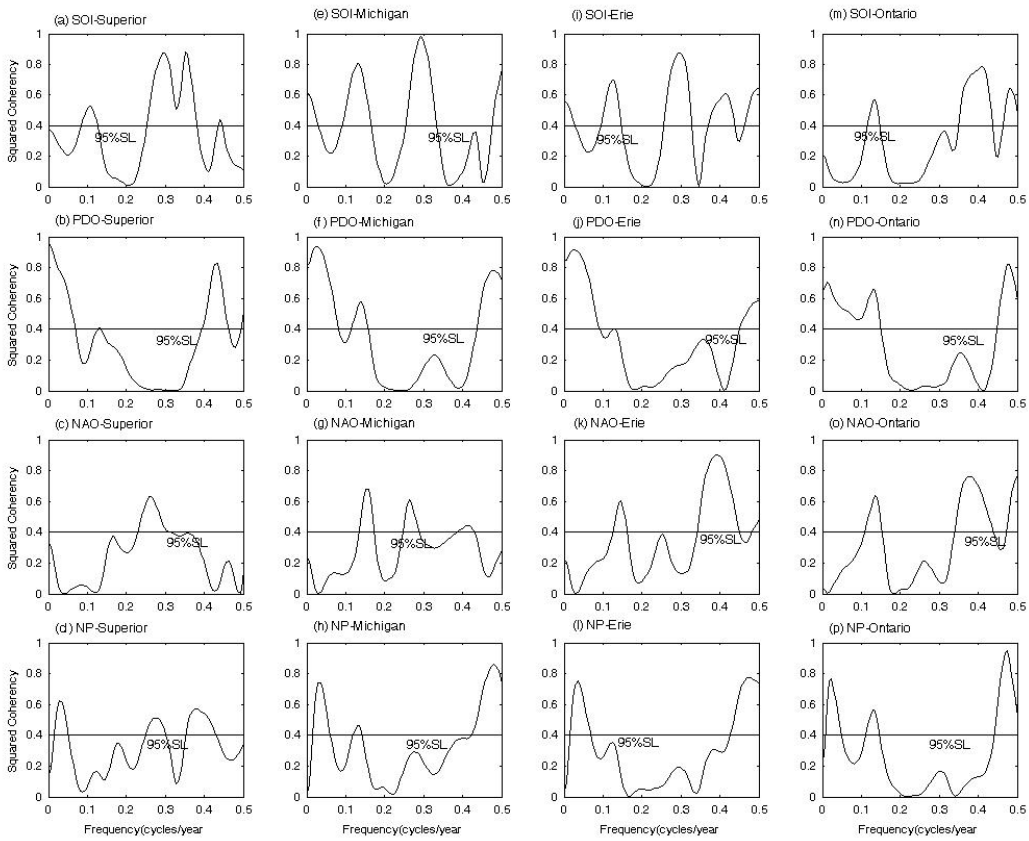



**Figure 4.** Squared coherencies of (teleconnections, Great Lakes water level) pairs

Figure 6 and Table 2 show the results from coherency analysis between precipitation, groundwater level and lake level.

## CONCLUSIONS AND RECOMMENDATIONS –

Large-scale climate signals affect Great Lakes levels. The effect is verified by significant coherence between signals and lake level time series, between signals and over lake precipitation and lake evaporation series, and between precipitation and evaporation and lake levels series. The relations are clear for the upstream lakes, and more complex for the downstream lakes, where lake levels are affected by stream flow from the upstream lakes and their contributing watersheds.

Large-scale signals affect groundwater level in Wisconsin. The effect is verified by significant coherence between signals and groundwater level time series, between signals and precipitation series, and between

precipitation and groundwater level series. The relations are clear for the forested area of Wisconsin and more complex for the agricultural area of the State.
At the watershed scale (Trout Lake watershed), there is significant coherence between precipitation and groundwater level at high frequencies (of the order of days) and low frequencies (of the order of years), between precipitation and lake levels (at low frequencies), and between groundwater level and lake levels (at low frequencies).

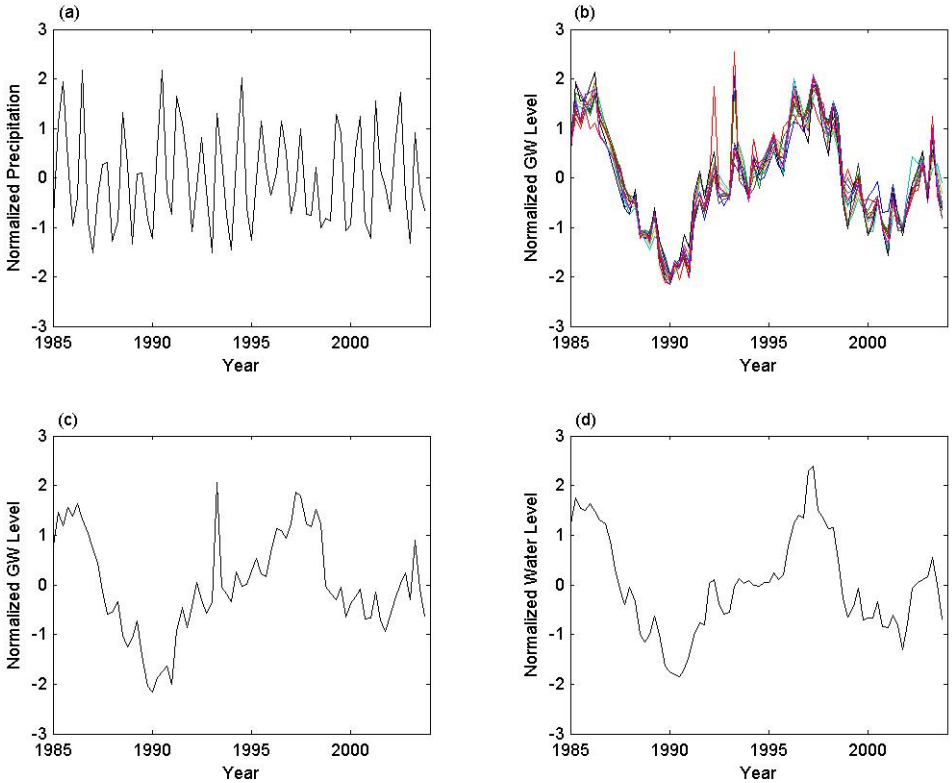



**Figure 5.** Time series used in coherency analysis: a) quarterly precipitation time series at Minocqua Dam; b) Quarterly groundwater level time series in the whole well network; c) Quarterly groundwater level time series at well # K2; d) Quarterly Big Muskellunge Lake water level time series

The use of spectral methods in the Trout Lake watershed showed that there are significant low frequency oscillations (of the order of 10 years) in lake levels, and significant oscillations in streamflow. These identified oscillations can help to improve groundwater- lake level modeling.

Large-scale signals affect the ice cover duration in Lake Mendota, Wisconsin. The effect is verified by significant coherence between signals and ice cover variables (ice cover duration, ice-on and ice-off dates), between signals and local climate (air temperature, snowfall and snow depth), and between local climate and ice duration variables.

## REFERENCES –

Bloomfield P., 1976. Fourier Analysis of Time Series: An Introduction. J. Wiley and Sons, New York.

Box, G.E.P., and G.M. Jenkins, 1970. Time series analysis: Forecasting and control, Holden-Day, San Francisco.

| | | |
|---|---|---|
| Precipitation and Groundwater Level | Frequency Cycles year$^{-1}$ | $(2.0\text{-}8.0)^{-1}$ |
| | | $(1.4\text{-}1.6)^{-1}$ |
| | | $(0.9\text{-}1.1)^{-1}$ |
| | | $(0.66\text{-}0.7)^{-1}$ |
| | Squared Coherency | 0.65 |
| | | 0.57 |
| | | 0.73 |
| | | 0.53 |
| Precipitation and Lake Level | Frequency Cycles year$^{-1}$ | $(2.2\text{-}8.0)^{-1}$ |
| | | $(1.3\text{-}1.6)^{-1}$ |
| | | $(0.9\text{-}1.0)^{-1}$ |
| | | $(0.6\text{-}0.67)^{-1}$ |
| | Squared Coherency | 0.71 |
| | | 0.66 |
| | | 0.55 |
| | | 0.61 |
| Groundwater Level and Lake Level | Frequency Cycles | $(>2.4)^{-1\ 1}$ |
| | | $(0.9\text{-}1.25)^{-1}$ |
| | Squared Coherency | 0.99 |
| | | 0.77 |

**Table 2.** Squared coherency and significant frequency bands between precipitation, groundwater level and lake level in Trout Lake basin

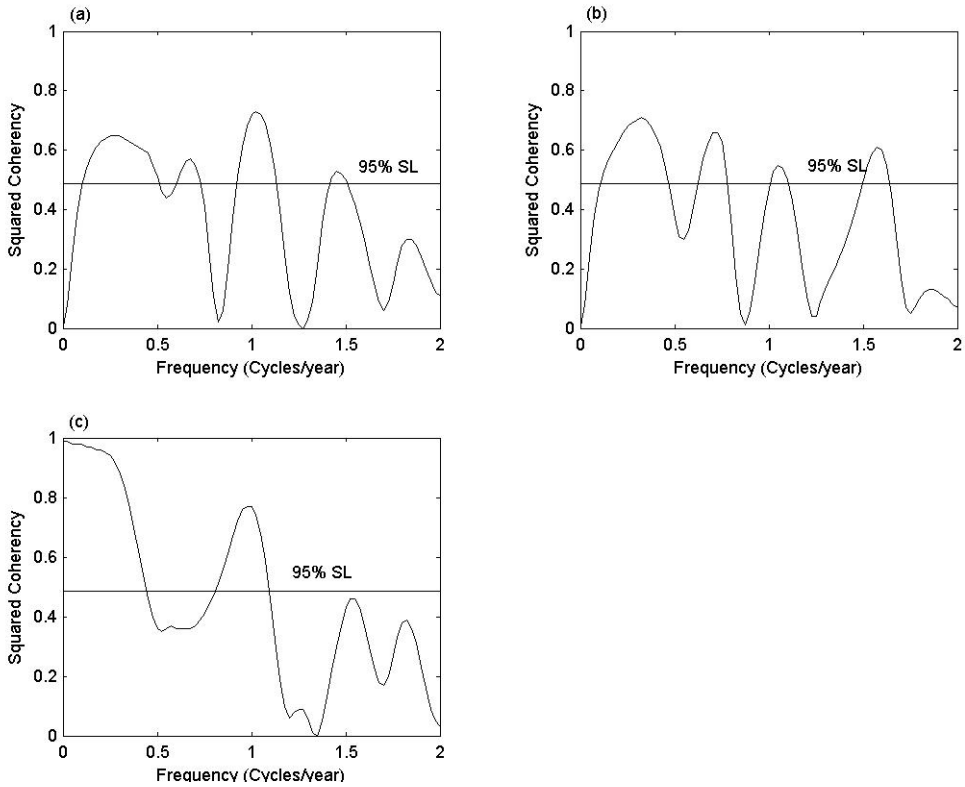



**Figure 6.** Coherency analysis results: a) squared coherency between precipitation and groundwater level; b) squared coherency between precipitation and lake level; c) squared coherency between groundwater level and lake level

Dettinger M. D., Ghil M., Strong C. M., Weibel W., Yiou P., 1995. Software expedites singular-spectrum analysis of noisy time series. Eos. Trans. AGU 76(2), 12, 14, 21. (Version 4.1 available on the World Wide Web at http://www.atmos.ucla.edu/tcd/ssa).

Dripps, W.R., 2003. The spatial and temporal variability of groundwater recharge within the Trout Lake basin in Northern Wisconsin. Dissertation submitted in partial fulfillment of the requirements for the PhD degree, University of Wisconsin-Madison.

Ghil, M., M.R. Allen, M.D Dettinger, K. Ide, D. Kondrashov, M.E. Mann, A.W. Robertson, A. Saunders, Y. Tian, F. Varadi and P. Yiou, 2002. Advanced spectral methods for climatic time series, Reviews of Geophysics 40, 1.

Hanson, R.T., M.W. Newhouse and M.D. Dettinger, 2004. A methodology to assess relations between climatic variability and variations in hydrologic time series in the southwestern United States. J. Hydrol., 287(1-4), 253-270.

Intergovernmental Panel on Climate Change, 2007. Climate Change 2007 – The Physical Science Basis, Working Group I Contribution to the Fourth Assessment Report of the IPCC, Cambridge University Press.

Jenkins, G.M., and D.G. Watts, 1968. Spectral analysis and its applications, Holden-Day, San Francisco.

Kuo C., Lindberg C., Thomson D. J., 1990. Coherence established between atmospheric carbon dioxide and global temperature. Nature 343, 709-713.

Mantua, N., S. Hare, Y. Zhang, J.M. Wallace, and R. Francis, 1997. A Pacific Interdecadal Climate Oscillation with Impacts on Salmon Production, Bulletin of American Meteorological Society, 78, 1069-1079.

Namdar-Ghanbari, R, 2007. Climate signals in groundwater and surface water systems: Spectral analysis of hydrologic processes, PhD Dissertation, University of Wisconsin-Milwaukee.

Namdar-Ghanbari, R. and Bravo, H.R., 2008. Coherence between teleconnections, regional climate and Great Lakes levels, Advances in Water Resources, doi: 10.1016/j.advwatres.2008.05.002.

Numerical Algorithm (NAG) Routines, 1999. Wilkinson House, Jordan Hill Road, OXFORD OX2 8DR, United Kingdom.

Piechota, T.C., J.D. Garbrecht and J.M. Schneider, 2006. Climate Variability and Climate Change, in Climate Variations, Climate Change, and Water Resources Engineering, Garbrecht and Piechota, eds., ASCE.

Press, W.H, B.P. Flannery, S.A. Teukolski and W.T. Vettering, 1992. Numerical Recipes in FORTRAN 77: The Art of Scientific Computing, Second Edition, Volume 1 of Fortran Numerical Recipes, Cambridge Univ. Press, New York.

Ropelewski, C.F. and Jones, P.D., 1987: An extension of the Tahiti-Darwin Southern Oscillation Index. Monthly Weather Review 115, 2161-2165.

The Math Works, Inc., 2004. MATLAB 7.

**APPENDIX A: Awards, Publications, Reports, Patents and Presentations –**

Namdar-Ghanbari, R, 2007. Climate signals in groundwater and surface water systems: Spectral analysis of hydrologic processes, PhD Dissertation, University of Wisconsin-Milwaukee.

Namdar-Ghanbari, R. and Bravo, H.R., 2008. Coherence between teleconnections, regional climate and Great Lakes levels, Advances in Water Resources, doi: 10.1016/j.advwatres.2008.05.002.

Namdar G. R., Bravo H. R., 2007. Trend and Oscillations in the Ice Cover Duration of Lake Mendota, Wisconsin, presented at the 32nd Congress of the International Association of Hydraulic Engineering and Research, IAHR, Venice, Italy.

Namdar Ghanbari, R., Bravo, H.R, Magnuson, J.J., Hyzer, W.G. and Benson, B.J., 2008. Coherence between lake ice cover, local climate and teleconnections (Lake Mendota, Wisconsin), submitted to Journal of Hydrology.

# Grant No. 04HQGR0034 – The Role of Dissolved Organic Carbon in Aquatic Mercury Cycling – The Transport, Fate and Cycling of Mercury in Watersheds and Air Sheds

## Basic Information

| | |
|---|---|
| **Title:** | Grant No. 04HQGR0034 – The Role of Dissolved Organic Carbon in Aquatic Mercury Cycling – The Transport, Fate and Cycling of Mercury in Watersheds and Air Sheds |
| **Project Number:** | 2005WI150S |
| **Start Date:** | 11/15/2003 |
| **End Date:** | 9/14/2008 |
| **Funding Source:** | Supplemental |
| **Congressional District:** | |
| **Research Category:** | Not Applicable |
| **Focus Category:** | None, None, None |
| **Descriptors:** | |
| **Principal Investigators:** | Jim Hurley |

## Publication


1. Gorski, P.R., DE. Armstrong, J.P. Hurley and M.M. Shafer. 2006. Speciation of aqueous methylmercury influences uptake by a freshwater alga (Selenastrum capricornutum). Environmental Toxicology and Contamination. 25 (2): 534−540.
2. Branfireun, B.A., D. P. Krabbenhoft, H. Hintelmann, R. J. Hunt, J. P. Hurley, and J.W.M. Rudd. 2005. The Transport And Speciation Of Atmospheric Mercury In A Boreal Forest Wetland: A Stable Mercury Isotope Approach. Water Resources Research, v. 41, W06016, oi:10.1029/2004WR003219, 2005.
3. Hall, B.D., H. Manolopoulos, J.P. Hurley, J. J. Schauer, V.L. St. Louis, D. Kenski, J. Graydon, C.L. Babiarz, L.B. Cleckner, and G.J. Keeler. 2005. Methyl and total mercury in precipitation in the Great Lakes region. Atmospheric Environment. 39(39):7557−7569.
4. Stoor, R.W., J.P. Hurley, C.L. Babiarz and D.E. Armstrong. 2006. Subsurface Sources of Methylmercury to Lake Superior from a Wetland−Forested Watershed. Science of the Total Environment. 368(1) pp99−110
5. Chadwick, S.P., C.L. Babiarz, J.P. Hurley and D.E. Armstrong. 2006. Influences of iron, manganese, and dissolved organic carbon on the hypolimnetic cycling of amended mercury. Science of the Total Environment. 368(1) pp177−188
6. Reed Harris , Marc Amyot , Christopher Babiarz , Ken Beaty , Paul Blanchfield , R. A. (Drew) Bodaly , Brian Branfireun , Cynthia Gilmour , Jennifer Graydon , Andrew Heyes , Holger Hintelmann , James Hurley , Carol Kelly , David Krabbenhoft , Steve Lindberg , Robert Mason , Michael Paterson , Cheryl Podemski , Art Robinson , Ken Sandilands , George Southworth , Vincent St. Louis and Michael Tate. 2007. Whole−Ecosystem Study Shows Rapid Fish Mercury Response to Changes in Mercury Deposition. Proc. Nat. Acad. Sci. v104 pp16586−16591

# Annual Progress Report

**Selected Reporting Period:** 7/1/2007 - 6/30/2008

**Submitted By:** David Krabbenhoft
**Submitted:** 7/9/2008

## Project Title

WR03R010: The Role of Dissolved Organic Carbon in Aquatic Mercury Cycling

## Project Investigators

James Hurley, University of Wisconsin Sea Grant Institute
David Krabbenhoft, Other
Michael Tate, University of Wisconsin-Madison

## Progress Statement

During the time period 3/1/2007 to 2/29/2008 the project completed the seventh year of intensive study on the Mercury Experiment to Assesses Atmospheric Loadings in Canada and the US (METAALICUS) project. Our portion of the project is to monitor the watershed-scale response of the artificial load of mercury that is being administered with three different stable isotopes (198Hg, 201Hg, 202Hg) to the study wetland, uplands and lake, respectively. The seventh, and last, mercury load conducted in 2007 will conclude the loading phase of this project and we will now ensue with monitoring the mercury "load reduction" response.

## Principal Findings and Significance

## Principal Findings and Significance

**Description** Results from the past year of data collection revealed that the watershed continued to show greater fluxes of 198Hg and 200Hg from the wetland and uplands, respectively, demonstrating the atmospheric loading rates do play a direct role in regulating mercury fluxes from watersheds. The data also clearly show that climatic variables, particularly precipitation rate, are even more important in determining the flux of mercury from watersheds, drawing attention to seemingly unrelated factors (e.g., climate change) in controlling future mercury fluxes to down-gradient aquatic ecosystems.

## Interactions

**Description** Project summary presentation to the US EPA and Environment Canada

**Event Date** 4/16/2008

## Journal Articles & Other Publications

| | |
|---|---|
| **Publication Type** | Peer-Reviewed Journal Article/Book Chapter |
| **Title** | Whole-Ecosystem Study Shows Rapid Fish Mercury Response to Changes in Mercury Deposition |
| **Author(s)** | Reed Harris , Marc Amyot , Christopher Babiarz , Ken Beaty , Paul Blanchfield , R. A. (Drew) Bodaly , Brian Branfireun , Cynthia Gilmour , Jennifer Graydon , Andrew Heyes , Holger Hintelmann , James Hurley , Carol Kelly , David Krabbenhoft , Steve Lindberg , Robert Mason , Michael Paterson , Cheryl Podemski , Art Robinson , Ken Sandilands , George Southworth , Vincent St. Louis , Michael Tate |
| **Publication/Publisher** | Proceedings of the National Academy of Sciences |
| **Year Published** | 2007 |
| **Volume & Number** | 104 |
| **Number of Pages** | 16586-16591 |
| **Description** | Mercury contamination of fisheries, from centuries of industrial atmospheric emissions, negatively impacts humans and wildlife worldwide. The response of fish mercury concentrations to changes in mercury deposition has been difficult to establish, though, because sediments/soils contain large pools of historical contamination, and many factors in addition to deposition affect fish mercury concentrations. To directly test the response of fish contamination to changing mercury deposition, we conducted a whole-ecosystem, multi-year experiment in which the mercury load to a boreal headwater lake and its watershed was increased using enriched stable mercury isotopes. The use of stable isotopes allowed us to follow new mercury deposition separately from stored pools, and to examine bioaccumulation of mercury deposited to different parts of the watershed. Fish mercury concentrations responded rapidly to changes in mercury deposition over the first three years of study. Essentially all of the increase in fish mercury concentrations was derived from mercury deposited directly to the lake surface. In contrast, <1 % of the mercury isotope deposited to the watershed was exported to the lake. Equilibrium was not reached within three years. Lake mercury isotope concentrations were still rising in lake biota, and watershed mercury isotope concentrations were increasing slowly in runoff. Therefore, we predict that mercury emissions reductions will yield rapid (years) reductions in fish mercury concentrations, and concomitant reductions in risk. However, a full response will be delayed by watershed retention of mercury. The rate of response will vary among lakes depending on the relative surface areas of water and watershed. |
| **Any Additional Citation Information** | |

## Partners

| | |
|---|---|
| **Name/Organization** | Michael Patterson |
| **Affiliation** | Department of Fisheries and Oceans, Canada |
| **Affiliation Type** | International |
| **Email** | Michael.Paterson@dfo-mpo.gc.ca |
| **Description** | |

| | |
|---|---|
| **Name/Organization** | George Aiken |
| **Affiliation** | USGS, National Research Program |
| **Affiliation Type** | Federal |

| | |
|---|---|
| **Email** | graiken@usgs.gov |
| **Description** | |

## Presentations & Public Appearances

| | |
|---|---|
| **Title** | Estimating Ecosystem Responses to Changes in Mercury Loading: Lessons Learned from the METAALICUS Project |
| **Presenter(s)** | David P. Krabbenhoft, Mike Tate, Reed Harris, Vince St. Louis, Jennifer Graydon, Brian Branfireun, and Andrew Heyes |
| **Presentation Type** | Professional meeting |
| **Event Name** | American Geophysical Union |
| **Event Location** | San Francisco, California |
| **Event Date** | 12/11/2007 |
| **Target Audience** | Scientific audience |
| **Audience Size** | 125 |
| **Description** | Special session on mercury contamination of aquatic ecosystems. |

# Arsenic Species (III,V) Distribution in Wisconsin Groundwaters: Field Measurements and Prediction Using Multivariate Analysis of Geochemical Data

## Basic Information

| | |
|---|---|
| **Title:** | Arsenic Species (III,V) Distribution in Wisconsin Groundwaters: Field Measurements and Prediction Using Multivariate Analysis of Geochemical Data |
| **Project Number:** | 2005WI155O |
| **Start Date:** | 7/1/2005 |
| **End Date:** | 6/30/2007 |
| **Funding Source:** | Other |
| **Congressional District:** | 2nd |
| **Research Category:** | Water Quality |
| **Focus Category:** | Groundwater, Geochemical Processes, Water Quality |
| **Descriptors:** | arsenic speciation; analytical chemistry |
| **Principal Investigators:** | Martin Shafer, James Schauer |

## Publication


1. Kerr S.C., M.M. Shafer, J. Overdier, and D.E. Armstrong. 2008. Hydrologic and biogeochemical controls on trace element export from Northern Wisconsin wetlands. Accepted for publication in Biogeochemistry (01/19/2008).
2. Shafer M.M., J. Overdier, and D.E. Armstrong. Controls on arsenic oxidation state speciation in Wisconsin groundwaters. Manuscript in−preparation for submission to Aquatic Geochemistry.

**Project Final Report**

# Arsenic Species (III,V) Distribution In Wisconsin Groundwaters: Field Measurements and Prediction Using Multivariate Analysis of Geochemical Data

**(06-CTP-03, WR05R001)**

**By**

M.M. Shafer, Joel T. Overdier, and S.C. Kerr
Environmental Chemistry & Technology Program
Water Science & Engineering Laboratory
660 North Park Street
Madison, WI 53706

Funded By

The State of Wisconsin Groundwater Research Program

through the

University of Wisconsin Water Resources Institute
1975 Willow Drive
Madison, WI 53706

November, 2007

## TABLE of CONTENTS


| | Page # |
|---|---|
| List of Figures and Tables | 03 |
| Project Summary | 04 |
| Introduction | 06 |
| Procedures and Methods | 08 |
| Results and Discussion | 10 |
| Meta-analysis | 10 |
| Field Studies | 11 |
| Conclusions and Recommendations | 14 |
| References | 15 |
| Appendix A: Presentations | 16 |
| Appendix B: Supplemental Information | 16 |
| Arsenic Speciation & Geochemistry | 16 |
| Methods Detail | 18 |
| Supplemental Figures | 20 |

## LIST OF FIGURES and TABLES


| | | Page # |
|---|---|---|
| **Table 1.** | Electrochemical series | 07 |
| **Table 2.** | Well sampling sites | 10 |
| **Table 3.** | Selected Regression Model [%As(III)] Outcomes | 13 |
| **Figure 1**. | Concentration Ranking of Measured Total Arsenic and As(III) | 11 |
| **Figure 2.** | Arsenic, Arsenic(III) and Fe(II) Distributions | 12 |
| **Figure 3.** | Arsenic Speciation [% As(III)] versus Redox Potential | 12 |
| **Figure 4.** | Eh-pH Surface Plot of Well Arsenic Data. | 13 |
| **Figure B-1** | Arsenic Speciation [% As(III)] versus Redox along a Groundwater Flow Path | 20 |
| **Figure B-2** | Site Matrix: Quartile Distribution by Iron | 21 |
| **Figure B-3** | Site Matrix: Quartile Distribution by Calcium | 21 |

# PROJECT SUMMARY

**Title:** Arsenic Species (III,V) Distribution In Wisconsin Groundwaters: Field Measurements And Prediction Using Multivariate Analysis Of Geochemical Data.

**Project I.D.:** 06-CTP-03, WR05R001

**Investigators:** Principal Investigator: Martin Shafer PhD, Associate Scientist, UW-Madison Environmental Chemistry & Technology Program (EC&T).
Research Associate: Joel Overdier, Associate Researcher, UW-Madison EC&T Program.
Research Assistant: Sara Kerr,UW-Madison EC&T Program.
Undergraduate Assistant: Jackson Helmer.

**Contract Period:** July 01, 2005 through June 30, 2007.

**Background/Need:** The environmental fate, toxicity, and mitigation strategies of arsenic are dependent upon its complex chemical speciation. Thus critical information pertinent to identification of arsenic release mechanisms can be obtained through studies of arsenic speciation (especially oxidation state). Only trace quantities of organic arsenic species are found in WI groundwaters, thus the study focused on the more toxic and dominant inorganic forms of arsenic (arsenate and arsenite). Arsenate (As V) is the oxidized form of arsenic and is anionic at relevant groundwater pH ranges. Arsenite (AsIII) is the reduced form of arsenic and is uncharged under typical groundwater pH ranges. Arsenate, because of its charge, has a stronger capacity to sorb to aquifer surfaces and is therefore less mobile in groundwater systems than the reduced (arsenite form).

**Objectives:** The four principal goals of this study were to:

1. Perform a meta-analysis of existing groundwater data for co-variation of geochemical analytes and test their association with total and speciated arsenic concentrations using multivariate statistical methods.
2. Determine the concentrations of arsenic and primary redox-active species [Fe(II/III), nitrate/ammonia, sulfate/sulfide, oxygen, DOC] in Wisconsin groundwaters.
3. Quantify the occurrence and distribution of arsenic species (III and V) in Wisconsin groundwaters.
4. Examine relationships between arsenic oxidation state speciation and aquifer geochemistry and test the hypothesis that arsenic speciation can be predicted from aquifer geochemistry.

**Methods:** The study included a meta-analysis of existing groundwater data, a detailed field study of 57 wells in Wisconsin, and multivariate statistical analyses. The field study focused on measuring arsenic speciation (III and V) and important

geochemical parameters in 57 sites in Wisconsin. A 4x4 matrix of sites was constructed with Ca and Fe as the primary variables, and sulfate and total As levels secondary variables. This construct facilitated ANOVA statistical testing. Arsenic species separation was performed on-site using As(V)-specific solid-phase extraction columns. This approach avoided the speciation changes that occur as a result of redox transformations of common drivers during storage. Arsenic (along with a large suite of other elements) was determined using high-resolution ICP-MS, which with an As reporting limit of 0.02 μg $L^{-1}$, ensured that the study matrix was complete and accurate.

**Results and Discussion:** Analysis of >5300 well records compiled from nine states showed that the data sets have very limited information on arsenic speciation, redox sensitive species, and are compromised by poor detection limits. Thus global models of arsenic speciation based upon these existing data were of only limited value. Meta-analyses identified several potentially predictive, commonly measured, geochemical analytes (calcium, iron, sulfate, and sodium) and field study was structured around these variables. Regression models demonstrated that a large fraction of the variance in the measured fraction of total arsenic present as As(III) could be explained by redox (Eh) levels. In multiple regression models, only a few other geochemical factors (pH, Ca, sulfate) enhanced predictive power over that of redox alone, and their contribution was comparatively minor. Redox, however, was a relatively poor predictor of total arsenic levels. The field data generated in this study clearly confirmed theoretical Eh-pH arsenic speciation relationships, a finding that few other studies have documented.

**Conclusions/Implications/Recommendations:** Our primary conclusion from this effort is that a large proportion of the variance in the measured fraction of total arsenic present as As(III) can be explained by redox (Eh) levels. The practical implication of this finding is that one may be able to use the relatively un-demanding redox measurement as an acceptable surrogate for arsenic oxidation state speciation. This work also provides a tool to use extant or basic geochemical data, where arsenic concentrations are not available, or are suspect, to estimate the proportion of the most toxic form of arsenic

## Related Publications and Presentations:


1. Kerr S.C., M.M. Shafer, J. Overdier, and D.E. Armstrong. **2008.** Hydrologic and biogeochemical controls on trace element export from Northern Wisconsin wetlands. Accepted for publication in *Biogeochemistry* (01/19/2008).
2. Shafer M.M., J. Overdier, and D.E. Armstrong. Controls on arsenic oxidation state speciation in Wisconsin groundwaters. Manuscript in-preparation for submission to *Aquatic Geochemistry.*



**Key Words:** Arsenic, Groundwater, Speciation, Redox, Geochemistry

**Funding:** State of Wisconsin Groundwater Coordination Council through the University of Wisconsin Water Resources Institute.

## INTRODUCTION

There are widespread occurrences of elevated arsenic (As) levels in ground and drinking waters throughout Wisconsin (Burkell and Stoll 1995, WDNR, 2000, Thornburg and Sahai 2004). Ingestion of inorganic As has been shown to cause skin, bladder and lung cancers (NRC, 1999). The Wisconsin drinking water standard for As is based on the EPA's maximum contaminant level and was 50 $\mu gL^{-1}$ in 1980 (US EPA 1980), but was recently decreased to 10 $\mu gL^{-1}$ (World Health Organization guideline, WHO 1993). As of 2003, 17% of 3300 wells sampled in Outagamie and Winnebago counties had As levels between 10 $\mu gL^{-1}$ and 50 $\mu gL^{-1}$ and 3% of the As concentrations in these wells exceeded of 50$\mu gL^{-1}$ (WDNR, 2003). Therefore, a critical need exists to develop tools which will improve our ability to identify aquifers with potential for elevated As levels.

Arsenic is a metalloid whose environmental fate, toxicity and mitigation strategies vary according to its complex chemical speciation. Arsenic in groundwater systems exists primarily as either oxidized (arsenate, AsV) or reduced (arsenite, AsIII) oxyanions (refer to Appendix B for additional details on As speciation and chemistry). Isolated occurrences of methylated forms have been noted, particularly in organic-influenced aquifers, but are generally insignificant in regional groundwater supplies. Arsenate ($pK_a1$ = 2.19) is negatively charged at pH levels in common groundwater (6-9), where AsIII ($pK_a1$ = 9.20) is uncharged. Arsenate sorbs more strongly to common minerals and aquifer matrices and is therefore less mobile than uncharged AsIII (Smedley and Kinniburgh 2002). Due to its electroneutrality, AsIII is more difficult to remediate from drinking water, which is why a pre-oxidation step is typically required. Arsenite is generally more toxic to humans than AsV, and is retained in tissues to a greater extent than arsenate (NRC 1999). The toxicity of AsIII is driven by the binding to sulfur groups in important proteins. Arsenate is a biological analogue for phosphate and can therefore disrupt the production of ATP. Since mobility, toxicity and mitigation varies with the speciation of As, it is important to identify As release mechanisms in a species-specific (III or V) manner.

Two principal mechanisms have been identified for release of As from aquifers, both relevant to Wisconsin groundwaters. Arsenic contained in the sulfide bearing cement horizon is released when the iron sulfide minerals are oxidized.

**(1)** $\mathbf{2FeS_2 + 7O_2 + 2H_2O = 2Fe^{2+} + 4H^+ + 4SO_4^{2-}}$

In the regions where the static water level is close to the cement horizon, oxidative dissolution of the As rich pyrite/marcasite minerals is the likely driving force for AsV mobilization (i.e. the oxidation hypothesis). Therefore if this is the driving factor affecting AsV mobilization, the iron and sulfate would be closely correlated with higher AsV/AsIII concentration ratios.

Reductive dissolution has also been identified as a possible dominant factor in As mobilization in aquifers in Bangladesh (Ahmed et al. 2004), Illinois (Holm, 2003) and southeastern Wisconsin (Gotkowitz et al. 2003). This occurs when the Fe in the iron oxy-hydroxides is reduced thereby releasing sorbed As (i.e. the reduction hypothesis). The reductive dissolution process can be represented by the following mechanism:

**(2)** $\mathbf{4FeOOH + CH_2O + 7H_2CO_3 \rightarrow 4Fe^{2+} + 8HCO_3^- + 6H_2O.}$

This mechanism results in the release of both sorbed As(V) and As(III), with the preferential release of AsIII, and is accompanied by microbial reduction of As(V) to arsenite. A correlation of total As and $HCO_3^-$ was observed by Nickson et al. 2000, which is suggestive of the reductive hypothesis. This association, however, could be established with much greater certainty if As(III) concentrations were compared rather than just total arsenic.

The concentration of the As species released from the mechanisms described above can be modified or even reversed by surrounding geochemical factors. For example, at groundwater pH ranges, most soluble Fe species are positively charged and will strongly bind anions such as As(V). Ions and chemical constituents other than those described above ($HCO_3^-$, $Fe^{2+}$ and $SO_4^{2-}$) may be involved in both the redox chemistry and mobilization of arsenic. Factors such as groundwater age and residence time, kinetic constraints of mineral dissolution and anthropogenic influence will influence arsenic release. Arsenic in groundwater was found to increase over time in Glacial Drift aquifers in Illinois, therefore there may be an association of mobilized As with groundwater residence time as measured by oxygen isotope ratios. The reductive dissolution of metal oxyhydroxides and the oxidation of sulfide minerals could also occur for manganese based minerals.

Some ions may be directly involved in As release; namely $PO_4^{3-}$, $HCO_3^-$, $Fe^{2+}/Fe^{3+}$ and $SO_4^{2-}$, while other ions (e.g. $NH_4^+$) are good indicators of redox potential (Eh) of the groundwater system **(Table 1**). In fact, early predications held that AsIII/AsV ratios would follow redox profiles in groundwater systems, though demonstrating this in actual environmental settings has been difficult due to the complexities of the groundwater systems (Smith et al. 2003) and challenging analytical issues. It is also important to note that As concentrations in groundwater cannot simply be predicted by presence in the solid phase (Warner, 2001).

**Table 1. Electrochemical Series**

| Redox half reaction | Std. Electrode Potential (V) |
|---|---|
| $N_2O + 2H^+ + 2e^- = N_2 + H_2O$ | 1.77 |
| $O_{2(g)} + 4H^+ + 4e^- = 2H_2O$ | 1.23 |
| $Fe(OH)_3 + 3H^+ + e^- = Fe^{2+} + 3H_2O$ | 0.95 |
| $Fe^{3+} + e^- = Fe^{2+}$ | 0.771 |
| $H_3AsO_4 + 2H^+ + 2e^- = H_3AsO_3 + H_2O$ | 0.58 |
| $NO_3^- + H_2O + 2e^- = NO_2^- + 2OH^-$ | 0.01 |
| $N_2 + 2H_2O + 6H^+ + 6e^- = 2NH_4OH$ | 0.092 |
| $S(s) + 2e^- = S^{2-}$ | -0.47 |
| $SO_3^{2-} + 3H_2O + 4e^- = S_2O_3^{2-} + 6OH^-$ | -0.57 |
| $SO_4^{2-} + H_2O + 2e^- = SO_3^{2-} + 2OH^-$ | -0.93 |

A multivariate approach is warranted to elucidate driving mechanisms in AsV/AsIII mobilization in groundwater, and speciation will assist in the distinction between the various mechanistic possibilities (Smith et al. 2003; Meglen, RR 1992), improving upon earlier bivariate analyses (Holm et al. 2004, IDWR 2004).

The **four principal goals** of this study were therefore to:

1. Perform a meta-analysis of existing groundwater data for co-variation of geochemical analytes and test their association with total and speciated arsenic concentrations using multivariate statistical methods.
2. Determine the concentrations of arsenic and primary redox-active species [Fe(II/III), nitrate/ammonia, sulfate/sulfide, oxygen, DOC] in Wisconsin groundwaters.
3. Quantify the occurrence and distribution of arsenic species (III and V) in Wisconsin groundwaters.
4. Examine relationships between arsenic oxidation state speciation and aquifer geochemistry and test the hypothesis that arsenic speciation can be predicted from aquifer geochemistry.

## PROCEDURES and METHODS

The study included a meta-analysis of existing groundwater data, a detailed field study of 60 wells in Wisconsin, and multivariate statistical analyses.

**A. Meta-analysis:** Data from the following sources were assembled for the meta-analysis:
**1.** Oakland County Michigan. 37 samples. [Ground-Water Quality Atlas of Oakland County, MI. Water-Resources Investigation Report 00-4120]
**2.** Mahomet Aquifer Illinois; Champaign and Tazwell counties. 144 samples. [Illinois Department of Natural Resources, WMRC Report RR-107, May 2004].
**3.** Idaho – Washington County. 75 samples. [Ground water Quality Technical Report No. 6. Idaho Division of Environmental Quality, September 1995].
**4.** Minnesota Pollution Control Authority. 954 samples.
**5.** New Jersey. 170 samples. [Ambient Ground Water Quality in the Newark Basin, New Jersey. By M.S. Serfes, Digital compilation by G.C. Herman and M.S. Serfes, N.J. Geol. Survey Digital Geodata Series DGS96-3].
**6.** Ohio. 72 samples. [WDR-OH-AR-02.2. 2003 USGS Water Data Report OH-3-2].
**7.** Ohio. 21 samples. [Miami, OH].
**8.** New England Coastal Basin. 804 samples. [USGS Water Resources Investigations Report 99-4162]. 1999.
**9.** Wisconsin. 2648 samples. [Department of Natural Resources, Municipal and Private Wells].
**10.** Ontario, Canada. 430 samples.

