57th Midwest Ground Water Conference

Groundwater Opportunities and Conflicts in the 21st Century: Economy to Ecology

Program with Abstracts

October 1-3, 2012

hosted by the Minnesota Ground Water Association

October 1

Time	Concurrent Sessions		
8:00	Plenary Session		
10:00	*Break*		
10:30	Groundwater and Energy Production From Frac Sand Mines to Oil Shale Plays	Groundwater Modeling — I	
11:50	*Lunch*		
1:00	Groundwater Management — I	Aquifer Characterization — I	Groundwater/Surface-Water Interface — I
2:40	*Break*		
3:10	Groundwater Management — II	Aquifer Characterization — II & Urban Hydrogeology - II	Karst — I
5:00	Reception – Social Hour (included)		
6:30 - 8:00	Banquet (included)		
7:30	*Speaker: Stephen Brand* , Conoco/Phillips, Vice President of Technology and Development, *retired*	*Technological Drivers Behind the Domestic Boom in Oil and Gas Exploration*	

October 2

Time	Concurrent Sessions		
8:00	Urban Hydrogeology — II	Groundwater Management — III	Geothermal
9:40	*Break*		
10:10	Groundwater Quality — I	Groundwater/Surface-Water Interface — II	
11:50	*Lunch*		
1:00	Groundwater Quality — II	Groundwater Modeling — II	
2:20	*Break*		
3:00	Groundwater Quality — III	Karst — II	

October 3

8:00 - 4:30	Field Trip

Groundwater in an Urban Setting: A Hydrogeologic and Historical Tour of the Twin Cities

57th Annual
Midwest Ground Water Conference

October 1-3, 2012 • Minneapolis, Minnesota

Welcome to the 57th Midwest Ground Water Conference.

We hope you will enjoy the presentations on current groundwater issues in the Midwestern United States. Enjoy your stay, see our fall colors, and we'll see you again in Bismarck, North Dakota in 2013.
Feel free to contact any one of us during the meeting if you have questions, needs or comments.
Sincerely,

Conference Organizing Team

Kelton Barr, MGWA President – Team Lead
Steve Robertson, MN Dept. of Health – Field Trip
Jim Aiken, Barr Eng.Co, Sponsors
Joy Loughry, MN Dept of Health, Technology
Jeanette Leete, MN DNR, Logistics
Sean Hunt, MN DNR, Web
Bob Tipping, MN Geological Survey – Field Trip
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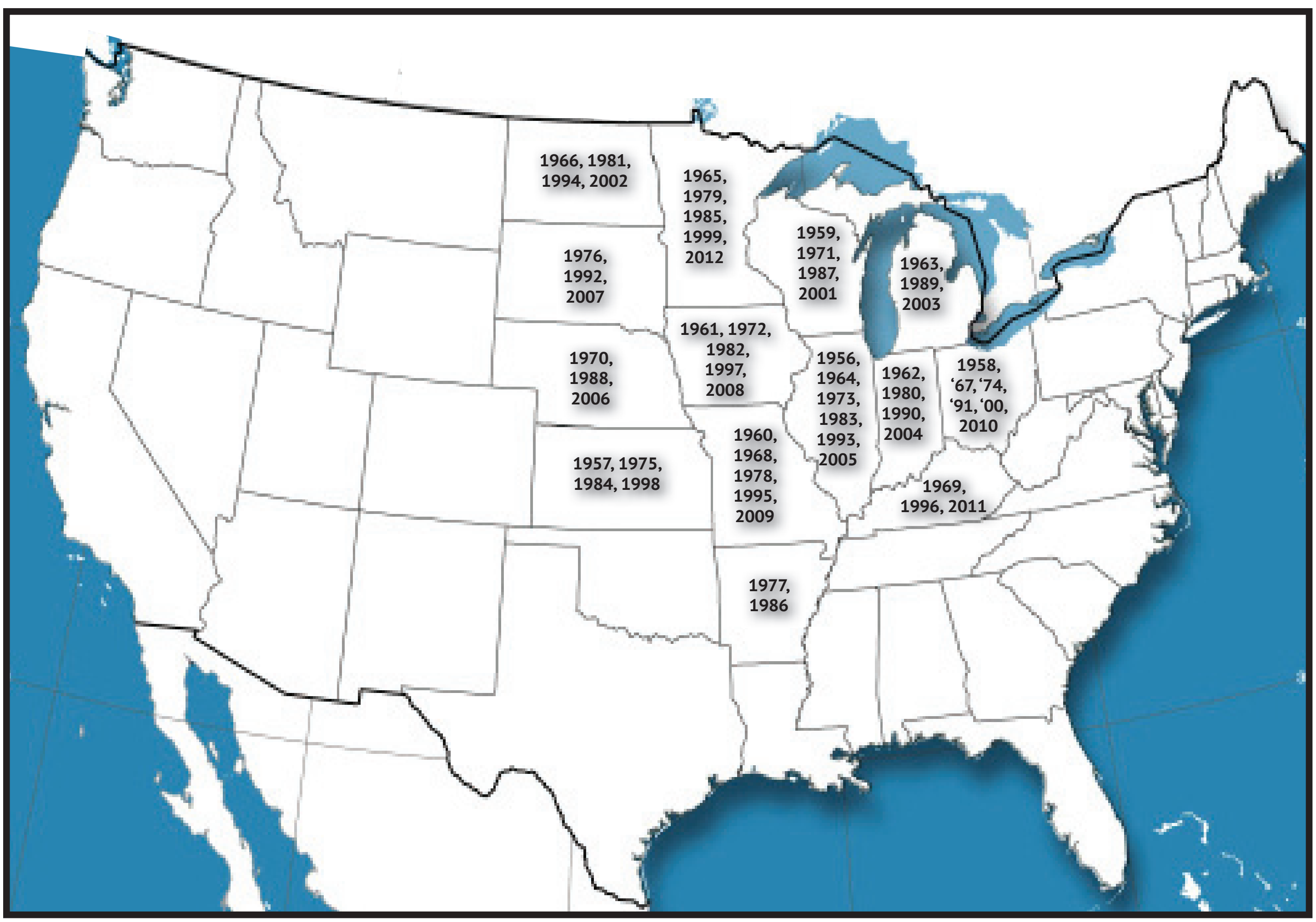

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Midwest Ground Water Conference History

History of the Midwest Ground Water Conference as viewed from Minnesota

Groundwater has become an increasingly more important resource in the Midwest during the past 150 years. By the early 1950s groundwater specialists in a number of states in this region became concerned with how groundwater issues, research, information distribution, and funding should be addressed on both the national level and the state level.

Minnesota's Governor Luther Youngdahl convened the first known groundwater gathering in the Midwest to discuss groundwater management in 1950. In his welcoming address the Governor said:

"This isn't the largest conference that we had occasion to call in discussing important issues in our State, but I know of no conference that has any more far-reaching implications or significance than this one.

The conference here today, of course, is one that is gotten together for the purpose of discussing an issue that is of vital concern to the welfare of our people. We are coming more and more to appreciate the fact that, ladies and gentlemen, we can't have our cake and eat it too. We can't continue to have a strong country unless we discipline ourselves for it. We can't continue to have natural resources unless we exercise a wise and judicious care of those resources now, while we still continue to enjoy them in such tremendous abundance. And in whatever activity it may be that concerns our natural resources, we always come down to the same fundamental concept that we have got to be willing to pay a price in order to continue to preserve those resources for the future and for posterity.(…)

Already there are signs in some places that excessive use may some day reach the point of overtaxing the capacity of the underground reservoir. It therefore behooves us to make an intelligent appraisal of the effects of past and present use, the depletion of water reserves that has taken place, and the volume of anticipated needs so that with this information we may attempt to plan for the future.

In making this study we must constantly bear in mind that the maintenance of our present population and industry, as well as all future development, depends directly on the availability of adequate supplies of water"

The Director of the Minnesota Department of Natural Resources (DNR), Division of Waters at the time, Sidney Frellsen, in framing objectives for the conference said, in part:

"Unregulated appropriation of water by municipalities, industries, farmers, irrigation interests and many other users are diverting water which, in the early years, went directly to add to the flow in our streams. Changing land use and farm practices also have tended to decrease the amount of water which supplies our underground water reservoir. With this effect on stream flow and continued discharge of waste from municipalities and industrial processing plants into our streams, the use of surface water as a source of supply for processing and manufacturing has tended to decrease while underground waters have been placed at a premium because of their relative purity. Furthermore, the low temperature of underground waters has made them particularly valuable in metropolitan areas and in certain types of industrial plants and places of business as a means of economical cooling. (…)

The extent to which ground waters may be used, and the degree of dependence which can be placed upon this water as a source of continued supply over a long period of years, is a problem that needs clarification. One other objective sought is to ascertain through this conference what basic data can and should be obtained on a State-wide basis for immediate application to the problems at hand. Voluminous data should not be obtained merely for the sake of itself, but for its value to engineers, public officials and others concerned with the underground water problem."

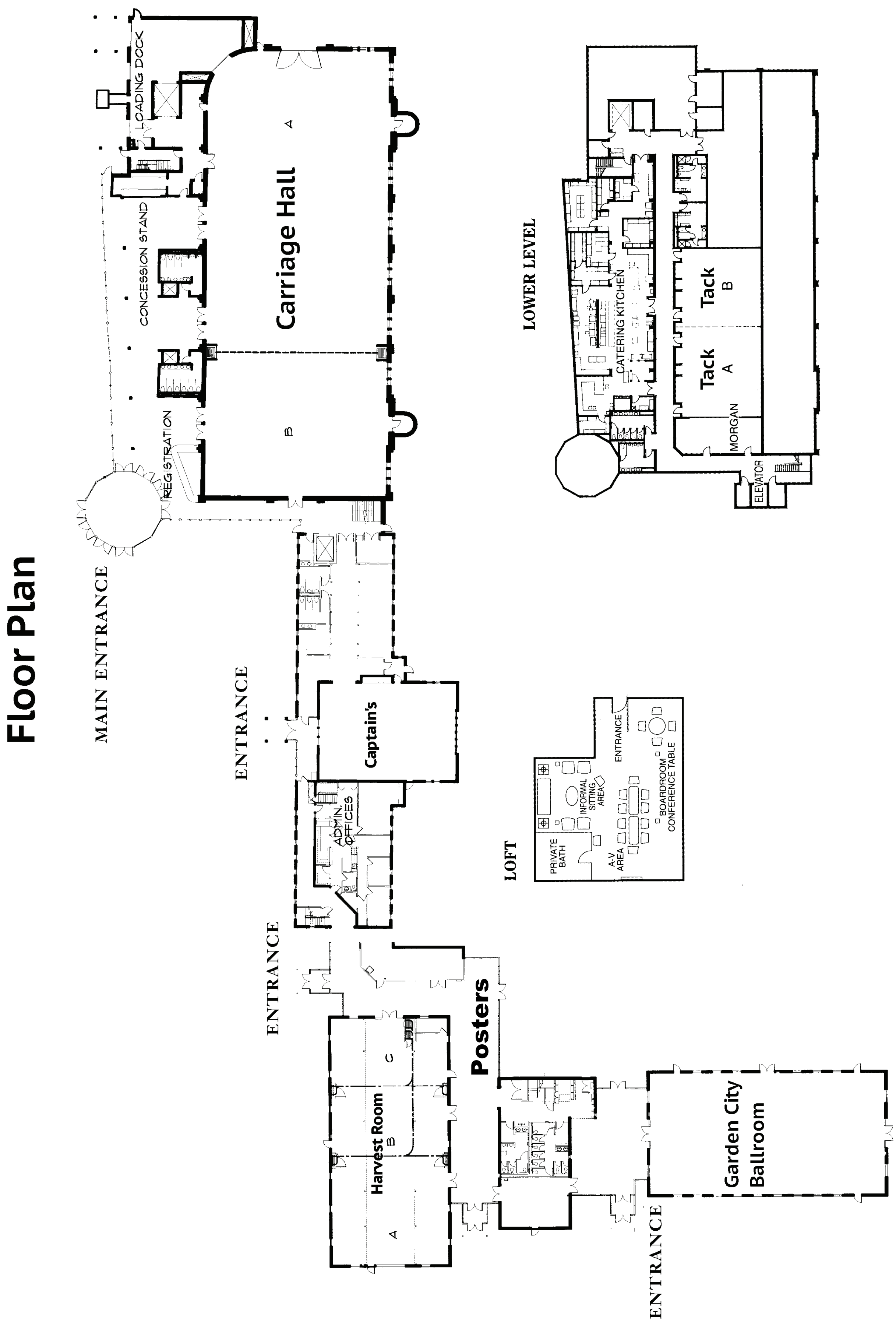
When mutual concerns over water supply issues led water supply specialists to gather in Champaign, Illinois in 1956 for discussion, Minnesotans were on hand. The assembly decided to set up an informal group called the Midwest Ground Water Conference. Within a few years an annual gathering several days in length had participants from 14 states attending. Minnesota DNR's Division of Waters hosted the conference in 1965, 1979, 1985, and 1999.

Midwest Ground Water Conference attendees have included staff from various state agencies, universities, engineers, federal agencies, water supply providers, students, and many individuals with varying interests in all aspects of ground water. The Conference is intentionally operated on a lower-cost, few frills basis, and the program is informal in order to maximize interaction and discussion among the attendees.

The decision was made early on to not set up any formal organizational structure for the Conference. An individual from Illinois was designated as historian, an unofficial position that would maintain a file of each host's organizing activities for that year's Conference, a copy of the program, and a compilation of other pertinent information. The historian, in carrying out the unofficial job of keeping Conference history going, would assist each host with suggestions on organizing an upcoming Conference. The Conference has had two historians with the current one, Ross Brower, serving since 1983.

This and all other annual gatherings have been organized and conducted by a program committee set up by a groundwater organization or institution of the hosting State. This committee is composed of interested parties in that state and it develops the program, puts out a call for papers, conducts the Conference, pays the expenses, and compiles a wrap-up after the Conference. The wrap-up includes a summary of that year's Conference for the benefit of the host that has volunteered to organize the Conference for the following year. The broad range of groundwater related topics covered by the Midwest Ground Water Conference annually draws 75 to 350 attendees.