In addition to the total arsenic data (speciated in a just a few studies), we have incorporated the following supporting geochemical data from each sample into the database (Note: the degree of comprehensiveness of the geochemical data varies greatly among the databases assembled – some e.g. only have total arsenic): 1. Well depth; 2. Temperature; 3. pH; 4. Specific Conductance; 5. Dissolved Oxygen; 6. Dissolved Solids 7. Hardness/Alkalinity; 8. Carbonate/Bicarbonate; 9. Sulfate; 10. Phosphate; 11. Chloride; 12. Bromide; 13. Fluoride; 14. Calcium; 15. Magnesium; 16. Potassium; 17. Silica; 18. Nitrogen Species (ammonia, nitrate, nitrite); 19. Dissolved Organic Carbon; 20. Trace metals.

**B. Field Studies:** The field study focused on measuring arsenic speciation (III and V) and a large suite of geochemical parameters in 57 of the previously statistically analyzed sites (all in Wisconsin). Low volume purging and pumping techniques were used for the collection of samples (Creasey and Flegel 1999, Shafer et al. 1991). In-line filtration was performed with pre-cleaned, high capacity, all polypropylene 0.45µm-rated filter capsules.

Arsenic species separation was performed on-site using As(V)-specific solid-phase extraction columns (refer to Appendix B). This approach avoided the speciation changes that occur as a result of redox transformations of common drivers during storage (even when "preservatives" such as HCl/EDTA are added). Arsenic (along with a large suite of other elements) was determined using high-resolution ICP-MS, which with a reporting limit of 0.02 µg $L^{-1}$, ensured that the study matrix was complete and accurate. Traditional ICP-MS techniques for arsenic are compromised by severe ArCl and other mass overlaps at m/z 75 (As). The high resolution capability of this ICP-MS eliminates (mass-resolves) interferences at mass 75.

The critical redox sensitive species measured included:

1. Iron Oxidation State (II and III)
   a. Ferrous (II). On-site ferrozine complexation
   b. Total (Ferrous + Ferric). HR-ICP-MS
2. Nitrogen species
   a. Nitrate+Nitrite. Lachet discrete analyzer
   b. Ammonia. Lachet discrete analyzer
3. Suflur Spcies
   a. Sulfate. Ion chromatography
   b. Sulfide. Ion selective electrode
4. Dissolved Oxygen and Redox by multiparameter sonde

Other Supporting Analytes measured included:

5. Chloride and Phosphate by Ion Chromatography
6. Elemental Analysis by High Resolution ICP-MS (52 elements; refer to App. B)
7. Dissolved Organic Carbon (DOC) by high temperature combustion
8. Oxygen isotopes ($^{18}O/^{16}O$) by Isotope Ratio Mass Spectrometry
9. Temperature, pH, Specific Conductance, by multiparameter sonde

A 4x4 matrix of sites was constructed with using nearly universally available well concentrations of calcium and iron as the primary stratification variables, and sulfate and total arsenic levels as secondary variables (gradients within each cell). This construct facilitated ANOVA statistical testing.

**Table 2.** Sampling Site Matrix.

| | 1<br>5<br>9<br>13 | 2<br>6<br>10<br>14 | 3<br>7<br>11<br>15 | 4<br>8<br>12<br>16 |
|---|---|---|---|---|
| (Iron-ppb)<br>Site ID<br>(SpCond-µS) | Major Ion Level 1<br>Calcium < 20 ppm<br>SpCond < 200 µS | Major Ion Level 2<br>Calcium 20 - 53 ppm<br>SpCond 200 - 530 µS | Major Ion Level 3<br>Calcium 54 - 72.5 ppm<br>SpCond 540 - 725 µS | Major Ion Level 4<br>Calcium > 72.5 ppm<br>SpCond > 725 µS |
| Iron Level 1<br>< 25 ppb | (0.8) T5 20.4 (48)<br>(0.6) T5 20.2 (43)<br>(2.3) T5 10.3 (55) | (26) Twin Valley (342)<br>(4.4) Devil's Lake Quartzite (319)<br>(3.7) Devil's Lake East (229)<br>(7.2) Devil's Lake Ice Age (232) | (1.9) Kegonsa Family Camp (710)<br>(6.0) Kegonsa Beach (710)<br>(12) KMspr FH Peter Farm (639)<br>(11) Beloit (611)<br>(1.7) Mackenzie Wildlife (574)<br>(2.1) Mackenzie Picnic (605) | (0.8) Mendota #1 MHH (814)<br>(5.1) Lomira (828)<br>(3.2) UW Arlington Farm (730)<br>(7.4) Mendota #2 MHH (729) |
| Iron Level 2<br>25 - 185 ppb | (27) T5 10.1 (57)<br>(30) M 36.96 (123)<br>(27) M 36.5 (111)<br>(53) T2 10.7 (155) | (32) Hickory Ridge (328)<br>(55) Plamann Pavilion (516)<br>(159) Plamann Shelter (529) | (143) KMspr FH Bld #2 (636)<br>(52) PSL/SRC (543) | (86) EAA 3674 (928) |
| Iron Level 3<br>185 - 1400<br>ppb | (547) T5 30.5 (58)<br>(229) T2 90.4 (91)<br>(1015) M 25.3 (86)<br>(1110) M 35.5 (84) | (478) Buboltz Nat. Ctr. (528)<br>(326) Navarion Nat. Ctr. (299)<br>(581) Rest Area #2 (526)<br>(852) Reek School (467)<br>(1137) Fendryk House (509) | (1077) Picket GELC (606)<br>(558) KMSP Mauthe Bathhouse (561)<br>(841) KMSP Long Lake (683)<br>(1399) Rest Area #3 (581)<br>(1378) Okauchee Lake #1 (695) | (426) EAA 50 (770)<br>(1129) KMspr FH Bld #1 (733) |
| Iron Level 4<br>> 1150 ppb | (1997) T5 60.4 (117)<br>(4142) T2 10.3 (106)<br>(3663) T5 95.4 (126) | (5273) Kegonsa Boat Landing (498)<br>(1625) Ledge House (438)<br>(2470) KMSP Horse Camp (492)<br>(2827) ENEE (506) | (2550) EAA TV055 (565)<br>(2626) KMSP Mauthe 500s (573)<br>(5459) Ledge Camp area (680)<br>(1484) Okauchee Lake #2 (668)<br>(1647) Rest Area #1 (579) | (7184) Neenah (1437)<br>(3296) Picket CC (807) |

## RESULTS and DISCUSSION

**A. Meta-analysis:** The first 6+ months of this two-year project were dedicated to mining extant databases that we obtained from the Wisconsin Department of Natural Resources and other groundwater geochemistry databases from around the country [refer to list above]. The geology represents several aquifers across the Midwest, with a range of deposit types as well (Precambrian, Cambrian, Ordovician, Cretaceous, Devonian, and mixed Quaternary). Basic geochemical and arsenic data from these systems/studies was assembled into a large Access database. This effort likely represents the largest of its type to date. These data were analyzed by multivariate statistical methods including factor analysis. Analysis of the >5300 well records compiled from nine states showed that the data sets have very limited information on arsenic speciation, redox sensitive species, and are compromised by poor detection limits. Even after segregating the larger database into sub-sets of wells with similar data completeness, it still proved quite difficult to generate stable and robust factor models. Further complicating this statistical analysis was the need, because of extant data quality/quantity issues, to run multiple models to cover the desired range of site geochemistries. Thus global models of arsenic speciation based upon these existing data were of only limited value. Meta-analyses, however, identified several potentially predictive, commonly measured, geochemical analytes (calcium, iron, sulfate, and sodium) and the field study was structured around these variables. The large geochemical databases that we

assembled from the meta-analyses of extant data and our detailed field studies will be made available for use by researchers and regulatory agencies.

**B. Field studies:** 57 wells from within Wisconsin were chosen [as described above] for detailed chemical characterization. These sites were very carefully sampled and analyzed for the suite of analytes listed in the methods section above [and in Appendix B]. This new large and complete data set was analyzed using multivariate statistical methods to assess the predictive power of geochemical variables for major As species.

The sampling/analytical program generated data for the following arsenic species:
(a) Total Arsenic: (Dissolved + Particulate; III + V)
(b) Particulate Arsenic: (> 0.4 μm; (III + V)
(c) Dissolved Arsenic: (< 0.4 μm) (i) dissolved **Arsenic III** (ii) dissolved **Arsenic V**

The well sampling program was very successful in capturing the desired concentration range of each geochemical variable, and thereby validating the primary and secondary matrix sampling constructs (refer to Appendix B). For example: calcium over the range of 5 to >200 mg/L; iron over the range of 0.001 to >20 mg/L (Figure 2); sulfate over the range of below detection to >250 mg/L; pH over the range of 5.5 to 8.5; dissolved oxygen over the range of below detection to nearly saturated; sulfide over the range of below detection to >100 ppb; and total arsenic from 0.02 to over 85 ppb (Figure 1).

**Figure 1.** Concentration Ranking of Measured Total Arsenic and As(III).

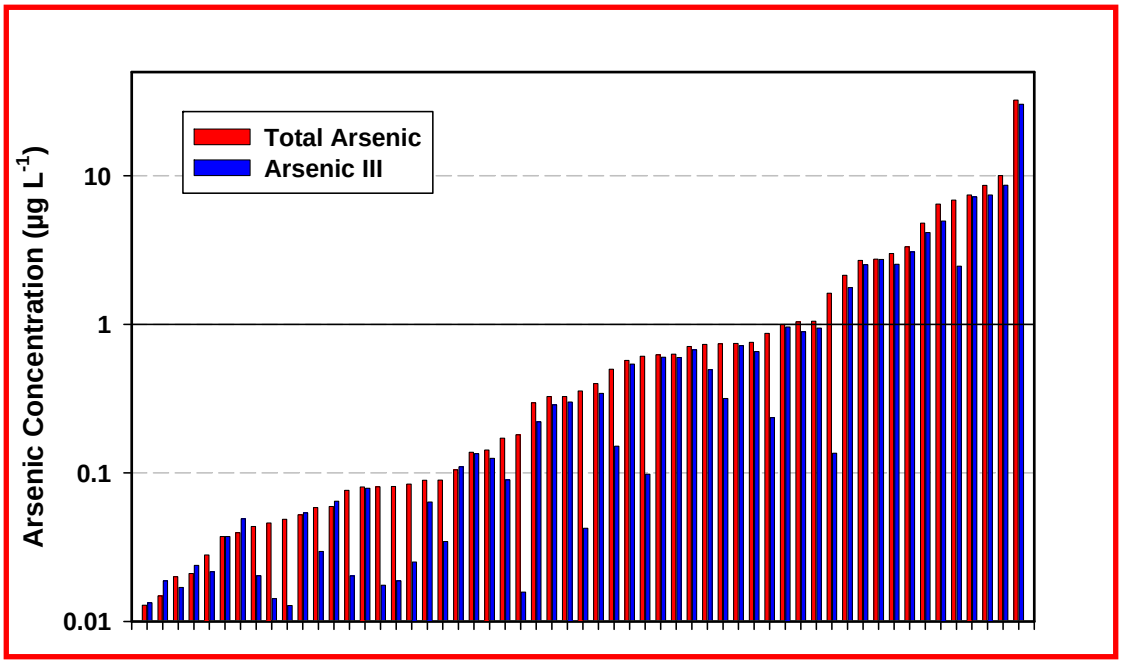
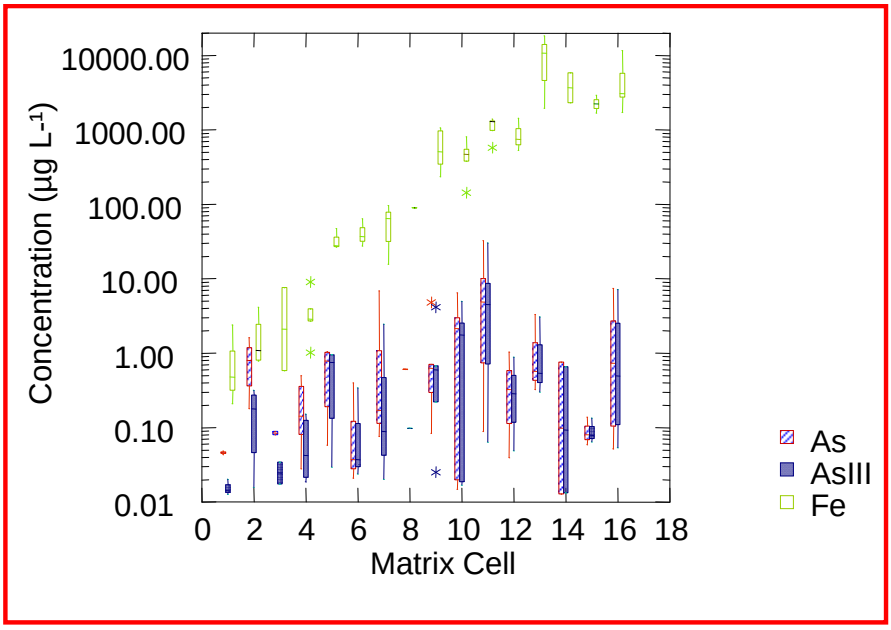


**Figure 2.** Arsenic, Arsenic(III) and Fe(II) Concentration Distributions.




The study matrix effectively represented the range in ferrous (Fe(II)) concentrations in moving from matrix cell 1 to cell 16 (**Figure 2**). Total arsenic and arsenic III concentrations were well correlated with Fe(II) through the first three iron quartiles (**Figure 2**). Average total arsenic and arsenic III levels were not significantly different among the Ca quartiles.

**Figure 3**. Arsenic Speciation [% As(III)] versus Redox Potential.

The fraction of total arsenic present as As(III) is highly correlated with redox (Eh) (r= 0.69), (**Figure 3**). The correlation with redox is even stronger (r = 0.89) when one restricts the analysis to 14 samples collected along a single groundwater flow-path (Appendix B; **Figure B-1**).

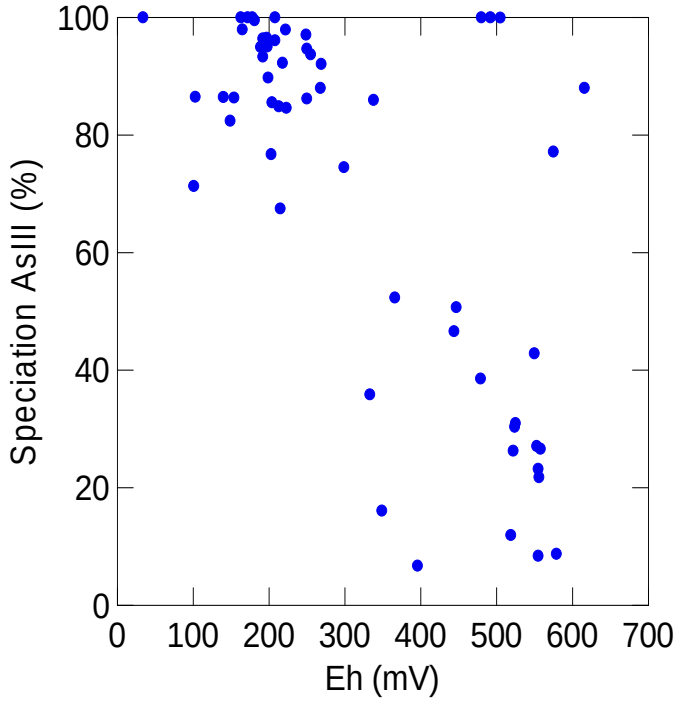
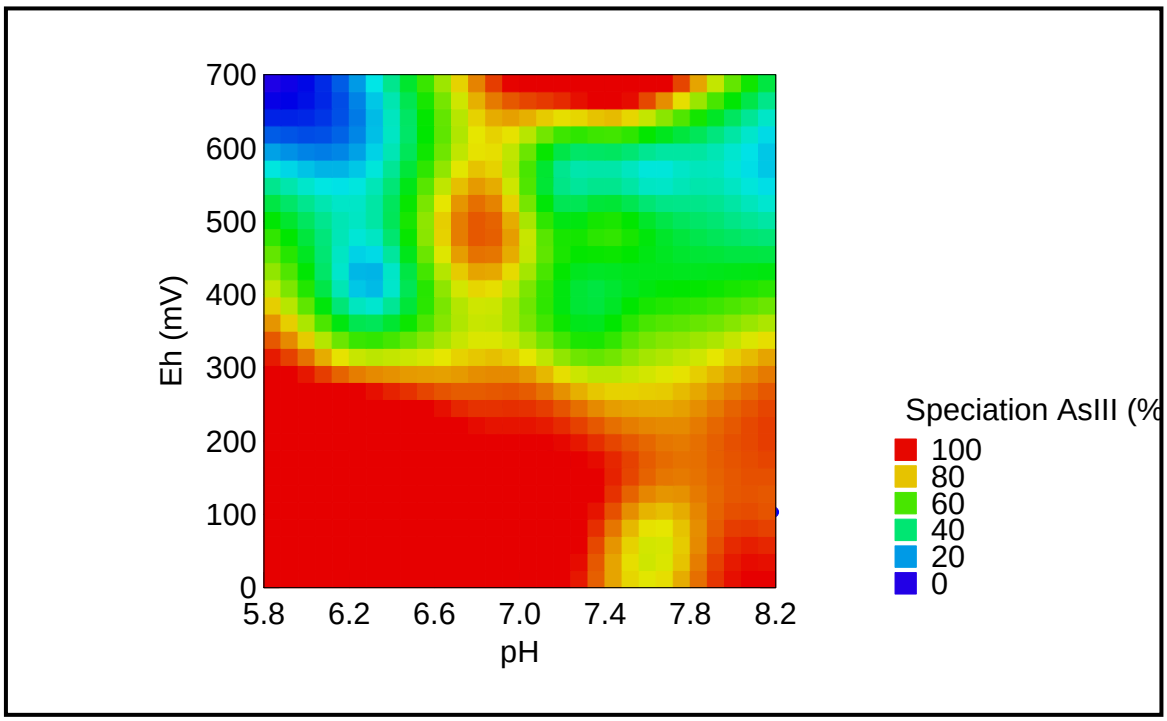


**Table 3.** Selected Multiple-Linear Regression Model [%As(III)] Outcomes

| | Eh | FeII | Ca | $SO_4$ | Na | R = | Adjusted $R^2$ |
|---|---|---|---|---|---|---|---|
| %AsIII | x | | | | | 0.692 | 0.469 |
| %AsIII | | x | | | | 0.494 | 0.231 |
| %AsIII | | | x | | | 0.110 | 0.011 |
| %AsIII | | | | x | | 0.070 | 0.003 |
| %AsIII | | | | | x | 0.080 | 0.005 |
| %AsIII | x | x | | | | 0.710 | 0.486 |
| %AsIII | | x | | x | | 0.542 | 0.268 |
| %AsIII | x | x | | x | | 0.716 | 0.485 |
| %AsIII | x | x | x | x | | 0.722 | 0.484 |
| %AsIII | x | | | x | | 0.692 | 0.460 |
| %AsIII | | | | x | | 0.066 | 0.003 |
| %AsIII | x | x | x | | x | 0.717 | 0.476 |
| %AsIII | x | | x | | x | 0.708 | 0.473 |
| %AsIII | x | | | | x | 0.699 | 0.470 |
| %AsIII | x | | x | | | 0.696 | 0.465 |
| %AsIII | | x | x | x | x | 0.554 | 0.254 |

Regression models demonstrated that a large fraction of the variance in the measured fraction of total arsenic present **as As(III)** could be explained by redox (Eh) levels (**Table 3**). In multiple regression models, only a few other geochemical factors (pH, Ca, sulfate) enhanced predictive power over that of redox alone, and their contribution was comparatively minor. Redox, however, was a relatively poor predictor of **total** arsenic levels. The field data generated in this study (**Figure 4**) clearly confirmed theoretical Eh-pH arsenic speciation relationships (Appendix B), a finding that few other studies have documented.

**Figure 4.** Eh-pH Surface Plot of Well Arsenic Data.



## CONCLUSIONS and RECOMMENDATIONS

Our primary conclusion from this effort is that a large proportion of the variance in the measured fraction of total arsenic present as As(III) can be explained by redox (Eh) levels. This clearly confirmed theoretical Eh-pH arsenic speciation relationships, a finding that few other studies have documented. The practical implication of this finding is that one should be able to use the relatively un-demanding redox measurement as an acceptable surrogate for the fraction of total arsenic present as As(III), i.e. arsenic speciation. Redox, however, was a relatively poor predictor of total arsenic levels. In multiple regression models, only a few other geochemical factors (pH, Ca, sulfate) enhanced predictive power over that of redox alone, and their contribution was comparatively minor. This work significantly improves on past studies (McArthur et al. 2001, Ahmed et al. 2004) due to the addition of arsenic chemical speciation measurements as well as improved statistical methods (Holm, 2003, IDWR, 2004).

Our study data and findings have broader implications for: (1) identifying release mechanisms form aquifer matrices, (2) geochemical associations, (3) mitigation strategies, (4) toxicity – health base decision/monitoring, and (5) tools for prediction of speciation.

**A.** The release mechanism for arsenic in ground water is a critical factor for understanding and predicting levels of arsenic species in ground/drinking water. Therefore this effort should be of interest to environmental chemists and environmental health scientists. These results will be useful to regulators for health-based decision making and prioritization of monitoring efforts. This work may also provide a tool to use extant geochemical data, where arsenic concentrations are not available, or are suspect, to estimate the proportion of the most toxic form.

**B.** Our well sampling program incorporated a set of private (homeowner) water supplies. These interactions are increasing awareness among the public of issues surrounding groundwater arsenic and providing visibility to research programs at the UW-Madison.

**C.** In developing/providing a very comprehensive geochemical database/analysis (cations and anions) of each of the study systems we are documenting the full suite and range of groundwater geochemistries that arsenic removal/treatment strategies will encounter. This information should ultimately help regulators and technology providers select/develop more robust treatment systems.

**D.** We are reporting concentrations for nearly 40 elements in the groundwaters, many of which are rarely if ever measured. In providing data for these elements, many of which are classed as potentially toxic, we are establishing critical "baseline" data that follow-up studies can benchmark.

Work remaining to be completed includes incorporating oxygen isotope data (to assess groundwater age – speciation relationships) into the models and performing additional statistical factor analyses.

The large geochemical databases that we assembled from the meta-analyses of extant data and our detailed field studies will be made available for use by researchers and regulatory agencies.

## REFERENCES


Ahmed KM, Bhattacharya P, Hasan MA, Akhter SH, Alam SMM, Bhuyian MAH, Imam MB, Khan AA, Sracek O. App Geochem 19:181-200. 2004.

Burkel RS and Stoll RC. Ground Wat Monit Remed 19(2)114-121. 1999.

Cai Y, Cabrera JC, Georgiadis M, Jayachandran K. Sci Tot Environ. 291 :123-134.

Creasey CL, Flegal AR. Hydrogeo. J. 7:161-167. 1999.

Gotkowitz MB, Simo JA, Schreiber M. „Geologic and Geochemical Controls on Arsenic in Groundwater in Northeaster Wisconsin." Report to WDNR. WGNHS Open-file Report 2003-01.

Holm TR, Kelly WR, Wilson SD, Roadcap GS. "Arsenic Geochemistry and Distribution in the Mahomet Aquifer, Illinois. WMRC Reports. http://www.wmrc.uiuc.edu.

Idaho Department of Water Resources. "Groundwater Technical Brief. Arsenic Speciation Results (2002 and 2003)." Edward F. Hagan. September 2004.

McArthur JM, Ravenscroft P, Safiulla S, Thirwall MF. Wat Resour. Res. 37(1)109-117. 2001.

Meglen RR. Mar Chem 39:217-237. 1992.

Natural Research Council. Arsenic in Drinking Water. Board on Environmental Studies and Toxicology. Division of Earth and Life Sciences. 1999.

Schreiber ME, Simo JA, Freiberg. Hydrogeo. J. 8:161-176. 2000.

Shafer MM, Dean KE, Armstrong DE. Role of Mobile Colloids in the Transport of Chemical Contaminants in Groundwaters. Final Report to USGS and University of Wisconsin Water Resources Center, 26 pages. 1991.

Smedley PL, Kinniburgh DG. App Geochem. 17:517. 2002.

Smith JVS, Jankowski J, Sammut J. App Geochem 18:1479-1496. 2003.

Thornburg K, Sahai N Environ Sci Technol 38(19)5087-5094. 2004.

United States Environmental Protection Agency. Ambient water quality criteria for arsenic. EPA 440/5-80-021. US Environmental Protection Agency, Washington DC. 1980.

Warner KL. Groundwater. 39(3)433-442. 2001.

Wisconsin Department of Natural Resources. http://www.dnr.state.wi.us/org/water/dwg/arsenic/occur.htm

World Health Organization. Guidelines for Drinking Water Quality. Final task group meeting, 21-25 September 1992. World Health Organization, Geneva. 1993.

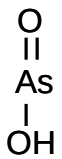
## APPENDIX A: Publications, Reports, and Presentations

1. Kerr S.C., M.M. Shafer, J. Overdier, and D.E. Armstrong. **2008.** Hydrologic and biogeochemical controls on trace element export from Northern Wisconsin wetlands. Accepted for publication in *Biogeochemistry* (01/19/2008).
2. Shafer M.M., J. Overdier, and D.E. Armstrong. Controls on arsenic oxidation state speciation in Wisconsin groundwaters. Manuscript in-preparation for submission to *Aquatic Geochemistry.*
3. Shafer M.M. Arsenic (III/V) Distribution in Wisconsin Groundwaters. Presentation before the Wisconsin Groundwater Coordinating Council (March 3, 2008)

## APPENDIX B: Supplemental Information

### B1. Arsenic Speciation & Geochemistry

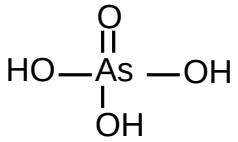
**Arsenic Species**



**Arsenite: As (III), Arsenous Acid**

**$H_3AsO_3$** **$pK_a1 = 9.20$**

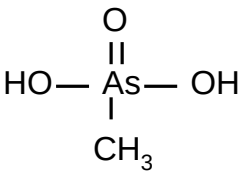
**Mobile, toxic.**
**(binds to sulfur groups in proteins)**



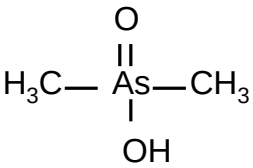
**Arsenate: As(V), Arsenic Acid**

**$H_2AsO_4^-$** **$pK_a1 = 2.19$** **$HAsO_4^{2-}$**

**Less Mobile, less toxic.**
**(phosphate analogue, ATP disruption)**



Monomethylarsonic Acid: MMAA



Dimethylarsinic Acid: DMAA

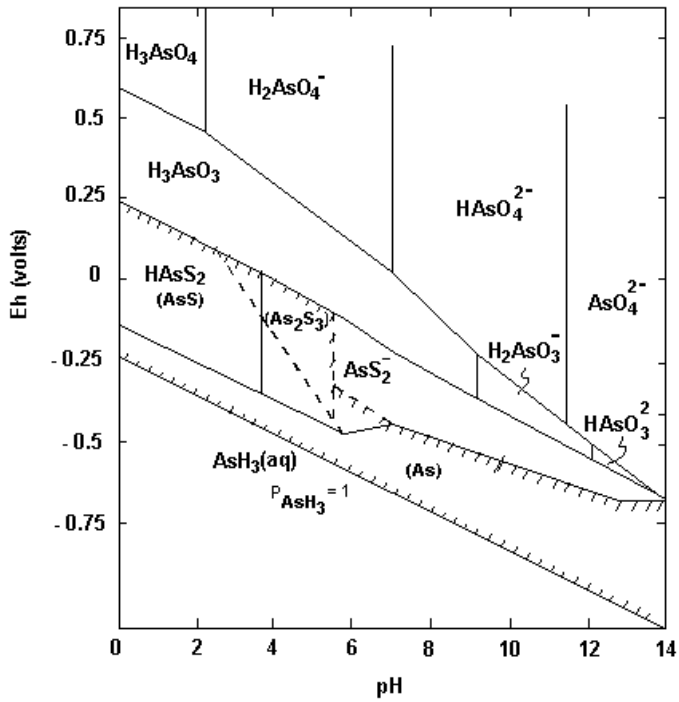



Fig. 2. The Eh-pH diagram for As at 25 °C and one atmosphere with total arsenic 10-5 mol/litre and total sulfur 10-3 mol/litre. Solid species are enclosed in parentheses in cross-hatched area, which indicates solubility less than 10 5.3 mol/litre (From: Ferguson & Gavis, 1972).

| Electrochemical potential of some environmentally important redox pairs | |
|---|---|
| **Chemical pair** | **$E'_0$ (mV)** |
| $O_2/H_2O$ | +818 |
| $SeO_4^{2-}$ / $SeO_3^{2-}$ | +440 |
| $NO_3^-$ /$NO_2^-$ | +430 |
| $Fe^{3+}/Fe^{2+}$ | +100 |
| $HAsO_4^{2-}$ /$H_3AsO_3$ | +60 |
| $SO_4^{2-}$ /$HS^-$ | -220 |
| $CO_2/CH_4$ | -244 |
| $S_0/HS^-$ | -270 |
| Compiled from Bard et al. [71], Thauer et al. [72] and Macy [73]. FEMS Microbiology Ecology 48 (2004) pp.15-27 | |

### B2. Methods Detail

a. On-Site Separation of Arsenic Species

**Arsenic Speciation**
**Oxidation State: On-Site Separation**

- In-line filtration to remove particulate species.
- In-line cartridge packed with As(V)-selective adsorbant (2.5 grams of aluminosilicate).
- 50 mL of groundwater sample collected after passage of 10 mL of rinse. **= As(III).**
- Elute cartridge with dilute HCl. **= As(V).**
- Or: **Filtered sample – As(III) = As(V).**
- Quantitative in pH range from 4 to 9.
- Flow rate of 10-20 mL per minute.
- Rapid, minimizes speciation changes.
- Meng et al. 2001. Environ. Sci. Technol. 35:3476-3481.

b. Ferrous ion measurements ($Fe^{2+}$)

Ferrous ion was measured using a modified version of the ferrozine complexation method, originally presented in Stookey 1970. In this method, ferrozine is added in the field to a sample collected into an Ar-purged bottle. The ferrozine binds the $Fe^{2+}$ from solution and forms a magenta colored complex which is measured @ 562nm on a low noise, dual beam spectrophotometer.

## c. Nitrogen Species Measurements ($NH_4^+$, $NO_3$-$NO_2$)

Modified versions of EPA Methods 350.1 and 353.2 were used to simultaneously measure $NH_3$-N and $NO_3^-$+$NO_2^-$-N (Wisconsin State Lab of Hygiene (WSLH) ESS INO Method 220.3 rev 6). Sub-samples are preserved in the field with sulfuric acid. Quantitation limits are 0.048 mg $NH_3$-N/L and 0.061 mg $NO_3$+$NO_2$-N/L. Total nitrogen is determined by high temperature combustion followed by chemiluminescence detection of NO.

## d. Sulfate/Sulfide measurements

Total sulfur was determined by HR-ICP-MS, with a quantification limit of 10 µg $L^{-1}$. Sulfide was determined with an ion-selective electrode. Sub-samples for sulfide are collected directly into SAOB buffer and $S^{2-}$ is determined to a level of 2 µg$L^{-1}$. Sulfate is quantified using Ion Chromatography.

## e. Elemental Analysis

Total Fe, Mn and a large suite of other elements (see table below) were measured using HR-ICP-MS.

| Element Group | N | Elements Examined |
|---|---|---|
| **Alkali Metals** | **5** | **Li, Na, K, Rb, Cs** |
| **Alkaline Earths** | **5** | **Be, Mg, Ca, Sr, Ba** |
| **Transition Metal Groups 3,4** | **5** | **Sc, Y, Ti, Zr, Hf** |
| **Transition Metal Groups 5, 6** | **4** | **V, Cr, Mo, W** |
| **Transition Metal Groups 7, 8, 9, 10** | **4** | **Mn, Fe, Co, Ni** |
| **Platinum Group** | **3** | **Rh, Pd, Pt** |
| **Transition Metal Groups 11, 12** | **5** | **Cu, Ag, Zn, Cd, Hg** |
| **Lanthanides** | **9** | **La, Ce, Nd, Sm, Eu, Tb, Dy, Er, Yb** |
| **Actinides** | **2** | **Th, U** |
| **Semi-Metals** | **5** | **Al, Sn, Sb, Tl, Pb** |
| **Non-Metals** | **5** | **Si, P, S, As, Se** |

## f. Oxygen Isotope Ratios

Oxygen isotope ($^{18}O/^{16}O$) ratios are determined to estimate groundwater age. Established isotope ratio mass spectrometer techniques were employed.

g. Total Organic Carbon

Total organic carbon was measured using high temperature combustion (720°C) with NDIR detection (Shimadzu TOCV) with a detection limit of 20 ppb.

## B3. Supplemental Figures

**Figure B-1.** Arsenic speciation [%As(III)] versus Eh along a groundwater flowpath in Vilas Co. WI (Big Muskie Lake to Allequash Creek flowpath).

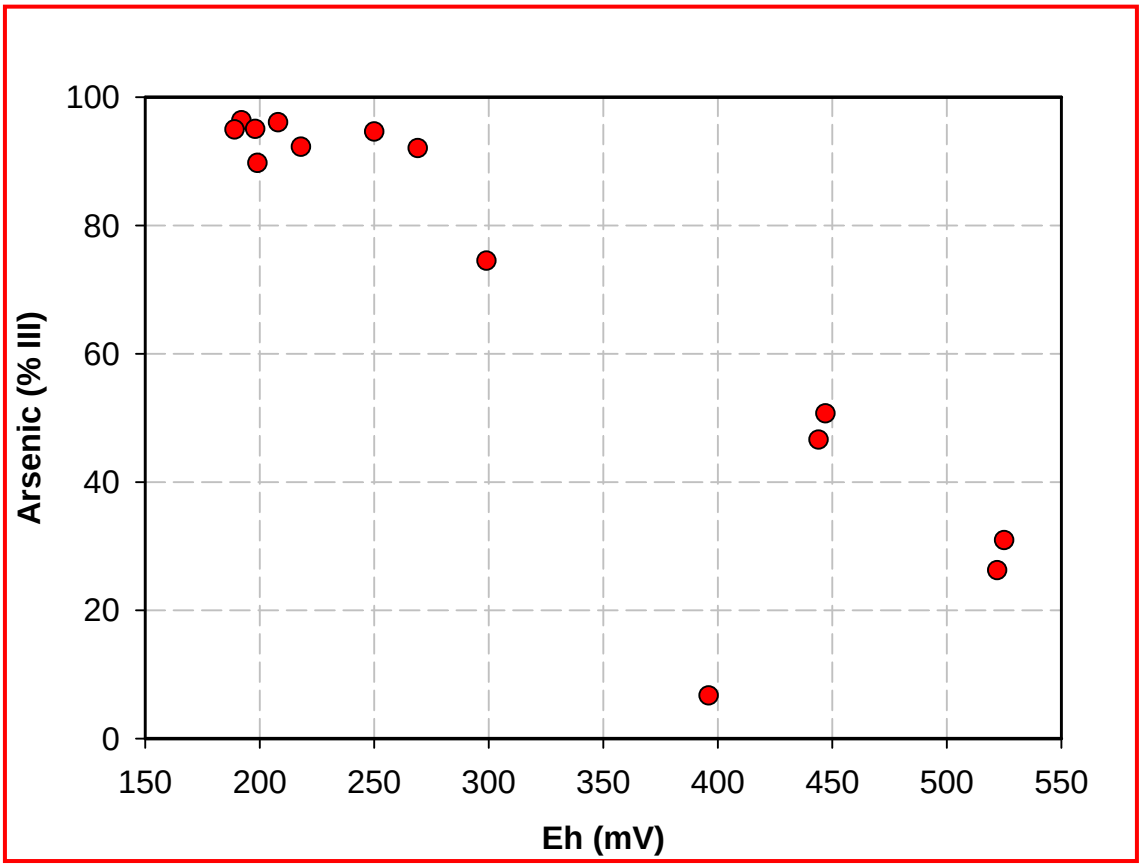


**Figure B-2**. Site Matrix: Quartile Distribution by Iron

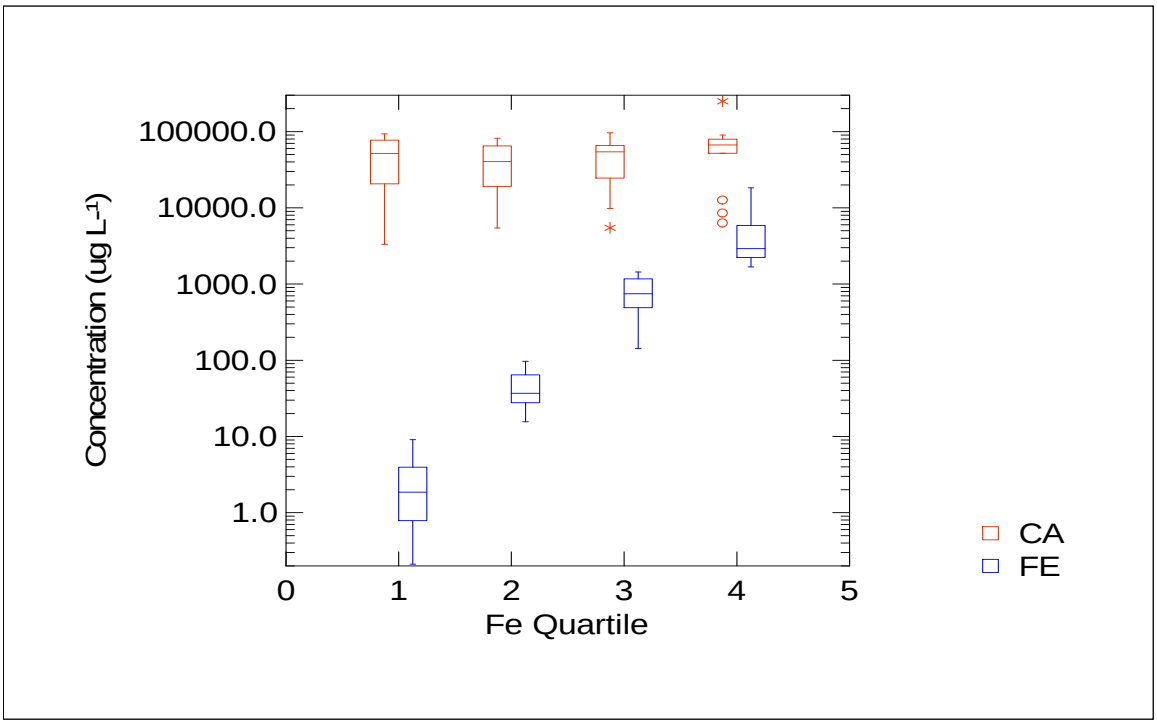
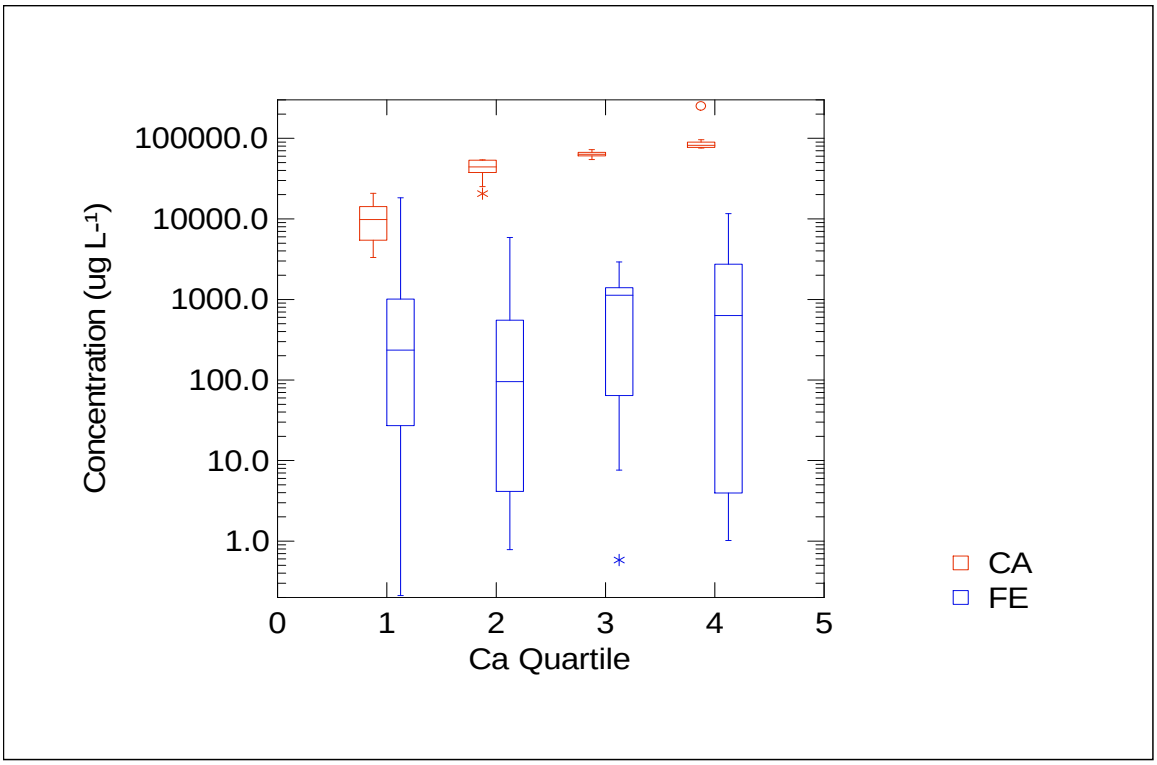



**Figure B-3**. Site Matrix: Quartile Distribution by Calcium



# Transient Functioning of a Groundwater Wetland Complex, Allequash basin, Wisconsin

## Basic Information

| | |
|---|---|
| **Title:** | Transient Functioning of a Groundwater Wetland Complex, Allequash basin, Wisconsin |
| **Project Number:** | 2005WI159O |
| **Start Date:** | 7/1/2005 |
| **End Date:** | 6/30/2007 |
| **Funding Source:** | Other |
| **Congressional District:** | 2nd |
| **Research Category:** | Climate and Hydrologic Processes |
| **Focus Category:** | Wetlands, Groundwater, Climatological Processes |
| **Descriptors:** | goundwater modeling; wetlands; riparian zone |
| **Principal Investigators:** | Mary Anderson |

## Publication


1. Lowry, C.S., M.P. Anderson, R.J. Hunt. 2006. Modeling groundwater flow and heat transport within a fen/stream complex. In: Proceedings of MODFLOW and More 2006: Managing ground water systems, IGWMC, Golden, Colo. 5 pp.
2. C. S. Lowry, J.F. Walker, R.J. Hunt, M.P. Anderson. 2007. Identifying spatial variability of groundwater discharge in a wetland stream using a distributed temperature sensor. Water Resources Research, doi:10.1029/2007WR006145.
3. Lowry, C.S., in Preparation, expected August 2008. Controls on groundwater flow in a peat dominated wetland/stream complex, Allequash Wetland, Northern Wisconsin, University of Wisconsin−Madison, PhD Thesis.
4. Lowry, C.S., D. Fratta, and M.P. Anderson. in Preparation. Linking basin geometry to groundwater/surface water interactions in a peat dominated wetland using Ground Penetrating Radar. To be submitted to Ground Water.

# Annual Progress Report

**Reporting Period:** 7/1/2006 - 6/30/2007

**Submitted By:** Mary Anderson
**Submitted:** 5/17/2007

## Project Title

WR05R007: Transient Functioning of a Groundwater Wetland Complex, Allequash basin, Wisconsin

## Project Investigators

Mary Anderson, University of Wisconsin-Madison

## Progress Statement

We are investigating transient hydrologic processes in a wetland in northern Wisconsin (Vilas County). Two monitoring transects have been established across the wetland. In this reporting period, we continued monitoring broundwater heads and temperautres in the transects as well as streamflow. We also conducted two major field experiments, described below, and are completing work on on groundwater flow model of the system.

Distributed Temperature work
A one-kilometer long fiber-optic based distributed temperature sensor (DTS) was placed just below the stream/sediment interface in Allequash Creek, to measure variations in temperature. The difference in temperature between groundwater and surface water was used to identify gaining and losing reaches along the stream. Results show a pattern of focused zones of groundwater discharge within the streambed. The presence of important zones of focused groundwater discharge within the stream is a significant finding as the existing paradigm calls for diffuse flow. One possible explanation for focused zones of groundwater discharge is the presence of soil pipes within the peat. Discharge rates at these zones of focused discharge were measured using seepage-meterss. Seepage meter results showed two orders of magnitude more discharge as compared to non-focused discharge zones.

Geophysics
A large scale ground penetrating radar survey (GPR) was conducted within Allequash Wetland in order to determine the extent of the peat. Based on the results from the GPR survey we have identified subsurface features that appear to control the position of springs, ponds and stream discharge zones within the wetland. Springs, ponds and stream discharge zones line up with breaks in slope in the peat/sand and gravel interface. We believe that these breaks in slope cause a refraction of groundwater flow lines causing groundwater to discharge at the surface.

Modeling
A two-dimensional groundwater flow and heat transport modeling using the groundwater flow MODFLOW linked to MT3DMS (modified for heat transport)l was calibrated with head and temperature measurements collected at three sets of nested piezometers in a north-south transect (Transect 1). The field data were collected using both discrete and continuous sampling methods. The parameter estimation code PEST was used to calibrate the model and determine sensitivity to input parameters. Simulating both groundwater flow and heat transport helped constrain parameters that are difficult to determine, such as hydraulic conductivity of peat. Results based on the 2D model are currently being used to build a 3D coupled groundwater flow and heat transport model using the code SEAWAT. The new 3D model takes into account temperature dependent changes in

viscosity and density of groundwater, which have been shown to change flowpaths within the wetland.

## Impacts

**Description** --Our use of Ground Penetrating Radar to delineate the vertical extent of peat in the wetland has yielded significant results in that we were able to identify structures that appear to control groundwater discharge to the wetland.

**Description** Measurments beneath the streambed using a distributed temperature sensor helped identify important zones of focused groundwater discharge to the streambed, showing that the current paradigm of diffuse groundwater discharge to a stream does not apply here.

## Awards, Honors & Recognition

**Title** Best student paper award
**Event Year** 2007
**Recipient** Chris Lowry
**Presented By** Wisconsin Ground Water Association
**Description** Cash prize to the best student paper (oral) presented at the annual conference of the WGWA.

.....

**Title** Best student paper award
**Event Year** 2007
**Recipient** Chris Lowry
**Presented By** Wisconsin AWRA
**Description** Best student paper award (oral) given at the annual conference of the WI AWRA.

.....

**Title** Morgridge Distinguished Graduate Fellowship
**Event Year** 2007
**Recipient** Chris Lowry
**Presented By** Dept of Geology & Geophysics, UW-Madison
**Description** 9 month fellowship which includes a half-time RA appointment, a cash research award, and full tuition. Given for the period Sept 2007-May 2008

## Interactions

**Description** We have interated with a research group in Germany who have developed a heat transport code called SHEMAT.
**Event Date**

| | |
|---|---|
| **Description** | We have interacted with the Limnology Lab and Prof. Emily Stanley. |
| **Event Date** | |

## Journal Articles & Other Publications

| | |
|---|---|
| **Publication Type** | Other |
| **Title** | Modeling groundwater flow and heat transport within a fen/stream complex |
| **Author(s)** | Lowry, C.S., M.P. Anderson, R.J. Hunt |
| **Publication/Publisher** | MODFLOW and More 2006: Managing ground water systems, IGWMC, Golden, CO |
| **Year Published** | 2006 |
| **Volume & Number** | |
| **Number of Pages** | 5 |
| **Description** | Proceedings volume. Paper presented at an international conference in May 2006 |
| **Any Additional Citation Information** | |

| | |
|---|---|
| **Publication Type** | Peer-Reviewed Journal Article/Book Chapter |
| **Title** | Identifying spatial variability of groundwater discharge in a wetland stream using a distributed temperature sensor. |
| **Author(s)** | C. S. Lowry, J.F. Walker, R.J. Hunt, M.P. Anderson |
| **Publication/Publisher** | Water Resource Research |
| **Year Published** | In Review |
| **Volume & Number** | |
| **Number of Pages** | |
| **Description** | |
| **Any Additional Citation Information** | |

## Other Project Support

| | |
|---|---|
| **Source** | USGS |
| **Dollar Value** | $100,000 |
| **Description** | The USGS provides logistical support and transportation to and from the site. |
| **Start Date** | |
| **End Date** | |

| | |
|---|---|
| **Source** | LTER/Trout Lake Lab |
| **Dollar Value** | $1,000 |

| | |
|---|---|
| **Description** | logistical support at the field site and free housing |
| **Start Date** | 6/1/2006 |
| **End Date** | 8/31/2008 |

## Partners

| | |
|---|---|
| **Name/Organization** | Randy Hunt & John Walker |
| **Affiliation** | U.S. Geological Survey |
| **Affiliation Type** | Federal |
| **Email** | |
| **Description** | We work closely with the USGS- Middleton, WI office on all aspects of this project. They provide logistical support for field, lab and modeling work and some additional funding as well as field eqipment and free consultation. |

.....

| | |
|---|---|
| **Name/Organization** | Long Term Ecological Research Project (LTER) |
| **Affiliation** | UW-Madison |
| **Affiliation Type** | Academic Institutions |
| **Email** | |
| **Description** | We are working at the LTER site in Northern Wisconsin which is administered by the UW-Madision through its NSF sporspored research project at Trout Lake.<br><br>Housing is provided free of charge at the Trout Lake Station. Some field eqipment is also provided. |

## Presentations & Public Appearances

| | |
|---|---|
| **Title** | Modeling Groundwater Flow and Heat Transport within a Fen/Stream complex. |
| **Presenter(s)** | Lowry, C., M.P. Anderson, and R.J. Hunt |
| **Presentation Type** | Poster session |
| **Event Name** | MODFLOW2006 |
| **Event Location** | Golden, Colorado |
| **Event Date** | 6/23/2006 |
| **Target Audience** | Scientific audience |
| **Audience Size** | 400 |
| **Description** | |

.....

| | |
|---|---|
| **Title** | Evidence for Focused Groundwater/Surface water Interaction Using a Distributed Temperature Sensor |
| **Presenter(s)** | Lowry, C.S., Walker, J.F., Hunt, R.J., and Anderson, M.P. |
| **Presentation Type** | Professional meeting |
| **Event Name** | Wisconsin Section of the American Water Resources Association, |
| **Event Location** | Wisconsin Dells |
| **Event Date** | 3/1/2007 |

| | |
|---|---|
| **Target Audience** | Mixed |
| **Audience Size** | 100 |
| **Description** | |

.....

| | |
|---|---|
| **Title** | Geophysical and temperature characterization of groundwater/surface water interactions in a peat-dominated wetland |
| **Presenter(s)** | Lowry, C.S., Walker, J.F., Hunt, R.J., Fratta, D., and Anderson, M.P. |
| **Presentation Type** | Professional meeting |
| **Event Name** | Wisconsin Ground Water Association, |
| **Event Location** | Wisconsin Dells |
| **Event Date** | 2/23/2007 |
| **Target Audience** | Mixed |
| **Audience Size** | 200 |
| **Description** | |

## Students & Post-Docs Supported

| | |
|---|---|
| **Student Name** | Christopher Lowry |
| **Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Advisor Name** | Mary Anderson |
| **Advisor Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Degree** | PhD |
| **Graduation Month** | June |
| **Graduation Year** | 2008 |
| **Department** | Geology & Geophysics |
| **Program** | Geology |
| **Thesis Title** | Transient groundwater hydrology in a wetland (working title) |
| **Thesis Abstract** | not yet available |

# Evaluation of On−Site Wastewater Treatment as a Source of Antibiotic Resistance Genes in Groundwater

## Basic Information

| | |
|---|---|
| **Title:** | Evaluation of On−Site Wastewater Treatment as a Source of Antibiotic Resistance Genes in Groundwater |
| **Project Number:** | 2005WI161O |
| **Start Date:** | 7/1/2005 |
| **End Date:** | 6/30/2007 |
| **Funding Source:** | Other |
| **Congressional District:** | 2nd |
| **Research Category:** | Biological Sciences |
| **Focus Category:** | Toxic Substances, Solute Transport, None |
| **Descriptors:** | microbiology; antibiotics; on−site treatment |
| **Principal Investigators:** | Trina McMahon |

## Publication

# Annual Progress Report

**Reporting Period:** 7/1/2006 - 6/30/2007

**Submitted By:** Katherine McMahon
**Submitted:** 6/18/2007

## Project Title

WR05R006: Evaluation of On-Site Wastewater Treatment as a Source of Antibiotic Resistance Genes in Groundwater

## Project Investigators

Katherine McMahon, University of Wisconsin-Madison

## Progress Statement

We have collected samples from three groundwater monitoring wells, two water supply wells, and two septic tanks at our study site (a subdivision near Sun Prairie, WI). We have analyzed them for the presence of ten tetracycline resistance genes using a qualitative PCR assay that provides presence/absence information. We are currently performing quantitative PCR assays to determine the absolute abundance of three different resistance genes.

Monitoring wells that were presumably previously impacted by agricultural activity, but that are not currently impacted by septic tank effluent, contained several resistance gene types. Septic tanks contained more different types. We observed some differences in the number and types of genes detected, across our sampling events.

## Impacts

| | |
|---|---|
| **Description** | Our results suggest that some types of tetracycline resistance were already present in groundwater at this site and therefore may reduce the level of concern about resistance proliferation from septic tank effluent. |

## Students & Post-Docs Supported

| | |
|---|---|
| **Student Name** | Erin Seyfried |
| **Campus** | University of Wisconsin-Madison |
| **Advisor Name** | Katherine McMahon |
| **Advisor Campus** | University of Wisconsin-Madison |
| **Degree** | Masters |
| **Graduation Month** | August |
| **Graduation Year** | 2007 |
| **Department** | |

| | |
|---|---|
| | Civil and Environmental Engineering |
| **Program** | Environmental Engineering |
| **Thesis Title** | TBD |
| **Thesis Abstract** | |

# Measuring and Modeling Macroporous Soil Water and Solute Flux Below the Root Zone of a Plano Silt−Loam Soil

## Basic Information

| | |
|---|---|
| **Title:** | Measuring and Modeling Macroporous Soil Water and Solute Flux Below the Root Zone of a Plano Silt−Loam Soil |
| **Project Number:** | 2006WI135B |
| **Start Date:** | 3/1/2006 |
| **End Date:** | 6/30/2007 |
| **Funding Source:** | 104B |
| **Congressional District:** | WI 2nd |
| **Research Category:** | Ground−water Flow and Transport |
| **Focus Category:** | Hydrology, Groundwater, Models |
| **Descriptors:** | |
| **Principal Investigators:** | Birl Lowery, John Norman |

## Publication


1. Lepore, B. 2007. Measuring and Modeling of Water and Solute Flow in Macroporous Silt Loam Soils. Ph.D. Dissertation. Department of Soil Science, College of Agricultural and Life Sciences, University of Wisconsin, Madison, Wisconsin, 178 pages.

# Measuring and Modeling Macroporous Soil Water and Solute Flux Below the Root Zone of a Plano Silt-Loam Soil

**Project Number WR05R002**

**Investigators: Birl Lowery and John Norman**
**Department of Soil Science**
**1525 Observatory Drive**
**University of Wisconsin-Madison**
**Madison, WI 53706-1299**

**Funding:**

**University of Wisconsin Water Resources Institute Groundwater Research; and Nonpoint Project, Department of Soil Science, College of Agriculture and Life Sciences**

## TABLE OF CONTENTS


| | Page |
|---|---|
| Cover page | 1 |
| List of figures and tables | 2 |
| Project summary | 3 |
| Title | 3 |
| Project I.D. | 3 |
| Investigators | 3 |
| Period of Contract | 3 |
| Background/Need | 3 |
| Objectives | 3 |
| Methods | 3 |
| Results and Discussion | 4 |
| Conclusions/Implications/Recommendations | 4 |
| Related Publications | 4 |
| Key Words | 4 |
| Funding | 4 |
| Introduction | 5 |
| Objectives | 6 |
| Procedures and Methods | 6 |
| Results and Discussion | 9 |
| Conclusions and Recommendations | 11 |
| Reference | 11 |


## LIST OF FIGURES AND TABLES


| | | |
|---|---|---|
| Figure 1. | A 3-D Soil Landscape Model for Plano silt loam soil at Arlington, WI. | 5 |
| Figure 2 | Schematic of ALF showing connection to AETL. | 8 |
| Figure 3. | Ninety-six well microplate (85 x 127 mm) with eight replicates of standards Containing, left to right, 0, 0.5, 1.5, 2.5, 4, 5, 7, 9, 10, 12, 15 and 20 mg L-1 Br-, showing the transition from the yellow color of unreacted phenol red to the reaction product, bromophenol blue. | 10 |

## PROJECT SUMMARY

**Title:** Measuring and Modeling Macroporous Soil Water and Solute Flux Below the Root Zone of a Plano Silt-Loam Soil

**Project I.D.:** University of Wisconsin System (UWS) project numbers WR05R002

**Investigators:** Birl Lowery
Professor
Department of Soil Science
University of Wisconsin-Madison

John M. Norman
Professor
Department of Soil Science
University of Wisconsin-Madison

Research Assistant
Brian Lepore
Graduate research assistant (Ph.D.)
Department of Soil Science
University of Wisconsin-Madison

**Period of Contract:** July 1, 2005 to June 30, 2007

**Background/Need:** Groundwater is a very important natural resource in Wisconsin, much of the United States, and throughout the world. While being the main source for drinking water, it is heavily used in various industries and agriculture for irrigation. Thus, rapid groundwater recharge is important. While groundwater is recharged rapidly via water flowing through macropores, especially in fine textured soils, there are some negative impacts associated with this rapid recharge. The impact of water and solutes flowing through macropores on groundwater quantity and quality is known to be significant, yet it remains poorly understood, and there are limited models available to simulate this. In addition to a lack of good simulation models, methods for real time sampling of macroporous water and solute fluxes are limited as well.

**Objectives:** **(a)** Measure macroporous water and solute flow in-situ in a well drained silt loam soil under varying conditions, and (**b)** to use the data to derive critical parameters of macropore simulation models.

**Methods:** The field aspect of the study was conducted at the University of Wisconsin-Madison Arlington Research Farm, Arlington, WI on a Plano silt loam soil. The site was cropped to corn (*Zea mays* L.).

Soil water status was monitored with time domain reflectometry (TDR) probes and tensiometers, equipped with pressure transducers. Data from both the TDR probes and tensiometers were

recorded with commercially available dataloggers. A new technique for monitoring macropore fluxes, an Automated Lysimeter Fluxmeter (ALF), was developed and used in several in-situ ponded infiltration experiments. A new microplate colorimetric method for analyzing bromide concentrations was also developed. This procedure was used to measure bromide concentrations in soil leachate, as bromide was used as a tracer in this research.

Computer simulation models, Macropore-Matrix (M&M), submodel of the Precision Agricultural-Landscape Modeling System (PALMS), and HYDRUS-1D were tested using data from this study. The major modeling effort concentrated on improving the M&M submodel of PALMS so that it improved estimates of macropore flow.

**Results and Discussion:** Results from field based water and solute flux experiments led to estimates of profile macropore volume and interaggregate half-slit width ($B_{ped,s}$), which were used to parameterize the M&M component of PALMS. The M&M model infiltrates surface water through interaggregate cracks (macropores) and water moves into soil aggregates as prescribed by Darcy's equation. Results from the field ponded-water infiltration experiments led to estimates of profile macropore volume percentages of 1.1 ±0.4% and $B_{ped,s}$ of 125 ±34 μm. The estimate of $B_{ped,s}$ was used to parameterize the M&M and PALMS. The revised PALMS and M&M (PALMS-M&M) predicted 79% greater cumulative drainage for the 1996 growing season than with PALMS using the conventional Green and Ampt infiltration (PALMS-G&A). The PALMS-M&M drainage prediction compared better with in-situ drainage measured by Equilibrium Tension Lysimeters (ETLs). Root-mean-square error (RMSE) values between predicted and measured soil volumetric water content ($\theta_v$; $m^3\ m^{-3}$) at 10, 50, and 100-cm depths did not change significantly with PALMS-M&M vs. PALMS-G&A. However, throughout most of the growing season, $\theta_v$ was slightly greater for PALMS-M&M (<2%) at 50 and 100-cm depths, indicating deeper and more rapid infiltration when incorporating a macropore infiltration model into PALMS. Preliminary comparisons between the field data and the HYDRUS-1D model presented some formidable challenges that remain to be resolved.

**Conclusions/Implications/Recommendations:** The revised PALMS can better estimate water fluxes in macropores. Given the estimates of profile macropore volume percentages of 1.1 and $B_{ped,s}$ of 125 ±34 μm, water and solute will rapidly move to groundwater beneath Plano and similar soils in Wisconsin, with the solute posing a treat to this valuable resource.

**Related Publication:**

Lepore, B. 2007. Measuring and Modeling of Water and Solute Flow in Macroporous Silt Loam Soils. Ph.D. Dissertation. Department of Soil Science, University of Wisconsin-Madison. 178 pp.

**Key Words:** Real-time water flux measurement, models, water flux, macropores, solute flux, infiltration.

**Funding:** (1) University of Wisconsin Water Resources Institute Groundwater Research; (2) Nonpoint Project, Department of Soil Science, College of Agriculture and Life Sciences.

## INTRODUCTION

Previous research by scientists in the Soil Science Department, University of Wisconsin-Madison, has resulted in significant progress toward obtaining a better understanding of soil spatial variability on relatively young landscapes with respect to identifying critical sites for environmental pollution (Samuelson, 1999). This progress has included developing three dimensional (3-D) soil maps displaying soil variability in both the vertical and horizontal directions (Fig. 1) and obtaining a better understanding of soil hydraulic properties including hydraulic conductivity, runoff (runoff contribution areas) and drainage rates (Samuelson. 1999; Rooney and Lowery, 2000; Grunwald et al., 2001a,b,c; Grunwald et al., 2000a,b; Richmond, 2002; Arriaga and Lowery, 2002; Morgan, 2000; Johnson et al., 2005; Arriaga et al., 2002).

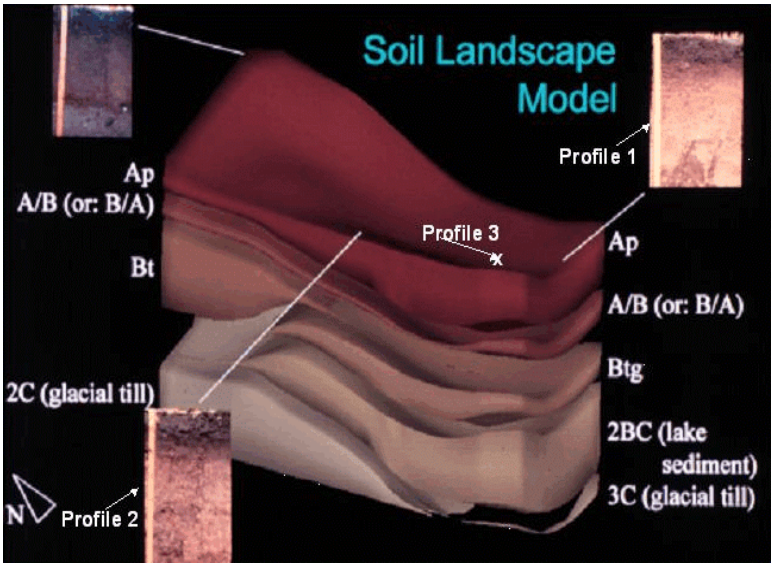



Figure 1. A 3-D Soil Landscape Model for Plano silt loam soil at Arlington, WI.

Both field measurements and computer model simulations (Precision Agricultural-Landscape Modeling System (PALMS), Morgan, 2000; Molling, 2003) have been used to assess water and solute fluxes at a landscape or watershed scale. However, we still have considerable ground to cover before we understand this rather complex problem of identifying critical sites and defining management systems to reduce the chances of groundwater contamination in areas with immature drainage systems. One problem with characterizing critical sites is that two difficult issues are extremely important; namely, runoff and infiltration. Excess leaching in basin areas is caused by runoff from adjacent areas, which in turn is related to infiltration in these adjacent areas. Soil structural properties at the surface (sealing, cracking) and with depth (macropores) are critical influences on runoff and infiltration. We have found that our 3-D maps, which are based on high resolution digital elevation models (DEM's) and cone penetration data, serve as a good basis for outlining critical sites, such as depressions, on a landscape that contribute the majority of groundwater contamination in agricultural watersheds in certain glaciated landscapes (Samuelson, 1999; Park et al., 2001); in addition macropores contribute significantly to

groundwater contamination in any landscape (Beven and Germann, 1982; Mdaghri et al., 1997). For 3-D soil maps to be more useful they must include soil hydraulic data. This data set will be useful for parameterizing computer models of solute and water fluxes. However, these data alone are not going be adequate. With recent documentation of soil structural variability that can control water flux in certain landscape positions, we have found that there is greater flux of some solutes, namely pesticides, in basins (depressional areas) and we can classify these as critical sites. However, we found that other areas, such as up-slope and transition areas, contribute significantly to solute flux because of macropores and associated soil structural properties. These macropores act as major conducting pathways for solute flux in an area that is not obvious to the average scientist as a being a critical area. We think this has contributed to poor computer model performance despite our quality soil hydraulic data set and associated 3-D soil maps. This research was designed to provide innovative measurements for characterizing, in real time, soil water and solute fluxes. These data can then be used to further develop and test geostatistically based data and models for assessing water and solute fluxes (Kosugi and Katsuyama, 2004) within watersheds, including closed basins.

Groundwater is a very important natural resource in Wisconsin, much of the United States, and throughout the world. While being the main source for drinking water, it is heavily used in various industries and agriculture for irrigation. Thus, rapid groundwater recharge is important. While groundwater can be recharged rapidly via water flowing through macropores, found commonly in fine textured soils, there are some negative impacts associated with this rapid recharge. The impact of water and solutes flowing through macropores on groundwater quantity and quality is known to be significant, yet it remains poorly understood and there are limited models available to simulate this. In addition to a lack of good simulation models, methods for real time sampling of macroporous water and solute fluxes are limited as well.

### Objectives: Objectives

The objectives of this study were:

1) Measure water and solute fluxes, under various boundary conditions, near the bottom of the root zone of twelve undisturbed Plano silt-loam soil profiles using newly developed lysimeter fluxmeters in an effort to determine the primary factors responsible for rapid water and solute breakthrough in well structured soils.

2) Use measured flux data to characterize the spatial distribution and temporal change of parameters in two computer models that have very different approaches to macropore flow, and assess the utility of each.

3) Assess the ability of two rapid field measurement techniques; a hollow porous cone-penetrometer and tension infiltrometer, to acquire macropore model parameters (Only part of this objective was completed. The hollow porous cone-penetrometer was not developed).

## PROCEDURES AND METHODS

### Field Site Description

The field research site was located at the University of Wisconsin-Madison Arlington Agricultural Research Station, Arlington, WI. The soil at the site is classified as a Plano Silt Loam (fine-silty, mixed mesic Typic Argiudolls) with < 3% slopes. This soil was developed under tall-grass prairie vegetation, and the area was part of an extensive dry to dry-mesic prairie

named the Empire Prairie that stretched across much of Columbia and Dane counties in south central Wisconsin (WDNR, 2005). Sixteen field plots were established in Fall, 1994. The plots were established in a randomized complete block design of continuous corn with eight chiselplow (CP) and eight no-tillage (NT) managed plots in two blocks each of fertilized (F) (180 kg N $ha^{-1}$) and non-fertilized (NF) treatment. In spring 2001 an additional block of two CP and two NT plots was added to the experiment. In the spring of 2001 and 2002 only, the added plots received 145 kg dairy manure-N $ha^{-1}$ in addition to 180 kg fertilizer N $ha^{-1}$. After 2002, the new plots received 180 kg fertilizer-N $ha^{-1}$ during the spring of each year. The plots were cropped to corn. Water and solute flux data were collected from various fertilizer treatments with lysimeters located near the bottom of the active root zone.

**Equilibrium Tension Lysimeters (ETL) and Automated (AETL) Tension Lysimeters**

The ETLs were composed of 25 cm wide by 76 cm long by 15 cm tall (28.5 L) stainless steel pan with a porous stainless steel top. A vacuum equivalent to the soil matric potential, $\psi_m$, plus 2 kPa to overcome the plate's flow resistance, was maintained inside the lysimeter. The soil tension was measured using a heat dissipation tensiometer, and a battery-operated circuit was used to maintain equilibrium between the lysimeter and the bulk soil. Details of the design and operation of ETLs were reported by Brye et al. (1999) and Brye (1997). The AETLs maintain equilibrium between the lysimeters and the bulk soil via a programmable data logger, a 12V low duty-cycle vacuum pump and a series of solenoid valves. Details of the control system and logger program were reported by Masarik et al. (Masarik et al., 2004). Twelve ETLs were installed between 1995 and 2001 and were converted to AETLs in 2001. A single AETL control system was used to control two AETLs in adjacent plots.

**Automated Lysimeter Fluxmeters (ALF)**

As shown in Fig. 2, the ALF consists of four primary components: a control unit, a monitoring trap, an ISCO portable sampler (3700; Teldyne ISCO, Lincoln, NE), and connections among ALF components and between ALF and AETL. Complete details of design, parts and dimensions can be obtained by contacting the corresponding author or via the internet at: http://www.soils.wisc.edu/~lepore/ALF.

Water flow was monitored with time domain reflectometry (TDR) probes (Campbell Scientific, Logan, UT) and tensiometers (Soil Moisture Equipment, Corp., Santa Barbara, CA) equipped with pressure transducers (Omegadyne, Stamford, CT) and commercially available dataloggers (Campbell Scientific, Logan, UT). A new method of monitoring fluxes through macropores, an Automated Lysimeter Fluxmeter (ALF), was developed and used in several in-situ ponded infiltration experiments.

A new microplate colorimetric method for analyzing soil-leachate bromide concentrations was also developed. This procedure was used to measure bromide, which was used as a tracer in this research.

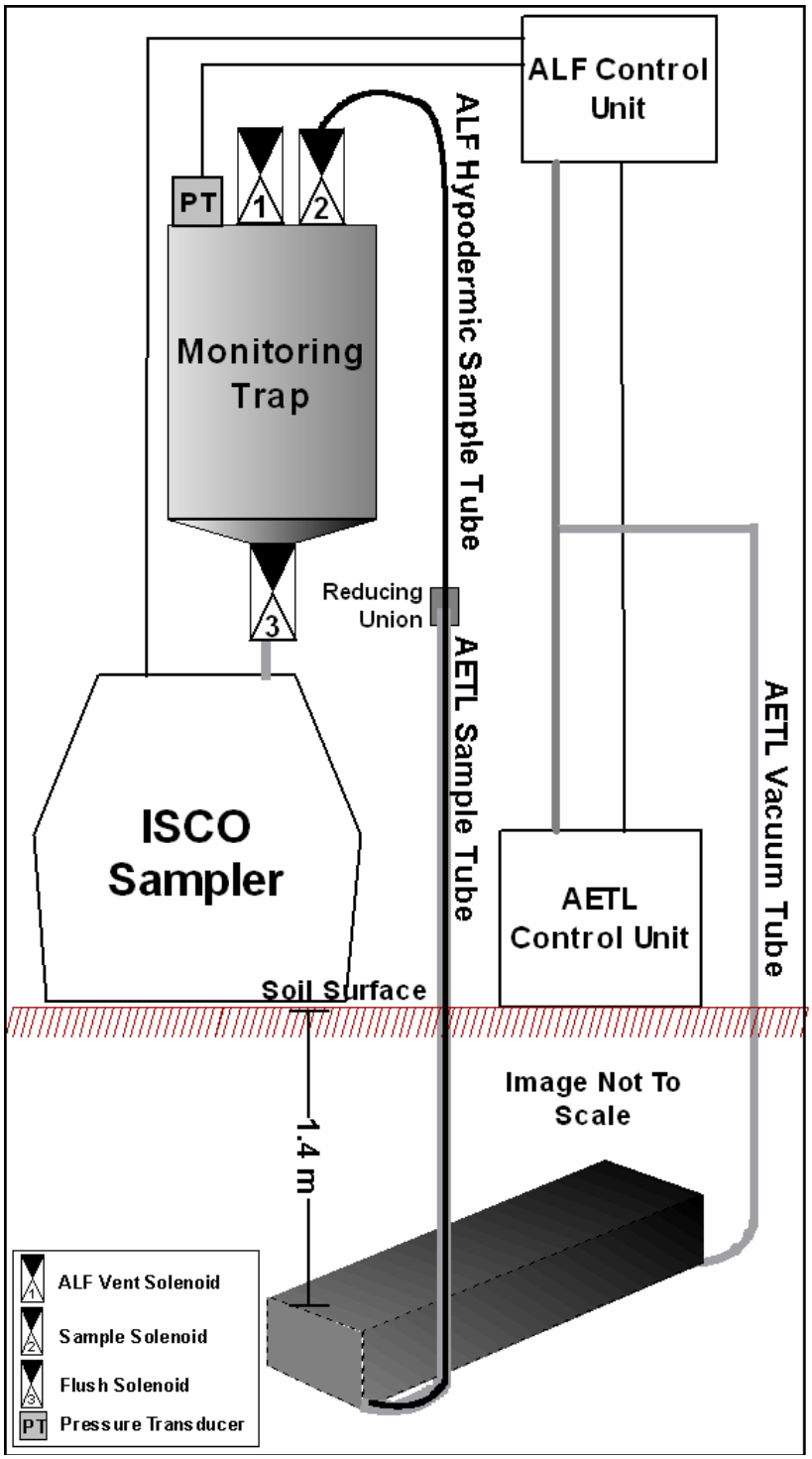



Figure 2. Schematic of ALF showing connection to AETL.

Results from the field experiments led to estimates of profile macropore volume and estimates of the interaggregate half-slit width ($B_{ped,s}$) which were used to parameterize a Macropore-Matrix (M&M) (Morgan, 2004) component of the Precision Agricultural-Landscape Modeling System (PALMS) computer simulation model. The M&M submodel infiltrates surface water through interaggregate cracks (macropores) and water moves into soil aggregates using Darcy's equation. The HYDRUS-1D model (Simunek et al., 1998, 2003) was also evaluated.

## RESULTS AND DISCUSSION

Field scale assessment of soil water and solutes fluxes has been fraught with difficulty because of three issues: 1) spatial and temporal variability, 2) upscaling of measurements and 3) the introduction of unrepresentative boundary conditions by the measurements themselves. Because of increased velocities, these problems are only exacerbated when considering preferential flows. A prototype Automated Lysimeter Fluxmeter (ALF) was developed to improve the Automated Equilibrium Tension Lysimeter (AETL). The ALF continuously and precisely monitors real-time AETL water flux of rates up to hundreds of centimeters per hour, limited only by the permeability of the lysimeter, while simultaneously separating collected lysimeter leachate into discrete samples based on programmable time or volume intervals. The ALF was tested on preliminary field measurements under natural and simulated precipitation (rainfall).

Twelve AETLs were also excavated after 5 to 10 years of burial. Age-related compaction of soil above the AETLs led to 17% increases in average bulk density of soil and slurry above the lysimeters, with a maximum increase in soil bulk density of 49%.

Macropore flow through soils with strongly expressed structure and abundant biota, such as earthworms, has significant impacts on water and chemical transport; yet because of difficulty in parameterization it is rarely considered when using computer simulation models for soil and water resource management decisions. Four constant pond height experiments were conducted adjacent to two soil pits in Plano Series silt loam soil. Using changes in volumetric water content ($\theta_v$) and drainage fluxes after termination of ponding, estimates of profile biopore and macropore volumes and interaggregate half-slit width at soil saturation ($B_{ped,s}$) were 0.3 ± 0.2%, 0.8 ± 0.2 %, and 125 ± 34 $\mu$ m, respectively.

Bromide ($Br^-$) is commonly used as a tracer in studies of water, chemical and microorganism transport in soil and rock because it is relatively nonreactive with soil and rock constituents and because of its low environmental background concentrations. Based upon a largely ignored modification of the standard colorimetric method for determining bromide using phenol red and chloramine-T, we correct an internal error and recast the technique for use with 96-well microplates (Fig. 3). Furthermore, the addition of thiosulfate to quench the undesirable chlorination reaction as previously published is shown to be unnecessary and even detrimental following the use of ammonium to produce chloramine from excess chlorine species. By manipulating sample size and concentrations of phenol red and chloramine-T, the concentration range can be expanded from 12 mg $L^{-1}$ $Br^-$ to much as 300 mg $L^{-1}$ $Br^-$.

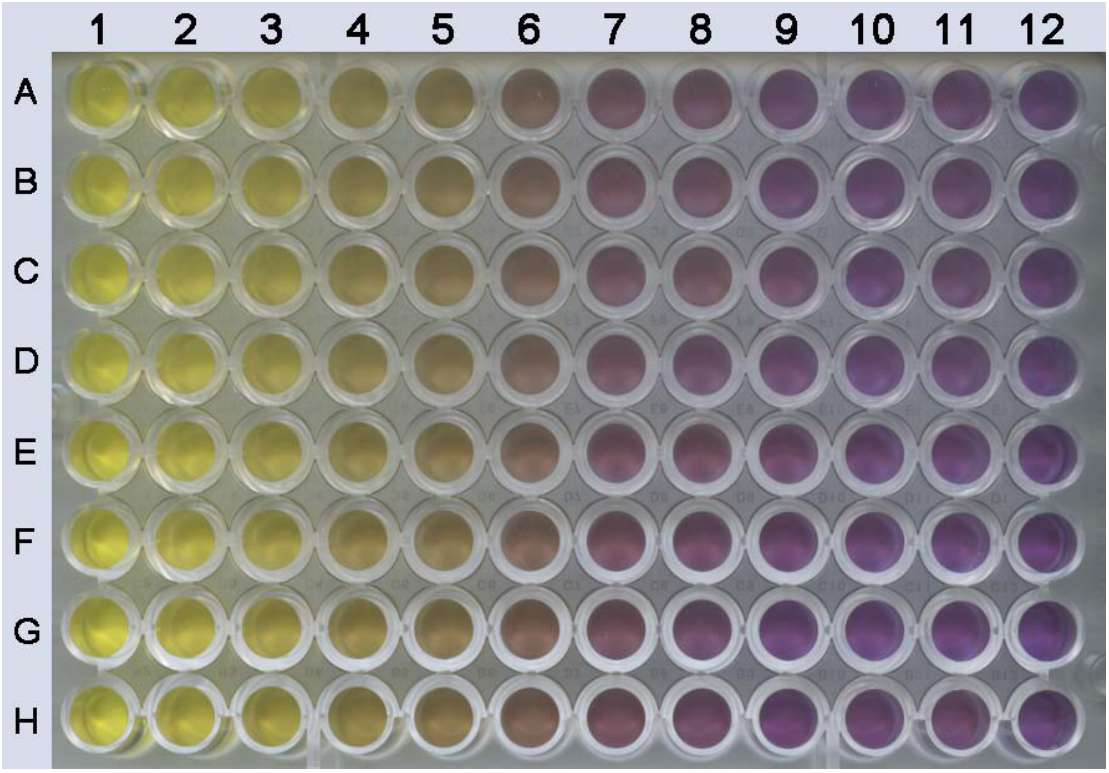



Figure 3. Ninety-six well microplate (85 x 127 mm) with eight replicates of standards containing, left to right, 0, 0.5, 1.5, 2.5, 4, 5, 7, 9, 10, 12, 15, and 20 mg $L^{-1}$ $Br^{-}$, showing the transition from the yellow color of unreacted phenol red to the reaction product, bromophenol blue.

Results from field based water and solute flux experiments led to estimates of profile macropore volume and interaggregate half-slit width ($B_{ped,s}$), which were used to parameterize the M&M component of PALMS. The M&M model infiltrates surface water through interaggregate cracks (macropores) and water moves into soil aggregates as prescribed by Darcy's equation. Results from the field ponded-water infiltration experiments led to estimates of profile macropore volume percentages of 1.1 ±0.4% and $B_{ped,s}$ of 125 ±34 μm. The estimate of $B_{ped,s}$ was used to parameterize M&M and PALMS. The revised PALMS and M&M (PALMS-M&M) predicted 79% greater cumulative drainage for the 1996 growing season than with PALMS using the conventional Green and Ampt infiltration (PALMS-G&A). The PALMS-M&M drainage prediction compared better with in-situ drainage measured by Equilibrium Tension Lysimeters (ETLs). Root-mean-square error (RMSE) values between predicted and measured soil volumetric water content ($\theta_v$; $m^3$ $m^{-3}$) at 10, 50, and 100-cm depths did not change significantly with PALMS-M&M vs. PALMS-G&A. However, throughout most of the growing season, $\theta_v$ was slightly greater for PALMS-M&M (<2%) at 50 and 100-cm depths, indicating deeper and more rapid infiltration when incorporating a macropore infiltration model into PALMS. Preliminary comparisons between the field data and the HYDRUS-1D model presented some formidable challenges that remain to be resolved.