Conference Venue



57th Midwest Ground Water Conference Presentations

DAY ONE -- OCTOBER 1, 2012

CARRIAGE HALL A

PLENARY SESSION (Kelton Barr, chair)

8:00	**Kelton Barr**	President, Minnesota Ground Water Association	Welcome and Introductory Remarks
8:15	**Robert Shaver**	Director, Water Appropriations Division, North Dakota State Water Commission	Water Management Issues Associated with Bakken Oil Shale Development in Western North Dakota
8:35	**David R. Steward**	Kansas State University	Groundwater to Sustain Agriculture in the Midwest's Prairies: Interdisciplinary, Integrated Modeling Approaches
8:55	**Donald O. Rosenberry**	U. S. Geological Survey	The Pursuit of Science at the Groundwater/Surface-Water Interface: Examples of Societal Relevance from the Midwest and Beyond
9:15	**Ken Bradbury**	Wisconsin Geological and Natural History Survey	Groundwater Science Meets Public Policy in Wisconsin
9:35	**Deborah Swackhamer**	U of MN Water Resource Center	Sustaining Water Resources into the Future - Science and Policy Challenges

10:00-10:30 BREAK (Carriage Hall B and Captain's Room)

GROUNDWATER AND ENERGY PRODUCTION: FROM FRAC SAND MINES TO OIL SHALE PLAYS (Tony Runkel, chair)

10:30	**Bruce Hicks**	Assistant Director, Oil and Gas Division, North Dakota Dept. of Mineral Resources	Overview of the Bakken Shale development with emphasis on hydraulic fracturing and wastewater treatment and disposal
10:50	**Tony Runkel**	Chief Geologist, Minnesota Geological Survey	Silica sand mining in the midcontinent region: Why here, what does the "boom" look like, and what are the concerns?
11:10	**Dan Masterpole**	Chippewa Co Dept of Land Conservation & Forest Mngt.	Overview of Chippewa County Groundwater Study To Evaluate The Impacts of Non-Metallic Mining And Irrigated Agriculture in Western Chippewa County, Wisconsin
11:30	**Jeffrey A. Green**	Minnesota Department of Natural Resources	Results and Recommendations from the Minnesota Department of Natural Resources Study on Limestone Quarry Impacts on Groundwater Systems and its Applicability for Frac Sand Mining

57th Midwest Ground Water Conference Presentations

DAY ONE -- OCTOBER 1, 2012

HARVEST ROOM B & C

GROUNDWATER MODELING -- I (Madeline Gotkowitz, David Steward, and Otto D.L. Strack, co-chairs)

10:30	**Henk Haitjema**	Indiana University	Modeling transit time distributions with MODFLOW/MODPATH
10:55	**Randal J. Barnes**	University of Minnesota	Inferring the Effective Hydraulic Conductivity Using a Simple Model and the Available Information
11:20	**Otto D. L. Strack**	University of Minnesota	The effect of Abandoned Wells on Irrigation and Pumping

57th Midwest Ground Water Conference Presentations

DAY ONE -- OCTOBER 1, 2012

11:50 - 1:00 LUNCH (Carriage Hall A)

CARRIAGE HALL A

GROUNDWATER MANAGEMENT -- I: GROUNDWATER APPROPRIATION CHALLENGES IN IRRIGATED AREAS IN THE NORTHERN LAKES STATES (Princesa VanBuren Hansen, Cathy O'Dell, and George Kraft, co-chairs)

1:00	**George Kraft and David Mechenich**	University of Wisconsin-Stevens Point	Irrigation impacts in the Northern Great Lake States with the Wisconsin Central Sands as case study
1:20	**Mallika Nocco and Mack Naber**	University of Wisconsin-Madison	Conceptual to quantitative frameworks for evaluating irrigation and groundwater pumping impacts in the Northern Lake States
1:40	**Maribeth Kniffen**	University of Wisconsin-Madison	Investigating the effects of high capacity irrigation well pumping on groundwater recharge and evapotranspiration in the Central Sands of Wisconsin
2:00	**Andrew Streitz**	Minnesota Pollution Control Agency	Analysis of changes to base flow across Minnesota and a profile of the Little Rock Creek study area
2:20	**Jesse Holzer**	University of Wisconsin – Madison	Optimization modeling for groundwater management in the Wisconsin Central Sands

2:40 - 3:10 BREAK (Carriage Hall B and Captain's Room)

GROUNDWATER MANAGEMENT -- II: GROUNDWATER MANAGEMENT AND POLICY FRAMEWORK IN THE NORTHERN GREAT LAKES REGION (Princesa VanBuren Hansen, Cathy O'Dell, and George Kraft, co-chairs)

3:10	**Julie Ekman and Princesa VanBuren Hansen**	Minnesota Department of Natural Resources	Water appropriation permitting in Minnesota
3:30	**Greg Kruse**	Minnesota Department of Natural Resources	Water quantity monitoring in Minnesota: present and future
3:50	**Jason Moeckel**	Minnesota Department of Natural Resources	Using groundwater in the 21st century
4:10	**Eric Ebersberger**	Wisconsin Department of Natural Resources	Groundwater Management in Wisconsin: Current Status & Gaps
4:30	**Panel Discussion** until 5:30	George Kraft, Eric Ebersberger, Jason Moeckel, Jim Stark	

5:00 - 6:30 SOCIAL HOUR (CARRIAGE HALL B and CAPTAIN'S ROOM)

57th Midwest Ground Water Conference Presentations

DAY ONE -- OCTOBER 1, 2012

11:50 - 1:00 LUNCH (Carriage Hall A)

HARVEST ROOM B & C

AQUIFER CHARACTERIZATION -- I (Justin Blum, chair)

1:00	**John Dustman**	Summit Envirosolutions, Inc.	A real-time groundwater monitoring system in three communities in the larger Twin Cities Basin
1:20	**Rich Soule**	Minnesota Department of Health	Specific capacity vs. aquifer test -- this time it's personal!
1:40	**Scott Alexander**	University of Minnesota	Jacob and Goldilocks: How to define small "u" for Jacob Pumping Test Analysis
2:00	**Justin Blum**	Minnesota Department of Health	A Distance-Drawdown Analysis Procedure to Identify the Effects of Bedding Plane Fractures and Improve the Estimates of Hydraulic Properties in the Paleozoic Bedrock Aquifers of Southeastern Minnesota
2:20	**Michael K. Anderson**	Iowa DNR, Water Supply Engineering Section	Discussion of an aquifer storage and recovery (ASR) permit program, eleven years experience in Iowa (2000-2011)

2:40 - 3:10 BREAK (Carriage Hall B and Captain's Room)

AQUIFER CHARACTERIZATION -- II/URBAN HYDROGEOLOGY -- I (Justin Blum, Bob Tipping, and Mike Trojan, co-chairs)

3:10	**Dan Kelleher**	Midwest GeoSciences Group	Using The Stratigraphic Framework Based on Depositional Environments to Design A Ground Water Monitoring System and Calculate Vertical Seepage in Glacial Settings – Two Case Studies
3:30	**Jeremy Rivord**	Minnesota Department of Natural Resources	Mapping Glacial Aquifers In a Central Minnesota County as a Resource for Local Management
3:50	**Carl Keller**	FLUTe	Site Characterization Methods with a Flexible Borehole Liner
4:10	**Todd A. Petersen**	Minnesota Department of Natural Resources	Hydrogeology of McLeod and Carver Counties, Minnesota
4:30	**Greg Brick**	University of Minnesota, Department of Earth Sciences	Feverish Nymphs: The Subterranean Springs of Minneapolis

57th Midwest Ground Water Conference Presentations

DAY ONE -- OCTOBER 1, 2012

11:50 - 1:00 LUNCH (Carriage Hall A)

HARVEST ROOM A

GROUNDWATER/SURFACE-WATER INTERFACE -- I (Donald Rosenberry and Perry Jones, co-chairs)

1:00	**Jim Almendinger**	St. Croix Watershed Research Station	Ups and Downs at Valley Creek: The Influence of climate, urbanization, and ground-water withdrawals on baseflow of a trout stream in eastern Minnesota
1:20	**Trisha Moore**	University of Minnesota	Stormwater to Baseflow? Investigating surface-groundwater interactions in Minnehaha Creek for stormwater management and ecosystem enhancement
1:40	**Philip J. Gerla**	University of North Dakota and The Nature Conservancy	Challenges of Protecting and Restoring a Groundwater - Dependent Prairie Stream: Iron Springs Creek, Southeastern North Dakota
2:00	**Henry Hunt**	Layne Christensen	Unique Tunnel Riverbank Filtration System to Supply Louisville with Filtered Water
2:20	**Tim Cowdery**	U. S. Geological Survey	Water-budget changes from precipitation variability at the Glacial Ridge National Wildlife Refuge, northwestern Minnesota

2:40 - 3:10 BREAK (Carriage Hall B and Captain's Room)

KARST -- I: KARST WATER QUALITY AND LAND USE (Jeff Green and E. Calvin Alexander, Jr., co-chairs)

3:10	**Bob Libra**	Iowa Geological Survey	Lessons from long-term monitoring in the Big Spring groundwater basin, Iowa
3:40	**Kelton D. L. Barr, Braun Intertec Corporation and E. Calvin Alexander, Jr.**	University of Minnesota	Examples of Hypogenic Karst Collapse Structures in the Twin Cities Metropolitan Area, Minnesota
4:00	**Stuart Grubb**	Grubb Environmental Services	New Minnesota Landfill Siting Rules and Karst
4:20	**Marc Hugunin**	Friends of Washington County	New Minnesota Landfill Siting Rules: The Political Dimension

57th Midwest Ground Water Conference Presentations

DAY TWO -- OCTOBER 2, 2012

TACK ROOM A & B

URBAN HYDROGEOLOGY -- II (Bob Tipping and Mike Trojan, co-chairs)

8:00	**Gilbert Gabanski and Mary Finch**	Hennepin County Dept Environmental Services and Barr Engineering	Big-Picture Groundwater Perspective Supports Urban Redevelopment
8:20	**Walton R. Kelly**	Illinois State Water Survey	Road Salt and the Salinization of Surface Waters and Groundwater of the Chicago Region
8:40	**Bruce Wilson and Mike Trojan**	Minnesota Pollution Control Agency	Management of stormwater runoff through infiltration
9:00	**Mark Doneux**	Capital Region Watershed District	Volume Reduction BMPs to address flooding and water quality problems in the Capitol Region Watershed District, St. Paul, MN
9:20	**John S. Gulliver**	University of Minnesota, Department of Civil Engineering	Pollution of Drinking Water Aquifers due to Stormwater Infiltration

9:40 - 10:10 BREAK (Carriage Hall B and Captain's Room)

GROUNDWATER QUALITY -- I: CONTAMINANTS OF EMERGING CONCERN (Melinda Erickson and Bill Simpkins, co-chairs)

10:10	**Virginia Yingling**	Minnesota Department of Health	Genesis and Response to a Perfluorochemical (PFC) Megaplume – Washington County, Minnesota
10:40	**Dana Kolpin**	U. S. Geological Survey, Iowa WSC	Contaminants of emerging concern: Groundwater research by the USGS TOXICs Program
11:10	**Richard Kiesling**	U. S. Geological Survey	Emerging contaminants in Minnesota seepage lakes: role of shallow groundwater inflow
11:30	**Melinda Erickson**	U. S. Geological Survey	Contaminants of Emerging Concern in Minnesota Groundwater

57th Midwest Ground Water Conference Presentations

DAY TWO -- OCTOBER 2, 2012

HARVEST ROOM B & C

GROUNDWATER MANAGEMENT -- III: PROGRESS AND APPROACHES TO ADDRESSING GROUNDWATER ALLOCATIONS AND CONFLICTS IN THE MIDWEST REGION (Princesa VanBuren Hansen, Cathy O'Dell, George Kraft, co-chairs)

8:00	**Phil Gerla**	The Nature Conservancy/University of North Dakota	Managing groundwater withdrawals to sustain aquatic ecosystems
8:20	**Jennifer Morin**	North Dakota State Water Commission	Using Simple Groundwater Models to Inform the Decision in Areas of Sparse Data
8:40	**Tylr Naprstek**	Lower Loup Natural Resources District – Nebraska	Using the Elkhorn-Loup model for groundwater management in the Lower Loup Natural Resource District of Nebraska
9:00	**James Stark**	US Geological Survey	Implementing the Minnesota Water Sustainability Framework: Taking a step toward ensuring sustainable water for Minnesota
9:20	**Stephen C. Thompson**	Minnesota Pollution Control Agency	Minnesota Watershed Budgets – By the Numbers

9:40 - 10:10 BREAK (Carriage Hall B and Captain's Room)

GROUNDWATER/SURFACE-WATER INTERFACE -- II (Donald Rosenberry and Perry Jones, co-chairs)

10:10	**Bill Simpkins**	Iowa State University	CSI Meets Groundwater: “Autopsying" the Effect of a “500-year” Flood on a Sand and Gravel Aquifer in Ames, Iowa
10:30	**Royce Cline and Steve Pusc**	North Dakota StateWater Commission	Impact of the 2011 Missouri River Flooding on Groundwater Levels in Bismarck and Mandan, North Dakota
10:50	**Perry M. Jones, Jared Trost, and Don Rosenberry**	U. S. Geological Survey	Groundwater and Surface-Water Interactions in White Bear Lake
11:10	**Andrew Streitz**	Minnesota Pollution Control Agency	Changing Rainfall Intensity and its Possible Influence on Lake-Groundwater Interactions
11:30	**Don Rosenberry**	U. S. Geological Survey	Moderated Discussion

57th Midwest Ground Water Conference Presentations

DAY TWO -- OCTOBER 2, 2012

HARVEST ROOM A

GEOTHERMAL (Kelton Barr and Martin Saar, co-chairs)

8:00	**Martin Saar**	University of Minnesota	The multi-functionality of geologically sequestered carbon dioxide: From geothermal energy extraction to renewable energy storage
8:20	**A. C. Samuelson**	Ball State University	Assessing the impacts of geology and groundwater flow (the hydrogeologic situation) on the ground-source geothermal system at Ball State University
8:40	**Craig V. Lemma**	HGA Architects and Engineers LLC	Design and Construction Factors for the Installation of Minnesota's Largest Operational Geothermal Loop Field
9:00	**Jimmy Randolph**	University of Minnesota	CO2 plume geothermal (CPGZ) systems for power production, energy storage and waste heat recovery
9:20	**Benjamin Tutolo and Martin Saar**	University of Minnesota	Geothermal energy in Minnesota: Revised prospects based on new heat flow measurements

57th Midwest Ground Water Conference Presentations

DAY TWO -- OCTOBER 2, 2012

11:50 - 1:00 LUNCH (Carriage Hall A and Garden City Ballroom)

TACK ROOM A & B

GROUNDWATER QUALITY -- II: NITROGEN (Melinda Erickson and Bill Simpkins, co-chairs)

1:00	**Kimberly Kaiser**	Minnesota Department of Agriculture	Minnesota Central Sands Private Well Network 2011 Nitrate-N Results Summary
1:20	**Greg Brick**	University of Minnesota, Department of Earth Sciences	Where in Minnesota Can You Find 35,000 PPM Nitrate?
1:40	**William Schuh**	North Dakota State Water Commission	Nitrate-N Loading Assessment and Remediation in a Shallow Unconfined Aquifer
2:00	**Scott F. Korom**	University of North Dakota, Grand Forks	Modeling the Electron Donor Contributions to Aquifer Denitrification, Karlsruhe, ND

2:20 - 3:00 BREAK (Carriage Hall B and Captain's Room)

GROUNDWATER QUALITY -- III: GEOCHEMISTRY, AGE, AND RESIDENCE TIMES (Melinda Erickson and Bill Simpkins, co-chairs)

3:00	**Madeline Gotkowitz**	Wisconsin Geologic and Natural History Survey	Hydrogeologic evidence of preferential pathways near municipal supply wells
3:30	**Sharon Kroening**	Minnesota Pollution Control Agency	The Minnesota Pollution Control Agency's Statewide Ambient Groundwater Monitoring Network
3:50	**Virginia L. McGuire**	U. S. Geological Survey - Nebraska	Groundwater age and quality, Papio-Missouri River Natural Resources District, Eastern Nebraska
4:20	**BJ Bonin**	WSB and Associates	Using Cuttings to Identify Arsenic Risk During Well Construction in Unconsolidated Aquifers

57th Midwest Ground Water Conference Presentations

DAY TWO -- OCTOBER 2, 2012

11:50 - 1:00 LUNCH (Carriage Hall A and Garden City Ballroom)