## CONCLUSIONS AND RECOMMENDATIONS

The underlying motivation for this work was to improve our ability to simulate the impacts of preferential water and solute flow (that is water and solute flow through macropores) within landscapes with well-structured soils that are used for agricultural purposes. Knowledge of preferential water and solute-flow hydraulic parameters at the landscape scale is critical to such an effort. To this end, this work offers significant contributions. Preferential flow in well structured soils is conceptually divided into macropore and biopore flow, macropore being interaggregate slit flow and biopore being flow through large cylindrical channels such as earthworm burrows. A new device for monitoring time-resolved solute and water fluxes into tension lysimeters when preferential flow is occurring was designed, built and put to use. In addition, a microplate method for rapid determination of bromide concentration was developed. This new method allowed for unlimited sampling of the tracer in this preferential flow study. Finally, a field method and analysis procedure, for ponded infiltration experiments that provide estimates of macropore and biopore parameters, central to a preferential flow model, were developed. To simulate anything, one must choose a model. For landscape scale water and solute applications, two essential requirements of the model are that it runs quickly on a computer, and that its parameters are obtainable throughout the landscape. For these reasons, the simple M&M submodel, that simulates laminar water flow in macropores, was selected. The simplicity of M&M satisfies the former of the aforementioned requirements, while the improvements in measurement described above begins to satisfy the latter. We have improved M&M by incorporating unsaturated macropore flow and implemented it in the Precision Agricultural Landscape Modeling System (PALMS). In so doing, we have begun investigation into the impact of preferential flow on a whole host of important goods and services associated with agriculture. An example of questions we begin to ask is "How does soil structure, and its related macroporosity, impact grain yield in a year with more than adequate rainfall?" Future work should include the addition of solute transport to the M & M model, refining measurement techniques so that parameters and their variability can be assessed more quickly and inexpensively, and we will continue improving the model as comparisons between simulations and observations lead us to do so.

## REFERENCES


Arriaga, F.J., and B. Lowery. 2002. A three-dimensional representation of soil profile depth and crop yield over an eroded landscape. *In* Proc. 12th International Soil Conservation Organization Conf. 4:287-390, Beijing, China, 26-31 May 2002.

Arriaga , F.J., D.J. Reinert, B. Lowery, and K. McSweeney. 2002. Development of three-dimensional maps of eroded soil with data from a profile cone penetrometer. (CD-ROM): p. 1390.1-7. International Union of Soil Science, 17th World Congress of Soil Science, 14-21 Aug., Bangkok, Thailand.

Beven, K., and P. Germann. 1982. Macropores and water flow in soils. Water Resources Research 18: 1311- 1325.

Brye, K.R. 1997. Water budget evaluation of natural and managed ecosystems emplying an imporved field drainage measurement technique. MS Thesis. University of Wisconsin-Madison. Department of Soil Science.

Brye, K.R., J.M. Norman, L.G. Bundy, and S.T. Gower. 1999. An equilibrium tension lysimeter for measuring drainage through soil. Soil Sci. Soc. Am. J. 63:536–543.

Germann P.F., and L. DiPietro. 1996. When is porous-media flow preferential? A hydromechanical perspective. Geoderma 74: 1-21

Grunwald S., D.J. Rooney, K. McSweeney, and B. Lowery. 2001. Development of pedotransfer functions for a profile cone penetrometer. Geoderma. 100:25-47.

Grunwald S., B. Lowery, D.J. Rooney, and K. McSweeney. 2001. Profile cone penetrometer data used to distinguish between soil materials. Soil & Tillage Res. 62:27-40.

Grunwald S., K. McSweeney, D.J. Rooney, and B. Lowery. 2001. Soil layer model created with profile cone penetrometer data. Geoderma. 103:181-201.

Johnson, D.O., Arriaga, F.J., and B. Lowery. 2005. Automation of a falling head permeameter for rapid determination of hydraulic conductivity of multiple samples. Soil Sci. Soc. Am. J. 69:828-833.

Molling, C. 2003. Precision Agriculture. Available at http://emily.soils.wisc.edu/RESAC/agric/modeling.html . verified Nov 14, 2003.

Kosugi, K., and M. Katsuyama. 2004. Controlled-suction period lysimeter for measuring vertical water flux and convective chemical fluxes. Soil Sci. Soc. Am. J. 68:371–382

Masarik, K.C., J.M. Norman, K.R. Brye, and J.M Baker. 2004. Improvements to measuring water flux in the vadose zone. J Environ Qual. 33: 1152-1158.

Mdaghri Alaoui A., P. Germann, L. Lichner, and, V. Novak. 1997. Preferential transport of water and 131iodide in a clay loam assessed with TDR-techniques and boundary-layer flow theory. Hydrology and Earth Systems Science 4: 813-822

Morgan, C.L.S. 2004. Quantifying Soil Morphological Properties For Landscape Management Applications. PhD Thesis. University of Wisconsin, Madison, Wisconsin.

Morgan, C.L.S. 2000. Quantifying Plant-Available Water Across Landscapes Using an Inverse Yield Model and Electromagnetic Induction. M.S. Thesis. University of Wisconsin, Madison, Wisconsin

Park, S.J., McSweeney, K. and Lowery, B. 2001. Identification of the spatial distribution of soils using a process-based terrain characterization. Geoderma. 103:249-272.

Richmond, J.E. 2002. Characterization of Surface Runoff Contributing Areas Using Ceramic Beads, Simulated Rainfall and Magnetic Susceptibility. M.S., Thesis. University of Wisconsin, Madison, Wisconsin.

Rooney D., and B. Lowery. 2000. A profile cone penetrometer for mapping soil horizons. Soil Sci. Soc. Am. J. 64:2136-2139.

Samuelson, J.R. 1999. Atrazine and Nitrate Leaching in a Glacial Landscape. M.S., Thesis. University of Wisconsin, Madison, Wisconsin.

Simunek, J., K. Huang, M. Sejna, and M.Th. van Genuchten. 1998. The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media. Version 1.0, IGWMC-TPS-70, International Ground Water Modeling Center, Colorado School of Mines, Golden, Colorado, 186 pp.

Simunek, J., N. J. Jarvis, M. Th. van Genuchten, and A. Gärdenäs. 2003. Review and comparison of models for describing non-equilibrium and preferential flow and transport in the vadose zone. J. Hydrology. 272:14-35.

# Assessing the Ecological Status and Vulnerability of Springs in Wisconsin

## Basic Information

| | |
|---|---|
| **Title:** | Assessing the Ecological Status and Vulnerability of Springs in Wisconsin |
| **Project Number:** | 2006WI136B |
| **Start Date:** | 3/1/2006 |
| **End Date:** | 6/30/2007 |
| **Funding Source:** | 104B |
| **Congressional District:** | WI 1st; 2nd |
| **Research Category:** | Ground−water Flow and Transport |
| **Focus Category:** | Ecology, Groundwater, Hydrology |
| **Descriptors:** | |
| **Principal Investigators:** | Susan Swanson, Kenneth R Bradbury, David John Hart, David Zaber |

## Publication

# ASSESSING THE ECOLOGICAL STATUS AND VULNERABILITY OF SPRINGS IN WISCONSIN

Susan K. Swanson, Associate Professor, Department of Geology, Beloit College

Kenneth R. Bradbury, Hydrogeologist/Professor, Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension

David J. Hart, Hydrogeologist/Associate Professor, Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension

**TABLE OF CONTENTS**

**Title Page** 1
**Table of Contents** 2
**List of Figures** 3
**Project Summary** 4
**Introduction** 6
*Purpose and Scope* 6
*Study Areas* 6
**Procedures and Methods** 7
*Historical Surveys* 7
*Verification of Spring Locations* 7
*Selection of Representative Springs* 7
*Comprehensive Surveys* 7
*Bimonthly Surveys* 8
**Results and Discussion** 8
*Distribution of Springs* 8
*Physical Characteristics* 9
*Ecological Characteristics* 12
**Conclusions and Recommendations** 13
*Status of Spring Ecosystems* 13
*Conceptual Models and Vulnerability of Springs to Withdrawals* 13
**References** 15

**Appendix A:** Presentations and Awards
**Appendix B:** Field Survey Form from Springer et al. (in prep.)
**Appendix C:** Regional Information on the Distribution of Springs in Iowa County
**Appendix D:** Geochemistry Results and Charts
**Appendix E:** Vegetation Diversity Charts, Plant Species Lists, and Importance Values
**Appendix F:** Distribution of Springs and High-Capacity Wells in Iowa and Waukesha Counties
**Appendix G:** Acknowledgements

## LIST OF FIGURES

**Figure 1.** Location of Iowa and Waukesha Counties. **6**
**Figure 2.** Distribution of a) historical, b) confirmed, and c) surveyed springs in Iowa County and d) historical, e) confirmed, and f) surveyed springs in Waukesha County. **9**
**Figure 3.** Distribution of springs within major stratigraphic units, Iowa County. **9**
**Figure 4.** Spring flow (cfs) in Iowa and Waukesha Counties June-August, 2006. **10**
**Figure 5.** Spring flow measurements for two springs in Iowa County. **10**
**Figure 6.** Concentrations of a) Chloride and b) Nitrate as N at springs near Highland, Otter Creek, and Governor Dodge State Park, Iowa County. **11**
**Figure 7.** Cluster analysis results, Waukesha County. **11**
**Figure 8.** Distribution of geochemical groups and bedrock geology (after Mudrey et al., 2007). **12**
**Figure 9.** Distribution of Group 3 springs relative to the Kettle Moraine (after Clayton, 2001). **12**
**Figure 10.** Distribution of Vegetative Strata Cover in a) Iowa County and b) Waukesha County. **13**

## PROJECT SUMMARY

**Title:** Assessing the Ecological Status and Vulnerability of Springs in Wisconsin

**Project I.D.:** WR05R004

**Investigator(s):** Susan K. Swanson, Associate Professor, Department of Geology, Beloit College

Kenneth R. Bradbury, Hydrogeologist/Professor, Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension

David J. Hart, Hydrogeologist/Associate Professor, Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension

**Period of Contract:** 07/01/05 – 06/30/07

**Background/ Need:** The need for a clear understanding of the range of physical and ecological characteristics of springs in Wisconsin provides the overall motivation for this project. The topic is relevant in Wisconsin because the Wisconsin Department of Natural Resources must evaluate whether groundwater pumping by new high-capacity wells will result in significant environmental impacts to springs that result "in a current of flowing water with flows of a minimum of one cubic foot per second at least 80% of the time (2003 WI Act 310, p.2)". However, Wisconsin's springs, irrespective of the flow criterion, are poorly studied, resulting in a lack of information for use in determining significance of impacts.

**Objectives:** Our primary goal is to collect, classify, and evaluate baseline data on physicochemical characteristics and biological communities of Wisconsin's spring resources. Using historical spring surveys and a comprehensive springs classification system developed by Springer et al. (in prep.), the physical, biological, and sociocultural characteristics of typical spring systems in two regions of the state were documented. The two regions differ in their topography, geology, land use, and development pressures. The approach allows the assessment of the physical and ecological status of spring systems and the formulation of hydrogeological conceptual models of springs in these settings.

**Methods:** The methodology involves mapping springs in Iowa and Waukesha Counties, conducting surveys of representative springs in each county, building a database for the spring-related information, and interpreting these data in association with regional information on geology and topography to assess vulnerability to groundwater withdrawals. The study represents the first assessment of spring resources in these regions in approximately 50 years.

**Results and Discussion:** Iowa County is rich in spring resources; any loss of spring resources over the last 50 years is minimal. Field data support conceptual models for springs in Iowa County that are based on a typical contact spring. Springs are associated with every major stratigraphic unit, but are most commonly found in association with the Sinnipee Group, near the upper contact of the St. Peter Fm., or near the upper contact of the Cambrian sandstones. Therefore, heterogeneities like vertical and horizontal fractures, both of which are prevalent in the Sinnipee Group rocks, or partings along major stratigraphic contacts may be particularly important in promoting discrete flow in the region. Spring waters discharging from different geologic units can be

distinguished on the basis of major ion geochemistry, and springs discharging from stratigraphically higher units have more variable flow.

In Waukesha County, much of the land that historically contained springs has been developed for residential or commercial purposes. The spatial distribution of springs was historically influenced by the glacial topography and the position of the Maquoketa shale subcrop. Geochemical groups of spring waters suggest that although flow paths originate in the unlithified aquifer, groundwater may flow through shallow bedrock before discharging as depression springs in low-lying wetlands or near streams.

Agricultural and historical uses of spring water have impacted the ecological status of springs in both regions. Plant diversity is somewhat higher at the Waukesha County springs, but the percent cover of native plants is lower and the percent cover of invasive plants is higher. Benthic fauna communities are dominated by non-insect taxa (Amphipoda, Isopoda, Gastropoda), although low numbers of aquatic insects (Tricoptera and Diptera) were found in most springs.

**Conclusions/ Implications/ Recommendations:** Overall confidence in historical spring locations is high, which allows their use in association with patterns of regional geology and topography. This regional information is complemented by the depth of the site-specific information collected using the Springer et al. (in prep.) system. At least 20 springs were surveyed in each county. This number of springs provided sufficient data to develop conceptual models and preliminarily assess vulnerability to pumping, which suggests the overall approach may also be successful elsewhere in Wisconsin.

Springs discharging from stratigraphically higher units in Iowa County are likely to be vulnerable to pumping from wells along ridge tops that are installed in these aquifers or that span multiple aquifers. Because recharge areas for these springs are probably small and shallow, pumping could result in substantially reduced spring flow or complete loss of flow to small springs. Springs discharging from stratigraphically lower units are probably less vulnerable, due in part to broader contributing areas, but also because most high-capacity wells that pump water from the Cambrian sandstones are located in the floodplain of the Wisconsin River, where few springs exist. Because regional pumping in southeastern Wisconsin affects shallow flow patterns and downward flow from the shallow to the deep parts of the system occurs, springs in Waukesha County are vulnerable to additional groundwater withdrawals from both the shallow and deep parts of the system.

**Related Publications:**

Bartkowiak, B.M. and Swanson, S.K., March 2007. Geochemical and flow characteristics of two contact springs in Iowa County, Wisconsin, American Water Resources Association - WI Section Annual Meeting, Wisconsin Dells, Wisconsin.

Swanson, S.K., March 2007. Assessing the ecological significance and vulnerability of springs in southern Wisconsin, American Water Resources Association - WI Section Annual Meeting, Wisconsin Dells, Wisconsin.

**Key Words:** Springs, Iowa County, Waukesha County

**Funding:** University of Wisconsin System; Wisconsin Department of Natural Resources; U.S. Geological Survey

## INTRODUCTION

*Purpose and Scope*

The need for a clear understanding of the range of physical and ecological characteristics of springs in Wisconsin provides the overall motivation for this project. The topic is relevant in Wisconsin because the Wisconsin Department of Natural Resources (WDNR) must evaluate whether groundwater pumping by new high-capacity wells (≥ 100,000 gpd) will result in significant environmental impacts to springs that result "in a current of flowing water with flows of a minimum of one cubic foot per second at least 80% of the time (2003 WI Act 310, p.2)". However, Wisconsin's springs, irrespective of the flow criterion, are poorly studied, resulting in a lack of information for use in determining significance of impacts.

The primary goal of this investigation is to collect, classify, and evaluate baseline data on physicochemical characteristics and biological communities of Wisconsin's spring resources. Using historical spring surveys and a comprehensive springs classification system developed by Springer et al. (in prep.), the physical, biological, and sociocultural characteristics of typical spring systems in two regions of the state were documented. The two regions differ in their topography, geology, land use, and development pressures. The approach allows the assessment of the physical and ecological status of typical spring systems and the formulation of hydrogeological conceptual models of springs in these settings, both of which are critical steps in assessing vulnerability to pumping. The methodology involves mapping springs in Iowa and Waukesha Counties, conducting surveys of representative springs in each county, building a database for the spring-related information, and interpreting these data in association with regional information on geology and topography to assess vulnerability to groundwater withdrawals. The study represents the first assessment of spring resources in these regions in approximately 50 years.

*Study Areas*

Iowa County is located in southwestern Wisconsin in the Driftless Area (Fig. 1). Land surface elevations range from 630 to 1720 feet above mean sea level (amsl), and the region is characterized by nearly horizontal, Cambrian and Ordovician sandstone and carbonate rocks that are exposed in steep and narrow valleys. Pleistocene deposits are absent except for thin layers of loess and/or hillslope sediments on valleys sides and stream sediment in valley bottoms (Clayton and Attig, 1998). The primary land uses in the county are agricultural (68%), followed by forested lands (20%), federal, state, and county lands (6%), and wetlands (5%). Urban land uses (residential, commercial, and manufacturing) account for less than 3% of the total land use. The population of Iowa County grew by 13% from 1993 to 2003, but as of 2000 the population was less that 23,000 (SWWRPC, 2005).

**Figure 1.** Location of Iowa and Waukesha Counties.

Land surface elevations in Waukesha County (Fig. 1) range from 700 to 1230 feet amsl, and the bedrock is composed of Cambrian, Ordovician, and Silurian sedimentary strata. Units older and deeper than the Ordovician Maquoketa Formation are often lumped together and referred to as the *deep sandstone aquifer* for purposes of describing and modeling regional groundwater flow (Feinstein et al., 2005). The bedrock is overlain by thick (up to 140m) Pleistocene deposits throughout much of the county. One of the most prominent glacial features in the county is the Kettle Moraine, which is an irregular ridge extending from the southwest corner to the northcentral edge of the county (Clayton, 2001). Waukesha County, along with much of southeastern Wisconsin, is one of the most rapidly developing regions of the state. The rate of land conversion from rural to urban uses during the 1990s was approximately 4.7 square miles per year, and the current population of Waukesha County is over 377,000. In 2000, agricultural (30%) and natural areas (27%) remained the largest land uses; however, urban land uses rose from 29% to 37% in the preceding ten years. Much of the increase in urban land uses is attributed to the area of land used for residential purposes (Waukesha County Department of Parks and Land Use, 2006).

## PROCEDURES AND METHODS

*Historical Surveys*

Surveys that document spring locations in Wisconsin were conducted in the early 1800's (1834 to 1836) by the U.S. government and in 1937 by the U.S. Geological Survey (USGS), i.e., the Bordner Survey. These spring surveys were updated for fish management purposes by the Wisconsin Conservation Department (WCD) from 1956 to 1968 for about 60% of the counties in the state. The WCD gathered data on location, flow rate, land use, and a variety of other spring characteristics relating to the potential to support fisheries. These surveys serve as the basis for the historical information on spring locations in Iowa and Waukesha Counties and were supplemented by springs documented in the USGS Geographic Names Information System, WDNR Surface Water Resources reports, WGNHS publications for southwest Wisconsin (DeGeoffroy, 1969), and publications by local experts (Schoenknecht, 2003).

All historical data were converted to an electronic format by scanning, georeferencing, digitizing, and then saving spring positions as ArcGIS shapefiles. All of the spring attribute data in the WCD surveys were also transposed to a Microsoft Access database. Six-digit unique identifiers were assigned to each spring using the county code and by then numbering the springs in the order they appeared in the WCD surveys. ArcGIS shapefiles and the Access database are available at the UW-Water Resources Library.

*Verification of Spring Locations*

Spring locations were verified by identifying the current owners of properties that, according to historical data, contain springs. Property ownership was determined using land atlas plat books and geodatabases of tax parcels and ownership data supplied by local land information offices. Phone numbers for owners were determined using phone books and on-line resources. WDNR Land Managers were also identified for state lands. Contact information was found for approximately 68% of the relevant property owners in each county. Owners were contacted, asked whether a spring exists on the land today. If so, the owner was asked to describe the emergent setting, the volume of spring flow, and the persistence of spring flow.

*Selection of Representative Springs*

In Iowa County, the geographic positions of historical springs were used in association with property owners' descriptions and physical characteristics of the region to select a set of 24 representative springs to survey. The physical characteristics include elevation, slope, and aspect, as determined from a 10-meter digital elevation model, and stratigraphic position and position with respect to stratigraphic contacts, based on the state-wide geologic map of Wisconsin (Mudrey et al., 2007). Elevation and aspect can affect the development of microclimates, and slope and aspect can be valuable in predicting the distribution of biota due to variations in solar energy (Wadsworth and Treweek, 1999). Stratigraphic position may indicate the nature of aquifer heterogeneities that are responsible for springs. Historical spring locations were overlaid onto the regional datasets to determine if spatial relationships between spring position and the physical property exist. Where relationships are thought to exist, springs were selected so as to closely reproduce the distributions observed in the historical data. In Waukesha County, very few historical springs could be verified (see Results and Discussion). Therefore, 20 springs were selected primarily on the basis of property owners' descriptions, access to public or private property, and, to some degree, the geologic setting and geographic distribution of springs within the county.

*Comprehensive Surveys*

Springer et al. (in prep.) identify the need for an integrated springs classification system to further recognition, management, and conservation of springs ecosystems. They have developed a system that builds on the historical Meinzer (1927) spring discharge classification scheme by incorporating a comprehensive set of spring characteristics including information on spring location, weather conditions, site environmental conditions and land use, habitat, vegetation, wildlife, aquatic and terrestrial invertebrates, geomorphic conditions, geologic conditions, flow characteristics, and water quality. Surveys based on this classification system were conducted at the 24 representative springs in Iowa

County during June and July 2006 and the 20 representative springs in Waukesha County during July and August 2006. Teams of three or four spent two to four hours characterizing each spring. The classification system was modified slightly to reflect the expertise of the sampling team. For example, terrestrial invertebrates were not sampled. A copy of the field survey form is provided in Appendix B. All spring data are stored in the Access database.

Standard methods were applied for all field measurements and the collection of all field samples. Aquatic macroinvertebrates were collected prior to disturbance by site description and physicochemical sampling. The samples were collected using a 12-inch Surber net, a 6-inch Surber net, a D-net, or by hand-picking, where appropriate. Samples were transferred to plastic bags, kept cool, and preserved within 12 hours with 70% Ethyl Alcohol/$H_2O$ solution prior to separation from substrate materials. Specimens were separated from substrate materials by hand-picking and suspension in freshwater, then returned to sealed glass vials for later identification. The number of samples collected at each spring location reflects the size and structural heterogeneity of the spring site. At a minimum, benthic fauna was sampled at the orifice of each spring; all but the smallest springs were also sampled at downstream locations, along springbrooks and, in some cases, at the spring channel/receiving waterbody confluence. Although detailed sampling was conducted, only qualitative analysis of these data was completed.

Water quality samples were collected at the orifice of each spring and analyzed for concentrations of major ions (calcium, magnesium, sodium, potassium, bicarbonate, sulfate, nitrate, and chloride), iron, phosphorous, total dissolved solids (TDS), and alkalinity. Samples were field-filtered, preserved with sulfuric (nutrients) or nitric (metals) acid, as appropriate, and processed at the Wisconsin State Laboratory of Hygiene. Dissolved oxygen (DO), pH, conductivity, temperature, and alkalinity were also measured in the field. Geochemical results were used to calculate charge balances to insure that errors were approximately ±5% or less.

*Bimonthly Surveys*

Three additional springs in Iowa County were monitored bimonthly in 2006 for the full suite of spring characteristics, including sampling for oxygen-18 and deuterium (Fig. 2). Flow was measured on a monthly basis. The three springs occur at different stratigraphic positions, elevations, and aspects. They also vary by level of disturbance. A spring near Highland is thought to discharge from the Prairie du Chien Group and occurs on a steep and wooded, south-facing slope. Another spring, near Otter Creek, is thought to discharge from the Jordan Formation. It is encased in a concrete spring pool, which occurs in an open setting, near a valley bottom. The third spring, in Governor Dodge State Park, discharges into a spring house, which is located near the upper contact of the St. Peter Formation with the Sinnipee Group. It was monitored in association with the WGNHS and UW-Madison (Carter, in prep.).

## RESULTS AND DISCUSSION

*Distribution of Springs*

This investigation found approximately 407 and 282 historically documented springs in Iowa and Waukesha Counties, respectively (Fig. 2). Contact information was available for 274 property owners in Iowa County, of whom 190 could be reached. Property owners confirmed the presence of 175 of these springs, and access was granted to nearly all of them. Conversations with property owners and observations in the field suggest that many other springs that were not historically mapped also exist in Iowa County. Contact information was available for 193 property owners in Waukesha County, of whom 138 could be reached. Property owners confirmed the presence of approximately 43 of the historical springs, and access was granted to only 25. Conversations with property owners and observations in the field suggest that much of the land that historically contained springs has been developed for residential or commercial purposes. Ponds have also been created on at least six of the properties that once contained distinct springs. Because access was granted to only 25 springs, there was very little flexibility in the selection of springs for surveys in Waukesha County.

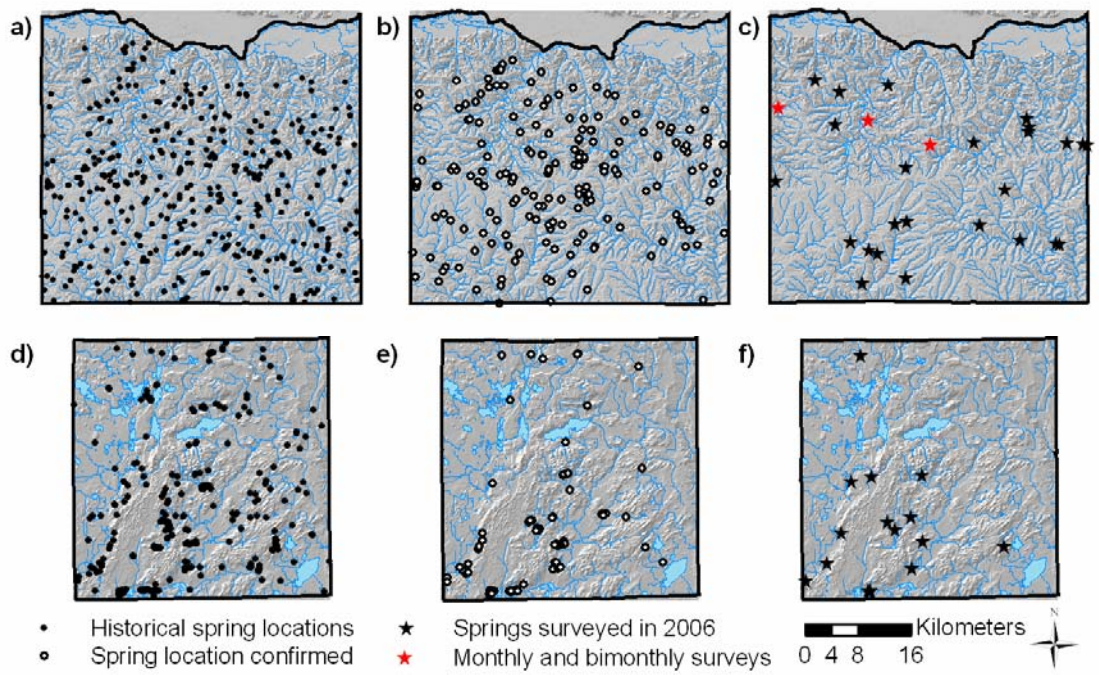



**Figure 2.** Distribution of a) historical, b) confirmed, and c) surveyed springs in Iowa County and d) historical, e) confirmed, and f) surveyed springs in Waukesha County.

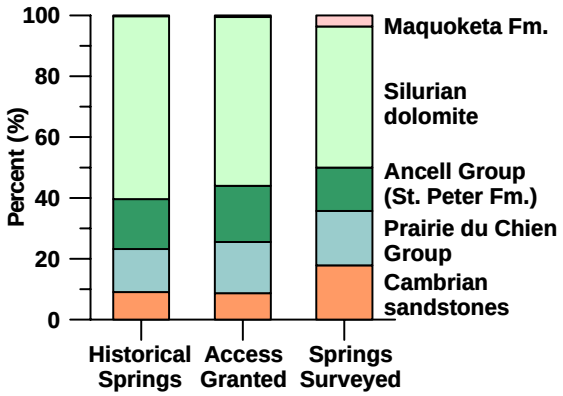



**Figure 3.** Distribution of springs within major stratigraphic units, Iowa County

Access was granted to nearly 175 springs in Iowa County, so the distribution of springs relative to regional physical conditions could be considered in selecting springs for surveys. On the basis of the historical data, springs are associated with every major stratigraphic unit in Iowa County; however, spatial overlays of the historical springs onto the regional bedrock map show that the springs are not distributed randomly across the landscape. They are most commonly found in association with the Sinnipee Group rocks, near the upper contact of the St. Peter Formation with the Sinnipee Group rocks, or near the upper contact of the Cambrian sandstones with the Prairie du Chien Group (Appendix C). The 24 springs selected for surveying closely resemble these relationships (Fig. 3). Springs exist throughout the ranges of elevation, slope, and aspect in Iowa County. However, the distributions of springs relative to these properties do not differ significantly from the countywide distributions ($\alpha = 0.05$), so no distinct relationships between spring position and these three properties are thought to exist. However, in selecting representative springs, an effort was made to choose springs from a variety of elevations, slopes, and aspects, thus helping to insure that the springs surveyed are representative of the diversity of physical and ecological conditions in the county (Appendix C).

*Physical Characteristics*

Flow was measurable at 36 of the 47 springs that were surveyed. The mean discharge for all surveyed springs is 0.24 cfs, but the median is 0.08 cfs (Fig. 4). Among the springs that were monitored, there is no clear relationship between the magnitude of flow and the major stratigraphic unit from which the spring discharges. Three springs discharged at rates of 1 cfs or more at the time of monitoring; however,

one of these springs has been ponded, so the measurement probably includes a significant component of diffuse groundwater discharge. All three of these springs are located in Iowa County.

Fig. 5 shows spring flow hydrographs for two of the springs that were monitored on a monthly basis in Iowa County. The flow record for the third spring in Governor Dodge State Park is less complete and less reliable. Flow measurements are difficult at this site because the water depth is too low for a current meter and the bedrock channel hinders the use of a cutthroat flume. The records show that while the Otter Creek spring responds to seasonal patterns in precipitation, the response is damped, i.e., the total variation in flow throughout the period is relatively low. Discharge at the spring near Highland is more variable and may be more sensitive to storm events.

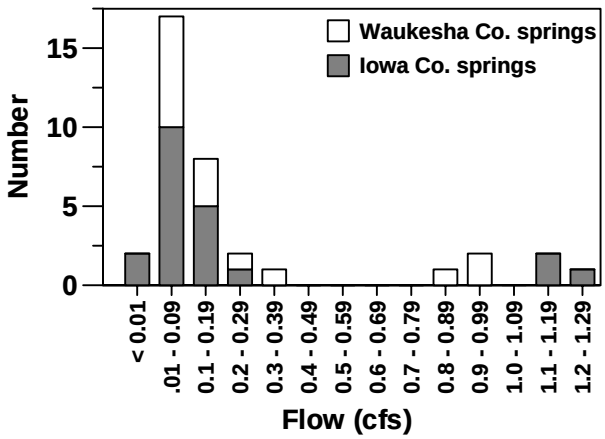



**Figure 4.** Spring flow (cfs) in Iowa and Waukesha Counties June-August, 2006.

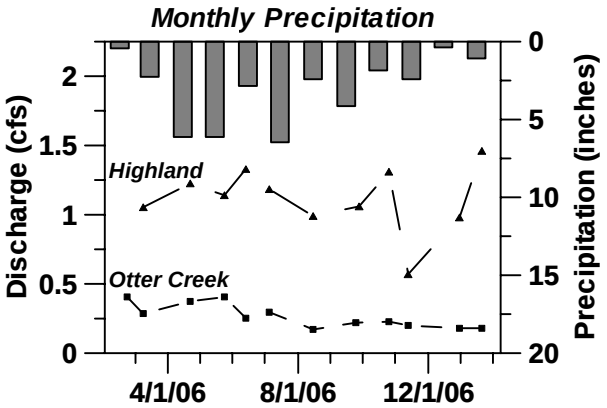



**Figure 5.** Spring flow measurements for two springs in Iowa County.

Piper diagrams, plots of ion concentrations, and plots of field parameters (Appendix D) show the overall similarity in geochemistry among spring waters in Iowa and Waukesha Counties. For example, water discharging from springs in both counties are a Calcium-magnesium Bicarbonate type. To differentiate possible groundwater flow paths to springs, concentrations of analytes were plotted according to the major stratigraphic unit from which the spring is thought to discharge. This approach assumes that the hydrogeologic properties of the units differ enough to treat each unit as a separate hydrostratigraphic unit. In Iowa County, mean TDS, pH, and nitrate concentrations in spring waters differ significantly ($\alpha = 0.05$) among major stratigraphic units. TDS concentrations in groundwater often increase along a flow path (Freeze and Cherry, 1979). Groundwater flowing along a simplified flow path in Iowa County might originate in a recharge area on a ridge and pass through the Sinnipee Group, the St. Peter Formation, the Prairie du Chien Group, and finally, the Cambrian sandstones. However, not all ridges are composed limestone and dolomite belonging to the Sinnipee Group, and groundwater is probably recharged along some slopes as well as ridge tops. In addition, flow through fractures may dominate in some units, whereas porous media flow dominates in others, resulting in a variety of possible flow paths and residence times. TDS is high in water discharging from the Sinnipee Group rocks and low in water discharging from the Cambrian sandstones. Therefore, TDS concentrations may be more representative of equilibrium conditions within particular units rather than the position along a simplified flow path.

Values of pH that are associated with the stratigraphic units in Iowa County are more indicative of a typical chemical evolution path for water dissolving calcite (Freeze and Cherry, 1979). The values increase from a mean pH of 6.9 for water discharging from the Sinnipee Group to a mean of 7.4 for water discharging from the Cambrian sandstones. Calcite saturation indexes ($SI_{cal}$) suggest the same chemical evolution path. They generally increase (become more saturated) along the simplified flow path; however, differences in the mean $SI_{cal}$ among stratigraphic units are not significant.

Nitrate concentrations are highest and most variable in springs discharging from the Sinnipee Group. Concentrations are progressively lower and less variable in water discharging from the St. Peter Fm., the Prairie du Chien Group, and the Cambrian sandstones. These relationships are not surprising because many areas that are used for row crops coincide with the areas mapped as the Sinnipee Group.

Bi-monthly sampling results for the springs near Highland, Otter Creek, and Governor Dodge State Park show very little temporal variation in ion concentrations or in environmental isotopes (Appendix D). Even nitrate and chloride concentrations, which could vary in response to seasonal inputs of fertilizers or road salts, are relatively constant (Fig. 6). Concentrations of both ions do vary at the Governor Dodge spring. However, samples collected from this spring are the only ones that were not analyzed at the WI State Laboratory of Hygiene and which have charge balance errors that are consistently greater that 5% (Carter, in prep.). Therefore, it is unclear if the variation in concentration is real or a result of inaccuracies in the analyses. Concentrations of both ions are consistently greater at the stratigraphically higher Highland and Governor Dodge springs.

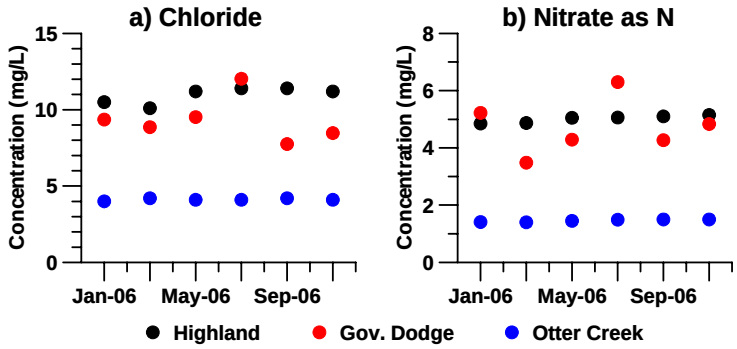



**Figure 6.** Concentrations of a) Chloride and b) Nitrate as N at springs near Highland, Otter Creek, and Gov. Dodge State Park.

In Waukesha County, relationships between major ion concentrations and stratigraphic units are less clear. Calcium, magnesium, and TDS concentrations appear to be related to stratigraphic units (Appendix D); however, differences in concentrations among the units are not significant ($\alpha$=0.05). This is not surprising because water discharging to springs in the region also flows through overlying glacial deposits; some springs may exist where groundwater flows exclusively through unconsolidated materials. Therefore, hierarchical cluster analysis of ion concentrations, which has been shown to be useful in discerning subtle geochemical differences among spring waters (Swanson et al., 2001), was used. Hierarchical clustering successively joins the most similar observations. Ward's hierarchical clustering method was chosen, and all analytical data were standardized prior to performing the analysis. Standardization is necessary because concentrations vary over a wide range among analytes. Readers are referred to Swanson et al. (2001) for further details of the approach. The analytes chosen for the cluster analysis are calcium, magnesium, TDS, and alkalinity, because these analytes were thought to be good indicators of aquifer materials. Fig. 7 shows that the cluster analysis results in four groups of springs, identified by spring number.

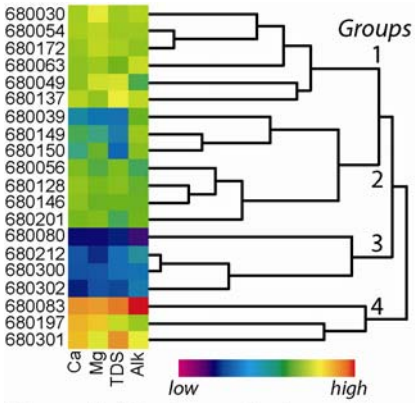



**Figure 7.** Cluster analysis results, Waukesha County.

Fig. 8 shows the spatial distribution of the four groups of springs overlaid onto a map of the bedrock geology in Waukesha County. Group 1 springs are broadly associated with areas mapped as Silurian dolomite, and Group 2 springs are broadly associated with areas mapped as the Sinnipee Group. Fig. 7 shows the similarity between these two groups of springs, which may help explain the position of one of the Group 2 springs (680056) in an area mapped as Silurian dolomite. Group 4 springs are broadly associated with areas mapped as Maquoketa Formation, but Group 3 springs do not appear to be associated with any of the mapped units. These springs have the lowest relative ion concentrations (Fig. 7), and when overlaid onto a digital elevation model (Fig. 9), it is clear that they align with the

Kettle Moraine, as do many other historical springs (Fig. 2). These observations, albeit preliminary, suggest that the Group 3 springs might be dominated by groundwater that flows primarily through unconsolidated deposits, whereas groundwater discharging to Groups 1, 2, and 4 springs may flow through bedrock somewhere along the flow path.

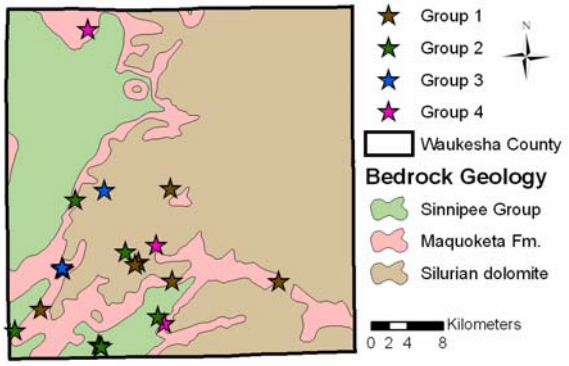



**Figure 8.** Distribution of geochemical groups and bedrock geology (after Mudrey et al., 2007).

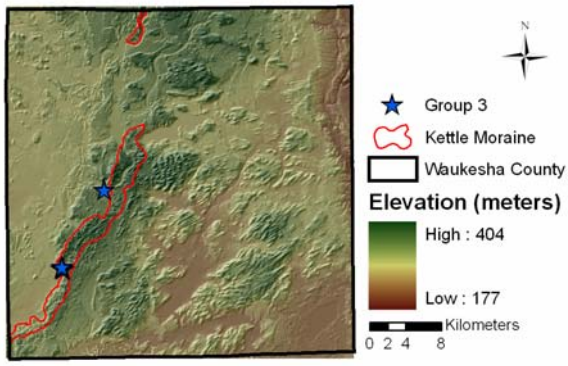



**Figure 9.** Distribution of Group 3 springs relative to the Kettle Moraine (after Clayton, 2001).

*Ecological Characteristics*

Ecological assessments of the 47 springs focus on qualitative descriptions macroinvertebrate diversity and quantitative measures of the diversity and distribution of vegetation. Invertebrates are widely used as indicators of water quality in streams, but no criteria currently exists for springs. Springer et al. (in prep.) state that a 95% inventory of aquatic macroinvertebrates may require five or more visits over two or more years. Even so, some general observations of macroinvertebrate diversity can be made on the basis of the sampling conducted during this study. Springs appear to support invertebrate communities that are similar to those observed in northwestern Illinois (Webb et al., 1998). Benthic fauna communities are dominated by non-insect taxa (Amphipoda, Isopoda, Gastropoda), although low numbers of aquatic insects (Tricoptera and Diptera) were found in most springs. Of note was the abundance of caddisfly larvae (Tricoptera) at the Highland spring and the prevalence of the terrestrial slug *Arion fasciatus***,** which was found in many of the Iowa County springs. As in other studies of cold-water spring fauna in the region (Webb et al., 1998), benthic invertebrate diversity in spring pools appears to be relatively low compared to other cold-water lotic communities, and downstream changes in diversity are expected due to variations in water temperature and chemistry, substrate, and flow regime (McCabe, 1998).

Ecological surveys that use rapid inventory techniques like those used in this study often assume that native invertebrate diversity will be reflected by native plant diversity (Crisp et al., 1998). Thorough baseline inventories of plants also require far fewer site visits than those needed for aquatic invertebrate inventories (Springer et al., in prep.). Although each of the springs in this study was visited only once, detailed descriptions of the type and prominence of plants were made. The types and proportions of geomorphic surfaces (e.g., pool, colluvial slope) were recorded, and the prominence of vegetative strata classes (e.g., tall canopy, herbaceous) were estimated within each surface type. In addition, species lists were generated and the prominence of each plant in each geomorphic surface type was recorded. Using these data, importance values (IV) and importance percentages (IP) for vascular plants by growth habit were calculated. The IV is the sum of the relative frequency of a given species and the relative coverage for that species; the IP is the IV divided by 2 and expressed as a percentage. Species with higher IVs are considered more dominant. Species lists by site and calculations of IV/IPs are provided in Appendix E.

To determine if patterns of plant diversity exist among springs, the percent cover for six vegetative strata cover classes were plotted for springs grouped by major stratigraphic unit (Fig. 10). Note that total cover can exceed 100% because canopy can coincide with other cover classes. In Iowa County, springs discharging from the stratigraphically higher Sinnipee Group are dominated by herbaceous plants. These

springs exist near ridge tops and edges of valleys where tree cover is relatively low. Dominance by trees (tall and mid-canopy) increases along valley slopes, which are often composed of the St. Peter Fm., the Prairie du Chien Group, or the Cambrian sandstones. Herbaceous plants are more dominant near valley bottoms. Herbaceous plants tend to dominate in Waukesha County, regardless of stratigraphic unit.

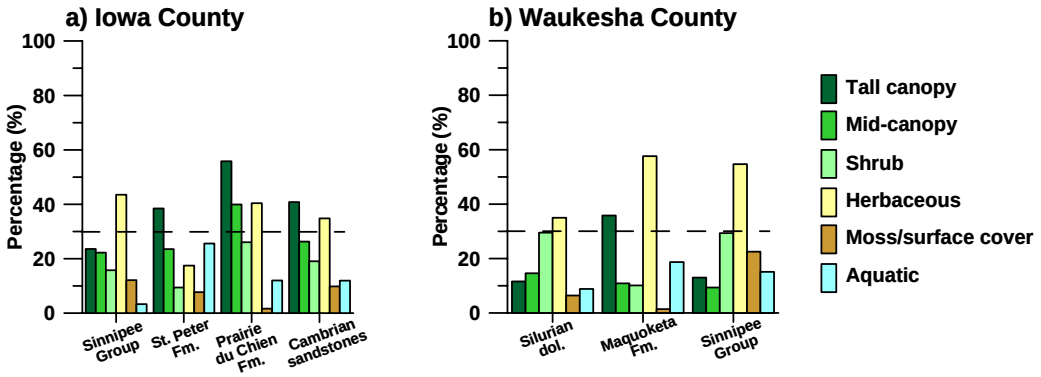



**Figure 10.** Distribution of Vegetative Strata Cover in a) Iowa County and b) Waukesha County.

For dominant vegetative strata cover classes within each stratigraphic group, i.e., those that exceed 30% cover (Fig. 10), Shannon's index of diversity (H'), the percent cover of native plants, and the percent cover of invasive plants were plotted (Appendix E). Results are similar among stratigraphic groups in Iowa County. Diversity ranges from 0.20 to 0.35 for trees (tall and mid-canopy) and herbaceous plants. The percent cover of native plants ranges from 65 to 100%, and the percent cover of invasive plants ranges from 10 to 38%. Results are also similar among stratigraphic groups of springs in Waukesha County, but diversity is generally higher for herbaceous plants (0.53 – 0.71). The percent cover of native plants ranges from 53 to 77%, and the percent cover of invasive plants is ranges from 21 to 52%.

## CONCLUSIONS AND RECOMMENDATIONS

*Status of Spring Ecosystems*

Iowa County is rich in spring resources, and any loss of spring resources over the last 50 years is minimal. When compared to springs in northwestern Illinois (Webb et al., 1998), the species richness and diversity for plants at the Iowa County springs appears to be a bit lower. However, the percent cover of native species is relatively high and the percent cover of invasives is relatively low. Agricultural and historical uses of spring water clearly impact the ecological status of springs in this region. Cattle currently have or have recently had direct access to nearly 30% of the springs that were surveyed, and three of the springs emerge from spring houses that were originally built as part of a farmstead.

Plant diversity is somewhat higher at the Waukesha County springs, but the percent cover of native plants is lower and the percent cover of invasive plants is higher. The historical use of spring water and associated modifications to springs in the City of Waukesha are very well-documented (Schoenknecht, 2003). None of the springs within the City of Waukesha were surveyed, but results suggest that the ecological status of springs elsewhere in the county has been similarly compromised by historical uses of the water. Approximately 45% of the springs surveyed have been significantly modified in some way. Some springs have pipes that direct flow and others have concrete boxes or spring houses that fully encase the spring and hinder recovery of the natural system.

*Conceptual Models and Vulnerability of Springs to Withdrawals*

Field data support conceptual models for springs in Iowa County that are based on typical contact springs, where water emerges along slopes and at lithologic contacts with differences in hydraulic conductivity. Springs are associated with every major stratigraphic unit in Iowa County, but are most commonly found in association with the Sinnipee Group, near the upper contact of the St. Peter Fm., or near the upper

contact of the Cambrian sandstones (Fig. 3, Appendix C). This indicates that aquifer heterogeneities like vertical and horizontal fractures, both of which are prevalent throughout the Sinnipee Group rocks, or partings along major stratigraphic contacts may be particularly important in promoting discrete flow in the region. There is some evidence that flow is more variable in springs discharging from stratigraphically higher geologic units, which supports a model that includes the influence of fractures. However, isotope levels and concentrations of most ions at these springs are relatively stable, indicating mixing along flow paths and/or a component of flow through porous media. In regions with high topographic relief, like Iowa County, groundwatersheds are more likely to coincide with surface watersheds (Toth, 1963). Therefore, stratigraphically higher springs may have small recharge areas that could be easily delineated by relying on topography. The wide range of nitrate concentrations in water discharging from these springs further supports the existence of small and shallow watersheds, where local land use influences geochemistry. There is also some evidence that flow is less variable in springs discharging from stratigraphically lower geologic units, which indicates longer or less direct flow paths. There is less variability in nitrate concentrations at these springs, and concentrations are generally lower. This indicates broader or deeper groundwatersheds, with a greater degree of mixing along flow paths.

The vulnerability to pumping of individual springs in Iowa County will require site-specific investigation because perched water tables and local aquitards are common in the Driftless Area (Krohelski et al., 2000). However, some generalizations can be made on the basis of the models presented above and the distribution of high-capacity wells in the county. Springs discharging from stratigraphically higher units are likely to be vulnerable to pumping from wells along ridge tops that are installed in these aquifers or that span multiple aquifers. Because recharge areas for these springs are probably small and shallow, pumping could result in substantially reduced spring flow or complete loss of flow to small springs. Springs discharging from stratigraphically lower units are probably less vulnerable, due in part to broader contributing areas, but also because most high-capacity wells that pump water from the Cambrian sandstones are located in the floodplain of the Wisconsin River, where few springs exist (Appendix F).

The spatial distribution of springs in Waukesha County is influenced by the glacial topography and the position of the Maquoketa shale subcrop. Springs were historically concentrated along the western margin of the Kettle Moraine and within the drumlinized zone the east (Fig. 2). Very few springs were mapped northwest of the Maquoketa shale subcrop, which is recognized as an important recharge area for the deep sandstone aquifer (Feinstein et al., 2005). The four geochemical groups of springs presented above require more thorough testing; however, results suggest that while flow paths originate in the unlithified aquifer, groundwater may flow through shallow bedrock before discharging as depression springs in low-lying wetlands or near streams. Regional flow modeling for southeastern Wisconsin supports this conceptual model, and shows local, topographically-controlled flow systems near the Kettle Moraine and other areas of relief. Particle tracking shows that groundwater intersects shallow bedrock before discharging to surface water bodies or at the water table (Feinstein et al., 2005). Although they are not explicitly modeled, groundwater may flow along similar paths to springs.

Feinstein et al. (2005) conclude that the widespread regional pumping in southeastern Wisconsin (Appendix F) has affected some shallow flow patterns, especially those west of the Maquoketa shale subcrop, and that downward flow from the shallow to the deep parts of the system occurs. Furthermore, their work shows that shallow high-capacity wells derive water primarily from diverted baseflow or induced flow from streams. Therefore, springs in Waukesha County are likely to be vulnerable to additional groundwater withdrawals from both the shallow and deep parts of the system. However, Group 3 springs are probably most vulnerable to withdrawals from the unlithified aquifer, and Group 1, 2, and 4 springs are most vulnerable to withdrawals from the shallow bedrock aquifer.

The approach to developing conceptual models of springs and assessing their vulnerability to pumping relies on gaining confidence in the positional accuracy of historical springs, as well as interpreting the

site-specific geochemical and spring flow data that were collected as part of this study. In Iowa County, 92% of the property owners that were interviewed confirmed the location of one or more springs on their property. Fewer springs remain in Waukesha County, but many owners recall the existence of a spring on their property in the past. Therefore, the overall confidence in historical spring locations is high, which allows their use in association with patterns of regional geology and topography. These regional data are complemented by the depth of the site-specific information collected using the Springer et al. (in prep.) system. At least 20 springs were surveyed in each county. This number of springs provided sufficient data to develop conceptual models and preliminarily assess vulnerability to pumping, suggesting that the overall approach may also be successful elsewhere in the state.

**REFERENCES**


Carter, J., in preparation, Investigation of perched and regional flow systems in bedrock aquifers, Iowa County, WI: Madison, WI, University of Wisconsin-Madison, M.S. Thesis.

Clayton, L., and Attig, J.W., 1997, Pleistocene geology of Dane County, WI: WGNHS Bulletin 95, 64p.

Clayton, L., 2001, Pleistocene geology of Waukesha County, WI: WGNHS Bulletin 99, 33p. plus map.

Craig, H., 1961, Isotopic variations in meteoric waters: Science, v. 133, no. 3465, p. 1702-1703.

Crisp, P.N., Dickinson, K.J.M., and Gibbs, G.W., 1998, Does native invertebrate diversity reflect native plant diversity?: Biological Conservation, vol. 83, no. 2, p.209-220.

DeGeoffroy, J., 1969, Geochemical prospecting by spring sampling in the southwest Wisconsin zinc mining area: WGNHS Information Circular 10, 28p.

Feinstein, D.T., Hart, D.J., Krohelski, J.T., Eaton, T.T., Bradbury, K.R., 2005, Simulation of regional groundwater flow in southeastern Wisconsin, Report 2: Model results and interpretation: U.S.G.S. and WGNHS Final Administrative Report to the Southeast WI Regional Planning Commission, 63p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, NJ, Prentice-Hall, Inc., 604p.

Krohelski, J.T., Bradbury, K.R., Hunt, R.J., and Swanson, S.K., 2000, Numerical simulation of groundwater flow in Dane County, Wisconsin: WGNHS Bulletin 98, 31p.

McCabe, D.J., 1998, Biological communities in springbrooks, *in* Botosaneanu, L., ed., Studies in crenobiology: the biology of springs and springbrooks: Leiden, Backhuys Publishers, p. 221-228.

Meinzer, O.E., 1927, Large springs in the United States: U.S.G.S. Water-Supply Paper 557, 94p.

Mudrey, M.G., Jr., Brown, B.A., and Greenberg, J.K., 2007, Bedrock geologic map of Wisconsin: WGNHS State Map 18-DI, version 1.0, 1 CD-ROM.

Schoenknecht, J.M., 2003, The Great Waukesha Springs Era, 1868-1918: Waukesha, WI, , 322p.

Springer, A.E., Stevens, L.E., Anderson, D.E., Parnell, R.A., Kreamer, D.K., and Flora, S.P., in prep., A comprehensive springs classification system: integrating geomorphic, hydrogeochemical, and ecological criteria, *in* Stevens, L.E., and Meretsky, V.J., eds., Every last drop: ecology and conservation of springs ecosystems in North America: Tucson, University of Arizona Press.

Southwest WI Regional Planning Commission (SWWRPC), 2005, Iowa County Comprehensive Plan: SWWRPC Planning Report No. 05/188.

Swanson, S.K., Bahr, J.M., Schwar, M.T., and Potter, K.W., 2001. Two-way cluster analysis of geochemical data to constrain spring source waters: Chemical Geology vol., 179, no. 1-4, p.73-91.

Swanson, S.K., Bahr, J.M., and Potter, K.W., 2006. A local meteoric water line for Madison, Wisconsin: WGNHS Open File Report 2006-01, 4 p.

Toth, J., 1963, A theoretical analysis of groundwater flow in small drainage basins: Journal of Geophysical Research, vol. 68, p.4795-4812.

Wadsworth, R., and Treweek, J., 1999, Geographical Information Systems for Ecology: Essex, England, Addison Wesley Longman Limited, 184p.

Waukesha County Department of Parks and Land Use, Land Resources Division, 2006, Waukesha County Land and Water Resource Management Plan 2006 – 2010: Waukesha, WI, 92p.

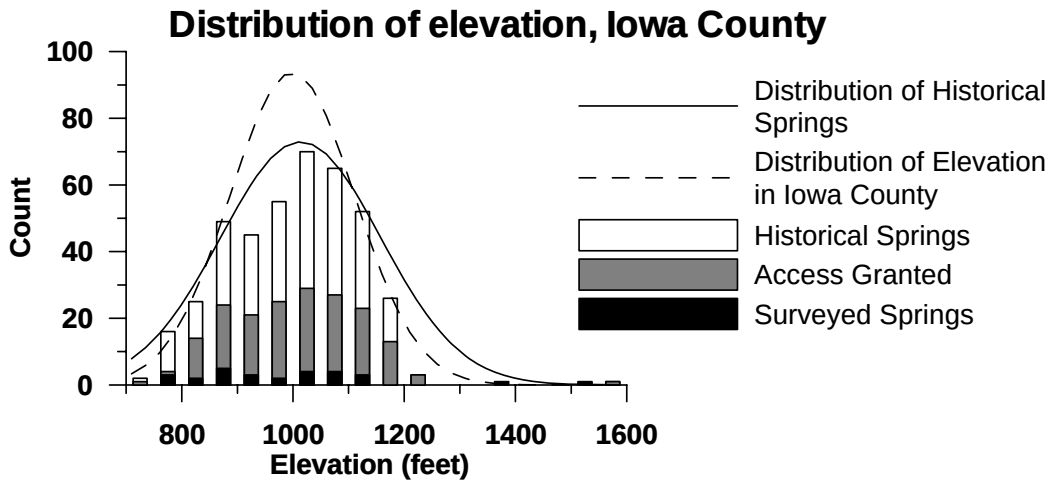
Webb, D.W., Wetzel, M.J., and Phillippe, L.R., 1998, The aquatic biota and groundwater quality of springs in the Lincoln Hills, Wisconsin Driftless, and Northern Till Plains of Illinois: Illinois Natural History Survey, Center for Biodiversity Technical Report 1998 (6), 164p.

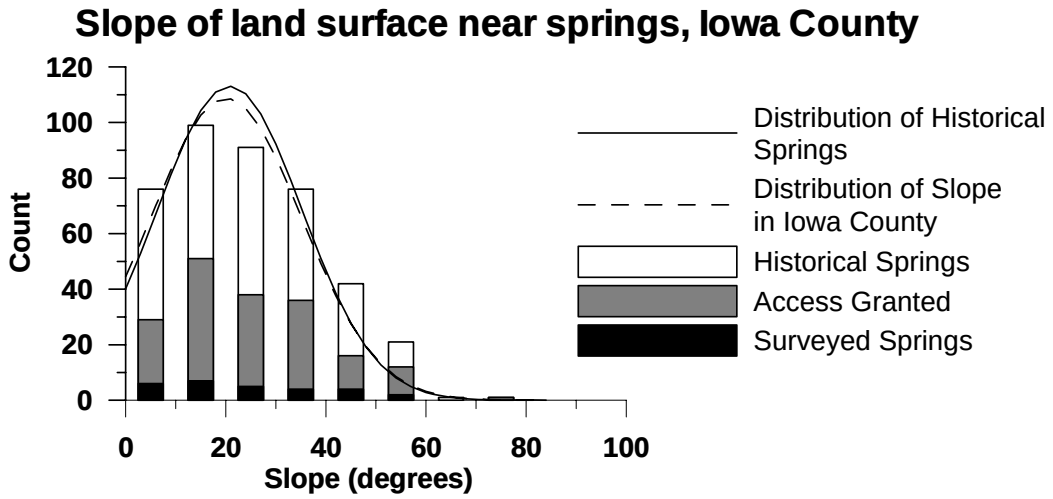
## APPENDIX A: Presentations and Awards

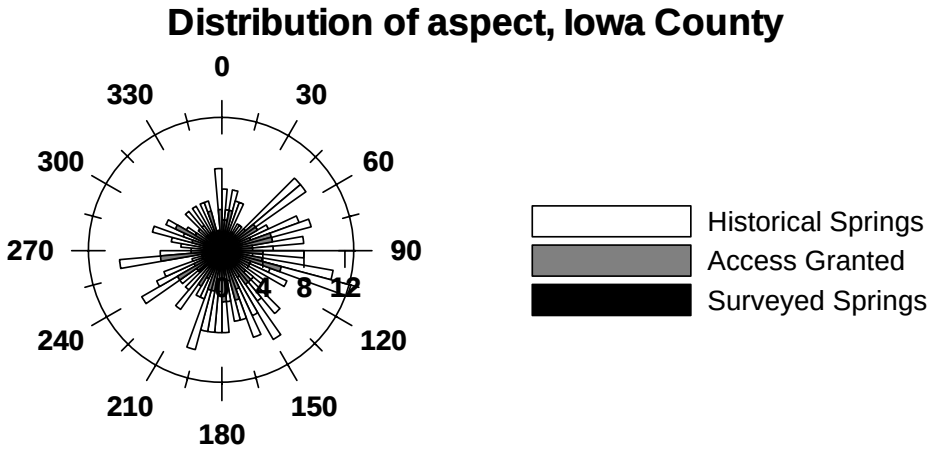
Swanson, S.K., March 2007. Assessing the ecological significance and vulnerability of springs in southern Wisconsin, American Water Resources Association - Wisconsin Section Annual Meeting, Wisconsin Dells, Wisconsin.

*Outstanding Undergraduate Presentation Award:*
Bartkowiak, B.M. and Swanson, S.K., March 2007. Geochemical and flow characteristics of two contact springs in Iowa County, Wisconsin, American Water Resources Association - Wisconsin Section Annual Meeting, Wisconsin Dells, Wisconsin.

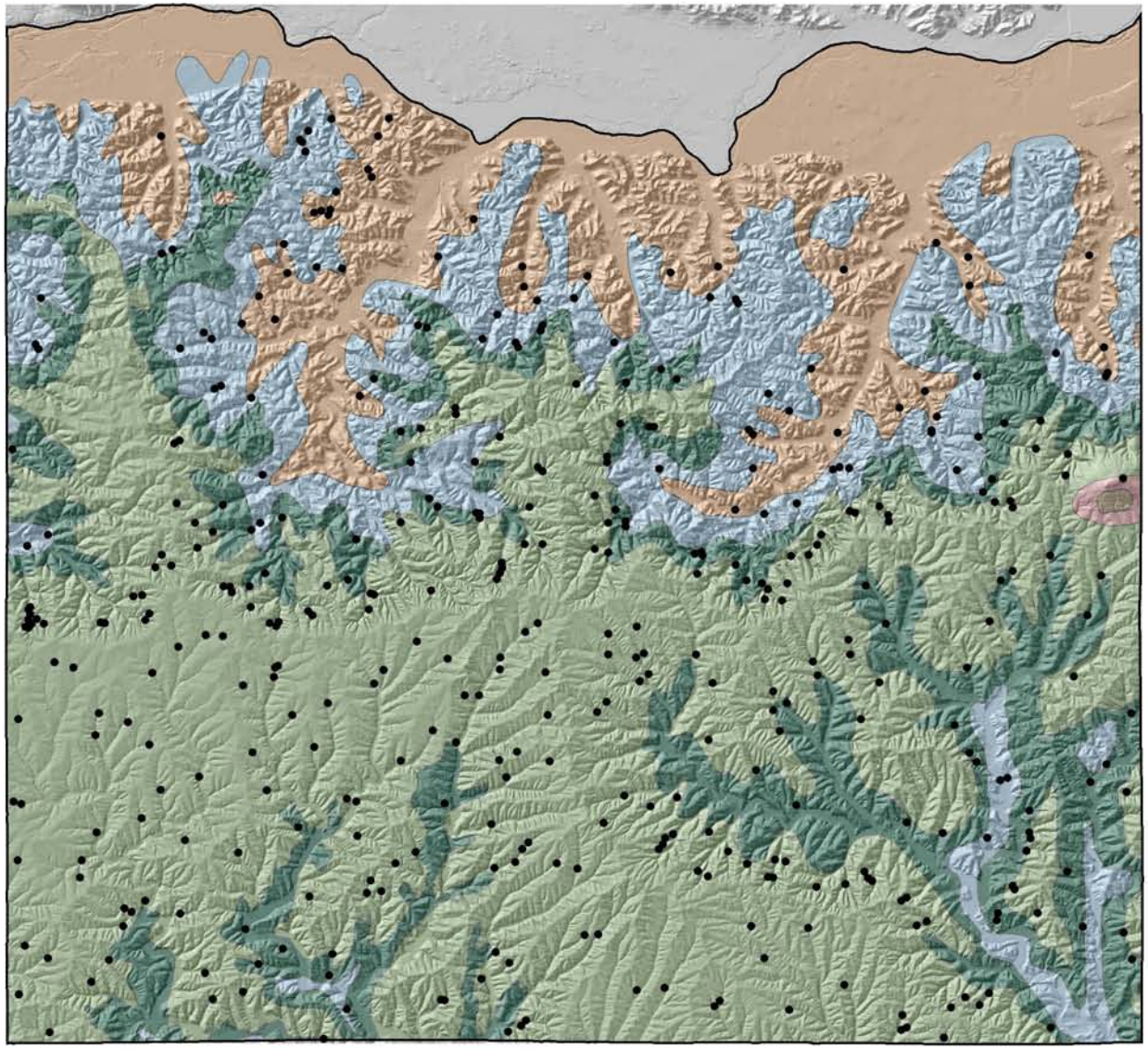
**APPENDIX C: Regional Information on the Distribution of Springs in Iowa County**



# *Distribution of Springs and Bedrock Geology in Iowa County, Wisconsin*



***Legend***

- Historical springs
- County boundary
- Silurian dolomite
- Maquoketa Formation
- Sinnipee Group
- Ancell Group (St. Peter Fm.)
- Prairie du Chien Group
- Cambrian sandstones

N

0 2.5 5 10 Kilometers

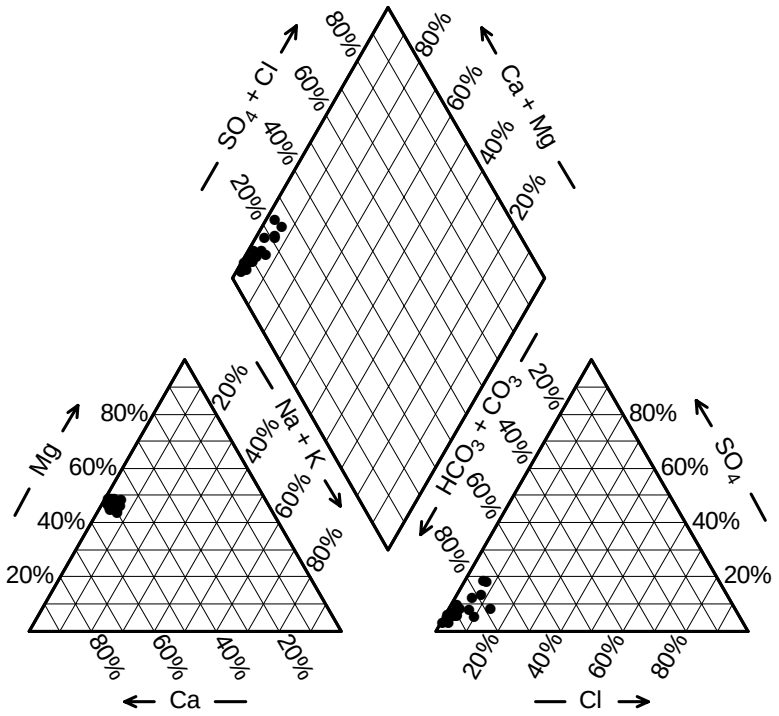
Source Information: Bedrock geology according to Mudrey et al., 2007.

Distribution of springs according to a 1958 survey by the Wisconsin Conservation Department.

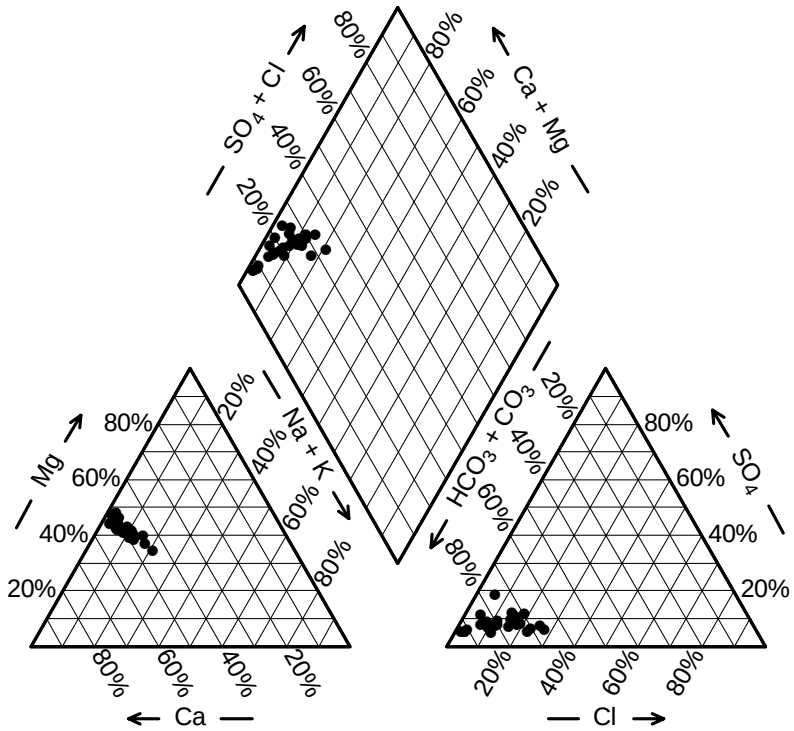
Drafted by Sue Swanson.
June 2007.

**APPENDIX D: Geochemistry Results and Charts**

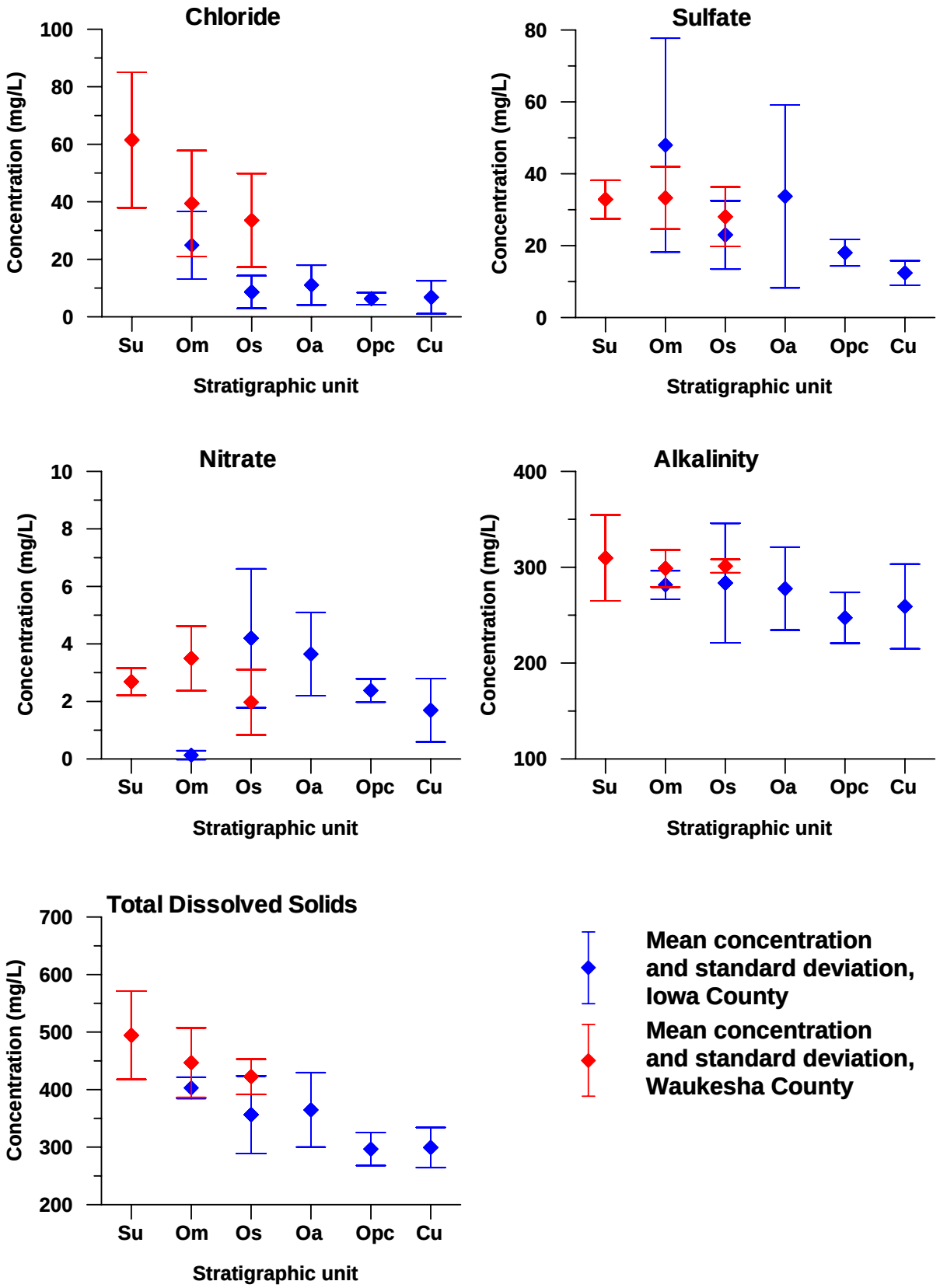
**Piper Diagram for Iowa County Springs**

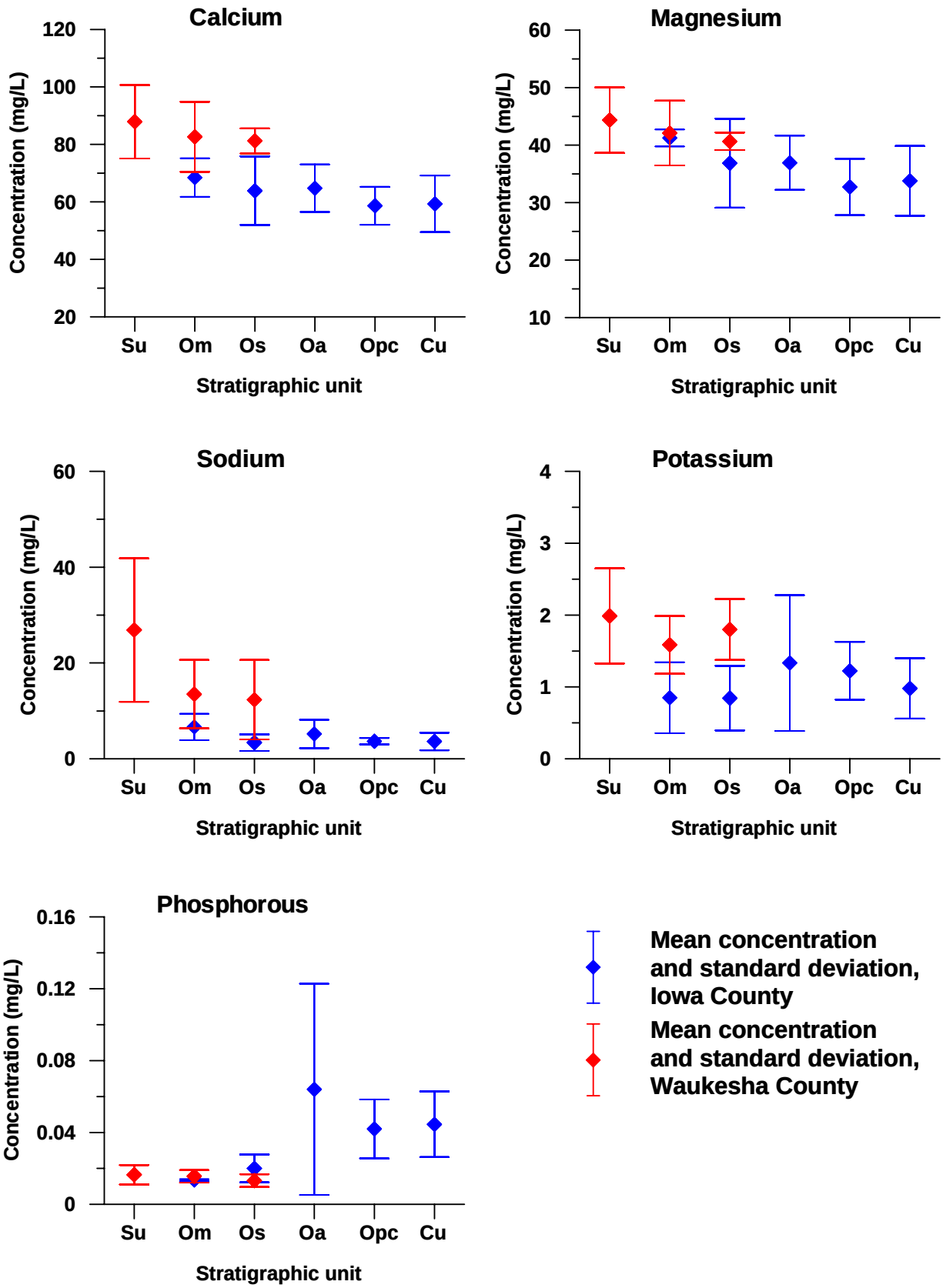


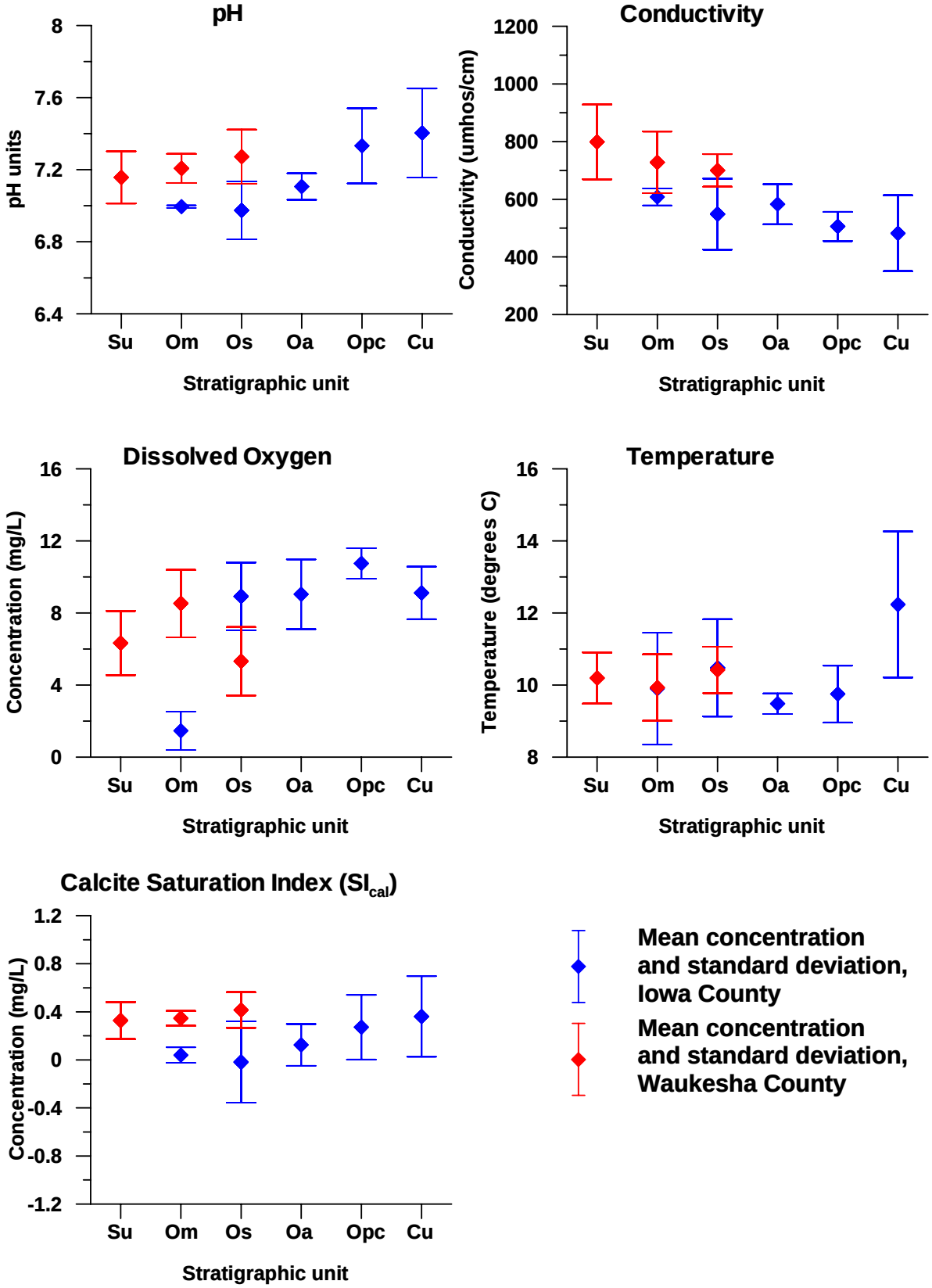

**Piper Diagram for Waukesha County Springs**



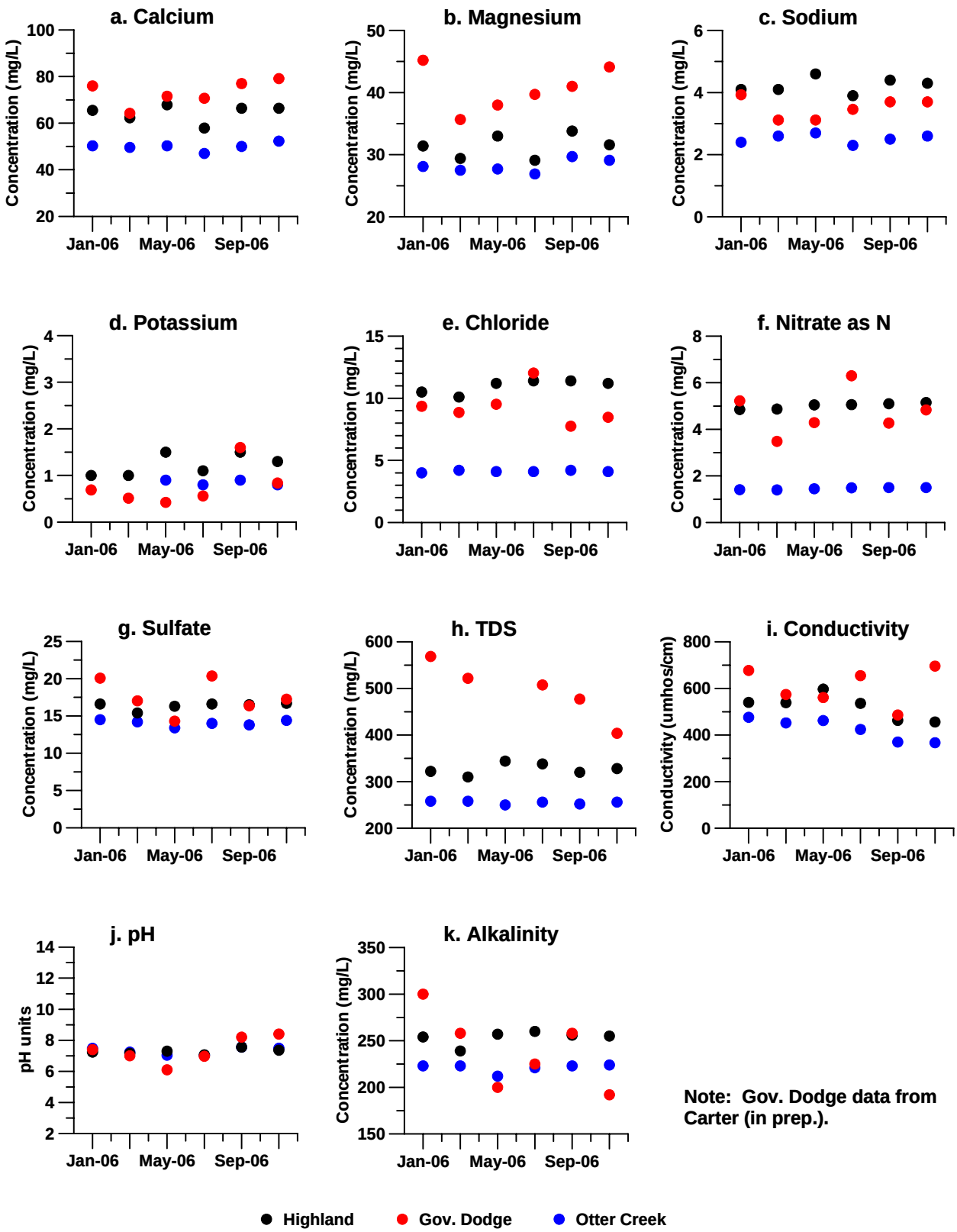
## Geochemical Results for Spring Surveys in Iowa and Waukesha Counties