HARVEST ROOM B & C

GROUNDWATER MODELING -- II (Madeline Gotkowitz, David Steward, and Otto D. L. Strack, co-chairs)

1:00	**Daniel Feinstein, Michael Fienen (WI WSC), Randy Hunt (WI WSC), Howard Reeves (MI WSC)**	U. S. Geological Survey	Application of a "semi-structured" approach with MODFLOW-USG to address local groundwater/surface-water interactions at the regional scale
1:20	**Michael Fienen**	U. S. Geological Survey, Wisconsin WSC	Emulating a Regional Groundwater Model with a Bayesian Decision Network for Efficient Decision Support
1:40	**David J. Hart**	Wisconsin Geological Survey	Fully three-dimensional poroelastic model simulating reverse groundwater fluctuations during aquifer pumping
2:00	**Paul Juckem**	U. S. Geological Survey	Mapping flow path uncertainty with an Analytic Element model and Monte Carlo techniques

2:20 - 3:00 BREAK (Carriage Hall B and Captain's Room)

KARST -- II: KARST GROUNDWATER RESOURCE CHARACTERIZATION (Jeff Green and E. Calvin Alexander, Jr., co-chairs)

3:00	**Mark Borchardt**	USDA-Agricultural Research Service	Viruses in Groundwater: From Disease Outbreaks to Sporadic Illness
3:30	**E. Calvin Alexander, Jr.**	University of Minnesota	Deep Time in the Upper Mississippi Valley Karst
3:50	**Carl Keller**	FLUTe	Flexible Liner Special Utility for Karst Formations
4:10	**Jeffrey A Green**	Minnesota Department of Natural Resources	Karst Hydrogeology Investigations in the Cambrian St. Lawrence Aquitard
5:00	***Embassy Suites***	Informal post-conference gathering	

DAY THREE -- OCTOBER 3, 2012

8:00 - 4:30 ***FIELD TRIP -- GROUNDWATER IN AN URBAN SETTING: A HYDROGEOLOGIC AND HISTORICAL TOUR OF THE TWIN CITIES (Bob Tipping and Steve Robertson, co-chairs)***

Abstracts

Plenary Session (Kelton Barr, chair)

Water Management Issues Associated with Bakken Oil Shale Development in Western North Dakota

Author - Robert Shaver
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The Bakken Shale in western North Dakota is estimated to contain 2.1 billion barrels of recoverable oil using horizontal drilling and hydrofracing techniques.Up to 2,500 new oil wells could be drilled per year for the next 10 to 15 years. Water requirements, primarily for hydrofracing, are estimated at 1.5 to 2.0 million gallons per oil well.Except for the Missouri River/Lake Sakakawea, western North Dakota has limited surface water and ground water resources.Other smaller rivers and streams are characterized by very low flows during most of the year making them unreliable water sources.

Ground water sources include the regional bedrock Fox Hills aquifer, and some small-scale aquifers of glaciofluvial origin.Large-scale water withdrawals for oil field use are not permitted from the Fox Hills aquifer because it is a major source of water for rural domestic and stock use.Declining Fox Hills pressure heads of between 1 and 2 feet per year are a major management concern and a regional computer modeling study has been initiated to address this issue. Glaciofluvial aquifers are of limited areal extent making them insufficient sources for large-scale water supplies, particularly during periods of extended drought.In addition, glaciofluvial aquifers are incised into sedimentary bedrock units and large-scale pumping can induce lateral flow of more saline bedrock ground water into the glaciofluvial aquifers thereby degrading water quality. Given the above, ground water withdrawals from glaciofluvial aquifers are managed using an "incremental development" approach that limits timely allocation of water.

In May 2010, the U.S. Army Corps of Engineers placed a moratorium on the issuance of permits to divert water from Lake Sakakawea, the most reliable water supply in terms of both quantity and quality in western North Dakota.In response, and to accommodate more efficient distribution of water for oil field industrial use, the State Engineer developed policies allowing for temporary diversion from other surface water bodies in western North Dakota (predominantly small-scale ponds and sloughs) and temporary conversion of existing irrigation water permits for industrial use. Oil field industrial demand for water is being met without causing aquifer depletion and undue harm to other water appropriators.

Groundwater to Sustain Agriculture in the Midwest's Prairies: Interdisciplinary, Integrated Modeling Approaches

Author - David R. Steward
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The prairies of the Midwest help to feed the world, and yet, weather variability in the grasslands provide challenges to agricultural production. Groundwater irrigation provides a resilient water source that sustains agriculture through dry periods, and yet, over-pumping in many regions threatens this source of nourishment. This presentation overviews recent groundwater studies of the Ogalalla Aquifer of the central plains. A variety of models from Modflow to those based upon the Analytic Element Method have been employed to study regional aquifer drawdown and the capacity of recharge to sustain and refill the aquifer. Integrated models have also been developed that link the results from these studies with agricultural production models and economic models. Findings help to substantiate the impacts of changes in policy, climate, and practices, not just on groundwater stores, but also on agricultural production and economic activity.

The Pursuit of Science at the Groundwater/Surface-water Interface: Examples of Societal Relevance from the Midwest and Beyond

Author - Donald Rosenberry
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The concept that groundwater and surface water are actually one resource, linked at the sediment-water interface of lakes, wetlands, and streams, is now widely accepted by water-resource scientists and managers alike. Recent improvements in tools and measurement resolution have led to better understanding of the physical, geochemical, and biological processes that occur at this important ecotone, but this research is not just the esoteric pursuit of scientists. These processes and linkages are directly relevant to the public, particularly when they affect property values or endangered species. Examples from out-of-control wetlands and lakes in North Dakota and Minnesota, to highly controlled lakes and rivers in Washington, California, Pennsylvania, and New Hampshire, will illustrate the dynamic nature of this interface and how the public is affected, sometimes greatly, by the linkage between groundwater and surface water.

Abstracts

Plenary Session (Kelton Barr, chair)

Groundwater Science Meets Public Policy in Wisconsin

Author - Kenneth R. Bradbury
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Wisconsin has a rich history of hydrogeologic studies and widespread availability of both data and technical expertise for water resources management. Citizens and scientists usually expect informed management of water resources to be based on sound science and careful technical evaluations. However, several recent events in Wisconsin demonstrate continuing disconnects between groundwater science and public policy decision-making. Recent examples of such disconnects include the following:

- Inability of "expert" members of a legislatively mandated Groundwater Advisory Committee to reach consensus on groundwater quantity management.
- The failure of proposed 2010 legislation that would have revised Wisconsin's high-capacity well approval policies.
- A legislative reversal of agency rules for municipal well disinfection even with documented health risk.
- Continued approval of onsite septic systems in areas of shallow bedrock despite evidence of resulting groundwater contamination in such settings.
- Ongoing arguments over the relationships between groundwater pumping, low water levels, and climate change.
- Inappropriate responses to extreme water levels (floods and droughts).

The causes of these disconnects include widespread misunderstandings of groundwater principles, poor communication of scientific uncertainty, a general mistrust of models, a desire for "one-size-fits-all" policies, and a lack of awareness of available data and past studies. Interest groups on all sides of issues sometimes interpret uncertainty as lack of knowledge and use this as justification for doing nothing in the face of increasingly significant consequences.

As water scientists, we have an obligation to ensure that legislators, regulators, and the public have the best possible technical information to inform their decisions. For meaningful decision-making to occur, both data and hydrogeologic interpretation must be made widely available. Modeling and quantitative analyses are now standards of our profession; we need to communicate this to regulators and to the public. Citizens should insist on science-based analyses of hydrologic issues, but should also be open to compromise through informed decision-making. Finally, good, timely, and understandable communication is absolutely critical.

Sustaining Water Resources into the Future - Science and Policy Challenges

Author - Deborah L. Swackhamer, PhD
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In 2009, the Minnesota Legislature commissioned the University of Minnesota's Water Resources Center (WRC) to develop a long-term strategy for how to achieve sustainability for its water resources, in part to help inform the long term investments of the Clean Water Fund created by the Clean Water, Land, and Legacy Amendment to the stateís constitution. The Legislature defined sustainable water use as that which "does not harm ecosystems, degrade water quality, or compromise the ability of future generations to meet their own needs". The Minnesota Water Sustainability Framework presents the 10 most pressing issues of the day that must be addressed to achieve sustainable water use, presents strategies for what should be done, and provides recommendations for how to meet these challenges. The Framework addresses long term needs, including how to know and manage our water supply, how to meet federal water quality standards and bring agriculture into the solution, recommendations for managing contaminants of emerging concern, the integration of land and water planning at the watershed scale, how to achieve ecological and hydrologic integrity, and how to manage the nexus of water and energy. The comprehensive plan also addresses economic and social issues that must be addressed to achieve water sustainability.

Abstracts

Groundwater and Energy Production: From Frac Sand Mines to Oil Shale Plays (Tony Runkel, chair)

Overview of the Bakken Shale Development with Emphasis on Hydraulic Fracturing and Wastewater Treatment and Disposal

Author - Bruce E. Hicks
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The presentation will include an update on oil and gas development in North Dakota, the technique utilized by companies while performing hydraulic fracture stimulation, and disposal of produced water. There are currently over 200 rigs operating in North Dakota and production has increased to over 600,000 barrels of oil per day (bopd), due solely to hydraulically fractured horizontal wells. Some forecasts have projected North Dakota's oil production to exceed 1,000,000 bopd. The hydraulic fracturing stimulation utilizes over 2 million gallons of water for each well. Operators are attempting to transport frac water via pipelines, which will reduce truck traffic, and in some instances, the same pipelines can be used to dispose of the waste water. Please visit the Oil and Gas Division's website (www.oilgas.nd.gov) to view this presentation. Our website has a wealth of information, including a GIS map server, activity reports, Director's Cut, and Recent Presentations.

Silica Sand Mining in the Midcontinent Region: Why Here, What Does the "Boom" Look Like, and What Are the Concerns?

Author - Anthony C. Runkel
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Paleozoic age bedrock layers of quartzose sandstone in the central midcontinent of North America have been mined since the 1800s to supply 'silica sand' for use in a number of industrial applications. They are well known to both sedimentologists and industry as some of the most mineralogically pure sandstone on Earth, composed of greater than 95 percent quartz. The recent rapid expansion of silica sand mining in the central midcontinent is driven by demand for proppant used in the process of hydrofracking for oil and natural gas.

Several attributes make the sandstone in the central midcontinent, especially parts of Minnesota, Wisconsin, Illinois and Iowa, particularly desirable. Not only are they composed mostly of high-strength and relatively inert quartz, the grains are especially well-rounded, well-sorted, relatively coarse-grained, and are poorly cemented. Furthermore, extraction and transport is relatively easy because the sandstone layers are at or near the land surface across aerially large footprints, and road and rail networks are well-developed.

Together, Minnesota and Wisconsin have expanded from what was likely fewer than 15 silica sand mining operations ten years ago, to 100 active or 'in development' mines according to recent estimates, the vast majority of them in Wisconsin. Nearly all mines are open excavations, but a few underground mines are also currently active. The regional industry may soon have the capacity to provide nearly 50 million tons of processed silica sand each year according to some estimates.

Concerns have been expressed about the expansion of silica sand mining. The most common are related to increased truck traffic, landscape aesthetics, surface and groundwater quality and quantity related to washing procedures and mine dewatering, and airborne silica dust. Many of these issues are addressed by state and local regulations developed originally for other mining activities such as aggregate extraction. However, several counties and townships have established temporary moratoriums on permitting of new mines, to provide time to develop strategies to address these concerns and manage the rapid expansion of the industry.

Overview of Chippewa County Groundwater Study to Evaluate The Impacts of Non-Metallic Mining and Irrigated Agriculture in Western Chippewa County, Wisconsin

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Current economic trends have placed additional demands on the land and water resource base of Midwestern states.Global demand for food, fiber, and energy have increased commodity prices, and have resulted in more intensive cropping patterns and an increase in the acres of irrigated cropland.

At the same time, global demand for energy has significantly increased the demand for "frac sand", used in oil and natural gas production. Much of this sand will be supplied by newly developed industrial mines that will be operated to extract sand and sandstone from high quality geologic deposits associated with the Jordan and Wonewoc formations, common to areas of Wisconsin and Minnesota.

In response to these trends, the public has expressed concern regarding the possible impacts associated with the expansion of irrigated agriculture and industrial sand mining.

One common question posed by the public is: How will existing and future groundwater recharge and pumping rates impact the availability of groundwater supplies that support surface water features such as streams and rivers?

To address this concern, Chippewa County, the Wisconsin Geological and Natural History Survey (WGNHS), and the U.S. Geological Survey (USGS) have developed a groundwater study that will improve our understanding of how the expansion of non-metallic mining and irrigated agriculture will affect groundwater resources in western Chippewa County and surrounding areas. The project scope includes development of a groundwater flow model to evaluate the impacts of changes to groundwater recharge and withdrawal on the hydrologic system. This groundwater study will benefit water resource management efforts in the region by characterizing hydrogeologic conditions and by incorporating this characterization into a computer model (MODFLOW), capable of evaluating a set of scenarios associated with alternative management plans and/or hydrologic conditions, including changes in water use or climatic conditions. Project results will be of direct benefit to local citizens, state and local government, and agricultural and mining interests. Most importantly, the

Groundwater and Energy Production: From Frac Sand Mines to Oil Shale Plays (Tony Runkel, chair)

results will provide all interested parties with quality scientific information to support informed decision making regarding the management of water resources.

The objectives of this study are to:

1. Develop soil water balance and groundwater flow models to evaluate the impacts of current and future water use and topography on the hydrologic system.
2. Disseminate the study results to project stakeholders and the general public.
3. Transfer the study results to similar geologic/hydrologic settings as appropriate.

This presentation will focus on the industrial mine expansion that has occurred in Chippewa County, Wisconsin, the public concerns associated with potential impacts on water resources, the response by the industrial sand industry, and the scope and objectives of the proposed groundwater study.

Results and Recommendations from the Minnesota Department of Natural Resources Study on Limestone Quarry Impacts on Groundwater Systems and its Applicability for Frac Sand Mining

Author - Jeffrey A. Green,
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The Minnesota Department of Natural Resources-Division of Waters conducted a four-year study into the impacts on groundwater systems from limestone quarries and gravel impacts. Our studies have shown that in certain areas, these mines can impact the local water resources. Quarries and pits that actively dewater may impact neighboring wells. Mine operations and dewatering schedules may need to be altered to minimize impacts on streams and springs. Some areas, particularly those with groundwater fed wetlands and where conduits in limestone are near the surface, may need to be avoided entirely. Good information is crucial in order to evaluate a mining operation. When a project is proposed, detailed maps of the topography, geology, and hydrology of the site and surrounding area should be provided. This will allow local governments to assess the impact of the mine on ground water flow, adjacent domestic wells, and surface water bodies. For limestone quarry sites, additional information on the location of sinkholes, stream sinks and springs in order to avoid those areas where quarry development might harm springs that discharge from the limestone. Mining and reclamation plans that show mining stages, site layout and post-mining land-use slope and vegetation should be provided. This will allow local governments to visualize the size and scope of the mine and the character of the site after mining.

Groundwater Modeling – I (Madeline Gotkowitz, David Steward, and Otto D.L. Strack, co-chairs)

Modeling Transit Time Distributions with MODFLOW/MODPATH

Authors – Henk Haitjema and Daniel Abrams
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Groundwater transit time distributions (TTDs) in watersheds are of interest for assessing the impacts of non-point source pollution on the water quality of the outlet stream. These TTDs are often generated with the groundwater flow model MODFLOW in combination with the particle-tracking program MODPATH. This is accomplished by tracing several thousand particles that are released at the aquifer top and are evenly distributed over the watershed. However, the accuracy of the resulting groundwater TTD is easily compromised by limited grid resolution and by incorrect treatment of weak sink streams in MODPATH. We offer a simple correction on calculated transit times to mitigate much of the error due to a coarse model grid. We also show that the default settings for weak sink streams in MODPATH are generally inappropriate for obtaining accurate transit time distributions and offer alternative settings. Interestingly, the TTD for a high capacity well is generally not affected by the grid resolution or weak sink settings of MODPATH. The transit time distributions generated with MODFLOW/MODPATH are validated by comparison with an analytic solution.

Inferring the Effective Hydraulic Conductivity Using a Simple Model and the Available Information

Author - Randal J. Barnes
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We consider a single aquifer. We model the aquifer as homogeneous and isotropic, with a constant thickness, and a horizontal base. We model the flow in the aquifer as steady and comprising three identifiable features: regional uniform recharge, regional uniform flow, and an arbitrary collection of pumping wells with known discharges.

We model the hydraulic conductivity and the uniform recharge rate as random variables with specified prior distributions. These prior distributions may be based upon subjective professional assessments and regional statistics.

The prior distributions are formally updated by incorporating the information from a set of noisy head measurements taken at known locations. We embrace the Bayesian perspective: probability characterizes uncertainty by quantifying a set of rational beliefs. The associated mathematical tools allow for updating these rational beliefs as new information becomes available.

The necessary computations are not difficult. The results are a powerful complement to pumping tests. We argue that this simple analysis should be applied before the construction of a more complex groundwater model.

Abstracts

Groundwater Modeling – I (Madeline Gotkowitz, David Steward, and Otto D.L. Strack, co-chairs)

The Effect of Abandoned Wells on Irrigation and Pumping

Author – Otto D. L. Strack
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Abandoned wells, i.e., wells that exist but are no longer in operation, may have a profound and often not clearly understood effect on wells drilled for the purpose of agricultural irrigation. The question we address is what the effect of abandoned wells, often unknown in location, could have on the flow in a system of two aquifers and, in particular, on the efficiency of the operation.This problem lends itself to a simple analytical solution that can easily be implemented in commercially available computer programs such as MATLAB®. The advantage of such work is that the interactive nature of the implementation of a relatively simple solution makes it possible to gain insight in practical issues with relatively little effort. This talk has an objective besides to present the solution to this problem in simple terms: to demonstrate that answers to simplified problems can provide insight with relatively little effort, given some knowledge of the basic equations that govern the problem. Such insight can then be used in implementations of the full problem in more advanced computer modeling software.

Groundwater Management – I: Groundwater Appropriation Challenges in Irrigated Areas in the Northern Lakes States (Princesa VanBuren Hansen, Cathy O'Dell, and George Kraft, Co-chairs)

Irrigation Impacts in the Northern Great Lake States with the Wisconsin Central Sands as Case Study

Authors - George J. Kraft and David J. Mechenich
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Irrigated agriculture in the US was once almost exclusive to the arid west, but during the last half-century has expanded greatly into the humid east, including the northern Great Lake States of Wisconsin, Minnesota, and Michigan, where groundwater is particularly well connected to abundant local surface waters. Source water in this region is usually obtained from glacial aquifers that are strongly connected to surface waters, so irrigation has a potential to locally decrease baseflows in streams and water levels in aquifers, lakes, and wetlands. Irrigation continues to expand rapidly and often without evaluations and management that protect resource health.

The Wisconsin Central Sands saw early growth and impacts of irrigation pumping, which were explored in works of some fame by Weeks et al. (1965) on the Little Plover River and Weeks and Stangland (1971) on "headwater area" streams and lakes. Four decades later, and after irrigation has grown to a dominant landscape presence, we revisited irrigation effects on central sands hydrology. Irrigation effects have been substantial, on average decreasing baseflows by a third or more in many stream headwaters and diminishing water levels by up to 1.2 m. This explains why some surface waters have become flow and stage impaired, sometimes to the point of drying, with attendant losses of aquatic ecosystems.

Irrigation exerts its effects by increasing evapotranspiration by an estimated 45 to 142 mm compared with pre-irrigated land cover. We conclude that irrigation water availability in the northern lake states and other regions with strong groundwater - surface water connections is tied to concerns for surface water health, demanding a focus on managing the upper few meters of aquifers on which surface waters depend rather than the depletability of an aquifer.

Conceptual to Quantitative Frameworks for Evaluating Irrigation and Groundwater Pumping Impacts in the Northern Lake States

Authors - Mallika Nocco and Mack Naber

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Irrigated agriculture mainly using groundwater has expanded greatly in the humid northern lake states of Wisconsin, Minnesota, and Michigan during the past half century. As groundwater in the region is strongly connected to local surface waters, irrigation can decrease base flows in streams and water levels in aquifers, lakes, and wetlands. Accounting for irrigation impacts in this setting is not a straightforward proposition that can be accurately modeled as a simple groundwater withdrawal. Rather, irrigation requires a consideration of the overall hydrology of irrigated fields compared to a reference condition, through all seasons and through cycles of wet and dry years. The reason for this is that evapotranspiration (ET) losses from the landscape will be great during most growing seasons compared to a native landscape, but the native landscape may have more ET (and hence less net recharge) in 'shoulder seasons' *i.e.*, the portions of springs and autumns when native landscapes are transpiring but croplands are not. We have been seeking to understand irrigation – ET – recharge dynamics in the Wisconsin Central Sands. As a result of past modeling and field work dating to the 1970s, and ongoing work involving Agro-IBIS and other vadose zone modeling, we semi-quantitatively understand that average annual ET is greater (and net recharge smaller) under irrigated corn compared with prairie or pine. The simulations also indicate important sensitivities that need to be further evaluated from specific seasonal evapotranspiration compartments, including evaporation from bare ground, residue, additional crops, canopy cover, and growing season length. These need to be understood to construct better groundwater models that will be useful management tools.

Investigating the Effects of High-Capacity Irrigation Well Pumping on Groundwater Recharge and Evapotranspiration in the Central Sands of Wisconsin

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Land-use change such as high capacity irrigation pumping has the potential to impact regional hydrologic budgets. To determine the impact of high-capacity irrigation well pumping on groundwater recharge in the unconfined aquifer in the Central Sands of Wisconsin, we constructed a Matlab model to estimate actual evapotranspiration using the Penman-Monteith approach and the Jarvis-Stewart model of stomatal conductance for five vegetation types. Measurements from five eddy flux covariance sites in and near WI were used to calibrate the evapotranspiration model for each of the vegetation types. A multiple linear regression was then conducted on water budget variables (change in storage, precipitation minus actual evapotranspiration) and the cumulative number of high capacity wells that were installed over time within the Central Sands study site. The multiple linear regression results showed that the coefficient for the cumulative number of irrigation wells over time was negative indicating that recharge is decreasing within the study site due to the expansion of high-capacity irrigation wells.

Analysis of Changes to Base Flow Across Minnesota and a Profile of the Little Rock Creek Study Area

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Declining trends in stream baseflow were observed in a majority of randomly selected rivers during a review of watersheds throughout the state of Minnesota. The baseflow declines were calculated for a period when statewide precipitation and annual average stream flow levels remained constant, and water appropriations for municipalities and irrigators were increasing at a statistically significant rate.

Previous studies focused on the relation between declining summer streamflow and water appropriations. New investigations have additionally identified increased field tiling, the rising frequency of larger intensity precipitation events, and higher annual temperatures as possible contributing factors in the decline of stream baseflow values.

The Little Rock Creek watershed was investigated as a demonstration case for statewide hydrologic watersheds, and included the development of a groundwater model. The model quantitatively tied declines in streamflow to increasing groundwater withdrawals.

Optimization Modeling for Groundwater Management in the Wisconsin Central Sands

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Groundwater management necessarily entails allocating water among appropriators while preserving the integrity aquatic ecosystems and supporting ecosystems users (fisherfolk, hunters, boaters, riparians, swimmers, and others). While the consequences of groundwater pumping on streamflows or lake and wetland levels can be reasonably evaluated with deterministic models, understanding the value of appropriated water against ecosystem and ecosystem user values is more complicated. Optimization modeling is a tool that helps develop this understanding. Given values for allocated water, ecosystems, and ecosystem users, an optimization model can explore tradeoffs.

We are developing an optimization model for groundwater management in the Wisconsin Central Sands built on top of a MODFLOW flow model of the region. The model considers agricultural irrigation use and residential, recreational and ecological interests to inform an optimal irrigation allocation policy. We consider different strategies for implementation of this optimal policy that are indicated by the results of the model. The large scale of the model poses a computational challenge, which we address by a variety of approximation schemes.

Abstracts

Groundwater Management – II: Groundwater Management and Policy Framework in the Northern Great Lakes Region (Princesa VanBuren Hansen, Cathy O'Dell, and George Kraft, co-chairs)

Water Appropriation Permitting in Minnesota

Authors - Julie Ekman and Princesa VanBuren Hansen
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Minnesota has a long history of water management stemming from the 1930s. The focus has varied widely from an emphasis on draining land for agricultural uses, to protecting water for human uses, to today's focus on ensuring clean and abundant water resources are available for people and to support ecological diversity for now and the future. Those who appropriate more than 10,000 gallons per day or one million gallons per year are required by MN law to obtain a permit, to measure the water appropriated, and report and pay fees on an annual basis. Water use data shows us that water uses have changed and grown significantly over the past several decades. In some areas of the state, competition for water resources is indicated by loss of wetland areas, lower stream flows and a change in water users' ability to pump to the volumes they need. What will the future of water management become in the state of Minnesota?

Water Quantity Monitoring in Minnesota in the Present and the Future

Author - Greg Kruse
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A high-quality hydrologic monitoring network informs decision-making related economic and community development, drought and flood emergency management and helps to maintain a balance between use and the environment. The cooperative efforts of federal, state and local governments, citizen observers and private industry have significantly expanded water quantity monitoring in Minnesota. The Minnesota Department of Natural Resources measures groundwater levels, precipitation, lake levels and stream flows at more than 2,800 locations across the state. This presentation will provide a brief description of those monitoring networks and future efforts to integrate Minnesota's hydrologic information.

Using Groundwater in the 21st Century

Author - Jason Moeckel
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As demand for water continues to increase, the need to manage it better is becoming even more important. Groundwater supplies over 75% of Minnesotan's drinking water, and supports innumerable lakes, streams and wetlands. Businesses and agriculture are increasingly depending on it. In fact, we are using more groundwater than ever before. This presentation will explore how principles of adaptive management and structured decision making can help overcome and manage risk and uncertainty. We'll describe the steps that Minnesota DNR and other partners are taking to support our legislative mandate to ensure adequate supply for current and future generations.

Groundwater Management in Wisconsin: Current Status & Gaps

Author - Eric Ebersberger
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A 2003 Wisconsin Groundwater Protection Act directed the Wisconsin Department of Natural Resources (WDNR) to designate two groundwater management areas and provided specific requirements for environmental review of high capacity wells if the proposed well was to be located within 1,200 feet from a trout stream or other designated high quality waters, would result in significant impacts to springs with normal flow greater than 1 cubic foot per second, or would result in a water loss greater than 95%. Generally, the DNR implemented this law such that if a proposed well would not result in a water loss greater than 95% and was not near a 1 cfs spring or within a groundwater protection area, the DNR conducted very little additional environmental review prior to issuing a high capacity well approval.

As a result of the Wisconsin Supreme Court's 2011 decision in Lake Beulah Management District v. State of Wisconsin Department of Natural Resources, 2011 WI 54 (2011) the WDNR modified its review process for high capacity well applications. The Court in Lake Beulah concluded that the DNR has the authority and a general duty to consider whether a proposed high capacity well may harm waters of the stateówhich is statutorily defined to include streams, lakes, wetlands and public and private wells. In response to the Courtís affirmation of agency authority, the WDNR has broadened the scope of its review of high capacity well applications beyond the specific considerations of the 2003 Groundwater Protection Act. Specifically, the WDNR now reviews these applications for potential impacts to all waters of the state, and conditions or denies applications for high capacity wells that would have a significant adverse impact. This presentation will provide an overview of groundwater management in Wisconsin, including public trust implications, the broadened scope of high capacity well review, and ongoing policy considerations and groundwater quantity issues.

Abstracts

Aquifer Characterization – I: (Justin Blum, chair)

A Real-Time Groundwater Monitoring System in Three Communities in the Larger Twin Cities Basin

Authors - John Dustman, Peter Bell,
Brian Gulbranson, Bill Gregg
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Groundwater systems can be investigated with remote sensing and direct measurement techniques. Current computer technologies are able to collect and store the massive data but fall short where more sophisticated trend analysis is essential to understanding the variability of the system. The management of the data stream becomes critical based on their ability to broadcast a significant quantity of data. Customized tools for data input using data bases are common but provide a static view of the data which can mask the relevance of the continuous data stream. Kriging algorithms and visualization tools are part of the solution to enhance the understandings which drive accurate conclusions. This presentation will present a comparative analysis of the data stream using a static assessment compared with the more dynamic assessment using the entire data set over the study period.

Conclusions and outcomes will be contrasted for environmental remediation, municipal water supply and mining applications.

Specific Capacity Vs. Aquifer Test – This Time It's Personal!

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While the value of a single drillers log may be suspect, useful information can be extracted from the hundreds of thousands of logs in the County Well Index (CWI) database. We will demonstrate that specific capacity test information in CWI can provide tens of thousands unbiased permeability estimates to supplement the few hundred available pumping tests. An estimate transmissivity from the single drawdown value provided in a specific capacity test must account for partial penetration, even though the aquifer thickness is commonly unknown. This is addressed using methods to identify the contacts of confining materials and to estimate aquifer thickness using spatial statistical methods. Comparison of over one hundred pumping tests shows that permeability estimates using the information from the driller is unbiased with a correlation coefficient of 0.75.Additional specific capacity tests near the pumping test wells suggest that permeability is spatially correlated with an average correlation length of approximately 1 km. This information also suggests that the permeability values from pumping tests conducted on high capacity wells may significantly overestimate the regional aquifer permeability. The state scale maps of aquifer thickness and permeability produced during this analysis may be useful in interpreting buried glacial stratigraphy.

Jacob and Goldilocks: How to define small "u" for Jacob Pumping Test Analysis

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Pumping tests are widely used to determine aquifer properties. While there are many variations and refinements of analytical methods the traditional Jacob analysis is still extensively used. A basic assumption of the Jacob analysis is that there is a small "u" value that allows a greatly simplified analytic solution. The value of "u" is a function of radial distance from the pumping well and pumping time. For "u" to be small radius must be small or pumping time must be long. Applying a too stringent requirement for small "u" can lead to elimination of data from wells deemed too far away and/or require long pumping times. Investigations at an extensively instrumented well field near Akeley, Minnesota have allowed better estimates of small "u" and point out potential problems with wells too close to the pumping well where separate assumptions of laminar flow and horizontal flow may be violated. Results from this field site suggest that values for a small "u" can range up to 0.2 as compared to textbook values ranging from 0.01 to 0.05.