Calcium
Concentration (mg/L)
120
100
80
60
40
20
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Magnesium
Concentration (mg/L)
60
50
40
30
20
10
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Sodium
Concentration (mg/L)
60
40
20
0
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Potassium
Concentration (mg/L)
4
3
2
1
0
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Phosphorous
Concentration (mg/L)
0.16
0.12
0.08
0.04
0
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Mean concentration and standard deviation, Iowa County
Mean concentration and standard deviation, Waukesha County

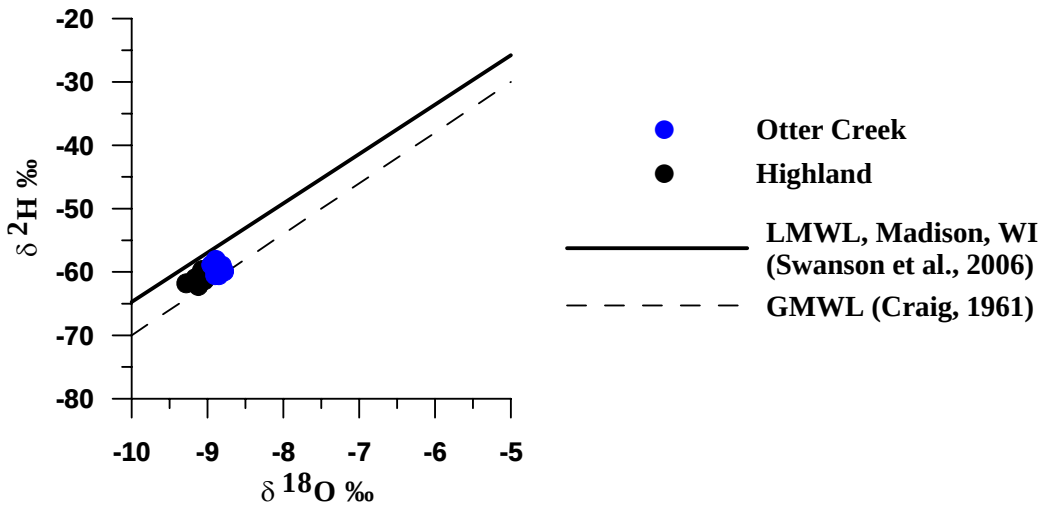

pH
pH units
8
7.6
7.2
6.8
6.4
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Conductivity
Conductivity (umhos/cm)
1200
1000
800
600
400
200
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Dissolved Oxygen
Concentration (mg/L)
16
12
8
4
0
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Temperature
Temperature (degrees C)
16
14
12
10
8
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Calcite Saturation Index ($SI_{cal}$)
Concentration (mg/L)
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
Su
Om
Os
Oa
Opc
Cu
Stratigraphic unit
Mean concentration and standard deviation, Iowa County
Mean concentration and standard deviation, Waukesha County

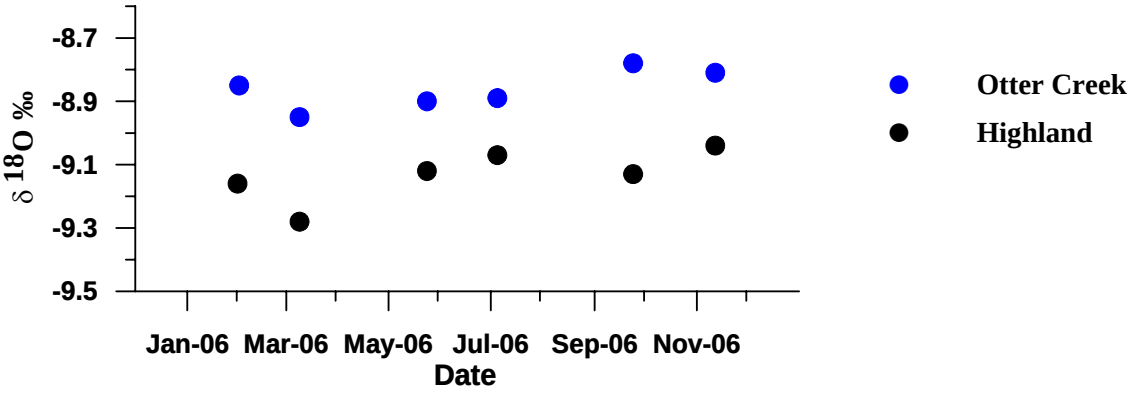
# Geochemical Results for Springs near Highland, Otter Creek and Gov. Dodge State Park

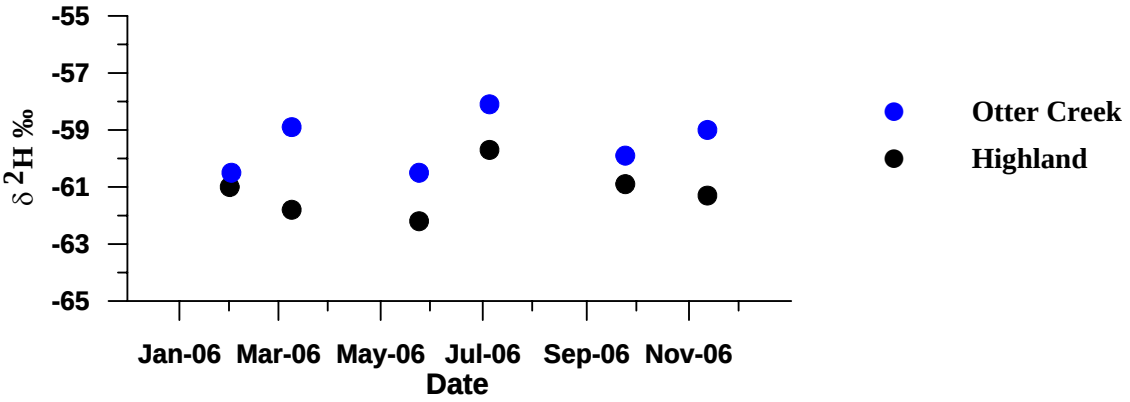



Note: Gov. Dodge data from Carter (in prep.).

**Stable Isotope Results for Springs near Highland and Otter Creek, Iowa County**

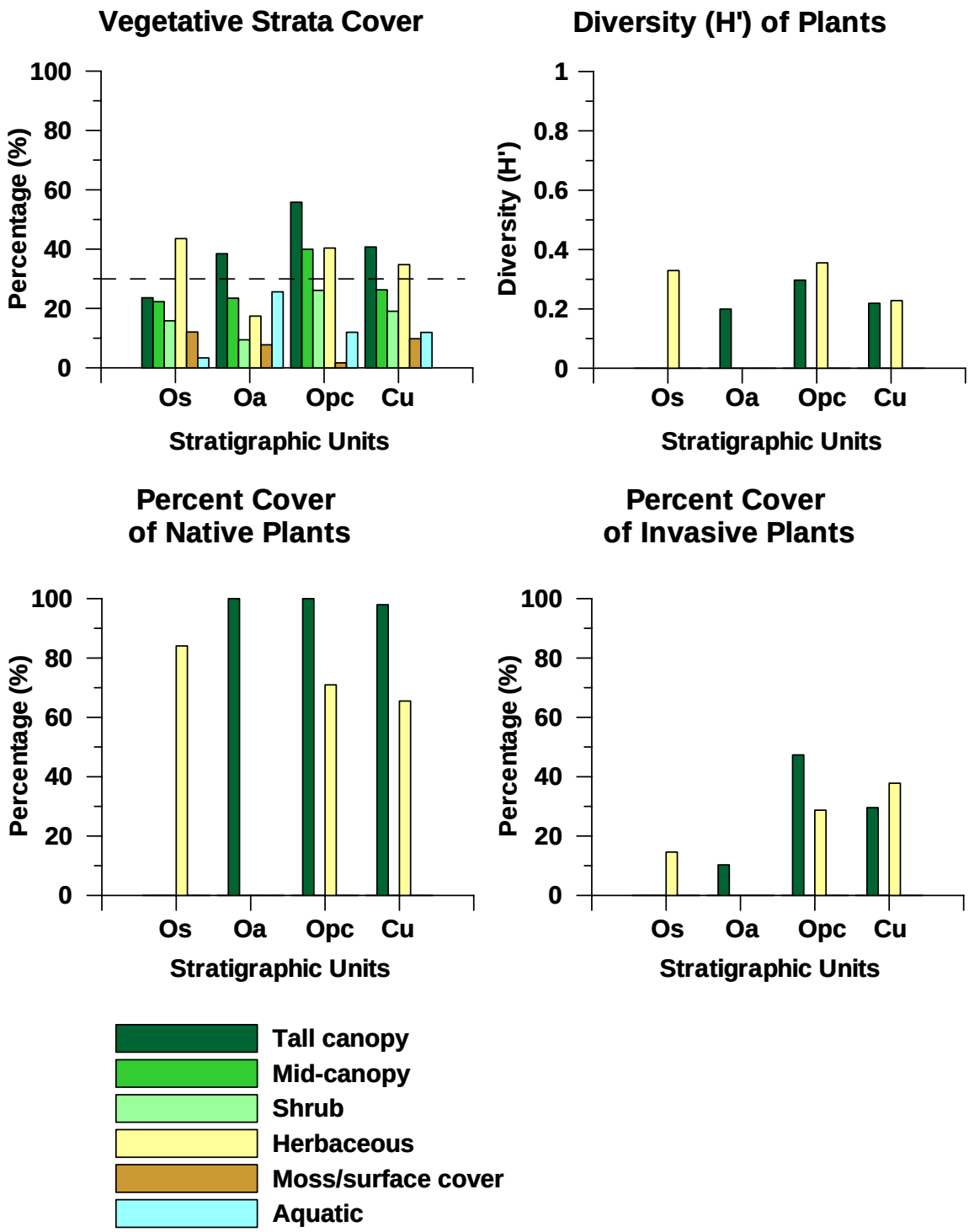


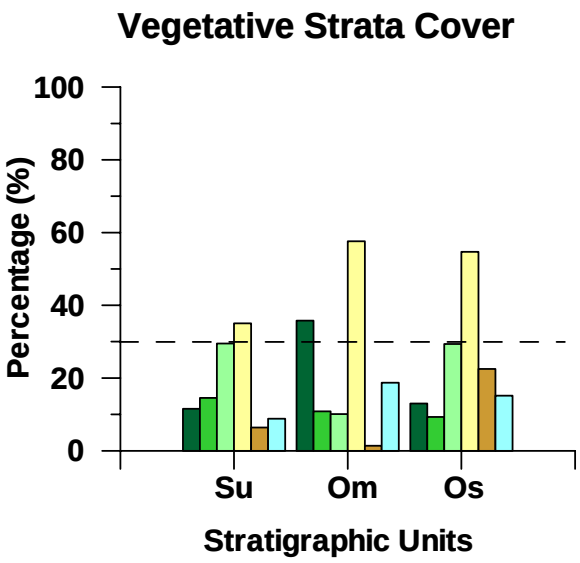



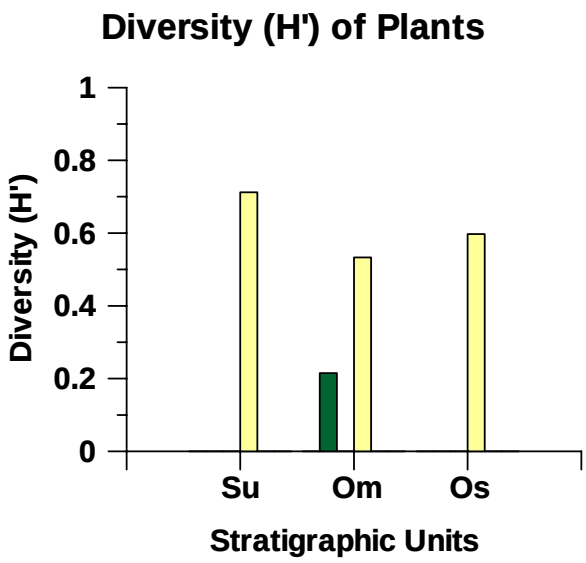
**Appendix E: Vegetation Diversity Charts, Plant Species Lists, and Importance Values**

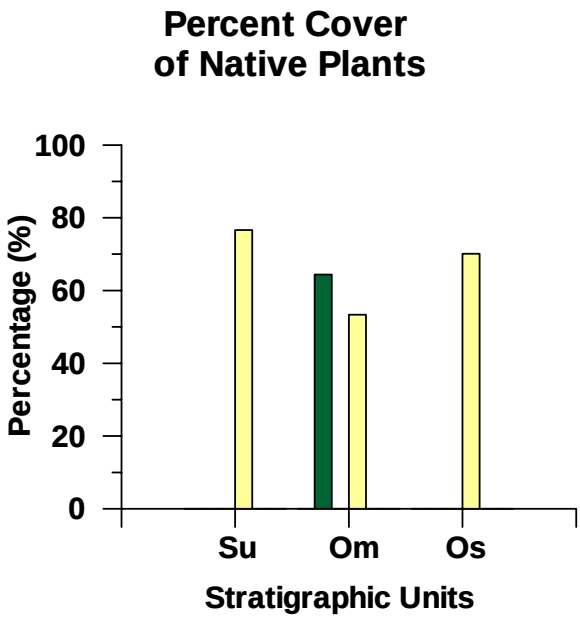
**Iowa Vegetation Diversity Charts**

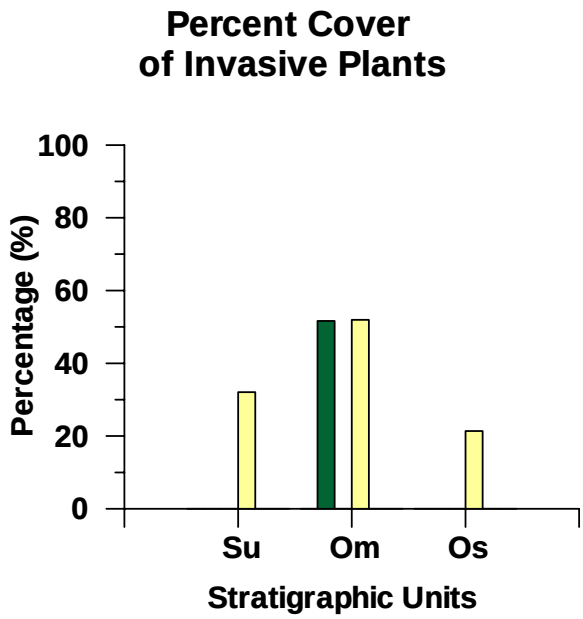


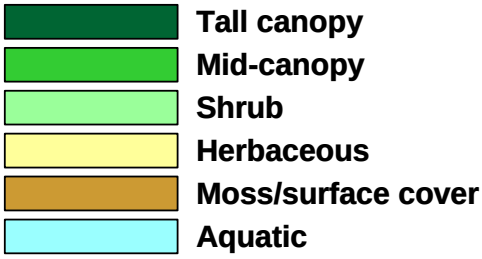
**Waukesha Vegetation Diversity Charts**



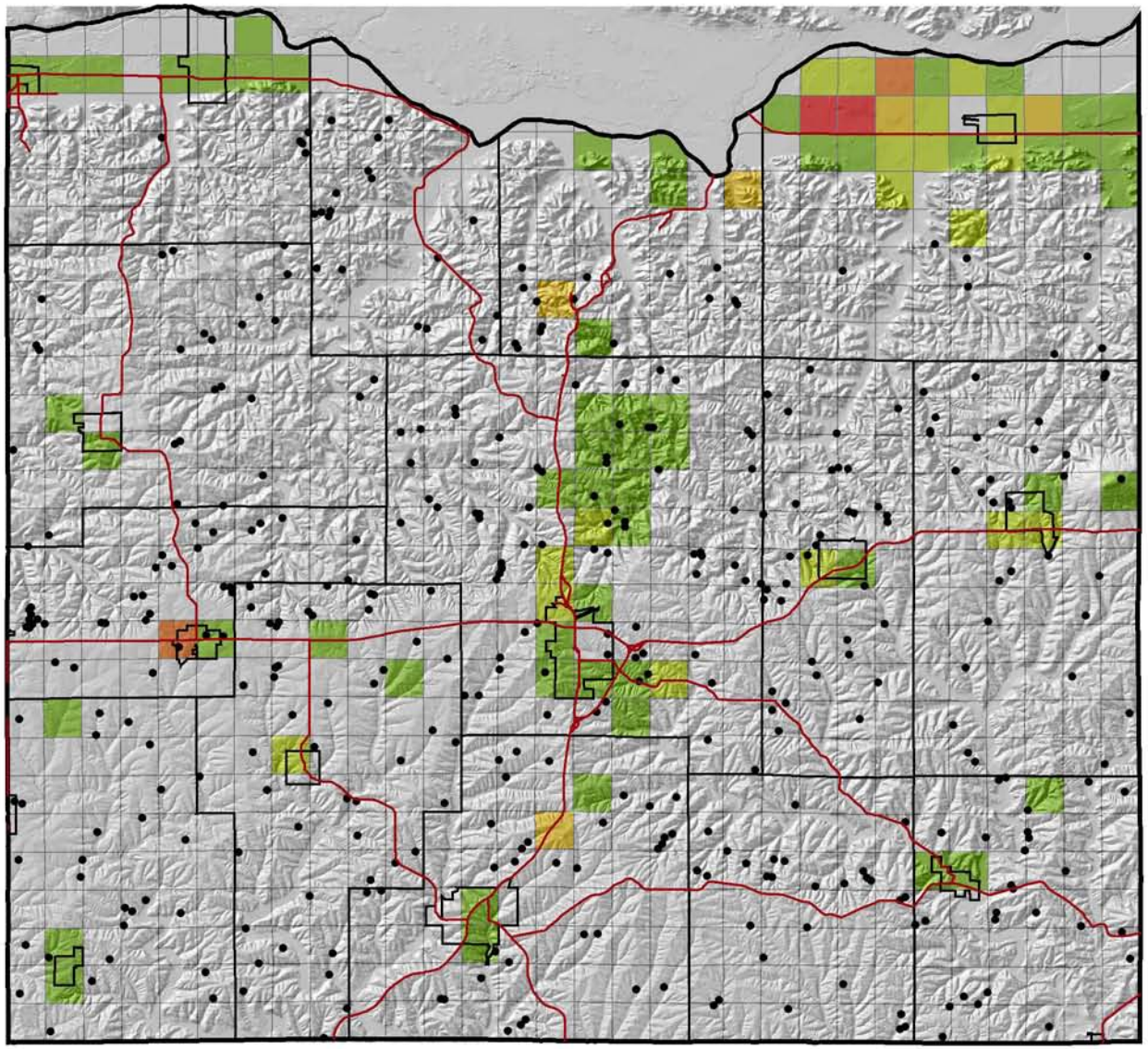



## APPENDIX F: Distribution of Springs and High-Capacity Wells in Iowa and Waukesha Counties

# *Distribution of Springs and High-Capacity Wells in Iowa County, Wisconsin*



***Legend***

- County boundary
- Municipalities
- Roads
- Historical springs

**Number of high-capacity wells**

- 0
- 1 - 2
- 3 - 4
- 5 - 6
- 7 - 8
- 9 - 10

N

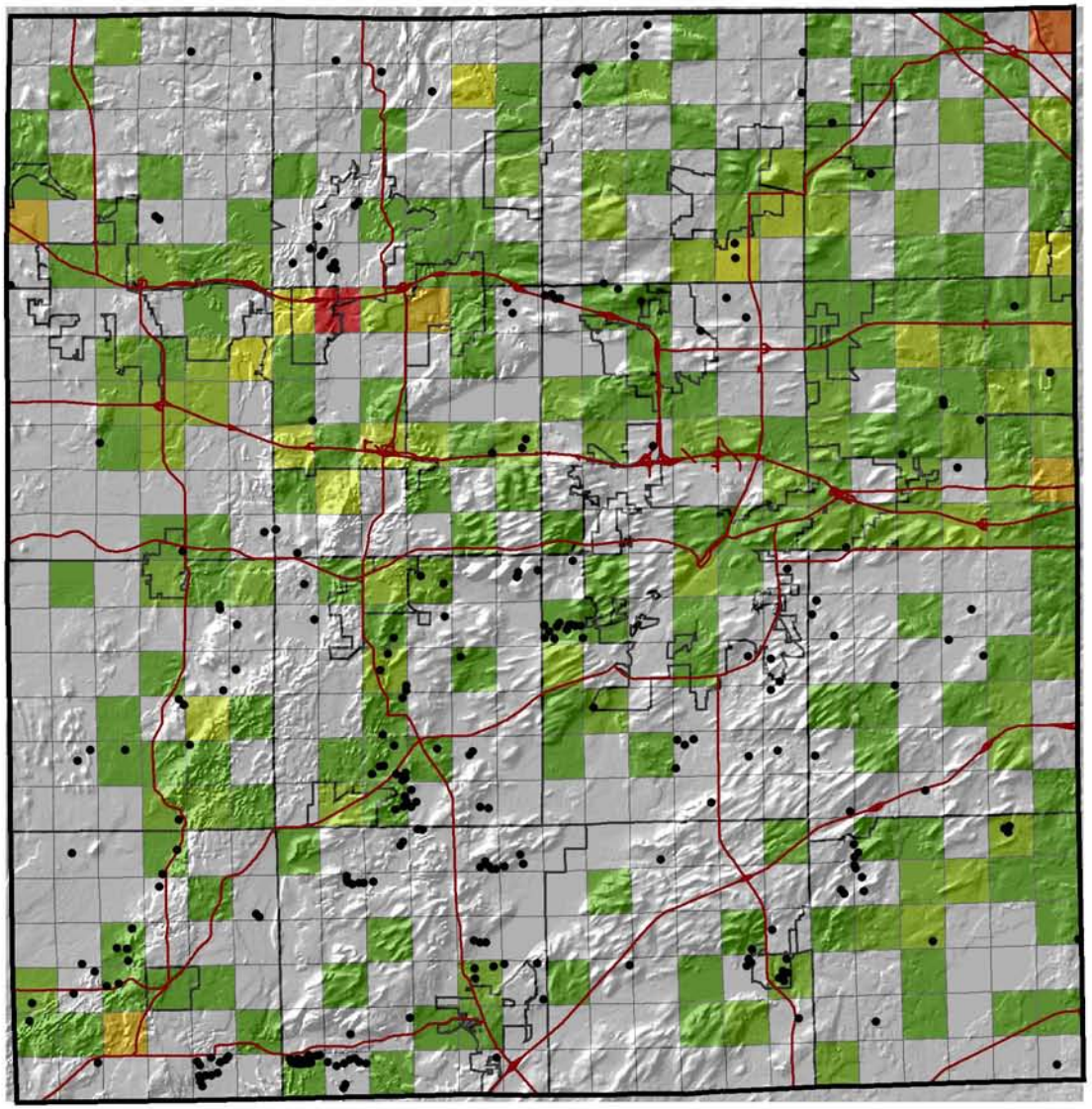
0 2.5 5 10 Kilometers

Source Information: Distribution of high-capacity wells by section, according to the WDNR Drinking Water database for high capacity wells. Wells are not differentiated by depth.

Distribution of springs according to a 1958 survey by the Wisconsin Conservation Department.

Drafted by Sue Swanson.
June 2007.

# *Distribution of Springs and High-Capacity Wells in Waukesha County, Wisconsin*



***Legend***

- Roads
- Municipalities
- County boundary
- Historical springs

**Number of high-capacity wells**

- 0
- 1 - 2
- 3 - 4
- 5 - 6
- 7 - 8
- 9 - 10
- 11 - 12
- 13 - 14
- 15 - 16
- 17 - 18
- 19 - 20

N

0 2.5 5 10 Kilometers

Source Information: Distribution of high-capacity wells by section, according to the WDNR Drinking Water database for high capacity wells. Wells are not differentiated by depth.

Distribution of springs according to a 1958 survey by the Wisconsin Conservation Department.

Drafted by Sue Swanson.
June 2007.

## APPENDIX G: Acknowledgements

This work was supported by the UW-Water Resources Institute, the USGS, and the WDNR. We thank the many property owners who assisted in this effort by sharing information and allowing access to their springs. We also thank Paul Ohlrogge (UW-Extension) and the many other county and state personnel who contributed background information. Sincere thanks to Dr. Yaffa Grossman (Beloit College), who provided assistance with interpretation of ecological data. Brandon Bartkowiak, Becky Carvin, Natalie Hunt, and David Zaber also provided valuable assistance in the field.

# Identifying High−Infiltration and Groundwater Recharge Areas

## Basic Information

| | |
|---|---|
| **Title:** | Identifying High−Infiltration and Groundwater Recharge Areas |
| **Project Number:** | 2006WI146G |
| **Start Date:** | 9/1/2006 |
| **End Date:** | 8/31/2008 |
| **Funding Source:** | 104G |
| **Congressional District:** | 2nd |
| **Research Category:** | Ground−water Flow and Transport |
| **Focus Category:** | Models, Groundwater, Water Quantity |
| **Descriptors:** | None |
| **Principal Investigators:** | Stephen J. Ventura, John Norman, Cynthia A. Stiles |

## Publication

# Annual Progress Report

**Selected Reporting Period:** 7/1/2007 - 6/30/2008

**Submitted By:** Steve Ventura
**Submitted:** 7/9/2008

## Project Title

WR06R004: Identifying High-Infiltration and Groundwater Recharge Areas

## Project Investigators

John Norman, University of Wisconsin-Madison
Cynthia Stiles, University of Wisconsin-Madison
Stephen Ventura, University of Wisconsin-Madison

## Progress Statement

In Summer 2007, we measured infiltration rates at 20 locations in a watershed in western Dane County. The sites were selected with a random spatial pattern in the watershed. Sites were selected to represent nine classes created from the combination of two variables with three levels each: estimated Ksat (low, medium and high) and land use (agricultural, residential and open). For this stratification, Ksat estimates were made using the textural class and bulk density of the surface horizon for the corresponding soil mapping units in the NASIS database. A table of national averages for Ksat in each textural class of both high and low bulk density was used to estimate Ksat. Land uses categories were determined from a GIS data layer developed by the Dane County Regional Planning Commission from 2005 orthophotos.

At each site, two infiltration measurements were made using steel frames (1m long, 0.5m wide, 0.3m deep and 0.3cm thick), which were placed 2 to 3 meters apart. A pond depth of approximately 5cm was established and maintained in each frame until the steady-state infiltration rate is reached, defined as three consecutive readings within 10% of each other with no clear trend. After the infiltration measurements were completed, soil cores (7.5cm diameter) were taken by hand at four depths: 0-15cm, 15-30cm, 30-45cm, and 45-60cm from the center of each frame. Soil samples (0-15cm) were analyzed in the laboratory for particle size (hydrometer method), bulk density and organic matter. Steady-state infiltration rates (assumed to be the average of the last three measurements taken) were converted to Ksat using the equations given by Reynolds (1993).

## Principal Findings and Significance

**Description**

For the 40 infiltration measurements taken in 2007, the average calculated Ksat steady-state infiltration rate was 221mm/hr. Ksat values ranged from 931mm/hr (a forested site that has been undisturbed since 1937) to 21 mm/hr (an agricultural field that has been planted in corn since 1975). The average Ksat value calculated for three land use categories was 90 mm/hr for Agriculture, 220 mm/hr for Residential and 274 mm/hr for Open land. The high average Ksat values for residential land can be attributed to two extraordinarily samples – high infiltration rates measured above a septic system and in a mulched garden area with large trees.

The data collected for this project in 2007 suggest that topographic and land cover data improve our ability to predict measured infiltration rates in Dane County compared to using soil properties alone. Best subsets regression was done to identify the best predictors among multiple soil properties. For this data set, percent organic matter, percent sand, and texture (R-squared adjusted: 0.18) provided the strongest regression, though this is still a generally weak model. When terrain variables calculated from a Digital Elevation Model (DEM) and land cover data were added to the analysis, the highest R2 (adjusted) value increased to 0.67 for the model that used the following predictors: percent organic matter, percent clay, elevation, aspect, planform curvature, and land cover. While this model still only accounts for about two-thirds of the variability of measured Ksat values, this analysis suggests that predictions of infiltration rates should be based on land cover and topographic information in addition to soil properties. Land cover information appears to be particularly valuable. In the regression analyses performed on the 2007 data, land cover was the best single predictor of measured infiltration rates.

## Committees, Memberships & Panels

| | |
|---|---|
| **Group Name** | National Cooperative Soil Survey |
| **Description** | This work was presented and discussed during an ad hoc committee meeting in Madison, WI. |
| **Start Date** | 6/6/2007 |
| **End Date** | 6/7/2007 |

## Interactions

| | |
|---|---|
| **Description** | We have been in contact with Chuck Dunning, a Hydrologist at the USGS Water Science Center in Middleton, Wisconsin. Chuck is leading a project to establish a state standard for measuring infiltration rates in Wisconsin in order to design management practices to promote infiltration of stormwater runoff. He is planning to determine if a single-ring infiltrometer (10 inch diameter) is an appropriate device for such a standard. At three of the locations where we measured infiltration rates in 2007, a student working with Chuck joined us and measured infiltration rates using both a single and double-ring infiltrometer. |
| **Event Date** | 9/1/2007 |

## Other Project Support

| | |
|---|---|
| **Source** | National Center for Rural Geospatial Innovations (USDA-CSREES) |
| **Dollar Value** | $ |
| **Description** | In-kind technical and GIS support for the project. |
| **Start Date** | |
| **End Date** | |

## Partners

| | |
|---|---|
| **Name/Organization** | Michelle Richardson |
| **Affiliation** | Dane County Land and Water Resources Department |

| | |
|---|---|
| **Affiliation Type** | Local & State |
| **Email** | michelle.richardson@co.dane.wi.us |
| **Description** | Michelle provided the GIS data layers of land use and parcels in Dane County. These were used extensively in the site selections for the infiltration measurements made in 2007. |

## Presentations & Public Appearances

| | |
|---|---|
| **Title** | Identifying High Infiltration and Ground Water Recharge Areas in Dane County, Wisconsin - an Integrated Field/GIS Study. |
| **Presenter(s)** | Stiles, Cynthia A. |
| **Presentation Type** | Professional meeting |
| **Event Name** | National Cooperative Soil Survey Conference. |
| **Event Location** | Madison, WI. |
| **Event Date** | 6/6/2007 |
| **Target Audience** | Federal agency |
| **Audience Size** | 20 |
| **Description** | This presentation provided and overview of the goals of the project and the field work planned for 2007. |

## Students & Post-Docs Supported

| | |
|---|---|
| **Student Name** | Kathleen Arrington |
| **Campus** | University of Wisconsin-Madison |
| **Advisor Name** | Steve Ventura |
| **Advisor Campus** | University of Wisconsin-Madison |
| **Degree** | PhD |
| **Graduation Month** | May |
| **Graduation Year** | 2009 |
| **Department** | Soil Science |
| **Program** | Soil Science |
| **Thesis Title** | |
| **Thesis Abstract** | |

# Grant No. 07HQGR0025 Effectiveness of Engineered Covers: From Modeling to Performance Monitoring

## Basic Information

| | |
|---|---|
| **Title:** | Grant No. 07HQGR0025 Effectiveness of Engineered Covers: From Modeling to Performance Monitoring |
| **Project Number:** | 2006WI179S |
| **Start Date:** | 12/1/2006 |
| **End Date:** | 1/15/2009 |
| **Funding Source:** | Supplemental |
| **Congressional District:** | 2 |
| **Research Category:** | Engineering |
| **Focus Category:** | Solute Transport, Models, None |
| **Descriptors:** | landfills |
| **Principal Investigators:** | Craig H Benson |

## Publication

# Annual Progress Report

**Selected Reporting Period:** 7/1/2007 - 6/30/2008

**Submitted By:** Craig Benson
**Submitted:** 7/9/2008

## Project Title

WR06R005: Effectiveness of Engineered Covers: From Modeling to Performance Monitoring

## Project Investigators

Craig Benson, University of Wisconsin-Madison

## Progress Statement

Please note that this project is collaborative with the project "ACAP Test Section Exhumation." Thus, the summary and findings are the same.

The overall objective of this project is to gather information needed to project the long-term performance of final covers and to interpret the performance of the landfill final cover test sections that were constructed and monitored as part of the Alternative Cover Assessment Program (ACAP). This information has been gathered as we have exhumed the ACAP test sections over the last 24 months. During each exhumation, we have conducted field hydraulic conductivity tests to evaluate how the properties of the final cover soils have changed, conducted geomorphological and vegetative surveys to understand how structure in the final cover soils has developed and how the plant community has evolved, and have collected large-scale undisturbed samples of the soil and geosynthetics for laboratory testing.

To date, we have exhumed 22 of the 28 ACAP test sections along with a full-scale final cover (non-ACAP) in Eau Claire, Wisconsin (2007). We will exhume three test sections in Omaha, Nebraska in May 2008. In addition, three ACAP test sections in Underwood, North Dakota in July 2008, and three in Helena/Polson, Montana in August 2008. We will also be sampling a full-scale final cover in Michigan in July 2008 (not part of ACAP) that contains a GCL installed beneath a geomembrane. The exhumations conducted this summer will complete the field component of the research program.

## Principal Findings and Significance

**Description**

The field and laboratory testing has shown that the hydraulic properties of final cover soils change in response to pedogenic processes that affect soil structure. These changes occur fairly rapidly (within 3-5 yr) and their magnitude is a function of the initial structure of the soil (larger changes in hydraulic properties occur for soils that are denser and less conductive when initially placed). An overall loosening of the soil occurs, which results in an increase in saturated hydraulic conductivity, as well as an increase in soil water storage capacity. In addition, the hydraulic properties converge to a relatively narrow band after several years of weathering. In particular, regardless of the initial condition, the saturated hydraulic conductivity ultimately falls within 10-4 to 10-3 cm/s, van

Genuchten's alpha parameter falls within 0.01-0.1 kPa-1, and van Genuchten's n parameter falls within 1.2-1.5.

These findings have two important practical implications for alternative covers. First, the universally narrow ranges for the hydraulic properties reduce the uncertainty in predictions of long-term cover performance and build confidence in alternative cover technology. Second, the findings suggest that alternative cover soils should not be densely compacted, and should be constructed with less plastic fine-textured soils when possible. Adopting both of these recommendations for cover soil selection and placement will result in covers that undergo smaller changes in hydraulic behavior over time, and therefore will exhibit more uniform performance over time.

Changes in the properties of geosynthetic materials have been less significant (except for geosynthetic clay liners). Wide-width tensile strengths, melt flow indices, and oxidation induction times of the geomembranes have remained essentially unchanged during the ACAP study. Small reductions (2x) in the transmissivity of geocomposite drainage layers have been observed. The permittivity of the overlying and underlying geotextiles in geocomposite drainage layers has also diminished modestly (2-3x) due to intrusion of fines. These changes are not significant enough to affect performance in the near term. However, performance may be affected over decades or centuries, which can be important for wastes with very long life spans (e.g., radionuclides). Interface shear strengths have remained essentially unchanged. However, appreciable reductions in the ply adhesion of geocomposite drainage layers have been observed at several sites, which may have implications for long-term stability.

Significant increases in the hydraulic conductivity of geosynthetic clay liners (GCLs) have been observed in some cases. These occurrences are generally in applications where the GCL was not overlain with a geomembrane, and are due to replacement of native Na in the bentonite with divalent cations (predominantly Ca, but also Mg) combined with hydration and dehydration processes. However, at one site where the GCL was covered with a geomembrane, manganese oxide precipitated along bundles of needle-punching fibers, resulting in preferential flow paths and an apparent hydraulic conductivity on the order of 10-5 cm/s (see Fig. 1, attached). We are currently working on identifying the most important mechanisms affecting these changes in hydraulic conductivity, particularly the dominant mechanisms in covers where the GCL is covered by a geomembrane

## Awards, Honors & Recognition

| | |
|---|---|
| **Title** | J. James Croes Medal |
| **Event Year** | |
| **Recipient** | |
| **Presented By** | ASCE |
| **Description** | |

## Committees, Memberships & Panels

| | |
|---|---|
| **Group Name** | US Department of Energy |
| **Description** | Chair, Independent Technical Review Committee for On-Site Disposal Facilities |
| **Start Date** | |
| **End Date** | |

| | |
|---|---|
| **Group Name** | ASTM |
| **Description** | D18 Executive Committee |
| **Start Date** | |
| **End Date** | |

| | |
|---|---|
| **Group Name** | Geo Institute |
| **Description** | Board of Governors |
| **Start Date** | |
| **End Date** | |

## Interactions

| | |
|---|---|
| **Description** | This project is a collaborative effort between the US Nuclear Regulatory Commission, US National Science Foundation, US Department of Energy, US Environmental Protection Agency, and the Environmental Research and Education Foundation. The Desert Research Institute of Reno, NV and California Polytech University are collaborators |
| **Event Date** | |

## Other Project Support

| | |
|---|---|
| **Source** | Multilple Agencies |
| **Dollar Value** | $ |
| **Description** | This project is benefiting from funding being provided by the following agencies as part of a collaborative effort to understand the temporal evolution of the characteristics of landfill final covers: US National Science Foundation, US Nuclear Regulatory Commission, US Department of Energy, US Environmental Protection Agency, and the Environmental Research and Education Foundation. |
| **Start Date** | |
| **End Date** | |

## Partners

| | |
|---|---|
| **Name/Organization** | William H. Albright |
| **Affiliation** | Desert Research Institute |
| **Affiliation Type** | Academic Institutions |
| **Email** | bill@dri.edu |
| **Description** | Co-PI |

## Presentations & Public Appearances

| | |
|---|---|
| **Title** | Design and Construction of Alternative Covers |
| **Presenter(s)** | |
| | Craig H. Benson, and William H. Albright Presentation Type: Workshop Event Name: Event location: |

Event Date: February 2008 Target Audience: Audience Size: 100 Description:

| | |
|---|---|
| **Presentation Type** | Workshop |
| **Event Name** | Design and Construction of Alternative Covers |
| **Event Location** | Portland, OR |
| **Event Date** | 2/1/2008 |
| **Target Audience** | Mixed |
| **Audience Size** | 100 |
| **Description** | 3-d workshop for engineering consultants, state regulators, and federal regulators |

## Students & Post-Docs Supported

| | |
|---|---|
| **Student Name** | Matthew Bennett |
| **Campus** | University of Wisconsin-Madison |
| **Advisor Name** | Craig Benson |
| **Advisor Campus** | University of Wisconsin-Madison |
| **Degree** | Masters |
| **Graduation Month** | December |
| **Graduation Year** | 2009 |
| **Department** | and Environmental Engineering |
| **Program** | Geo Engineering |
| **Thesis Title** | N/A |
| **Thesis Abstract** | N/A |

.....

| | |
|---|---|
| **Student Name** | Seunghak Lee |
| **Campus** | University of Wisconsin-Madison |
| **Advisor Name** | Craig Benson |
| **Advisor Campus** | University of Wisconsin-Madison |
| **Degree** | Post Doc |
| **Graduation Month** | April |
| **Graduation Year** | 2009 |
| **Department** | Civil and Environmental Engineering |
| **Program** | Geo Engineering |
| **Thesis Title** | N/A |
| **Thesis Abstract** | N/A |

.....

| | |
|---|---|
| **Student Name** | A. Hakan Oren |

| | |
|---|---|
| **Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Advisor Name** | Craig Benson |
| **Advisor Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Degree** | Post Doc |
| **Graduation Month** | August |
| **Graduation Year** | 2009 |
| **Department** | Civil and Environmental Engineering |
| **Program** | Geo Engineering |
| **Thesis Title** | N/A |
| **Thesis Abstract** | N/A |

.....

| | |
|---|---|
| **Student Name** | Paul Schlicht |
| **Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Advisor Name** | Craig Benson |
| **Advisor Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Degree** | Masters |
| **Graduation Month** | December |
| **Graduation Year** | 2009 |
| **Department** | Civil and Environmental Engineering |
| **Program** | Geo Engineering |
| **Thesis Title** | N/A |
| **Thesis Abstract** | N/A |

# Application of LSQR to Calibration of a Regional MODFLOW Model: Trout Lake Basin, Wisconsin

## Basic Information

| | |
|---|---|
| **Title:** | Application of LSQR to Calibration of a Regional MODFLOW Model: Trout Lake Basin, Wisconsin |
| **Project Number:** | 2006WI189O |
| **Start Date:** | 7/1/2006 |
| **End Date:** | 6/30/2007 |
| **Funding Source:** | Other |
| **Congressional District:** | 2nd |
| **Research Category:** | Ground−water Flow and Transport |
| **Focus Category:** | Groundwater, Hydrogeochemistry, None |
| **Descriptors:** | groundwater, modeling |
| **Principal Investigators:** | Mary Anderson |

## Publication


1. Muffels, C., M. Tonkin, H. Zhang, M. Anderson, T. Clemo. 2006. Application of LSQR to Calibration of a MODFLOW Model: A Synthetic Study. In, Managing Ground−Water Systems, International Ground Water Modeling Center, Colorado School of Mines Golden, Colorado Pages 283−287
2. Muffels, C. (in preparation, expected May 2008). A highly parameterized calibration of a groundwater flow model of the Trout Lake basin, Vilas County, Wisconsin. Master's thesis, Department of Geology and Geophysics, University of Wisconsin−Madison.

# Annual Progress Report

**Reporting Period:** 7/1/2006 - 6/30/2007

**Submitted By:** Mary Anderson
**Submitted:** 5/24/2007

## Project Title

WR06R003: Application of LSQR to Calibration of a Regional MODFLOW Model: Trout Lake Basin, Wisconsin

## Project Investigators

Mary Anderson, University of Wisconsin-Madison

Haiijang Zhang, University of Wisconsin-Madison

## Progress Statement

Our research addresses the need for new, improved calibration methods for predictive models. We focus on groundwater flow models and show how a technique known as LSQR, a matrix-equation solution technique, can be used to estimate parameters in a complex groundwater flow model of a system in northern Wisconsin. LSQR has been used to solve problems in geophysics; it is a powerful technique because it is able to solve inverse problems with many unknown parameters. In our research, LSQR was first used to solve a relatively simple synthetic linear groundwater model. Results from LSQR compared favorably with other inverse solutions.

An initial attempt to use LSQR (within PEST) with regularization to calibrate a complex groundwater flow model of a field situation, the Trout Lake basin in northern Wisconsin, was only partly successful. The calibration with LSQR successfully reduced the objective function but the resulting parameter set was unacceptable because many of the parameters were driven to their upper bounds. The Trout Lake model was restructured with more layers and a more explicit representation of the geology and explicit representation of low-lying wetland areas in an attempt to constrain parameters. LSQR is currently being used to calibrate the re-structured model and results will be compared with results from other inverse solution methods.

## Impacts

**Description**

Based on our initial successful testing of LSQR to solve inverse problems for groundwater flow, Dr. John Doherty, the developer of the well known and widely used parameter estimation code PEST, incorporated the LSQR method as a solution option in PEST. PEST can be downloaded free of charge. Hence, by using PEST, LSQR can be used for parameter estimation in other predictive groundwater models in Wisconsin and elsewhere.

## Interactions

**Description**

We are interacting with:
1. Dr. Randy Hunt, USGS, Middleton, WI
2. Dr. John Doherty of Watermark Numerical Computing, Brisbane, Australia;

| | |
|---|---|
| | 3. Mr. Matt Tonkin, S.S. Papdopulos and Associates;<br>4. Prof. Tom Clemo, Boise State University |
| **Event Date** | |

## Journal Articles & Other Publications

| | |
|---|---|
| **Publication Type** | Proceedings/Symposium |
| **Title** | Application of LSQR to Calibration of a MODFLOW Model: A Synthetic Study |
| **Author(s)** | Muffels, C., M. Tonkin, H. Zhang, M. Anderson, T. Clemo |
| **Publication/Publisher** | International Ground Water Modeling Center, Colorado School of Mines Golden, Colorado |
| **Year Published** | 2006 |
| **Volume & Number** | MODFLOW and More 2006, Managing Ground-Water Syste |
| **Number of Pages** | 283-287 |
| **Description** | Proceedings volume |
| **Any Additional Citation Information** | |

## Presentations & Public Appearances

| | |
|---|---|
| **Title** | LSQR and Tikhonov Regularization in the Calibration of a Complex MODFLOW Model |
| **Presenter(s)** | Muffels, C., J. Doherty, M. Anderson, R. Hunt, T. Clemo, M. Tonkin |
| **Presentation Type** | Poster session |
| **Event Name** | Geological Society of America Annual Meeting |
| **Event Location** | Pennsylvania Convention Center, Philadelphia PA |
| **Event Date** | 10/24/2006 |
| **Target Audience** | Mixed |
| **Audience Size** | 200 |
| **Description** | |

.....

| | |
|---|---|
| **Title** | Incorporating PROPACK into PEST to Estimate the Model Resolution Matrix for Large Groundwater Flow Models. |
| **Presenter(s)** | Muffels, C., H. Zhang, J. Doherty, R. Hunt, M. Anderson, M. Tonkin |
| **Presentation Type** | Poster session |
| **Event Name** | American Geophysical Union Fall Meeting |
| **Event Location** | San Francisco |
| **Event Date** | 12/12/2006 |
| **Target Audience** | Mixed |
| **Audience Size** | 200 |
| **Description** | |

.....

| | |
|---|---|
| **Title** | Regularized Inversion of a Groundwater Flow Model of the Trout Lake Basin. |

| | |
|---|---|
| **Presenter(s)** | Muffels, C., R. Hunt, J. Doherty, M. Anderson |
| **Presentation Type** | Professional meeting |
| **Event Name** | American Water Resources Association-Wisconsin Section |
| **Event Location** | Wisconsin Dells |
| **Event Date** | 3/1/2007 |
| **Target Audience** | Mixed |
| **Audience Size** | 150 |
| **Description** | oral presentation |

## Students & Post-Docs Supported

| | |
|---|---|
| **Student Name** | Christopher Muffels |
| **Campus** | University of Wisconsin-Madison |
| **Advisor Name** | Mary Anderson |
| **Advisor Campus** | University of Wisconsin-Madison |
| **Degree** | Masters |
| **Graduation Month** | December |
| **Graduation Year** | 2007 |
| **Department** | Geology & Geophysics |
| **Program** | MS |
| **Thesis Title** | Application of LSQR to Calibration of a Regional MODFLOW Model: Trout Lake Basin, Wisconsin |
| **Thesis Abstract** | not yet available |

# Enhanced Reductive Dechlorination of Chlorinated Aliphatic Hydrocarbons: Molecular and Biochemical Analyses

## Basic Information

| | |
|---|---|
| **Title:** | Enhanced Reductive Dechlorination of Chlorinated Aliphatic Hydrocarbons: Molecular and Biochemical Analyses |
| **Project Number:** | 2007WI164B |
| **Start Date:** | 7/1/2006 |
| **End Date:** | 6/30/2008 |
| **Funding Source:** | 104B |
| **Congressional District:** | 2nd |
| **Research Category:** | Water Quality |
| **Focus Category:** | Toxic Substances, Geochemical Processes, None |
| **Descriptors:** | |
| **Principal Investigators:** | Bill Hickey |

## Publication

# Annual Progress Report

**Selected Reporting Period:** 7/1/2007 - 6/30/2008

**Submitted By:** Ameesha Shetty
**Submitted:** 7/9/2008

## Project Title

WR06R002: Enhanced Reductive Dechlorination of Chlorinated Aliphatic Hydrocarbons: Molecular and Biochemical Analyses

## Project Investigators

William Hickey, University of Wisconsin-Madison

## Progress Statement

The objective accomplished during the period has been establishing microbial community profiles of the Enhanced Reductive Dechlorination (ERD) site samples. Automated Ribosomal Intergenic Sequence Analysis (ARISA) was used to understand the microbial community diversity. Samples were obtained from four different monitoring wells showing different stages and extent of dechlorination at four different time points over a year. The chemical changes in the groundwater differed, one location showing late stage dechlorination, with vinyl chloride (VC) being converted to ethene, whereas another displayed stalling at VC with little ethene being detected. The chemical profile of the wells changed with time as dechlorination proceeded. Cells in the groundwater samples were collected by filtration and DNA was extracted from them to use in ARISA. PCR was done using fluorescently labeled primers, and then the profile of fluorescent peaks for each sample was determined. Both Bacterial and Archaeal profiles have been established for the first three quarterly time points. ARISA is currently being carried out on the fourth quarter groundwater samples.
ARISA however provides information of community diversity but does not define community structure since organisms cannot be identified. 16S-ITS Clone libraries were set up for identification of the organisms represented by major peaks on the community profiles, or were consistently present over time. The DNA extracted from the groundwater samples was used to amplify the 16S-ITS regions of the template. These were then used for ligation and transformation to set up the clone libraries. The clones were screened and the ones that contain the ARISA fragment of interest were sequenced. Sequence similarities with the 16S gene were used for organism identification. These clone libraries have been used to identify some of the major peaks seen in the microbial community profiles of two of the sampling wells showing dechlorination to ethene (i.e. late stage dechlorination). Identification of the peaks in the VC stalled well (i.e. early stage reactions) is currently being worked on. Genus-level identification could not be obtained but class and family affiliations of the peaks could be determined. Once the Archaeal communities are identified, a complete picture of the microbial diversity at various stages of dechlorination will be obtained.

## Principal Findings and Significance

## Principal Findings and Significance

**Description**

ARISA has been used to study the changes occurring in the microbial communities as dechlorination proceeds. Shifts in community profile have been seen, corresponding with chemical changes in the groundwater. The major objective accomplished by this, is obtaining a snapshot of the microbial community dynamics in field samples, in response to dechlorination. In one of the sampling wells,

showing good late stage dechlorination, the same two dominant peaks were seen to be present at different time points. The peaks were identified as being related to Bacteroidetes family and Spirochaetes class respectively. Organisms belonging to this family have previously seen to be present in TCE degrading consortia and involved in breakdown of sugars as well as co-metabolism. Another well, also showing late stage dechlorination was assessed in a similar way. The major peaks seen in the community profile for this sample were different from the other well showing similar chemical changes. Two peaks were identified as being related to Clostridia and Psuedomonas family respectively. Therefore different families of organisms maybe involved depending on which ones were bio-stimulated upon electron donor augmentation. Certain families of organisms can be seen to be associated with reductive dechlorination processes. Work is currently being done on identification of the major organisms in samples showing only early stage and no late dechlorination. Identification of archaeal communities is also in progress. This information will help determine the differences in microbial community profiles involved in early and late stage reactions, both in terms of diversity and structure. This study also helps characterize a field community as different stages of dechlorination over time since samples are obtained from field as ERD is being carried out. Most of the community data obtained in other studies have involved enrichment cultures and consortia. This study helps track the changes in community profiles in field samples and with samples collected over a span of a year. A better understanding of the microbial players involved in ERD processes in field, will help determine why some dechlorination processes go to completion whereas some stall at earlier stages. This will strengthen the application of ERD for bioremediation of chlorinated aliphatic hydrocarbons.

## Students & Post-Docs Supported

| | |
|---|---|
| **Student Name** | Ameesha Shetty |
| **Campus** | University of Wisconsin-Madison |
| **Advisor Name** | William Hickey |
| **Advisor Campus** | University of Wisconsin-Madison |
| **Degree** | PhD |
| **Graduation Month** | |
| **Graduation Year** | |
| **Department** | Molecular and Environmental Toxicology Center |
| **Program** | Molecular and Environmental Toxicology |
| **Thesis Title** | |
| **Thesis Abstract** | |

# Grant No. 08HQGR0001 Alternative Cover Guidance Document

## Basic Information

| | |
|---|---|
| **Title:** | Grant No. 08HQGR0001 Alternative Cover Guidance Document |
| **Project Number:** | 2007WI199S |
| **Start Date:** | 10/1/2007 |
| **End Date:** | 9/30/2008 |
| **Funding Source:** | Supplemental |
| **Congressional District:** | 02 |
| **Research Category:** | Engineering |
| **Focus Category:** | Radioactive Substances, Groundwater, None |
| **Descriptors:** | |
| **Principal Investigators:** | Craig H Benson, Craig H Benson |

## Publication

# Annual Progress Report

**Selected Reporting Period:** 7/1/2007 - 6/30/2008

**Submitted By:** Craig Benson
**Submitted:** 7/9/2008

## Project Title

WR07R010: Alternative Cover Guidance Document

## Project Investigators

Craig Benson, University of Wisconsin-Madison

## Progress Statement

This project is focused on preparing a guidance document regarding design, construction, monitoring, and performance assessment of alternative covers for landfills. As of 29-Feb-08, we had prepared a detailed outline for the guidance document and have drafted some of the primary sections.

## Principal Findings and Significance

**Description**

This document is intended to provide engineers and scientists in the design and regulatory communities with the information s needed to effectively design, construct, monitor, and assess of alternative covers for landfills. When complete, this document will become the definitive source of information on the technology.

## Interactions

**Description**

This project involves interaction with Region 8 of US EPA and state environmental regulators in Colorado, Wyoming, and Montana.

**Event Date**

## Other Project Support

**Source** Multiple Agencies

**Dollar Value** $

**Description**

This project is benefiting from funding being provided by the following agencies as part of a

collaborative effort to understand the temporal evolution of the characteristics of landfill final covers: US National Science Foundation, US Nuclear Regulatory Commission, US Department of Energy, US Environmental Protection Agency, and the Environmental Research and Education Foundation.

**Start Date**
**End Date**

## Partners

| | |
|---|---|
| **Name/Organization** | William H. Albright |
| **Affiliation** | Desert Research Institute |
| **Affiliation Type** | Academic Institutions |
| **Email** | bill@dri.edu |
| **Description** | Co-PI |

## Presentations & Public Appearances

| | |
|---|---|
| **Title** | Design and Construction of Alternative Covers |
| **Presenter(s)** | Craig H. Benson, and William H. Albright Presentation Type: Workshop Event Name: Event location: Event Date: February 2008 Target Audience: Audience Size: 100 Description: |
| **Presentation Type** | Workshop |
| **Event Name** | Design and Construction of Alternative Covers |
| **Event Location** | Portland, OR |
| **Event Date** | 2/1/2008 |
| **Target Audience** | Mixed |
| **Audience Size** | 100 |
| **Description** | 3-d workshop for engineering consultants, state regulators, and federal regulators |

# Grant No. 07HQGR0170 ACAP Test Section Exhumation

## Basic Information

| | |
|---|---|
| **Title:** | Grant No. 07HQGR0170 ACAP Test Section Exhumation |
| **Project Number:** | 2007WI200S |
| **Start Date:** | 8/15/2007 |
| **End Date:** | 12/31/2008 |
| **Funding Source:** | Supplemental |
| **Congressional District:** | 02 |
| **Research Category:** | Engineering |
| **Focus Category:** | Radioactive Substances, Groundwater, None |
| **Descriptors:** | |
| **Principal Investigators:** | Craig H Benson, Craig H Benson |

## Publication

# Annual Progress Report

**Selected Reporting Period:** 7/1/2007 - 6/30/2008

**Submitted By:** Craig Benson
**Submitted:** 7/9/2008

## Project Title

WR07R009: ACAP Test Section Exhumation

## Project Investigators

Craig Benson, University of Wisconsin-Madison

## Progress Statement

Please note that this project is collaborative with the project "Effectiveness of Engineered Covers: From Modeling to Performance Monitoring." Thus, the summary and findings are the same.

The overall objective of this project is to gather information needed to project the long-term performance of final covers and to interpret the performance of the landfill final cover test sections that were constructed and monitored as part of the Alternative Cover Assessment Program (ACAP). This information has been gathered as we have exhumed the ACAP test sections over the last 24 months. During each exhumation, we have conducted field hydraulic conductivity tests to evaluate how the properties of the final cover soils have changed, conducted geomorphological and vegetative surveys to understand how structure in the final cover soils has developed and how the plant community has evolved, and have collected large-scale undisturbed samples of the soil and geosynthetics for laboratory testing.

To date, we have exhumed 22 of the 28 ACAP test sections along with a full-scale final cover (non-ACAP) in Eau Claire, Wisconsin (2007). We will exhume three test sections in Omaha, Nebraska in May 2008. In addition, three ACAP test sections in Underwood, North Dakota in July 2008, and three in Helena/Polson, Montana in August 2008. We will also be sampling a full-scale final cover in Michigan in July 2008 (not part of ACAP) that contains a GCL installed beneath a geomembrane. The exhumations conducted this summer will complete the field component of the research program.

## Principal Findings and Significance

**Description**

The field and laboratory testing has shown that the hydraulic properties of final cover soils change in response to pedogenic processes that affect soil structure. These changes occur fairly rapidly (within 3-5 yr) and their magnitude is a function of the initial structure of the soil (larger changes in hydraulic properties occur for soils that are denser and less conductive when initially placed). An overall loosening of the soil occurs, which results in an increase in saturated hydraulic conductivity, as well as an increase in soil water storage capacity. In addition, the hydraulic properties converge to a relatively narrow band after several years of weathering. In particular, regardless of the initial condition, the saturated hydraulic conductivity ultimately falls within 10-4 to 10-3 cm/s, van

Genuchten's alpha parameter falls within 0.01-0.1 kPa-1, and van Genuchten's n parameter falls within 1.2-1.5.

These findings have two important practical implications for alternative covers. First, the universally narrow ranges for the hydraulic properties reduce the uncertainty in predictions of long-term cover performance and build confidence in alternative cover technology. Second, the findings suggest that alternative cover soils should not be densely compacted, and should be constructed with less plastic fine-textured soils when possible. Adopting both of these recommendations for cover soil selection and placement will result in covers that undergo smaller changes in hydraulic behavior over time, and therefore will exhibit more uniform performance over time.

Changes in the properties of geosynthetic materials have been less significant (except for geosynthetic clay liners). Wide-width tensile strengths, melt flow indices, and oxidation induction times of the geomembranes have remained essentially unchanged during the ACAP study. Small reductions (2x) in the transmissivity of geocomposite drainage layers have been observed. The permittivity of the overlying and underlying geotextiles in geocomposite drainage layers has also diminished modestly (2-3x) due to intrusion of fines. These changes are not significant enough to affect performance in the near term. However, performance may be affected over decades or centuries, which can be important for wastes with very long life spans (e.g., radionuclides). Interface shear strengths have remained essentially unchanged. However, appreciable reductions in the ply adhesion of geocomposite drainage layers have been observed at several sites, which may have implications for long-term stability.

Significant increases in the hydraulic conductivity of geosynthetic clay liners (GCLs) have been observed in some cases. These occurrences are generally in applications where the GCL was not overlain with a geomembrane, and are due to replacement of native Na in the bentonite with divalent cations (predominantly Ca, but also Mg) combined with hydration and dehydration processes. However, at one site where the GCL was covered with a geomembrane, manganese oxide precipitated along bundles of needle-punching fibers, resulting in preferential flow paths and an apparent hydraulic conductivity on the order of 10-5 cm/s (see Fig. 1, attached). We are currently working on identifying the most important mechanisms affecting these changes in hydraulic conductivity, particularly the dominant mechanisms in covers where the GCL is covered by a geomembrane.

## Awards, Honors & Recognition

| | |
|---|---|
| **Title** | J. James Croes Medal |
| **Event Year** | |
| **Recipient** | |
| **Presented By** | ASCE |
| **Description** | |

## Committees, Memberships & Panels

| | |
|---|---|
| **Group Name** | US Department of Energy |
| **Description** | Chair, Independent Technical Review Committee for On-Site Disposal Facilities |
| **Start Date** | |
| **End Date** | |

| | |
|---|---|
| **Group Name** | ASTM |
| **Description** | D18 Executive Committee |
| **Start Date** | |
| **End Date** | |

| | |
|---|---|
| **Group Name** | Geo Institute |
| **Description** | Board of Governors |
| **Start Date** | |
| **End Date** | |

## Interactions

| | |
|---|---|
| **Description** | This project is a collaborative effort between the US Nuclear Regulatory Commission, US National Science Foundation, US Department of Energy, US Environmental Protection Agency, and the Environmental Research and Education Foundation. The Desert Research Institute of Reno, NV and California Polytech University are collaborators |
| **Event Date** | |

## Other Project Support

| | |
|---|---|
| **Source** | Multilple Agencies |
| **Dollar Value** | $ |
| **Description** | This project is benefiting from funding being provided by the following agencies as part of a collaborative effort to understand the temporal evolution of the characteristics of landfill final covers: US National Science Foundation, US Nuclear Regulatory Commission, US Department of Energy, US Environmental Protection Agency, and the Environmental Research and Education Foundation. |
| **Start Date** | |
| **End Date** | |

## Partners

| | |
|---|---|
| **Name/Organization** | William H. Albright |
| **Affiliation** | Desert Research Institute |
| **Affiliation Type** | Academic Institutions |
| **Email** | bill@dri.edu |
| **Description** | Co-PI |

## Presentations & Public Appearances

| | |
|---|---|
| **Title** | Design and Construction of Alternative Covers |
| **Presenter(s)** | Craig H. Benson, and William H. Albright Presentation Type: Workshop Event Name: Event location: |

Event Date: February 2008 Target Audience: Audience Size: 100 Description:

| | |
|---|---|
| **Presentation Type** | Workshop |
| **Event Name** | Design and Construction of Alternative Covers |
| **Event Location** | Portland, OR |
| **Event Date** | 2/1/2008 |
| **Target Audience** | Mixed |
| **Audience Size** | 100 |
| **Description** | 3-d workshop for engineering consultants, state regulators, and federal regulators |

## Students & Post-Docs Supported

| | |
|---|---|
| **Student Name** | Matthew Bennett |
| **Campus** | University of Wisconsin-Madison |
| **Advisor Name** | Craig Benson |
| **Advisor Campus** | University of Wisconsin-Madison |
| **Degree** | Masters |
| **Graduation Month** | December |
| **Graduation Year** | 2009 |
| **Department** | and Environmental Engineering |
| **Program** | Geo Engineering |
| **Thesis Title** | N/A |
| **Thesis Abstract** | N/A |

.....

| | |
|---|---|
| **Student Name** | Seunghak Lee |
| **Campus** | University of Wisconsin-Madison |
| **Advisor Name** | Craig Benson |
| **Advisor Campus** | University of Wisconsin-Madison |
| **Degree** | Post Doc |
| **Graduation Month** | April |
| **Graduation Year** | 2009 |
| **Department** | Civil and Environmental Engineering |
| **Program** | Geo Engineering |
| **Thesis Title** | N/A |
| **Thesis Abstract** | N/A |

.....

| | |
|---|---|
| **Student Name** | A. Hakan Oren |

| | |
|---|---|
| **Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Advisor Name** | Craig Benson |
| **Advisor Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Degree** | Post Doc |
| **Graduation Month** | August |
| **Graduation Year** | 2009 |
| **Department** | Civil and Environmental Engineering |
| **Program** | Geo Engineering |
| **Thesis Title** | N/A |
| **Thesis Abstract** | N/A |

.....

| | |
|---|---|
| **Student Name** | Paul Schlicht |
| **Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Advisor Name** | Craig Benson |
| **Advisor Campus** | University of Wisconsin-Madison |

| | |
|---|---|
| **Degree** | Masters |
| **Graduation Month** | December |
| **Graduation Year** | 2009 |
| **Department** | Civil and Environmental Engineering |
| **Program** | Geo Engineering |
| **Thesis Title** | N/A |
| **Thesis Abstract** | N/A |

# Wisconsin Groundwater Research and Monitoring Program

## Basic Information

| | |
|---|---|
| **Title:** | Wisconsin Groundwater Research and Monitoring Program |
| **Project Number:** | 2007WI201O |
| **Start Date:** | 7/1/2007 |
| **End Date:** | 6/30/2008 |
| **Funding Source:** | Other |
| **Congressional District:** | |
| **Research Category:** | Not Applicable |
| **Focus Category:** | Groundwater, None, None |
| **Descriptors:** | |
| **Principal Investigators:** | |

## Publication

# FY08 Wisconsin Groundwater Research and Monitoring Program

As established by Wisconsin's Groundwater Law of 1984, the state provides $300,000 annually to the UW System to support groundwater research and monitoring. In 1989, the WRI became the UW System's lead institution for coordinating the calls for proposals and peer reviews for distribution of the funds. To avoid duplication and better target groundwater research funding, several other state agencies (the departments of Commerce, Natural Resources, and Agriculture, Trade and Consumer Protection) agreed to partner with the WRI to establish an annual Joint Solicitation for Groundwater Research and Monitoring. This annual solicitation has funded more than 300 groundwater research and monitoring projects since its inception and has helped establish Wisconsin as a leader in groundwater research.

In FY2007, funding from the State of Wisconsin allowed the WRI to support an additional 16 projects and 21 students (7 undergrads, 4 Masters, 8 PhDs, and 2 Post-Docs) over and above the 15 students supported by federal funds (see the Student Support Table in the main report). This partnership between the UW system and the State is made possible because the WRI provides a mechanism to accept and distribute groundwater research funds. Without NIWR base support to maintain the WRI, this opportunity to leverage State funds would be lost. During this reporting period, seven projects concluded on June 30, 2007, one project continued, and eight projects were newly supported on July 1, 2007. Eight abstracts from the new projects follow the list of titles below:

Multi-Parameter, Remote Groundwater Monitoring with Referencing Using Crossed Optical Fiber Fluorescent Sensor Arrays. Peter Geissinger: University of Wisconsin – Milwuakee

Transport and Survival of Pathogenic Bacteria Associated With Dairy Manure in Soil and Groundwater. Jin Li, Ching-Hong Yang: University of Wisconsin – Milwuakee

Is Phosphorus-Enriched Groundwater Entering Wisconsin Streams? Bryant Browne: University of Wisconsin – Stevens Point

Occurrence and Generation of Nitrite in Ground and Surface Waters in an Agricultural Watershed. Emily Stanley: University of Wisconsin – Madison

Geochemical Characterization of Sulfide Mineralization in Eastern Wisconsin Carbonate Rocks. John Luczaj, Michael McIntire: University of Wisconsin – Green Bay

A Thermal Remote Sensing Tool for Mapping Spring and Diffuse Groundwater Discharge to Streams. Steven Loheide: University of Wisconsin – Madison

Monitoring Septic Effluent Transport and Attenuation using Geophysical Methods. Dante Fratta, David Hart, Kevin Masarik: University of Wisconsin – Madison, Wisconsin Geological and Natural History Survey, University of Wisconsin – Stevens Point

Influence of Wetland Hydrodynamics on Subsurface Microbial Redox Transformations of Nitrate and Iron. Jean Bahr, Eric Roden: University of Wisconsin – Madison

Controls on Methylation of Groundwater Hg(II) in Hyporheic Zones of Wetlands. Martin Shafer, Christopher Babiarz, David Armstrong & Eric Roden: University of Wisconsin – Madison

**WATER RESOURCES PROJECT SUMMARY FORM**

**INSTITUTION:** University of Wisconsin Water Resources Institute

**TITLE:** Transport and Survival of Pathogenic Bacteria Associated With Dairy Manure in Soil and Groundwater

| | | | |
|---|---|---|---|
| **PROJECT NUMBER:** | WR07R001 | **REVISION DATE:** | 6/14/2007 |
| **PROJECT STATUS:** | 1 | **INITIATION DATE:** | 7/1/2007 |
| **SUBPROGRAM:** | | **COMPLETION DATE:** | 6/30/2009 |


**PRINCIPAL INVESTIGATOR:** Li, Jin **EFFORT:** 1.0
**AFFILIATION:** University of Wisconsin-Milwaukee

**PRINCIPAL INVESTIGATOR:** Yang, Ching-Hong **EFFORT:** 1.0
**AFFILIATION:** University of Wisconsin-Milwaukee


| | | | |
|---|---|---|---|
| **AGENCY/DONOR FUNDS:** | | **STATE FUNDS:** | $38,329 |
| **LAST YEAR'S AGENCY/DONOR FUNDS:** | | **LAST YEAR'S STATE FUNDS:** | |
| **RELATED PROJECTS:** | | | |
| **PARENT PROJECT:** | | | |


**ABSTRACT:** Human pathogens in animal waste represent a severe health threat when the groundwater resources become contaminated as result of improper manure management practices. Currently, understanding of the fundamental mechanisms governing the fate and transport of pathogenic microorganisms associated with manure in soil and groundwater systems is still lagging despite federal regulatory efforts to boost drinking water quality and public health security through the introduction of the Ground Water Rule by the Environmental Protection Agency (EPA) in October 2006. The goal of this project is to evaluate the impact of various manure components, e.g., pH, organic matter, nutrients, particulate matter, and potential biofilm growth on the transport and survival characteristics of fecal indicators and pathogenic bacterium E. coli O157:H7. Research objectives will focus on determining the relationship between the deposition of indicator organisms E. coli and pathogenic serotype E. coli O157:H7 through well controlled laboratory column studies and examining the interactions between manure suspensions and bacterial strains and their associated transport behavior under different solution chemistry. In addition, the potential of biofilm formation as a result of various manure components and its impact on bacterial attachment and survival mechanisms will be investigated. These objectives will be achieved through a collaborative effort combining our expertise in the area of microbiology, molecular techniques and kinetic study. The results of this proposed research are expected to advance the basic understanding of mechanisms controlling the deposition and survival of fecal indicators and pathogenic bacteria, which are essential for the development and validation of predictive models for pathogen transport in soil and groundwater. The information will lead to an improvement of manure management practices, which are of interest to dairy farmers, policy makers and water professionals in the State of Wisconsin and across the country.

**WATER RESOURCES PROJECT SUMMARY FORM**

**INSTITUTION:** University of Wisconsin Water Resources Institute
**TITLE:** Is Phosphorus-Enriched Groundwater Entering Wisconsin Streams?

**PROJECT NUMBER:** WR07R002
**PROJECT STATUS:** 1
**SUBPROGRAM:**
**REVISION DATE:** 6/14/2007
**INITIATION DATE:** 7/1/2007
**COMPLETION DATE:** 6/30/2009

**PRINCIPAL INVESTIGATOR:** Browne, Bryant
**AFFILIATION:** University of Wisconsin-Stevens Point
**EFFORT:** 1.2

**AGENCY/DONOR FUNDS:**
**LAST YEAR'S AGENCY/DONOR FUNDS:**
**RELATED PROJECTS:**
**PARENT PROJECT:**
**STATE FUNDS:** $34,168
**LAST YEAR'S STATE FUNDS:**

**ABSTRACT:** Groundwater phosphorus (P) is generally hypothesized to be a negligible surface water input. But direct evidence for this supposition is sparse. Our recent work suggests that higher concentrations of dissolved P have been slowly developing since the 1960s beneath agricultural landscapes and that P enriched groundwater has begun to discharge to agricultural drainages in Wisconsin. The goal of this study will be to evaluate whether the groundwater transport of P to agricultural drainages is a potential threat to the trophic status of surface water. We will seek direct evidence by focusing on groundwater seepage as it enters agricultural drainages in southern Wisconsin. The work will include four tasks:
(a) A survey of the breadth and frequency distribution of apparent chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF6) recharge age-dates of groundwater seepage entering representative agricultural drainages in southern Wisconsin.
(b) A partitioning of the population of seepage sites into recharge age-date or residence time classes (e.g., decadal from 1950 to present), a selection of sampling locations to obtain a representative sub-population of each recharge age-date class, and three synoptic surveys (late spring, mid-summer, fall) of water quality and recharge age-dates at these locations.
(c) An analysis of trends in dissolved P concentration in groundwater seepage within and between recharge age-date classes to determine whether there is robust evidence of groundwater P enrichment of surface water in southern Wisconsin agricultural drainages.
(d) A forecast of the impact of the dissolved P trends on the surface water (baseflow) trophic classification using the theoretical approach developed by Browne and Guldan (2005).
This study will provide a set of recommendations/questions for research into groundwater P enrichment. The data will be ofinterest to water quality managers and researchers addressing agricultural P management.

**OBJECTIVES:** See proposal.

**METHODOLOGY:** See proposal.

**WATER RESOURCES PROJECT SUMMARY FORM**

**INSTITUTION:** University of Wisconsin Water Resources Institute

**TITLE:** Occurrence and Generation of Nitrite in Ground and Surface Waters in an Agricultural Watershed

| | | | |
|---|---|---|---|
| **PROJECT NUMBER:** | WR07R003 | **REVISION DATE:** | 6/14/2007 |
| **PROJECT STATUS:** | 1 | **INITIATION DATE:** | 7/1/2007 |
| **SUBPROGRAM:** | | **COMPLETION DATE:** | 6/30/2009 |

**PRINCIPAL INVESTIGATOR:** Stanley, Emily

**EFFORT:** 1.2

**AFFILIATION:** University of Wisconsin-Madison

**AGENCY/DONOR FUNDS:**

**STATE FUNDS:** $26,682

**LAST YEAR'S AGENCY/DONOR FUNDS:**

**LAST YEAR'S STATE FUNDS:**

**RELATED PROJECTS:**

**PARENT PROJECT:**

**ABSTRACT:** The goal of the proposed research is to better understand the extent of nitrite (NO2-) occurrence in groundwater, and the conditions that promote the accumulation of this potentially toxic form of nitrogen in both groundwater and surface waters of agriculturally-dominated catchments. The proposed study will (1) examine temporal patterns of groundwater and surface water chemistry and NO2- occurrence along four upland-to-stream transects, (2) measure NO2- generation in a series of controlled laboratory experiments to quantify rates and likely pathways of NO2- formation; and (3) conduct a survey of groundwater chemistry to determine if NO2- is present in groundwater at diverse locations in Wisconsin. This mixture of monitoring, surveys, and field and lab experiments should substantially expand our understanding of the processes and conditions leading to NO2- accumulation in water, and provide insights into a poorly understood pathway of nitrogen cycling: dissimilatory nitrate reduction to ammonium. This work is motivated by the occurrence of relatively high concentrations of NO2- in several Wisconsin streams and similar reports of elevated NO2- in N-enriched groundwater and interstitial riverine environments elsewhere. If NO2- exists at high concentrations in groundwater, it could pose a health risk to individuals who rely on this drinking water source. Further, discharge of N-rich groundwater leading to NO2- accumulation in streams creates similar stresses on sensitive aquatic communities, even at low concentrations. Thus, this proposal will provide valuable information on the extent of this chemical and the environmental circumstances in which it can occur- critical first steps for dealing with issues of nitrite contamination. We expect this work to be of broad interest to researchers interested in nitrogen biogeochemistry, particularly with respect to groundwater-surface water interactions, as well as to management agencies responsible for protecting in-stream habitats and communities and protecting vulnerable groundwater drinking water sources in agricultural landscapes.

**OBJECTIVES:** See proposal.

**METHODOLOGY:** See proposal.

**WATER RESOURCES PROJECT SUMMARY FORM**

**INSTITUTION:** University of Wisconsin Water Resources Institute
**TITLE:** Geochemical Characterization of Sulfide Mineralization in Eastern Wisconsin Carbonate Rocks

**PROJECT NUMBER:** WR07R004
**PROJECT STATUS:** 1
**SUBPROGRAM:**
**REVISION DATE:** 6/14/2007
**INITIATION DATE:** 7/1/2007
**COMPLETION DATE:** 6/30/2008

**PRINCIPAL INVESTIGATOR:** Luczaj, John
**AFFILIATION:** University of Wisconsin-Green Bay
**EFFORT:** 7.8

**PRINCIPAL INVESTIGATOR:** McIntire, Michael
**AFFILIATION:** University of Wisconsin-Green Bay
**EFFORT:** 1.2

**AGENCY/DONOR FUNDS:**
**LAST YEAR'S AGENCY/DONOR FUNDS:**
**RELATED PROJECTS:**
**PARENT PROJECT:**
**STATE FUNDS:** $8,860
**LAST YEAR'S STATE FUNDS:**

**ABSTRACT:** Much attention has been given to the problem of arsenic contamination in groundwater from northeastern Wisconsin. Previous research by others has detailed a corridor between Oshkosh and Green Bay in which the St. Peter Sandstone aquifer contains arsenic-bearing iron sulfide minerals. Little is known about the potential for arsenic and other metal contamination in Paleozoic rocks in Marinette, Oconto, and Shawano Counties. With parts of northeastern Wisconsin expecting significant population growth over the next 25 years, a better understanding of potential sources of groundwater contamination is needed, especially in rural areas where domestic water wells are prevalent.

Research by a principal investigator has shown that many of the Paleozoic rocks throughout eastern Wisconsin contain disseminated sulfide mineralization related to an ancient hydrothermal water-rock system. This ancient system was responsible for precipitation and replacement of a suite of sulfide minerals. Previous work by others regarding arsenic and metals concentrations in rock and ground water has focused on the St. Peter Sandstone over a small area in Winnebago and Outagamie Counties. Little information is known about the trace element signature of the carbonates in the region that host these same sulfide minerals. These rocks are the potential sources for contamination that might impact groundwater or surface water elsewhere in the region.

The goal of this project is to characterize the trace element composition of the carbonate rocks from outcrops and quarries in eastern Wisconsin to gain a better understanding of potential sources of arsenic and other metals of concern. This information will improve our understanding of the regional and stratigraphic distribution of these elements in different Paleozoic rocks of eastern Wisconsin. These activities will help to create a baseline for follow-up studies and for determining future impacts of groundwater arsenic.