A Distance-Drawdown Analysis Procedure to Identify the Effects of Bedding Plane Fractures and Improve the Estimates of Hydraulic Properties in the Paleozoic Bedrock Aquifers of Southeastern Minnesota

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The Minnesota Geological Survey has confirmed the presence of hydraulically active bedding plane fractures in many wells by geophysical and video logging techniques in the Paleozoic bedrock of southeastern Minnesota. Subsequently, several aquifer test datasets on-file at Minnesota state agencies were examined for the influence of bedding plane fractures and well construction practices such as blasting and bailing. A combination of transient and steady-state analysis techniques were found to be necessary to identify and account for the hydraulic response to bedding-plane fractures or an "enhanced" wellbore. The combination of techniques is effective over a range of hydraulic confining conditions because it requires consistency between storativity and leakage. The focus of the procedure is to identify well efficiency issues in or near the production well. After the efficiency of the pumping well is accounted for, observation wells that have responded anomalously are more easily identified. Therefore, it brings attention to boundary conditions and supports a consistent conceptual model of flow in the aquifer volume affected by pumping. This has significantly increased the confidence of transmissivity, storativity, and leakage estimates for the datasets examined so far. Experience applying this procedure to tests conducted in highly variable settings, such as layered glacial sediments, is quite limited. Nevertheless, it should be widely applicable to any test in porous media with sufficient data.

Abstracts

Aquifer Characterization – I: (Justin Blum, chair)

Discussion of an Aquifer Storage and Recovery (ASR) Permit Program, Eleven Years Experience in Iowa (2000-2011)

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In March, 1998 Iowa's Governor signed House File 2292. The Bill required Iowa DNR to initiate a permit program for persons to inject, store, and recover treated water from aquifers for potable use. Rules were written in consultation with an advisory committee consisting of ten representatives of professional/technical organizations, water utilities, and industry groups. The rules include the clarification of legal rights and obligations affecting ASR permit holders, the technical definition of the affected area within the aquifer, and provisions for "limited registration" for aquifer pre-testing before a 20-year ASR permit is issued. The rules were adopted in September of 1999. Engineering/hydrogeological criteria for the Departmentís ASR project application review process will be discussed. Four separate permits, covering six injection sites, have been issued in the ensuing years; Iowa's policy experience with these types of wells will be outlined.

Aquifer Characterization – II/Urban Hydrogeology – (Justin Blum, Bob Tipping, and Mike Trojan, co-chairs)

Using The Stratigraphic Framework Based on Depositional Environments to Design a Ground Water Monitoring System and Calculate Vertical Seepage in Glacial Settings – Two Case Studies

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Choosing a suitable groundwater monitoring zone or calculating vertical seepage rates in a sequence of glacial deposits is often complicated by the difficulty in determining which sand-and-gravel bodies are discontinuous and which are sufficiently continuous to constitute a preferential contaminant pathway. Upland glacial settings in the Midwestern United States are typically underlain by a sequence of fine-grained glacial sediments deposited by successive glacial advances. Stratified sand and gravels may occur at various stratigraphic positions within this fine-grained succession, depending on the history of glacial advances and on the resultant changes in depositional environments. Laterally extensive sand-and-gravel units, which constitute rational groundwater monitoring zones, are most likely to occur between the deposits of different glacial advances because this is the setting where widespread outwash deposition can take place; other sand-and-gravel units within the sequence tend to be discontinuous.

The key to determining a suitable groundwater monitoring zone and calculating vertical seepage through a sequence of stacked glacial units that each classify as a Lean Clay (CL) is determination of the boundary between different glacial advances in these successions. Use of the Unified Soil Classification System (USCS) or other tools that measure only contrasts of cohesive vs. granular materials (and their mixtures) is often inadequate because different fine-grained stratigraphic units from most localized areas commonly classify as the same in the USCS 'Hydrostratigraphy'. The sole independent variable for building the site stratigraphic framework is thus the depositional environment. In addition, the typical application of the USCS 'Hydrostratigraphy' does not consider secondary alterations from modern day or buried weathering zones in glacial successions.

Other information for recognizing and correlating fine-grained glacial stratigraphic units include sedimentary structure and secondary weathering zone alterations and properties. This paper presents the results of two case studies where groundwater flow conditions, selection of a site groundwater monitoring zone and calculation of vertical seepage rates depended on identifying stratigraphic units in a succession of fine-grained glacial deposits.

Abstracts

Aquifer Characterization– II/Urban Hydrogeology – (Justin Blum, Bob Tipping, and Mike Trojan, co-chairs)

Mapping Glacial Aquifers in a Central Minnesota County as a Resource for Local Management

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County-wide mapping of groundwater resources is useful in managing a finite groundwater resource in the glaciated terrain of Benton County in central Minnesota. Bordered by the Mississippi River on the west and underlain by crystalline bedrock, groundwater in Benton County, Minnesota is pumped primarily from four intermittent buried sand and gravel aquifer units as well as a limited surficial sand and gravel aquifer. Accounting for 85 percent of the 3.6 billion gallons of water pumped in the county in 2010, concentrated groundwater use in two major irrigation areas of the county has raised a potential threat to protected water resources. Water chemistry was analyzed from 96 wells in the county and concentrations of tritium and nitrate and the ratio of chloride to bromide concentrations (Cl/Br) were used to characterize aquifer residence times, confining conditions, and pollution sensitivity. Fifteen percent of the groundwater samples indicated recent-aged tritium concentrations and nine percent of the samples had nitrate concentrations greater than the EPA health standard of 10 parts per million. The presence of recent-aged tritium in water samples in all four buried aquifer units corresponds more with the presence of sand and gravel deposits at the surface than with well depth. Results show two area aquifer systems that exhibit vertical connections between the surface waters, water table, and buried aquifer units. Aquifer systems can be mapped to encourage local stakeholders to treat the resource as one interconnected entity and to assist with allocation and management.

Site Characterization Methods with a Flexible Borehole Liner

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The characterization of a site includes many desirable measurements. To do them all usually requires more funding and time than is available. Flexible liner methods can provide a great deal of hydrologic information at reasonable cost. This presentation describes the mechanics of an everting flexible liner normally used to seal a borehole. As the liner is being installed, a detailed profile can be obtained of the transmissivity distribution of the formation intersected by the borehole. Once the liner is in place, it is easy to obtain the highest head in any of several aquifers intersected by the borehole. Another simple procedure allows one to map the head distribution in the formation as the liner is removed in a stepwise manner. Once these characteristics are in hand, the selection of the intervals over which one desires water quality samples can be determined for a second liner system which allows multi-level water samples and head histories in the continuously sealed borehole for subsequent years. An explanation of these several methods is the point of this presentation.

Hydrogeology of McLeod and Carver Counties, Minnesota

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Adjacent McLeod and Carver counties are located in central Minnesota on the western edge of the Minneapolis-St. Paul Metropolitan Area. Clay-rich Des Moines lobe till is at the land surface over most of both counties and varies in thickness from about 70 to 150 feet. The Des Moines lobe till forms a protective barrier to surface infiltration of precipitation almost everywhere in both counties except in northeastern and southeastern Carver County. Deposited by multiple glacial advance and retreat events, buried discontinuous sand units were deposited between till sheets. In northeastern Carver County, thick sand deposits underlie a thin mantle, in places less than 20 feet thick, of Des Moines lobe till. In southeastern Carver County, the Glacial River Warren eroded the Des Moines lobe till and deposited terrace sands at the edge of the river valley that forms the southeast border of Carver County. Groundwater samples show that water of recent tritium age (eight or more tritium units) rarely penetrates more than 50 feet below land surface in McLeod County. This suggests that the Des Moines lobe till restricts the movement of water from the surface into the deeper groundwater system. In the terrace sands area of the Minnesota River valley in southeastern Carver County, water samples collected from both the glacial aquifers and the underlying bedrock aquifers from wells as deep as 190 feet had recent tritium age along with elevated nitrate and chloride concentrations indicative of anthropogenic sources. Many wells constructed in glacial sands adjacent to Des Moines lobe till have elevated arsenic values.

Aquifer Characterization – II/Urban Hydrogeology – (Justin Blum, Bob Tipping, and Mike Trojan, co-chairs)

Feverish Nymphs: The Subterranean Springs of Minneapolis

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A thermometric survey of tunnel springs along the convenient transect provided by the Washington Avenue deep storm sewer, located about 30 meters below downtown Minneapolis, was conducted on April 15, 2007. Groundwater drains from the St. Peter Sandstone through cracks in the concrete tunnel lining. Three of the largest springs, depositing iron oxides, had temperatures of 12.5, 13.0, and 14.0°C, as measured with a high-quality mercury thermometer. Minneapolis groundwater at this depth is thus on average elevated several degrees above the expected groundwater temperature of about 8°C for the corresponding latitude. On the same day, a thermometric survey was also made for drip waters in the largest cave under downtown Minneapolis, located in the St. Peter Sandstone, 23 meters below street level. This cave features the largest subterranean spring under the city, dubbed "Little Minnehaha Falls" by sewer workers long ago. This ceiling spring issues from a bedding plane in the Platteville Limestone ceiling of the sandstone cave. Here, the groundwater temperature was 17.1 °C, more than twice the expected value (19.0°C had been recorded on a previous visit years earlier). While we've all heard of the microclimatic "urban heat islands" generated by cities, does the same concept apply to urban groundwater? Does an "anthropogenic thermal anomaly" exist under cities? Is it thermal pollution owing to leakage from pipes? For definitive conclusions, much additional data needs to be collected, such as repeat measurements for seasonal trends, chemical analysis of the spring waters to determine their source, and comparison with the characteristics of nearby well waters from various depths. Difficulty of access remains a problem.

Groundwater/Surface-Water Interface–I (Donald Rosenberry and Perry Jones, co-chairs)

Ups and Downs at Valley Creek: The Influence of Climate, Urbanization, and Ground-Water Withdrawals on Baseflow of a Trout Stream in Eastern Minnesota

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Trout streams are highly valued, state-protected aquatic resources dependent on groundwater-driven baseflow to maintain the equably cool temperatures needed by trout. Any factor that alters baseflow, either its quantity or proportion relative to surficial runoff, could impact a trout stream. These factors include climate (here, monthly to interannual weather variability), land-cover changes such as urbanization, and ground-water withdrawals by high-capacity wells. To protect trout streams, resource managers must be able to distinguish among these factors to make objective decisions about allowable land and water use. Valley Creek is a trout stream at the southeastern fringe of the urbanizing Twin Cities (Minneapolis-St. Paul) metropolitan area. The directly contributing watershed comprises about 37 km^2 and is mostly rural. However, the ground-watershed of Valley Creek covers about 60-80 km^2 and extends northwestward into rapidly urbanizing areas, including the nearby city of Woodbury. In 2003 Woodbury began installation of several water-supply wells located near the western edge of the estimated ground-watershed of Valley Creek and screened in the same aquifer system (Prairie du Chien/Jordan) that feeds the creek. Managers are concerned that pumping from these wells could reduce baseflow in Valley Creek. Annual median flows (as a proxy for baseflow) did decline from about 20 to 12 cfs during 2003-2009, but have since rebounded to about 17 cfs. A multiple regression model indicated that most of this flow variability could be explained by climate, with the Palmer Hydrologic Drought Index (PHDI) lagged by up to two years as the independent variables. Still, measured flows have been consistently below modeled values since 2007, suggesting possible influence of factors other than climate. This presentation explores whether these residuals can be related to regional urbanization and pumping, or more directly to pumping from Woodbury's nearest and newest wells.

Abstracts

Groundwater/Surface-Water Interface–I (Donald Rosenberry and Perry Jones, co-chairs)

Stormwater to Baseflow? Investigating Surface-Groundwater Interactions in Minnehaha Creek for Stormwater Management and Ecosystem Enhancement

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Minnehaha Creek is among the most valued surface water features in the Twin Cities area and attracts roughly half a million visitors to its park and falls area located near its confluence with the Mississippi River in Minneapolis, MN. Flow in Minnehaha Creek is heavily dependent on discharge from the stream's origin at the Grays Bay outlet of Lake Minnetonka. To maintain lake elevation during dry periods, Grays Bay outlet is closed, resulting in low to zero flow conditions in Minnehaha Creek and contributing to the creek's impaired status for biotic integrity. Stormwater runoff from the creek's urbanized watershed exacerbates extremes in flow conditions. Given the cultural and ecological value of this stream system, there is great interest in enhancing the ecosystem services provided by Minnehaha Creek through improved stormwater management.

The objective of this project is to evaluate the potential to augment baseflow in Minnehaha Creek through infiltration and storage of stormwater runoff. An initial understanding of groundwater – surface water interactions in the watershed was developed through analysis of spatial, surficial geology datasets and application of streamflow-based systems models to infer physical characteristics of the shallow aquifer. Results of these approaches indicate that, in addition to the effects of closures at Grays Bay and probable effects of urban development throughout the watershed, sustained baseflow in Minnehaha Creek is likely also limited by rapid vertical transit of water infiltrated at the land surface to underlying bedrock aquifers, the median travel time of which is on the order of 0.5 years. As such, it is likely that only a small portion of the shallow aquifer (< 1%) contributes baseflow to the creek. Fieldwork to be completed this summer and fall will corroborate the results of multiple methodologies to further quantify the contributions of surface and groundwater to baseflow in the creek. These methodologies include thermal mapping of stream surface and pore waters to identify areas of groundwater discharge, direct measurement of groundwater discharge to Minnehaha Creek with seepage meters, monitoring of piezometers installed in the creek's riparian area to monitor stream-groundwater dynamics over time, and analysis of ^{18}O and deuterium isotopes in the creek, its contributing surface waters, and the shallow aquifer system to separate streamflow into its source components. The understanding of groundwater and surface flow interactions in Minnehaha Creek gained through these field methodologies will be used to develop models of the stream-aquifer system to simulate the effect of local infiltration and channel geometry on baseflow (to be completed by Fall 2013). These results will be used to guide stormwater management and stream restoration efforts by the Minnehaha Creek Watershed District.

Challenges of Protecting and Restoring a Groundwater - Dependent Prairie Stream: Iron Springs Creek, Southeastern North Dakota

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Groundwater-fed streams and their ecosystems can be irreparably damaged by land-use changes in spring and seep recharge zones and by diversion of surface water. Iron Springs Creek, a tributary to the Sheyenne River of eastern North Dakota, is one of few permanently flowing prairie streams in the region. The stream is fed by a series springs and seeps that developed during the Holocene and end of the Quaternary by slow headward incision into coarse underflow fan deposits of glacial Lake Agassiz. Prior to agricultural development, the discharge of mineralized groundwater created a riparian zone that hosted an unusual ecological niche. About 100 years ago, the region south of the creek was drained by the construction of Ditch 10, with runoff conveyed directly into the headwater springs of the creek. Modeling suggests that small wetlands within aeolian dunes, which host the federally threatened western prairie fringed orchid and comprise the creek's capture zone, were affected to a distance of 1.5 km from the ditch. Since 1993, long-term above average rainfall has led to a rapid incision at the head of the creek and a knick point that has migrated more than two km upstream. In addition, grazing damage, invasive weeds, expanded drainage, and sedimentation leave few, if any, options for restoration.

Unique Tunnel Riverbank Filtration System to Supply Louisville with Filtered Water

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Louisville, Kentucky and the surrounding area developed their initial water supply from the Ohio River as the first public water utility in the state in 1860. Since that time, the Louisville Water Company has developed the necessary infrastructure to produce up to 240 mgd of treated drinking water using two large water treatment plants to treat surface water pumped from the Ohio River. In the mid-1990s, as regulatory requirements of the Safe Drinking Water Act continued to evolve, the existing infrastructure was evaluated with respect to anticipated, more stringent, regulations to determine what improvements, if any, would be required to maintain compliance for the utility. This study identified potential options for improving the treatment efficiency and quality of the drinking water for their customers. One option, riverbank filtration, was identified to be very effective for meeting projected treatment needs, and was determined to be cost-effective when compared to other alternatives.

Riverbank filtration allows river water to be infiltrated naturally through the alluvial aquifer deposits along the Ohio River, thus removing a number of constituents of concern. Subsequently in Phase I, a radial collector well was construct-

Groundwater/Surface-Water Interface–I (Donald Rosenberry and Perry Jones, co-chairs)

ed in 1997 as a demonstration well to provide up to 15-20 mgd of riverbank filtered water into their B.E. Payne surface water treatment plant. Operation of this well produced water quality data that supported continued plans for implementing Phase II of the Riverbank Filtration Project in 2008. Phase II included the construction of a hard-rock tunnel, approximately a mile and a half long, that is connected to a central pumping station constructed within the plant property up on a terrace above the flood plain. This allows uninterrupted access to the pump station, even under record flood events. In addition, four radial collector wells were constructed along the riverfront area to produce the infiltrated water, which is then delivered into the tunnel by gravity through drop shafts drilled beneath the wells. The tunnel and flush-grade collector well systems were designed to result in a low-profile system that would accommodate local environmental and historical interests to maintain the integrity of the local setting to meet with public acceptance of the project. The design process, with local public acceptance in mind, and the tunnel and well construction process will be discussed.

Water-Budget Changes from Precipitation Variability at the Glacial Ridge National Wildlife Refuge, Northwestern Minnesota

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Surface water and surficial groundwater form one integrated dynamic hydrologic system at the Glacial Ridge National Wildlife Refuge near Crookston, in northwestern Minnesota. Surficial aquifers in this area are composed of beaches deposited on the eastern shores of Glacial Lake Agassiz from 13,600 to 10,600 years before the present. The original wetlands and prairies at the refuge were restored from agricultural uses during 2003-9.

To document the pre-restoration state of the hydrologic system, we measured or estimated the annual amount of water flowing through each part of the hydrologic system in the study area (51,000 acres) during the early restoration period (2003-5). Measurements were made with 8 rain gages (precipitation), 10 well gages (recharge), 6 ditch gages (surface runoff and groundwater discharge), and synoptic water-levels (~100 sites, change in groundwater storage). The water-balance residuals were attributed mostly to unmeasured evapotranspiration from closed basins and measurement error.

Pre-restoration results indicate that the flows through all components of the hydrologic system responded very quickly (within a year) to changes in precipitation, with the groundwater system buffering ditch flows. During a year of little change in groundwater storage (2005), most water left the area through runoff to and discharge to closed basins and then evapotranspiration (53 percent (%) of precipitation and 23%, respectively). Groundwater provided more water to ditches (15%) than did direct runoff (10%). Data collection to calculate post-restoration water flows began in 2011 and is ongoing. Water flow changes before and after restoration will quantify hydrologic changes resulting from wetland and prairie restoration.

Karst – I: Karst Water Quality and Land Use (Jeff Green and Calvin Alexander, co-chairs)

Lessons From Long-Term Monitoring in the Big Spring Groundwater Basin, Iowa

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The agricultural practices, hydrology, and water quality of the 267 km^2 Big Spring groundwater basin in Clayton County, Iowa, where monitored extensively from 1982-2002, and a low level of monitoring continues. Landuse is esssentially all agricultural. along with numerous small livestock operations; nitrate-nitrogen (nitrate-N) and herbicides are the resulting contaminants in ground- and surface water. The Ordovician Galena Group carbonates are the main aquifer in the basin. Recharge to this shallow, moderately karsted aquifer is dominantly by infiltration, augmented by sinkhole-captured runoff. Groundwater is discharged to the surface at Big Spring, where the quantity and quality of the discharge is monitored.

Monitoring has shown a three-fold increase in groundwater nitrate-N concentrations from the 1960's to the early 1980's, following a similar increase in nitrogen fertilizer applications. During the main monitoring period the nitrate-N discharged from the basin by ground- and surface water typically was equivalent to over one-third of the nitrogen fertilizer applied, with significanlty larger losses and greater concentrations occurring during wetter years. Atrazine is present in the groundwater year round. Contaminant concentrations in the groundwater respond directly to recharge events, and the unique chemical signatures of infiltration versus runoff recharge are detectable in the discharge from Big Spring.

Education and demonstration efforts decreased pesticide use and reduced per-acre nitrogen fertilizer application rates by one-third during the '80s and '90s, while crop yields were maintained. Relating the declines in nitrogen and pesticide inputs to nitrate and pesticide concentrations at Big Spring is problematic, and confounded by year-to-year variability in recharge. A preliminary analysis of more recent data suggests other factors are also involved. Row crop acreage has increased through time, from 45% of the basins land cover in the early 1980s to 71% by 2009, providing additional nitrogen inputs. This is a trend evident across much of northeast Iowa and adjacent areas.

Examples of Hypogenic Karst Collapse Structures in the Twin Cities Metropolitan Area, Minnesota

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Three collapse structures in the Twin Cities Metropolitan Area may be products of hypogenic karst processes. The features are associated with deeply entrenched bedrock valleys, one the current Mississippi River and the other two buried by glacial drift. These valleys have been discharge points for regional groundwater flow systems. The most recent occurred in October, 2005 in Woodbury, Minnesota in a newly constructed infiltration pond excavated into the subcrop-

Karst – I: Karst Water Quality and Land Use (Jeff Green and Calvin Alexander, co-chairs)

ping St. Peter Sandstone. The collapse event created several sinkholes on the sides and bottom of the pond. Excavation of three of twelve sinkholes revealed a major collapse structure comprised of several breccia pipes. These pipes are at least 10 to 15 m in diameter and extend up through almost 20 m of friable St. Peter from the underlying Prairie du Chien Group. A second occurred in 1989 in Mahtomedi, Minnesota. A hole 12.8 m wide and 11 m deep opened suddenly. Both of these collapses developed adjacent to river valleys buried under glacial sediments with subcropping St. Peter. The oldest feature is in eastern Minneapolis near the Mississippi River gorge. This closed depression in the land surface was incorporated into a park when Minneapolis was platted. This depression extends through the subcropping Platteville Formation to a large void in the underlying St. Peter Sandstone. A cave 250 m long in the St. Peter extends between the collapse and the Mississippi River with typical passages 15 m wide and 6 m high. Recent investigations of the Prairie du Chien have found extensive solution enlargement features on a regional scale; these features have several characteristics diagnostic of hypogenic speleogenesis. The possibility of other breccia pipes in the St. Peter within the metropolitan area is both probable and problematic.

New Minnesota Landfill Siting Rules and Karst

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In 2012 the Minnesota Pollution Control Agency adopted new rules on landfill siting, karst, and groundwater protection. The new rules state that landfills may not be sited where there is less than 50 vertical feet to carbonate bedrock or 200 horizontal feet to karst features. The rules also prohibit landfill siting where groundwater travel time from the landfill to the compliance boundary is less than 100 days. Several industry groups opposed the rules. The reasoning behind the new rules and the arguments against them will be reviewed.

New Minnesota Landfill Siting Rules: The Political Dimension

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The rule-making hinges on technical matters and the resulting rule is technical in nature. It would hardly be accurate, however, to say that the rule-making process is wholly technical. The decision to move forward with the rule-making is primarily a social, cultural and political decision, and social, cultural and political matters have a way of recurring throughout the process. We will review a chronology of social, cultural and political events that drove the rule-making, and offer some observations about the future of environmental protection in Minnesota in light of these factors.

Urban Hydrogeology – II (Bob Tibbing and Mike Trojan, co-chairs)

Big-Picture Groundwater Perspective Supports Urban Redevelopment

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An area-wide groundwater study aims to jumpstart redevelopment of an underutilized urban area. The 284-acre Bassett Creek Valley is a 130-year-old urban industrial area on the western edge of downtown Minneapolis. With residential homes abutting old industrial lots and buildings, many that sit vacant, residents in the area have been working to revitalize their neighborhood for years. Neighborhood and City representatives have been working together on a redevelopment committee since 2000 and have developed a city-approved master plan for redevelopment of the Valley. However, the dozens of brownfield sites in the Valley, and their often overlapping soil and groundwater impacts, have been a hindrance to redevelopment.

To facilitate redevelopment of the area, Hennepin County has worked to find ways to avoid the costly, traditional approach of characterizing groundwater conditions site-by-site. Using a portion of its proceeds from a U.S. EPA Revolving Loan Fund grant, the County has been gathering groundwater data and summarizing groundwater contamination in the Valley to create an easily-accessible resource that provides a comprehensive picture of the areaís groundwater contamination and also streamlines the process for obtaining liability assurances. The County has taken Minnesota Pollution Control Agency (MPCA) environmental site file information and compiled the key findings with historical information by site into concise summaries to both maximize the value of work already done and facilitate quicker site decisions in the future.

This site information will be made available to potential developers and the public through an interactive geographic-information-system mapping tool intended to be provided via the internet. Over 300 parcels are in the valley, and a developer or voluntary party interested in any of the parcels will be able to click on any parcel and pull up groundwater contamination, site environmental history, and data gap information specific to that parcel. This is intended to facilitate a more streamlined selection of sites for redevelopment, site investigations, acquisition of liability assurances, and management of environmental issues.

Concurrently, the MPCA is working collaboratively with the County to define the specifics of the Bassett Creek area-wide study and voluntary party use of existing information. The project has received strong support from the MPCA leadership and staff, who have established a work group to formalize the streamlined approach for obtaining liability assurance letters. The MPCA plans to use the project as a pilot study to develop future policy and guidance on area-wide studies.

Abstracts

Urban Hydrogeology – II (Bob Tibbing and Mike Trojan, co-chairs)

Road Salt and the Salinization of Surface Waters and Groundwater of the Chicago Region

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Road salt runoff has heavily impacted the water quality of surface water and groundwater in the Chicago, IL region. All parts of the hydrologic cycle are seeing increases in chloride (Cl-), sodium (Na), and total dissolved solids (TDS) concentrations: lakes, streams and rivers, groundwater, and soil water. Almost all of the rivers and streams being monitored in the region have had significant increases in Cl- and Na concentrations since the mid-1970s. Conversely, there were significantly decreasing trends at most locations for the other major anions, i.e., bicarbonate and sulfate. The rates of the increase in Cl- are in excess of 10 mg/L/yr for several streams, and at some sites the rates of increase appear to be accelerating with time. Baseflow concentrations of Cl- appear to be > 100 mg/L in most streams and rivers in the region, compared to natural background concentrations of Cl- between <1 and 15 mg/L. Concentrations of Cl- and Na are significantly higher during the winter months as a result of direct runoff from freshly salted roadways. Chloride concentrations > 2,000 mg/L have been measured in some streams, which is likely harmful to aquatic biota. In recent years, Cl- and Na concentrations have increased most rapidly in the Fox River Basin west of the Chicago metropolitan area, a region undergoing significant urbanization.

Chloride and Na concentrations are also increasing in shallow aquifers in the Chicago region. Geological conditions (i.e., till thickness) and stormwater management practices appear to be the primary factors affecting groundwater contamination by road salt runoff. Surface waters currently have approximately equimolar concentrations of Cl- and Na, while groundwater impacted by road salt tends to have an excess of Cl- relative to Na, suggesting Na retardation in the subsurface, likely due to cation exchange. A rough estimate of inputs and outputs of Cl- in the Chicago region suggests that most of the road salt applied in a year is removed by surface discharge. However, about 14 percent of the road salt is retained in the subsurface, approximately 50,000 metric tons of NaCl annually, representing a long-term source of Cl- and Na and other associated ions.

Management of Stormwater Runoff Through Infiltration

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Management of stormwater runoff quality has traditionally focused on treating runoff from low intensity storms (e.g. 1 and 2 year-24 hour storm events). Higher intensity events are managed by local units of government for flood control and public safety. Since the mid-1980's, most Minnesota communities have relied upon the basic stormwater pond (or Walker Pond) for controlling rates while obtaining some degree of water quality improvements. However, runoff volumes are generally not reduced with ponds.

This has led to water quality and quantity problems in downstream receiving waters. As summarized by the National Research Council (2008), "Past practices have been ineffective at protecting water quality in receiving waters and only partially effective in meeting flood control requirements. Stormwater control measures that harvest, infiltrate, and evaportranspirate stormwater are critical to reducing the volume and pollutant loading." This led to a unique coalition of partners and key legislators to mandate the development of low impact development techniques, credits, a standard calculator and ordinance goals for protect (antidegradation) and rehabilitation (Total Maximum Daily Loads) – and referred to the Minimal Impact Design Standards or MIDS.

This presentation will summarize a range of infiltration and green infrastructure practices (reuse, harvesting and evapotranspiration) best practices being emphasized for on-site management of stormwater. With variable climate-induced wet/dry cycles, stormwater is increasingly being viewed as a resource. Over the past 10 years of technological innovation, especially via the University of Minnesota, there is a growing emphasis on treatment trains or sequential use of structural (bioinfiltration/rain gardens, ponds etc) with nonstructural (street sweeping, reduced irrigational losses) best practices to achieve water quality objectives.

Volume Reduction BMPs to address flooding and water quality problems in the Capitol Region Watershed District, St. Paul, MN

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The Capitol Region Watershed District along with the Cities of St. Paul, Falcon Heights, Roseville and Ramsey County worked cooperatively to fund and construct stormwater facilities to address flooding, and water quality problems. Specifically, these problems existed in a subwatershed (#7) west of Como Lake in St. Paul, MN. Como Lake is a 303d impaired water for nutrients. To alleviate the flooding, the City of St. Paul increased the size of storm sewers as part of a street reconstruction project within the subwatershed. Subwatershed 7 discharged to Como Lake via a 60" pipe through Como Golf Course and frequently surcharged. A preliminary study indicated that an additional 60" pipe through the Golf Course was needed at an estimated cost of $2.5 million. The Como Subwatershed 7 Study was completed in 2003 and identified many volume and peak rate reduction BMPs to eliminate the need for an additional storm sewer through the Como Golf Course. The BMPs identified also would result in significant water quality improvement. In 2005 and 2006 these BMPs were constructed. They included the Arlington-Hamline Underground Storage Facility, and the Como Golf Course Pond. CRWD also funded 8 underground infiltration trenches under Arlington and Nebraska Avenues and 8 rain gardens in the project area.

The Arlington-Hamline Underground Storage Facility used 849 feet of 10' perforated corrugated metal pipes surrounded

Urban Hydrogeology – II (Bob Tibbing and Mike Trojan, co-chairs)

by 1-3" washed rock. This facility has 1.9 ac-ft of storage and utilized a proprietary water quality chamber upstream to remove solids. The drainage area to the facility is 47 acres. The facility is designed to remove 12 lbs of phosphorus on an annual basis. This project was located in parkland and after restoration was the same fully usable green space as before the project. The Arlington-Hamline Underground Storage Facility had construction cost of $480,000.