**WATER RESOURCES PROJECT SUMMARY FORM**

**INSTITUTION:** University of Wisconsin Water Resources Institute
**TITLE:** A Thermal Remote Sensing Tool for Mapping Spring and Diffuse Groundwater Discharge to Streams

| | | | |
|---|---|---|---|
| **PROJECT NUMBER:** | WR07R005 | **REVISION DATE:** | 6/14/2007 |
| **PROJECT STATUS:** | 1 | **INITIATION DATE:** | 7/1/2007 |
| **SUBPROGRAM:** | | **COMPLETION DATE:** | 6/30/2009 |

**PRINCIPAL INVESTIGATOR:** Loheide, Steven **EFFORT:** 1.0
**AFFILIATION:** University of Wisconsin-Madison

| | | | |
|---|---|---|---|
| **AGENCY/DONOR FUNDS:** | | **STATE FUNDS:** | $35,866 |
| **LAST YEAR'S AGENCY/DONOR FUNDS:** | | **LAST YEAR'S STATE FUNDS:** | |
| **RELATED PROJECTS:** | | | |
| **PARENT PROJECT:** | | | |

**ABSTRACT:** This research will be a proof-of-concept for using Unmanned Aerial Vehicles (UAVs) to collect thermal remote sensing data for mapping of groundwater discharge. The premise of the work is that the thermal signature of groundwater is relatively constant year round, but differs from the stream temperature which varies on diel and annual cycles. The approach implemented in this work will be to collect thermal imagery at the stream reach scale (several kms), at four times during the day – dawn, noon, 4pm, and dusk. From this imagery, springs will be visually identified and discharge rates estimated from the amount of cooling/warming observed. Diffuse flow will be identified by creating longitudinal profiles of stream temperature and locating subreaches with depressed maximum diel stream temperature and increased minimum diel stream temperature. Maps of both spring and diffuse groundwater discharge will be created that aid in 1) understanding of stream-aquifer interactions 2) providing insight into the underlying groundwater flow system 3) identifying reaches where groundwater discharge may threaten surface water quality through discharge of contaminated groundwater 4) developing a water quality monitoring program that can account for areas of known discharge and 5) targeting reaches for conservation or restoration where stream-aquifer interactions are favorable for supporting aquatic ecosystems.

This research will improve our understanding of stream-aquifer interactions, a specific research priority listed by UWS. In addition, this work will provide a cost-effective, transferable methodology for identification and mapping of springs, a research priority set by the DNR to support implementation of the 2003 Wisconsin Act 310.

**OBJECTIVES:** See proposal.

**METHODOLOGY:** See proposal.

**WATER RESOURCES PROJECT SUMMARY FORM**

**INSTITUTION:** University of Wisconsin Water Resources Institute

**TITLE:** Monitoring Septic Effluent Transport and Attenuation using Geophysical Methods

**PROJECT NUMBER:** WR07R006

**REVISION DATE:** 6/14/2007

**PROJECT STATUS:** 1

**INITIATION DATE:** 7/1/2007

**SUBPROGRAM:**

**COMPLETION DATE:** 6/30/2009


**PRINCIPAL INVESTIGATOR:** Fratta, Dante

**EFFORT:** 0.5

**AFFILIATION:** University of Wisconsin-Madison

**PRINCIPAL INVESTIGATOR:** Hart, David J.

**EFFORT:** 1.2

**AFFILIATION:** Wisconsin Geological and Natural History Survey

**PRINCIPAL INVESTIGATOR:** Masarik, Kevin

**EFFORT:** 0.6

**AFFILIATION:** University of Wisconsin-Stevens Point


**AGENCY/DONOR FUNDS:**

**STATE FUNDS:** $29,706

**LAST YEAR'S AGENCY/DONOR FUNDS:**

**LAST YEAR'S STATE FUNDS:**

**RELATED PROJECTS:**

**PARENT PROJECT:**


**ABSTRACT:** The objectives of this study is to use GPR and ERT surveys to image the attenuation of contaminant plumes leaving septic leach fields in sands and clayey tills in the south and central parts of Wisconsin. Knowledge of subsurface contaminant transport and fluid properties will help future developers to decide the location and depth of leach fields and private drinking water wells, especially when several homes are built near each other. Homeowners can apply knowledge learned in this study to avoid installing wells in the path of contaminants or to minimize contamination of groundwater down-gradient from their septic systems. Imaging of contaminants will help hydrogeologists understand principles controlling the flow of groundwater, so they, too, can educate the public about groundwater contamination.


**OBJECTIVES:** See proposal.

**METHODOLOGY:** See proposal.

**RATIONALE:** See proposal.

**WATER RESOURCES PROJECT SUMMARY FORM**

**INSTITUTION:** University of Wisconsin Water Resources Institute

**TITLE:** Influence of Wetland Hydrodynamics on Subsurface Microbial Redox Transformations of Nitrate and Iron

| | | | |
|---|---|---|---|
| **PROJECT NUMBER:** | WR07R007 | **REVISION DATE:** | 6/14/2007 |
| **PROJECT STATUS:** | 1 | **INITIATION DATE:** | 7/1/2007 |
| **SUBPROGRAM:** | | **COMPLETION DATE:** | 6/30/2009 |


**PRINCIPAL INVESTIGATOR:** Bahr, Jean **EFFORT:** 0.6
**AFFILIATION:** University of Wisconsin-Madison

**PRINCIPAL INVESTIGATOR:** Roden, Eric **EFFORT:** 0.6
**AFFILIATION:** University of Wisconsin-Madison


| | | | |
|---|---|---|---|
| **AGENCY/DONOR FUNDS:** | | **STATE FUNDS:** | $40,141 |
| **LAST YEAR'S AGENCY/DONOR FUNDS:** | | **LAST YEAR'S STATE FUNDS:** | |
| **RELATED PROJECTS:** | | | |
| **PARENT PROJECT:** | | | |


**ABSTRACT:** Understanding controls on the transport and fate of N in groundwater is critical to predicting the impact of human activity on the ecological health and economic viability of aquatic resources. Wetlands and riparian zones are major recipients of nitrate-polluted groundwater in Wisconsin and many other landscapes in the U.S. Denitrification in such environments is a well recognized mechanism that can limit transfer of agriculturally-derived groundwater nitrate to surface waters. However, the impact of competing microbial metabolic pathways and redox interactions are not well understood in relation to hydrological dynamics. In particular, interaction between N and Fe redox cycles represents a potentially important but poorly constrained driver of aquifer N dynamics. This project will examine the fate of groundwater nitrate in a hydrologically dynamic wetland system (Dorn Creek) in Dane County, WI. This aquifer system is representative of a many environments in Wisconsin that are strongly influenced by surface water-groundwater hydrologic exchange. Spatial and temporal variations in groundwater-surface water flux and a variety of geochemical parameters will be determined in multilevel samplers across a transect perpendicular to the creek. These data, in parallel with microbiological analyses, will be used to assess the significance of denitrification vs. reduction of nitrate to ammonium in relation to two key microbial Fe redox processes: dissimilatory iron oxide reduction (DIR) and subsequent nitrate-driven oxidation of the ferrous iron produced by DIR. The combination of hydrologic, geochemical, and microbiological data will allow us to assemble a robust conceptual model of how wetland hydrodynamics affect microbial redox metabolism and the fate of groundwater nitrate. The conceptual model will serve as the basis for development of a two-dimensional reactive transport model that will be useful for predicting the influence of groundwater-surface water interactions on the fate of N in a broad range of shallow aquifer systems in Wisconsin.


**OBJECTIVES:** See proposal.

**WATER RESOURCES PROJECT SUMMARY FORM**

**INSTITUTION:** University of Wisconsin Water Resources Institute
**TITLE:** Controls on Methylation of Groundwater Hg(II) in Hyporheic Zones of Wetlands

**PROJECT NUMBER:** WR07R008
**PROJECT STATUS:** 1
**SUBPROGRAM:**
**REVISION DATE:** 6/14/2007
**INITIATION DATE:** 7/1/2007
**COMPLETION DATE:** 6/30/2009


**PRINCIPAL INVESTIGATOR:** Shafer, Martin **EFFORT:** 1.2
**AFFILIATION:** University of Wisconsin-Madison

**PRINCIPAL INVESTIGATOR:** Babiarz, Christopher **EFFORT:** 1.0
**AFFILIATION:** University of Wisconsin-Madison

**PRINCIPAL INVESTIGATOR:** Armstrong, David **EFFORT:** 0.5
**AFFILIATION:** University of Wisconsin-Madison

**PRINCIPAL INVESTIGATOR:** Roden, Eric **EFFORT:** 0.5
**AFFILIATION:** University of Wisconsin-Madison


**AGENCY/DONOR FUNDS:**
**STATE FUNDS:** $43,468
**LAST YEAR'S AGENCY/DONOR FUNDS:**
**LAST YEAR'S STATE FUNDS:**
**RELATED PROJECTS:**
**PARENT PROJECT:**


**ABSTRACT:** Our proposal addresses the groundwater-related problem of methyl mercury (MeHg) formation in hyporheic zones. Groundwater transport of inorganic mercury, Hg(II), to hyporheic zones leads to bacterial transformation to MeHg and subsequent accumulation of the highly toxic MeHg in aquatic foodwebs. The Objective is to determine the main factors controlling the bioavailability of inorganic Hg(II) for production of MeHg in wetland hyporheic zones. Formation of MeHg, mainly by sulfate-reducing bacteria (SRB), is expected to depend on the activity of SRB and the concentration and speciation of Hg(II). Our Project Plan is to use a combination of field measurements and laboratory experiments to resolve the main factors controlling production of MeHg in hyporheic zones. In Field research at hyporheic sites in the Allequash Creek wetland, concurrent measurements of Hg(II) methylation rates, sediment pore-water chemistry, and microbial activity will be used to test the hypothesis that rates of Hg(II) methylation are dependent on both concentration and speciation of Hg(II) and microbial activity in hyporheic zones. In Laboratory Microcosm Experiments, sediments from hyporheic zones will be incubated in microcosms under different conditions to probe specific drivers of bioavailability. Response measures will include methylation potential and other indicators of Hg(II) bioavailability. Drivers to be varied are total concentrations of Hg(II), sulfide, NOM, pH, dominant electron acceptor for microbial respiration (Fe(III) vs. sulfate), and bacterial

activity. Methodology will include total Hg and MeHg by CVAFS; methylation potential by production of MeHg from isotope-enriched Hg(II); “potential bioavailability” by measurements of by Hg(II) uptake by sensor bacteria and by reducibility by Sn(II); Hg(II) speciation by modeling and experimental measurements; and microbial activity by 14C-acetate respiration.

**OBJECTIVES:** See proposal.

**METHODOLOGY:** See proposal.

**RATIONALE:** See proposal.

# Information Transfer Program Introduction

# University of Wisconsin Water Resources Institute − Information Transfer

## Basic Information

| | |
|---|---|
| **Title:** | University of Wisconsin Water Resources Institute − Information Transfer |
| **Project Number:** | 2005WI89B |
| **Start Date:** | 3/1/2005 |
| **End Date:** | 2/28/2008 |
| **Funding Source:** | 104B |
| **Congressional District:** | 2 |
| **Research Category:** | Not Applicable |
| **Focus Category:** | None, None, None |
| **Descriptors:** | |
| **Principal Investigators:** | Stephen Wittman, Jim Hurley |

## Publication


1. Karl, John; Margaret Bogue, Christopher Baruth, and Jonathan Chipman. 2007. Making Maps, Mapping History: 300 Years of Original Maps of Wisconsin and the Great Lakes Region. Madison: University of Wisconsin Aquatic Sciences Center. 40 pages.
2. Kline, Kathleen Schmitt. 2008. Great Waters of Wisconsin: 32nd Annual Meeting Program and Abstracts. American Water Resources Association−Wisconsin Section and Water Resources Institute, University of Wisconsin, Madison, Wis. 68 pages.
3. White, Elizabeth, ed. 2007. Aquatic Sciences Chronicle, Spring issue. Madison: University of Wisconsin Aquatic Sciences Center. 8 pages.
4. White, Elizabeth, ed. 2007. Aquatic Sciences Chronicle, Summer issue. Madison: University of Wisconsin Aquatic Sciences Center. 8 pages.
5. White, Elizabeth, ed. 2007. Aquatic Sciences Chronicle, Fall issue. Madison: University of Wisconsin Aquatic Sciences Center. 6 pages.
6. White, Elizabeth, ed. 2008. Aquatic Sciences Chronicle, Winter issue. Madison: University of Wisconsin Aquatic Sciences Center. 6 pages.
7. Wittman, Stephen. 2008. Climate Change in the Great Lakes Region: Starting a Public Discussion. Madison: University of Wisconsin Sea Grant Institute. Publ. No. WISCU−W−07−001, 80 pages + DVD.

## INSTITUTE WEBSITE REDESIGNED

The UW-Madison Water Resources Institute website (*www.wri.wisc.edu*) was rebuilt from ground(water) up to make it easier and faster for visitors to find information about WRI research projects and publications. Construction of the new site was a year-long team effort led by James Hurley, assistant director for research & outreach, and his assistant Liz Albertson, a recent graduate from the UW Water Resources Management program.

One of the goals of the website redesign was to provide the public with a real-time link to information about current research. To that end, the site was integrated with the UW Aquatic Sciences Center's interactive Project Reporting Online (iPRO) system, an online tool that allows principal investigators to report on the progress of their projects. The new site features a fresh design with better readability and vivid photography. The design is the first step in an effort to visually unify the UW-Madison Water Resources Institute, Sea Grant Institute and Aquatic Sciences Center websites.

The redesigned WRI website went online February 15, 2008, and through Feb. 29 (the end of the reporting period) it was already logging more than 200 visitors and 1,000 page views per week.

## REGIONAL CLIMATE CHANGE SEMINAR SERIES

The Wisconsin WRI helped support "Climate Change in the Great Lakes Region: Starting a Public Discussion," a seminar series sponsored by the UW Sea Grant Institute and Wisconsin Coastal Management Program. From March through September 2007, eight climate-effects experts spoke at seven sites around Wisconsin to discuss what is known, what is predicted and what can be done to adapt to a changing climate. The series began with a keynote presentation by Dr. Kevin Trenberth, a leading climate researcher from the National Center for Atmospheric Research and one of the authors of the 2007 report of the Intergovernmental Panel on Climate Change. Subsequent talks highlighted how climate change could affect public health, lakes and other water resources, fisheries, Great Lakes water levels and coastal infrastructure.

To continue and expand public discussion of what climate change means for the Great Lakes region, a written summary and video of each seminar PowerPoint presentation can be downloaded free of charge from the "The Seminars" section of the project website (*www.seagrant.wisc.edu/ ClimateChange/*). An 80-page summary report and a DVD featuring all eight seminars are available from the UW Aquatic Science Center's online Publications Store (*aqua.wisc.edu/publications/*).

## GROUNDWATER AWARENESS WEEK

A series of five press releases for the March 2008 "Groundwater Awareness Week" were distributed via the UW-Madison WRI's statewide media mailing list and the UW-Extension network. Phone calls from media looking for more information indicates at least some of the information made it into a number of Wisconsin newspapers and on radio and television. The WRI also arranged for Stephen Ales, drinking and groundwater team supervisor for the Wisconsin Department of Natural Resources, and Dr. Henry Anderson, chief medical officer for the Wisconsin Department of Health & Family Services, to be guests on the March 12 broadcast of Wisconsin

Public Radio's popular "Larry Meiller Show," a 45-minute live call-in talk show. Aired on WPR stations statewide, the program attracted a dozen callers from throughout the state, mainly with questions related to well water contaminant and testing issues. Program producers said the number of calls indicated strong enough statewide interest in the topic to merit additional shows on groundwater topics in the future. This was reinforced by the strong follow-up interest in topic as evidenced by more than 200 downloads of the streaming audio of the show logged on the WPR website since the broadcast.

**A.W.R.A. CONFERENCE**

The UW-Madison Water Resources Institute once again cosponsored the American Water Resources Association-Wisconsin Section's 2008 annual conference, "Great Waters of Wisconsin," held March 6-7 in Brookfield, Wis. Other sponsors included the UW-Stevens Point Center for Watershed Science & Education, Wisconsin Department of Natural Resources and U.S. Geological Survey-Wisconsin District.

About 150 water managers and scientists from throughout Wisconsin attended the conference, which featured more than 50 oral and poster presentations on a wide range of water resources topics. Plenary session topics included national-state water policies, surface water-groundwater interactions, hydrogeologic investigations, lake management, groundwater management areas, organic and microbiological contaminants, water resources planning and management, and stormwater, streams and runoff. This year's event also included a free post-conference career workshop for students.

**LIBRARY OUTREACH ACTIVITIES**

During the past year, Wisconsin's Water Library (WWL) has continued its involvement in outreach efforts while providing a full range of library services to faculty, staff and students of the University of Wisconsin System. During the reporting period, the library initiated several outreach projects to reach prospective new users.

The WWL partnered with the UW Sea Grant Institute, UW-Milwaukee American Geographical Society (AGS) Library and UW-Madison Space Science and Engineering Center to develop and host the "**Making Maps, Mapping History**" exhibit. Three hundred years of original maps of Wisconsin and the Great Lakes region were on display from March to July 2007 in the UW-Madison Memorial Library's Department of Special Collections. A lecture by Christopher Baruth, curator of the AGS Library, in April 2007 attracted 120 attendees. Eighty-five percent of exhibit attendees (based on 146 voluntary feedback questionnaires) gave the overall exhibit as well as exhibit components (print material, audio commentary and lecture) a rating of 4-5, with 5 the highest ranking possible. Ninety percent of visitors reported that they gained new insights into Wisconsin history and/or map making as a result. "The Making Maps, Mapping History" website over a four-month period attracted 3,199 visitors who spent more than six minutes per visit. During the same period, 1,027 downloads of 32 exhibit-related audio and video files were logged, and about 1,124 electronic copies of the exhibit map booklet were downloaded.

The library signed a memorandum of agreement with the **Wisconsin Wastewater Operator's Association** (WWOA) to catalog, house and loan essential technical manuals provided by WWOA to aid members in their required license examinations, as well as support the educational needs of their daily work.

Wisconsin's Water Library continues to catalog all WRI research reports into WorldCat and MadCat, two library indexing tools that provide both worldwide and statewide access to this research. By having this information permanently indexed, the research results are easily available to other scientists statewide as well as throughout the nation and the world.

Library staff also continued to be involved in the Allied Drive story hours. Allied Drive is a Madison neighborhood with the highest concentration of children of any urban neighborhood in Dane County and many families that live in poverty. The program is a partnership with eight specialized UW-Madison campus libraries, the UW-Madison School of Library and Information Studies, and the Madison School and Community Recreation Safe Haven Childcare Program. Each month, a different campus library hosts a reading hour with themes relating to their specialized subject area.

The main outreach tools used by the library are three library-related websites, each with a focus on a different user group:

The **UW-Madison Water Resources Institute Library** website (*wri.wisc.edu/library*) introduces UW-Madison faculty, staff and students to services tailored to them. Three of the most popular pages on that site are Finding Water Jobs (*…/finding_jobsall.html*), Water Journals (*…/wrrsjrnl.html*) and Water Websites for Kids (*…/WaterCurricula/WatEdWebs.html*). The average time spent on these sites is about 4 minutes, a sign that Web surfers are finding the information they need.

**Wisconsin's Water Library** (*aqua.wisc.edu/waterlibrary*) is an outreach site for those who want to know more about our state's water resources. It makes books and other materials in the library accessible to any Wisconsin resident. During the past year, library staff produced six bi-monthly lists of *Recent Acquisitions* and added several special features or annotated reading lists on such popular topics as "Flooding in Wisconsin" and "Readings on Aquaculture." As with the WRI Library site, users spend a significant amount of time on the site, reading the page they have chosen for up to 5 minutes. The most popular pages on the site are Water Facts (*…/facts.asp*), the special feature page on Native Americans and the Environment (*…/nativeamericans.asp*) and a reading list on Landscaping & Ponds (*…/books_ponds.asp*).

This online library also includes the **Water Library for Kids** website (*…/kids/*). This site features children's books with aquatic themes that have won awards or appeared on best books lists. Most books are for preschool through second grade children, although there are also materials for older kids. Besides fiction and nonfiction books, the Web site also has ideas and resources for story hours. Users can browse recommended reading lists by topic (frogs, fish and fishing, Great Lakes, water pollution, etc.) and by age group. Any adult Wisconsin resident can check out books online and pick them up at their local public library.

The popularity of the all three library websites continues to grow. From March 2007 through February 2008, the WRI Library website received **35,712 visits** with 43,726 page views. Wisconsin's Water Library website had **121,504 visits** with 146,044 page views during the same period.

## SPECIAL INFORMATION TRANSFER PROJECT

During 2007-08, the UW Water Resources Institute funded a special information and outreach (see project no. 2007WI163B) designed to document the accomplishments, impacts and benefits of Wisconsin's unique Groundwater Coordinating Council (GCC) and the state's Groundwater Research & Monitoring Program. The project resulted in a 20-page illustrated pamphlet and two-page executive summary describing the activities of GCC since its creation 20 years ago, along with a series of four fact sheets on Wisconsin's most important groundwater resource issues: nitrate, arsenic, manure and supply. These publications provide a complementary packet of information with long-term usefulness. Coordinated by the GCC Education Subcommittee, this project represents a truly collaborative effort involving all GCC members.

## WATER RESOURCES RESEARCH HIGHLIGHTED IN NEWSLETTER

During 2007-08, WRI research and activities were featured in all four issues of the UW Aquatic Sciences Center's quarterly newsletter, *Aquatic Sciences Chronicle*, which is distributed statewide and nationally to more than **2,500 subscribers**, including UW System faculty and students, local and state water management agencies, water-related NGOs, news media and WRIs in other states. Newsletter stories included the results of a WRI-funded study comparing groundwater use in two Wisconsin counties and a study examining whether estrogenic endocrine disruptors are entering the state's groundwater, the work of the state's Groundwater Coordinating Council, the WRI's new librarian and redesigned website, and the 2008 AWRA-Wisconsin conference.

## PUBLICATIONS DISTRIBUTION

During the reporting period, **425** print copies of WRI publications were requested and another **12,546** copies downloaded from the UW Aquatic Science Center's online Publications Store (*aqua.wisc.edu/publications/*). Electronic distribution of WRI publications via PDF downloads **saved more than $16,900 in mailing costs**.

## STUDENT SUPPORTED

*Name*: **Julia Cameron**
*Campus*: UW-Madison
*Advisor*: Greg Downey
*Advisor Campus*: UW-Madison
*Degree/Training* : Masters (M.S.) Expected
*Graduation*: August 2008
*Department*: Library and Information Studies
*Program of Degree*: n/a
*Thesis Title*: n/a
*Thesis Abstract:* n/a

# Protecting Wisconsin's Buried Treasure: Celebrating the Results of 20 Years of Coordinated Groundwater Research and Monitoring

## Basic Information

| | |
|---|---|
| **Title:** | Protecting Wisconsin's Buried Treasure: Celebrating the Results of 20 Years of Coordinated Groundwater Research and Monitoring |
| **Project Number:** | 2007WI163B |
| **Start Date:** | 3/1/2007 |
| **End Date:** | 2/29/2008 |
| **Funding Source:** | 104B |
| **Congressional District:** | 2 |
| **Research Category:** | Not Applicable |
| **Focus Category:** | Groundwater, Law, Institutions, and Policy, Management and Planning |
| **Descriptors:** | Wisconsin Groundwater Coordinating Council, Groundwater Research &Monitoring Program |
| **Principal Investigators:** | Stephen Wittman, Jim Hurley |

## Publication


1. Boger, Peter G. 2007. Protecting Wisconsin's Buried Treasure: Two Decades of Coordinated Groundwater Research and Monitoring. Water Resources Institute, University of Wisconsin, Madison, Wis. 20 pages.
2. Boger, Peter G. 2007. Overview of the Groundwater Coordinating Council. Water Resources Institute, University of Wisconsin, Madison, Wis. 2 pages.
3. Boger, Peter G. 2007. Nitrate in Groundwater. Water Resources Institute, University of Wisconsin, Madison, Wis. 2 pages.
4. Boger, Peter G. 2008 (in press). Arsenic in Groundwater. Water Resources Institute, University of Wisconsin, Madison, Wis. 2 pages.
5. Boger, Peter G. 2008 (in press). Groundwater Quantity. Water Resources Institute, University of Wisconsin, Madison, Wis. 2 pages.
6. Boger, Peter G. 2008 (in press). Manure and Groundwater. Water Resources Institute, University of Wisconsin, Madison, Wis. 2 pages.

## BACKGROUND

Ensuring a sustainable supply of safe, high-quality groundwater is of fundamental importance to the present and future health of the economy, environment and people of Wisconsin. The state has an estimated 1.2 quadrillion gallons of groundwater, from which 70 percent of Wisconsin's population draws its drinking water. Threats to Wisconsin's groundwater supply include excessive drawdown of aquifers in several areas, arsenic contamination and nitrate pollution, among others.

At the same time that Congress created the federal Water Resources Research Institute (WRRI) Program in the Water Resources Research Act of 1984, the Wisconsin Legislature enacted Act 410—the Groundwater Research and Monitoring Program (GRMP)—to improve the management of the state's groundwater. This act established a Groundwater Coordinating Council (GCC) made up of representatives of state agencies with groundwater protection responsibilities.

The GCC thus provides the mechanism whereby the University of Wisconsin System and the state departments of Commerce, Natural Resources, Health & Family Services, and Agriculture, Trade & Consumer Protection work together to pool limited state and federal resources to support a coordinated, comprehensive and multidisciplinary response to the state's critical water resource issues.

The coordination of groundwater research and monitoring among multiple state government agencies and the state's principal research university is unique to Wisconsin and offers a model for other states. Over the last two decades, the GRMP has played a significant role in establishing Wisconsin as a national leader in groundwater research and management and leveraging the state's WRRI funds to maximum effect.

## PROJECT OBJECTIVES

During 2007-08, the UW Water Resources Institute funded a special information and outreach project designed to document the accomplishments, impacts and benefits of Wisconsin's unique Groundwater Coordinating Council (GCC) and the state's Groundwater Research & Monitoring Program (GRMP). The UW Water Resources Institute, as the sole source of WRRI funding in the state, represents the entire UW System on the GCC and serves as the vehicle through which university researchers obtain GRMP grants.

The primary objective of this one-year project is to use the occasion of the GCC's 20th anniversary in 2006 to document the accomplishments, impacts and successes of both the GRMP and WRRI during their first 20 years. This project was designed to draw political (state and federal), news media and public attention to the results, impacts and benefits of the WRRI in Wisconsin as well as the state's unique Groundwater Research and Monitoring Program.

## RESULTS

**Publications:** This project resulted in a 20-page illustrated pamphlet and two-page executive summary describing the activities of GCC since its creation 20 years ago, and the development of a series of four fact sheets on Wisconsin's most important groundwater resource issues: nitrate,

arsenic, manure and supply. These publications provide a complementary packet of information with long-term usefulness for legislative, public and media relations for all GCC agencies. Coordinated by the GCC Education Subcommittee, this project represents a truly collaborative effort of all GCC members. A PowerPoint® presentation based on this information was requested by the WRI director for his use as well as that of other GCC members to assist in legislative and public outreach regarding Wisconsin groundwater issues.

**Groundwater Awareness Week:** As part of the GCC awareness project, a series of five press releases for the March 2008 "Groundwater Awareness Week" were distributed via the WRI's statewide media mailing list and the UW-Extension network. Phone calls from media looking for more information suggests at least some of the information made it into a number of Wisconsin newspapers and on radio and television.

The WRI also arranged for Stephen Ales, drinking and groundwater team supervisor for the Wisconsin Department of Natural Resources, and Dr. Henry Anderson, chief medical officer for the Wisconsin Department of Health & Family Services, to be guests on the March 12 broadcast of Wisconsin Public Radio's popular "Larry Meiller Show," a 45-minute live call-in talk show. Aired on WPR stations statewide, the program attracted a dozen callers from throughout the state, mainly with questions related to well water contaminant and testing issues. Program producers said the number of calls indicated strong enough statewide interest in the topic to merit additional shows on groundwater topics in the future. This was reinforced by the strong follow-up interest in topic as evidenced by more than 200 downloads of the streaming audio of the show logged on the WPR website since the broadcast.

## STUDENT SUPPORT

This project provided a UW-Madison graduate student in Land Resources Management with financial support via a one-year halftime project assistantship as well as valuable experience and training from researching and writing about groundwater research, interacting with officials of multiple state agencies, and working with the award-winning science communications professionals at the UW-Madison Aquatic Science Center, administrative home of the UW Water Resources Institute.

*Name*: **Peter G. Boger**
*Campus*: UW-Madison
*Advisor Name*: Nancy Mathews
*Advisor Campus*: UW-Madison
*Degree/Training*: Masters (M.S.) Expected
*Graduation*: August 2008
*Department*: Nelson Institute for Environmental Studies
*Program of Degree*: Environment and Resources
*Thesis Title*: n/a
*Thesis Abstract*: n/a

**COMMITTEES, MEMBERSHIPS & PANELS**

Groundwater Coordinating Council

GCC Education Subcommittee

**INTERACTIONS/PARTNERSHIPS**

Central Wisconsin Groundwater Center, University of Wisconsin-Stevens Point

Wisconsin Department of Agriculture, Trade & Consumer Protection

Wisconsin Department of Commerce

Wisconsin Department of Health & Family Services

Wisconsin Department of Natural Resources

Wisconsin Geological and Natural History Survey

Wisconsin Public Radio-Larry Meiller Show

Wisconsin State Laboratory of Hygiene

# USGS Summer Intern Program

None.

# Student Support

| Student Support | | | | | |
|---|---|---|---|---|---|
| **Category** | **Section 104 Base Grant** | **Section 104 NCGP Award** | **NIWR−USGS Internship** | **Supplemental Awards** | **Total** |
| **Undergraduate** | 3 | 0 | 0 | 0 | 3 |
| **Masters** | 4 | 0 | 0 | 2 | 6 |
| **Ph.D.** | 2 | 1 | 0 | 1 | 4 |
| **Post−Doc.** | 0 | 0 | 0 | 2 | 2 |
| **Total** | 9 | 1 | 0 | 5 | 15 |

# Notable Awards and Achievements

***By leveraging State of Wisconsin dollars through the Groundwater Research and Monitoring Program, the WI WRI supported an additional 16 research projects and 21 students (7 undergrads, 4 Masters, 8 PhDs, and 2 Post−Docs beyond the 15 students reported in the table above).*** This partnership between the State of Wisconsin and the Water Resources Institute is made possible because of the financial, technical, and administrative support of the NIWR.

Six peer−reviewed journals published special issues containing the conference proceedings from the Eighth International Conference on Mercury as a Global Pollutant (August 6−10, 2006; Madison, Wisconsin). The conference was spupported, in part, by the UW Water Resources Institute as outlined in the FY2006 Information Transfer project (2005WI89B). The special issues contained a total of 72 papers covering the following thematic areas: Analytical chemistry, wildlife toxicology, bioaccumulation and source apportionment, biogeochemical fate and transport, human health, and socioeconomics.

According to Essential Science Indicators, one of the most cited papers published in the field of Environment/Ecology during the last two years was a contribution from the Eighth International Conference on Mercury as a Global Pollutant (August 6−10, 2006; Madison, Wisconsin). The conference was supported, in part, by the UW Water Resources Institute as outlined in the FY2006 Information Transfer project (2005WI89B). Entitled “Effects of Environmental Methylmercury on the Health of Wild Birds, Mammals, and Fish” the paper was authored by Drs Anton Scheuhammer, Michael Meyer, Mark Sandheinrich, and Michael Murray (Ambio, Vol 36, Issue 1).

Research Highlights:

The seven−year loading phase of the Mercury Experiment To Assess Atmospheric Loading in Canada and the United States (METAALICUS) ended in the fall of 2007. Summary results from a WRI−funded METAALICUS subproject indicate that loading rates play a direct role in regulating mercury fluxes from watersheds. For example, precipitation rate is an important regulator of mercury flux from watersheds −− suggesting that climate change will have broad impacts on the global cycle of mercury.

The changing chemical and microbial community dynamics of well water were measured with time during an enhanced reductive dechlorination (ERD) process for aliphatic hydrocarbons. Clone libraries were used to identify specific families of bacterial organisms involved with the process. This information is critical for determining why some ERD processes go to completion while others stall at earlier stages. These results will strengthen the application of ERD for bioremediation of chlorinated aliphatic hydrocarbons.

Topographic and land cover data were shown to improve the predicted groundwater infiltration rates when compared to models based on soil properties alone. Approximately 2/3 of the variability in measured Ksat values could be predicted using the following variables: percent organic matter in the soil, percent clay in the soil, elevation, aspect, planform curvature, and land cover. Of these, land cover was the best single predictor of measured groundwater infiltration rates. This information is important for modeling the response of aquifers to incidents of high demand.

The hydraulic properties of soils used in engineered landfill covers were shown to change within 3−5 years after deployment. In general, an overall loosening of the soil increased both the hydraulic conductivity and soil water storage capacity. Significant increases have been observed for geosynthetic clay liners, suggesting that alternative cover soils should be loosely compacted, and should be constructed with less plastic fine−textured soils when possible.

Large−scale climate change signals were shown to affect water levels in the Great Lakes region and affect groundwater levels in Wisconsin. The use of novel spectral methods in the Trout Lake Watershed showed significant low frequency oscillations (~10 yrs) in lake levels and significant oscillations in stream flow. This information will help improve groundwater and lake−level modeling.

# Publications from Prior Years

1. 2004WI79B ("Fate of Representative Fluoroquinolone, Macrolide, Sulfonamide and Tetracycline Antibiotics in Subsurface Environments") − Articles in Refereed Scientific Journals − Gu C, KG Karthikeyan, SD Sibley and JA Pedersen, 2007 Complexation of the antibiotic tetracycline with humic acid. Chemosphere 66 p1494−1501.
2. 2004WI79B ("Fate of Representative Fluoroquinolone, Macrolide, Sulfonamide and Tetracycline Antibiotics in Subsurface Environments") − Articles in Refereed Scientific Journals − Sibley SD, and JA Pedersen 2008 Interaction of the macrolide antimicrobial clarithromycin with disolved humic acid. Environmental Science &Technology 42 p422−428.
3. 2004WI79B ("Fate of Representative Fluoroquinolone, Macrolide, Sulfonamide and Tetracycline Antibiotics in Subsurface Environments") − Book Chapters − Pedersen JA, KG Karthikeyan, HM Bialk (in press) Sorption of human and veterinary antibiotics to soils. In: Natural Organic Matter and Its Significance in the Environment Wu, F. &Xing, B. (eds); Science Press: Beijing, China
4. 2006WI180O ("Mercury Speciation along a Groundwater Flowpath") − Articles in Refereed Scientific Journals − Creswell J, C Babiarz, M Shafer, E Roden, and D Armstrong. Accepted. Temporal and spatial distribution of total mercury and methylmercury in hyporheic sediments of the Allequash Creek wetland. J. Geophys Res − Biogeosci
5. 2005WI0005O ("Climate Signals in Groundwater and Surface Water System: Spectral Analysis of Hydrologic Processes") − Dissertations − Namdar−Ghanbari Reza, 2007. Climate signals in groundwater and surface water system: spectral analysis of hydrologic processes, PhD dissertation, Engineering, University of Wisconsin, Milwaukee, WI, 202p
6. 2005WI159O ("Transient Functioning of a Groundwater Wetland Complex, Allequash basin, Wisconsin") − Water Resources Research Institute Reports − Anderson, Mary P, and Christopher Lowry, 2007, Transient functioning of a groundwater wetland complex, Allequash Basin, Wisconsin, Water Resources Institute, University of Wisconsin–Madison, Madison, Wisconsin, 16 p.
7. 2006WI189O ("Application of LSQR to Calibration of a Regional MODFLOW Model: Trout Lake Basin, Wisconsin") − Water Resources Research Institute Reports − Anderson, Mary P, Haijiang Zhang, and Chris Muffels, 2007, Application of LSQR to calibration of a regional MODFLOW model: Trout Lake Basin, Water Resources Institute, University of Wisconsin–Madison, Madison, Wisconsin, 16 p.
8. 2005WI0005O ("Climate signals in groundwater and surface water system: spectral analysis of hydrologic processes") − Water Resources Research Institute Reports − Bravo, Hector, 2007, Climate signals in groundwater and surface water system: spectral analysis of hydrologic processes, Water Resources Institute, University of Wisconsin–Madison, Madison, Wisconsin, 13 p.
9. 2005WI157O ("Measuring and Modeling Macroporous Soil Water and Solute Flux Below the Root Zone of a Plano Silt−Loam Soil") − Water Resources Research Institute Reports − Lowery, Birl and John Norman, 2007, Measuring and modeling macroporous soil water and solute flux below the root zone of a Plano silt−loam soil, Water Resources Institute, University of Wisconsin–Madison, Madison, Wisconsin, 12 p.
10. 2005WI161O ("Evaluation of On−Site Wastewater Treatment as a Source of Antibiotic Resistance Genes in Groundwater") − Water Resources Research Institute Reports − McMahon, Katherine D, and Erin Seyfried, 2007, Evaluation of on−site wastewater treatment as a source of antibiotic resistance genes in groundwater, Water Resources Institute, University of Wisconsin–Madison, Madison, Wisconsin, 15 p.
11. 2005WI155O ("Arsenic Species (III,V) Distribution in Wisconsin Groundwaters: Field Measurements and Prediction Using Multivariate Analysis of Geochemical Data Prediction Using Multivariate Analysis of Geochemical Data") − Water Resources Research Institute Reports − Shafer, Martin M, Joel Overdier, and Sara Kerr, 2007, Arsenic species (III, V) distribution in Wisconsin groundwaters: field measurements and prediction using multivariant analysis of geochemical data, Water Resources

Institute, University of Wisconsin–Madison, Madison, Wisconsin, 21 p.

12. 2005WI160O ("Assessing the Ecological Status and Vulnerability of Springs in Wisconsin") − Water Resources Research Institute Reports − Swanson, Susan , Kenneth Bradbury, and David Hart, 2007, Assessing the ecological status and vulnerability of springs in Wisconsin, Water Resources Institute, University of Wisconsin–Madison, Madison, Wisconsin, 40 p.
13. 2003WI006O ("Evaluation of volatile organic compounds in Wisconsin landfill leachate and lysimeter samples") − Water Resources Research Institute Reports − Klett N, T Edil, C Benson, and J Connelly, 2005, Evaluation of volatile organic compounts in Wisconsin landfill leachate and lysimeter samples, Water Resources Institute, University of Wisconsin–Madison, Madison, Wisconsin, 114 p.
14. 2004WI131O ("A Comparison of USEPA−Approved Enzyme−Based Total Coliform/E. coli Tests for Microbiological Groundwater Monitoring and Laboratory Consultation") − Articles in Refereed Scientific Journals − Olstadt J, J Schauer, J Standridge, and S. kluender (2007) A comparison of ten USEPA approved total coliform/E. coli tests. J Water Health 5 pp267−282
15. 2005WI89B ("University of Wisconsin−Water Resources Institute − Information Transfer") − Articles in Refereed Scientific Journals − Horvat M, and H Hintelmann; Eds (2007) Special Issue on Mercury Analysis containing six articles. Analytical and Bioanalytical Chemistry. 388(2) pp315−365
16. 2005WI89B ("University of Wisconsin−Water Resources Institute − Information Transfer") − Articles in Refereed Scientific Journals − Scheuhammer A, M Sandheinrich, Eds (2008) Special issue on the effects of methylmercury on wildlife containing seven articles. Ecotoxicology 17(2) pp67−141
17. 2005WI89B ("University of Wisconsin−Water Resources Institute − Information Transfer") − Articles in Refereed Scientific Journals − Sexauer M, A Kolker, and K Gardfeldt, Eds (2008) Special Issue on the tranpsort and fate of mercury in the environment containing 20 articles. Applied Geochemistry 23(3) pp343−602
18. 2005WI89B ("University of Wisconsin−Water Resources Institute − Information Transfer") − Articles in Refereed Scientific Journals − Anderson H, L Barregard, Eds (2008) Special Issue on Huyman Health and exposure to Methylmercury containing 17 articles. Environmental Research 107(1) pp1−138
19. 2005WI89B ("University of Wisconsin−Water Resources Institute − Information Transfer") − Articles in Refereed Scientific Journals − Harris R, K Kidd, and J Shanley, Eds (2008) Special issue on Mercury cycling and bioaccumulation in the environment containing 16 papers. Environmental Pollution 154(1) pp1−154
20. 2005WI89B ("University of Wisconsin−Water Resources Institute − Information Transfer") − Articles in Refereed Scientific Journals − Hurley J, D Krabbenhoft, J Wiener and C Babiarz, Eds (2007) Special Issue covering the conference plenary sessions and containing seven articles. Ambio 36(1) pp2−66