The Golf Course Pond was constructed during 2007. This project diverted flow to the pond from the northern part of the Como Subwatershed 7 to reduce peak flows and improve water quality. The Golf Course Pond project has approximately 10 ac-ft of storage and result in annual reduction in total phosphorus of 41 lbs. The estimated construction cost is $1,040,000. The infiltration trenches were constructed under the streets during the street reconstruction project. They were constructed in 2006 for a cost of $240,000. In total they provided 38,292 cu. ft. of storage volume. Sumped catchbasins and manholes with hoods provide pretreatment to prevent solids from entering the systems.

The rain gardens were constructed areas adjacent to the streets and within the right-of-way during the street reconstruction project. They were constructed in 2006 for a cost of $53,000. In total they provided 24,662 cu. ft. of storage volume. The District was able to construct these rain gardens because of street realignments that narrowed the intersections and removed pavement.

This project has resulted in significant water quality treat-

Pollution of Drinking Water Aquifers due to Stormwater Infiltration

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The Twin Cities Metro area has a rich history and connection with its waters. In an effort to keep surface waters clean, a wide variety of stormwater practices have been developed and installed throughout the Metro in recent years. Many of these, such as rain gardens and infiltration basins and trenches, are intended to reduce the total runoff volume by infiltrating stormwater. Six to seven aquifers underlie the Metro area and provide 70% of the regions residents with drinking water. There are concerns that contaminants commonly found in stormwater (VOCs, SVOCs, toxic metals, nutrients, chloride, etc.) are infiltrating through the Metro area practices into the groundwater. This presentation will cover the work that we have been conducting to monitor pollutants that enter into the various in-place infiltration systems in the Minneapolis-St. Paul metropolitan area. The purpose of the study is to evaluate whether these pollutants are retained within or pass through these infiltration systems. The impact of increasing the volume of infiltration in the future on contaminant transport will be discussed.

Groundwater Quality – I: Contaminants of Emerging Concern (Melinda Erickson and Bill Simpkins, co-chairs)

Genesis and Response to a Perfluorochemical (PFC) Megaplume - Washington County, Minnesota

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Perfluorinated chemicals (PFCs) were manufactured by 3M Corporation (3M) in Cottage Grove, Minnesota beginning in the late 1940s. PFC-bearing wastes were disposed of on-site at the manufacturing facility and in three major off-site disposal areas in Washington County, on the east side of the Twin Cities metropolitan area. Buried bedrock valleys, major bedrock faults, karst features, and groundwater-surface water interactions in the area, combined with the mobility and persistence of PFCs, have resulted in a complex, co-mingled PFC plume covering over 100 square miles. Eight municipal well systems and over 1,000 private wells have been impacted.

Several municipal wells in Oakdale, MN exceeded state drinking water standards, as did over 140 private wells in Lake Elmo, Oakdale, and Cottage Grove. The Minnesota Department of Health (MDH) and 3M worked with the city of Oakdale on the installation of a granular activated carbon (GAC) filtration system, and MDH assisted with citing a new city well and development of a well management regime to ensure state drinking water standards are met. The Minnesota Pollution Control Agency (MPCA) provides and maintains whole-house GAC filter systems on private wells that exceed state drinking water standards. Biomonitoring by MDH indicates these measures have helped to significantly lower the levels of PFCs in the blood of people drinking the filtered water.

Additional remedial activities have been undertaken by 3M and the MPCA at the waste disposal sites, including soil excavation, sediment dredging, and enhanced groundwater gradient control. It is too early to tell how effective these actions have been in reducing PFC concentrations in the groundwater.

This talk will help to provide context for some of the areas to be visited during the conference field trip.

Contaminants of Emerging Concern: Groundwater Research by the USGS TOXICs Program

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Contaminants of emerging concerns (CECs) encompass a vast array of environmental contaminants (e.g. pharmaceuticals, hormones, personal care products and their transforma-

tion products) and are derived from a variety of municipal, domestic, agricultural, and industrial waste sources. Substantial knowledge has been gained pertaining to CECs over the last decade, with hundreds of papers on this topic now being published annually. There is growing concern that such CEC may be bioactive and interactive (e.g. additive, synergistic, antagonistic effects) and potentially cause deleterious effects to ecosystem and human health. While it is no longer a question of whether CECs and their transformation products are occurring in the environment, new analytical methods are continually being developed that are ever expanding the detection capabilities and therefore the scope and range of contaminants covered under this broad contaminant category.

Continued research is needed to provide a better understanding of the relative contributions of specific source types to environmental loadings of CECs. For example, research has documented large CEC concentrations in a variety of sources such as septic systems, landfills, and land applications of animal and biosolids all of which can have direct impact to local groundwater systems.

A complex mixture of CECs have been documented in aquatic and terrestrial environmental compartments, including plant and animal tissue, groundwater, and drinking water. Although much is yet to be understood pertaining to long-term, low-level exposure to both individual and complex mixtures of CECs, there is a growing body of evidence suggesting that a variety of potential environmental effects are possible. Most environmental effects studies, however, have focused on a single chemical or chemical class, a specific mechanism, a specific assay, a single organism, or used exposure concentrations that far exceed environmentally relevant levels. Even less is known about potential human effects from exposure to CECs.

Emerging Contaminants in Minnesota Seepage Lakes: Role of Shallow Groundwater Inflow

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Previously published work by other authors has identified on-site septic systems as potential sources of emerging contaminants, such as pharmaceuticals (Phac) and endocrine active compounds (EACs), to lakes. Furthermore, detailed studies of septic system performance have shown how Phac and EAC constituents survive treatment and are discharged into shallow groundwater. Phacs, EACs, and other contaminants of emerging concern (CEC) were detected in water and sediment of 12 Minnesota lakes during a statewide study conducted by USGS Minnesota Water Science Center, Minnesota Pollution Control Agency, and St. Cloud State University. The most frequent detections of these compounds occurred in lakes with a high density of septic systems (i.e., onsite SSTS), suggesting a potential shallow groundwater discharge pathway for these compounds. Given these results, there is a need to know how vulnerable Minnesota lakes are to septic discharge of CECs. To answer this question, we are sampling 20 Minnesota lakes throughout the state with a high-density of septic systems in areas of known groundwater influence. Composite water and sediment samples for CEC analysis are being collected from near shore (< 2m depth) sites along transects of groundwater influence. Results to date have identified sites with a limited number of EACs, PAHs, and personal care products in water. Results from sediment samples are pending completion of laboratory analysis. Sites with known contamination are being studied in more detail for direct estimates of groundwater contributions. We will combine the results from the current study with those from the previous Statewide Survey to develop a CEC contaminant database for MN lakes. The database will be used to analyze for patterns in contaminant occurrence relative to groundwater and watershed characteristics.

Contaminants of Emerging Concern in Minnesota Groundwater

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Since 2009, the U.S. Geological Survey and the Minnesota Pollution Control Agency have been working cooperatively to assess the occurrence and distribution of contaminants of emerging concern (CEC) in shallow groundwater. CEC are a broad group of chemicals that usually have no established regulatory limit and presently include pharmaceuticals, surfactants, personal care products, plastic components, antimicrobials, and other chemicals. The subset of CEC that are of particular concern in this study are endocrine active compounds, which interfere with the normal secretion of hormones from the endocrine system glands and organs in terrestrial and aquatic animals.

The project includes analyses of water from monitoring and domestic wells in shallow, vulnerable aquifers in urban and urbanizing areas of the state. Target wells are located in different types of land use settings, including downgradient of closed landfills, in residential areas with and without centralized sewers, in commercial and industrial areas, and in undeveloped areas such as state forests. This presentation will provide a summary of CEC results from 2010 and 2011, the first two years of sampling. CEC have been found in groundwater throughout the state at low concentrations and are most prevalent in groundwater in proximity to landfills and in areas without centralized sewers.

Abstracts

Groundwater Management – III: Progress and Approaches To Addressing Groundwater Allocations and Conflicts in the Midwest Region (Princesa VanBuren Hansen, Cathy O'Dell, George Kraft, co-chairs)

Managing Groundwater Withdrawals to Sustain Aquatic Ecosystems

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Although it is well understood that groundwater discharge maintains crucial baseflows and moderates temperatures of springs, streams, and wetlands, few states limit groundwater withdrawals to sustain those discharges. One reason is a lack of scientific information to quantify reasonable limits. Even in places where impacts of groundwater pumping on surface-water baseflows are understood, the ecological responses to those impacts generally are not. In 2010, The Nature Conservancy began an initiative to improve understanding of ecological flow needs in Minnesota, and to establish ecological criteria for limiting flow alteration in aquatic systems. To date, we have worked with an interagency team of partners (primarily Minnesota DNR, MPCA, USGS, and University of Minnesota) to assess available data and tools (both in-state and external) and to recommend technical approaches that can be used in Minnesota to quantify relationships between flow alteration and ecological response, establish ecologically-based protective criteria for water bodies, and inform water resource permitting and watershed planning decisions. Practical options for linking flow-ecology response curves to surface- and groundwater permitting criteria will be reviewed, drawing from case studies including Michigan, Rhode Island, and Massachusetts.

Using Simple Groundwater Models to Inform the Decision in Areas of Sparse Data

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The recent oil production boom in western North Dakota has created an intense demand for water in a historically semi-arid and sparsely populated area. Requests for appropriations of groundwater have dramatically increased as local residents and incoming companies look to sell water to the local oil industry for hydraulic fracturing, waste brine dilution, and other oil field uses and to provide water for new housing developments.

A case study is presented of two recent requests for groundwater appropriations for industrial use from a shallow aquifer in northwest North Dakota with hydrologic connection to surficial lakes and wetlands. The aquifer is composed of sand and gravel outwash likely deposited by a proglacial meltwater stream during the last glaciation and occupies a narrow valley surrounded by low permeability glacial drift sediments. Available data for the aquifer consists of just a few test holes and observation wells and long term monitoring of water levels has not taken place. Concerns about the two requests were voiced by local domestic and stock well owners, who also divert water from the shallow aquifer, and by the United States Fish and Wildlife Service (USFWS), which owns land and has wetland easements overlying the aquifer.

Potential effects on water levels in the shallow aquifer and overlying water bodies were evaluated using a simple, one-layer, numerical model developed with the United States Geological Survey (USGS) MODFLOW software. Extent of the aquifer was compiled from surface elevation and surficial soils data. Surface water bodies were modeled as general head boundaries with their hydraulic connection to the aquifer controlled by conductance of the boundary cells, as water level data suggested that some of the wetlands were "perched" on low conductivity layers and "disconnected" from the aquifer. The aquifer was divided into two sections for modeling purposes, owing to a large discharge boundary (lake) occupying the surficial valley and separating the two applications.

The model demonstrated that a portion of the upgradient request, if granted, would not cause undue harm to prior appropriators, but that granting the entire request would not be sustainable due to the thin saturated thickness of the aquifer. The model also showed that granting the downgradient request, in addition to an existing appropriation at the same location, could be unsustainable over the long term and cause harm to nearby prior appropriators.Based on the degree of uncertainty regarding extent and saturated thickness of the aquifer and the potential for harm to nearby appropriators, recommendations were made to grant a portion of the upgradient request, holding the remainder of the request in abeyance, and to defer decision on the downgradient request until additional hydrologic data could be collected. Though unsophisticated and based on limited data, the model provided a valuable tool for testing assumptions about the aquifer and its boundary conditions and assisted in the overall decision.

Using the Elkhorn-Loup Model for Groundwater Management in the Lower Loup Natural Resource District of Nebraska

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The Elkhorn-Loup Model (ELM) is a multi-phase water modeling project characterizing the surface-water and groundwater resources in the Elkhorn and Loup River Basins. This study encompasses ~ 30,800 square miles and covers most of north-central Nebraska. The model was developed by the U.S.G.S. in coordination with 8 of Nebraskaís Natural Resources Districts (NRDs). Now in its third phase, one of the primary agencies responsible for developing ELM, the Lower Loup NRD, has begun utilizing products from ELM to tackle some of the more complex issues being faced in groundwater management.
In 2009, the State of Nebraska passed LB483 which allowed each NRD to develop 10,000 acres of additional irrigation over a four year period. The Lower Loup NRD is also responsible for the certification and transfer of irrigation rights and relies heavily on the model to assist with requests by groundwater users for variances to these processes. To date, the Lower Loup NRD has certified approximately 1.2 million irrigated acres and has been in a well drilling moratorium since 2007.

Groundwater Management – III: Progress and Approaches To Addressing Groundwater Allocations and Conflicts in the Midwest Region (Princesa VanBuren Hansen, Cathy O'Dell, George Kraft, co-chairs)

Implementing the Water Sustainability Framework: Taking a Step Toward Ensuring Sustainable Water for Minnesota

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In 2008, the citizens of Minnesota passed the Clean Water, Land and Legacy Amendment to the State constitution. The amendment added three- eights percent to the Stateís sales tax, and dedicated a portion of the increase to a Clean Water Fund to protect and enhance waters of the State. This created a unique opportunity for Minnesotans to do what few other states have done; to take action for a sustainable water future. After the amendment passed, the State Legislature directed the University of Minnesota's Water Resources Center to construct a framework describing what needed to be accomplished- based on the legislature's definition of sustainable – to do no harm to ecosystems, to prevent water-quality degradtion, and to avoid compromising water needs for future generations. Over an 18- month period, teams of experts synthesized the knowledge, insights, and perspectives of hundreds of the State's scientists and water-management professionals as well as taking input from citizens and interest groups. The resulting framework provides a roadmap toward water sustainability that identifies problems, offers solutions, and recommends actions based on current best practices and science.

The top priority of the framework is to preserve a sustainable and clean-water supply. The strategy includes a process to determine the State's water budget, and using that budget, to improve the State's water-appropriation permitting process. The framework also calls for protecting and restoring water quantity and quality through comprehensive, integrated policy and management that recognizes the interconnected nature of surface and groundwater as well as ecological needs during times on minimal streamflow. Most of the tools needed for sustainable water management already exist. The County Geological Atlas Programs coordinated by Minnesota Geological Survey and Minnesota Department of Natural Resources (MDNR) provide the geological and hydrological framework to understand aquifers for much of the State. MDNR and Minnesota Pollution Control Agency (MPCA) programs have collected, or are collecting, necessary information to assess ecological-flow conditions in streams. The U.S. Geological Survey (USGS) and MNDR programs provide real-time stream flow information for many watersheds throughout the State, and techniques are available to estimate stream flow in ungaged watersheds. Various estimates of groundwater recharge are available from studies conducted by the USGS, MDNR, and MPCA. The next major steps involve synthesizing and modeling these data to provide information to the State's water-appropriation permit program. A cooperative effort among State and Federal agencies could benefit the completion of these final steps to ensure sustainable water resources for future residents of Minnesota.

Minnesota Watershed Budgets – By the Numbers

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The Minnesota Pollution Control Agency is leading an inter-Agency effort to build monitoring networks and to measure and calculate water budgets for all 81 major watersheds in the state. Calculating watershed budgets has been established as a goal for Minnesota. A primary strategy of the 2011 Minnesota Water Sustainability Framework was to "determine the state's water balance". A permanent network, providing real-time recharge and outflow of water and pollutants from major watersheds will allow for better management of water resources, provide data for watershed restoration projects, and watershed protection activities, provide data needed to make better water permitting decisions (stormwater and wastewater), provide basis for data-based groundwater appropriations, and other water management needs.

This effort is being made possible by Clean Water Legacy funding which has allowed for enhancement of state-wide groundwater and surface monitoring efforts and upgrades to the State's water quality State's Hydrology Time-Series Database and water chemistry database (EQuIS). The effort has also benefited from increased cooperation and collaboration between state Agencies and other partners.

Watershed budgets will include the following monitoring components:

- Precipitation – Rain gages are being installed at all stream gaging stations which have telemetry (all major watershed outlets, some intermediate watershed gaging stations).
- Stream flow – Permanent, year-round flow gaging stations have been established at major watershed outlets (8 digit HUCs) and at many intermediate watersheds (12 digit HUCs). Flow gaging stations are maintained by MN DNR, USGS, Met Council.
- Stream water quality – MPCA operates a year-round Watershed Pollutant Load Monitoring program (yearly load calculations) at major watershed outlets (8 digit HUCs) and at many intermediate watershed outlets (10 digit HUCs).
- Groundwater quantity – DNR operates an extensive observation well network (GW elevations). All MPCA and MDA groundwater monitoring well elevation data shares a common database.

Groundwater Management – III: Progress and Approaches To Addressing Groundwater Allocations and Conflicts in the Midwest Region (Princesa VanBuren Hansen, Cathy O'Dell, George Kraft, co-chairs)

- Groundwater quality – MPCA and Mn Dept. of Agriculture operate ambient groundwater monitoring networks. MPCA remediation and permitting programs also provide GW quality data.
- Water discharges to watershed – MPCA/DNR's Hydrology Time-Series database will store municipal storm water and municipal waste discharge volume and contaminants.(in development)
- Groundwater Recharge – Estimation dataset. MPCA, USGS (in development)
- Groundwater extraction – Irrigation and municipal water supplies (DNR database)

Products produced from watershed budgets will include:

1. Mass balances per major watershed by 8 digit or 12 digit HUCs for water, pollutants, and sediments based upon measured data.
2. Web-accessed, real time measurements and estimate of watershed budgets.
3. Synthetic hydrographs to provide estimated flow between gaging stations.

Data and information provided by watershed budgets will be used for groundwater appropriation permitting, watershed modeling, identifying quality trends across the state, environmental reviews, TMDL and watershed restoration studies, watershed investigations and condition reports, and to inform water resource policy discussions.

Groundwater/Surface-Water Interface – II (Donald Rosenberry and Perry Jones, co-chairs)

CSI Meets Groundwater: "Autopsying" the Effect of a "500-year" Flood on a Sand and Gravel Aquifer in Ames, Iowa

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Flooding causes major property damage each year; however, relatively little attention has been given to its impact on aquifers. A "500-year" flood event in Ames, Iowa on August 11, 2010 provided a unique opportunity to investigate the impact of flooding on an alluvial/buried valley aquifer – the Ames aquifer – that supplies 2.2 billion gallons/year of drinking water to about 56,000 residents. Instead of ballistics tests or autopsies, this study used hydraulic head, groundwater temperature, stable isotope, and anion data to demonstrate that flood waters affected only the upper part of the aquifer and did not compromise drinking water. The 2010 flood event resulted from the South Skunk River and Squaw Creek watersheds receiving upwards of 10 inches of rain in the 24 hours prior to August 11. The South Skunk River crested at 19.55 ft at 1:00 pm at the USGS gage on Riverside Drive – the 4th highest stage on record – and discharge was ~13,800 cfs. In anticipation of a flood event, piezometers outfitted with pressure transducers were installed in 2008 at depths of 8, 14, 19, 24, 42, 69, and 97 ft in the sand and gravel aquifer adjacent to the river. Post-flood water samples were collected from the river and groundwater at this site within two days of the flood peak and continued through into November 2010. Samples from municipal wells were collected within two weeks. Anions and stable isotopes ($d^{18}O$ and $d^{2}H$) were analyzed by ion chromatography and a Picarro L1102-i Isotopic Liquid Water Analyzer, respectively.

Results suggest that precipitation, characterized by isotopically enriched $d^{18}O$ (-4.6) and Cl concentrations similar to rainfall and about 10x less than ambient stream values, dominated post-flood river water and shallow groundwater. Hydraulic head and temperature data showed that flood water increased the saturated thickness of the aquifer by about 12 ft. Isotope and Cl data also suggest that isotopically depleted (older?) groundwater was apparently 'pushed' by the flood water to a depth of 14 ft ($d^{18}O$ = -10.4) within two weeks of the event. Groundwater below that depth maintained a constant isotopic composition. Groundwater samples from municipal wells downstream showed no change in isotope or anion composition reflective of flood water. In summary, the "autopsy" results suggest that the "500-year" flood primarily drove river water into the "new" part of the aquifer, moved "older" water out of the upper part of the aquifer, and left drinking water from municipal wells unscathed.

Abstracts

Groundwater/Surface-Water Interface – II (Donald Rosenberry and Perry Jones, co-chairs)

Impact of the 2011 Missouri River Flooding on Groundwater Levels in Bismarck and Mandan, North Dakota

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The Missouri River at Bismarck, ND exceeded moderate flood stage for 76 days and major flood stage for 48 days during 2011. At the beginning of the flood in late May, besides the direct impact of the flooding, the Cities of Bismarck and Mandan became concerned about the impacts of rising groundwater levels on basements outside of the flooded area because it was projected that high releases through Garrison Dam would continue through the summer. The North Dakota State Water Commission (NDSWC) established a network of 94 observation wells to monitor water table changes consisting of existing wells, new wells, and monitoring wells installed by several engineering firms. Bismarck and Mandan provided water level elevations at 38 gate valve boxes and several lakes. This data was used to create weekly water table maps. By subtracting the water table map from a LIDAR DEM, a depth to water table map was created for each community which were provided on the NDSWC website. The hydrogeology of the South Bismarck and Heart River aquifers will be discussed along with the water table changes that occurred in these aquifers.

Groundwater and Surface-Water Interactions in White Bear Lake

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Between 2010 and 2011, White Bear Lake and other lakes in the northeastern portion of the Twin Cities metropolitan area were at historically low levels. Recent urban expansion and increased pumping from the Prairie du Chien aquifer have put into question whether a decline in precipitation is the sole cause for the recent water-level declines. The U. S. Geological Survey in cooperation with the White Bear Lake Conservation District, Minnesota Pollution Control Agency and other state, county, municipal, and regional planning agencies, watershed organizations, and private organizations, conducted a one-year study to characterize groundwater and surface-water interactions in White Bear Lake. Three methods were used to assess groundwater and surface-water interactions: 1) a historical assessment (1980-2010) of White Bear Lake levels, local groundwater levels, and their relation to historic precipitation and groundwater withdrawals in the White Bear Lake area, 2) recent (2010-2011) hydrologic and water-quality data collected in White Bear Lake, other lakes, and wells, and 3) water balance assessments for White Bear Lake in March and August 2011.

An analysis of covariance (ANCOVA) between annual lake-level change and annual precipitation indicated that the relation between the two variables was significantly different for the period 2003 through 2011 compared with 1978 through 2002, requiring an average of 4 more inches of precipitation per year to maintain the lake level. The combination of less precipitation and increased groundwater withdrawals can explain the change in the lake-level response to precipitation. Annual groundwater withdrawals from the Prairie du Chien-Jordan aquifer have more than doubled from 1980 through 2010. Water-quality analyses of pore water from nearshore lake-sediments and well-water samples, seepage meter measurements, and hydraulic-head differences measured in White Bear Lake indicated that groundwater was potentially entering White Bear Lake from shallow glacial aquifers to the east and south. Stable isotope analyses of well-water, precipitation, and lake-water samples indicate that wells downgradient of White Bear Lake screened in Quaternary glacial buried aquifer or open to the Prairie du Chien-Jordan aquifer receive a mixture of surface water and groundwater, with the largest surface-water contributions occurring in wells closer to White Bear Lake.

Changing Rainfall Intensity and its Possible Influence on Lake-Groundwater Interactions

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A recent US Geological Survey investigation of White Bear Lake (WBL) in Washington County Minnesota determined that a steep decline in lake levels from 2002-2010 was not related to changes in precipitation levels. The study concluded that rising groundwater withdrawals within the WBL's groundwatershed were primarily responsible for the decline. Building off of that investigation, frequency analyses of daily precipitation records were performed on the nearby Stillwater National Weather Service station dataset. It was found that the yearly frequency of high intensity events of greater than one inch a day correlated well with the changes in the entire 90 year WBL elevation record. Years containing a large number of days with rainfalls over one inch correlated with high lake levels, and years with fewer high intensity rainfalls correlated with low levels.

The proposed mechanism for this connection between high intensity events and rising lake levels is related to WBL's closed basin and its very small watershed to lake area ratio. High rainfall intensity places a greater percentage of precipitation into runoff due to saturation of pore spaces, while smaller rainfall intensities put a greater percentage into recharging groundwater. Because of the altered flow of groundwater away from WBL in recent years due to pumping, low rainfall intensities that facilitate groundwater recharge have less effect on the WBL levels. A statistically significant rising trend in the frequency of daily precipitation events greater than one inch was observed in the 90 year Stillwater dataset, a result which matches climate change predictions for increasing intensities throughout Minnesota. A possible conclusion is that these high intensity events may lead to a faster recovery of WBL levels than is currently considered possible.

Abstracts

Geothermal (Kelton Barr and Martin Saar, co-chairs)

The Multi-Functionality of Geologically Sequestered Carbon Dioxide: From Geothermal Energy Extraction to Renewable Energy Storage

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Carbon dioxide (CO2) in the atmosphere is generally considered the main driver of current global warming. As a result, CO2 capture (at fossil-fueled power plants) and geologic sequestration (CCS) has been proposed as a means to reduce the concentration of this green-house gas in the atmosphere to counteract such global warming. Unfortunately, high CCS costs typically render this process economically unfeasible. However, CO2 can serve as a high-efficiency geothermal heat mining fluid to generate electricity. This electricity can then be used to power the CO2 injection pumps of the CCS operation while revenue from excess electricity would offset or neutralize the carbon capture costs at the fossil-fueled power plant. If yet more electricity is generated, sales would result in additional profits. Consequently, this CO2-Plume Geothermal (CPG) technology would result in a CO2 sequestering geothermal power plant with a negative carbon footprint. Furthermore, such a geothermal power plant would preserve freshwater resources, and, due to its high efficiency, which allows utilization of lower-temperature resources, compared to water, allow expansion of regions worldwide where renewable geothermal energy can be economically mined. Finally, the CPG technology can be used as a type of high-efficiency 'battery' to store energy from only intermittently available, renewable energy resources such as wind and solar energy. Consequently, CPG would

1) make fossil-fueled power plants greener by allowing economically feasible CCS operations,

2) allow expansion of the geothermal resource base worldwide, and

3) firm up power from wind and solar renewable resources.

Assessing the Impacts of Geology and Groundwater Flow (the Hydrogeologic Situation) on the Ground-Source Geothermal System at Ball State University

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Ball State University (BSU) began installing the nation's largest ground-source geothermal project in 2009. During Phase 1, 1803 400-ft geothermal boreholes were drilled in a 15x15 ft grid in two large fields (North and South) in the northern part of campus. Two geothermal exchange loops were installed in each borehole to add or remove heat from the ground to moderate the temperature in buildings. To maintain a proper temperature differential between the exchange loops and the groundwater along with a high coefficient of performance, the groundwater temperature and flow are important. Students and faculty collected hydrogeologic and temperature data from a series of groundwater monitor wells beginning in Summer 2010. An additional 600 500-ft depth geothermal boreholes with single exchange loops are currently being drilled in the Phase 2 field location. By early October, we will begin to gather hydrogeologic information on Phase 2.

Despite the rise in community-scale ground-source geothermal energy systems, there is little empirical information on their effects upon the groundwater environment or the effects of the groundwater flow environment on the geothermal field. Previous studies have triggered concern over the impact of large-scale geothermal systems, such as in the Netherlands, where models predicted significant groundwater cooling, or, conversely, in New Jersey, where there were documented increases in groundwater temperatures. Since BSU initiated Phase 1 in late November 2011 with cold-water circulation (adding heat to the ground), the data indicate that the temperature increased 4-5 degrees Celsius in the center of the South Field, and temperatures are rising in other surrounding monitoring wells. Maintaining a temperature differential between the fluid inside the exchange loops and the geologic substrate and/or groundwater outside of the loops is crucial to the efficiency of the systems, which are typically designed so that temperatures will not increase or decrease considerably over the year. Although there has not as yet been a reverse to hot-water circulation (sending cooled water to the ground), adding heat in the field has led to significant temperature increases with distinctive differences between the upper highly hydraulically transmissive aquifers and the lower poorly conductive formations. The overall ground-source geothermal system will continue to be influenced by the stratigraphy and hydrogeologic transmissivity.

Design and Construction Factors for the Installation of Minnesota's Largest Operational Geothermal Loop Field

Authors - Craig V. Lemma, HGA Architects and Engineers, LLC, Phil Ramos, General Services Administration
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The B.H. Whipple Federal Office building obtained an ARRA grant in 2009 for a major renovation, including a replacement of the previous traditional heating and cooling systems with a ground source heating and cooling system. As the building has a total occupied area of approximately 850,000 square feet, the replacement ground source system is comprised of 800 vertical heat exchangers installed to a depth of 250 feet and is the largest currently constructed in Minnesota. The system has been completed and went into full operation on July 30, 2012.

The presentation will be an overview of the considerations of designing and constructing a large ground source heating and cooling system in a metropolitan area. A significant factor in the design of the system was the bedrock geology and hydrogeology underlying the site. As part of the case study, the presentation will include details on how the geology, hydrogeology, and environmental considerations played a role in shaping the approvals, design and construction of the project.

Abstracts

Geothermal (Kelton Barr and Martin Saar, co-chairs)

CO2 Plume Geothermal (CPG) Systems for Power Production, Energy Storage and Waste Heat Recovery

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Recent geotechnical research shows that geothermal heat can be efficiently mined by circulating carbon dioxide through naturally permeable rock formations. This method, called CO_2 Plume Geothermal (CPG), targets the same geologic reservoirs that are suitable for deep saline aquifer CO_2 sequestration. In CPG, a portion of geologically stored CO_2 is piped to the surface after being heated by Earth's natural in situ heat and background heat flux. At the surface, the CO_2 is routed through a turbine or heat exchanger to produce electricity and/or to provide heat for direct use before being returned to the geologic reservoir. Long-term, CO_2 in the subsurface is sequestered and, thus, CPG results in geothermal power production with a negative carbon footprint.

In addition to electricity generation, CPG shows potential as a method for storing electricity when supply exceeds demand, as is often the case with wind and solar systems. Large-scale storage is generally considered a critical addition to the US power grid should we hope to add more than 20-30 percent of intermittent renewables (i.e., wind and solar) to national energy supplies, and new technologies are needed to achieve sufficient storage. Moreover, elements of CPG can be applied to waste heat recovery from enhanced oil/hydrocarbon recovery (EOR) operations, extending the economically feasible lifespan of hydrocarbon fields while reducing requirements for power from the grid or local diesel generators.

Here, we will explore the above three flavors of CPG -- geothermal power production, energy storage, and waste energy conversion during hydrocarbon recovery.

Geothermal Energy in Minnesota: Revised Prospects Based on New Heat Flow Measurements

Authors - Benjamin M. Tutolo and Martin O. Saar

Geothermal electricity, particularly Enhanced Geothermal Systems (EGS) and CO2-based geothermal systems (e.g., CO2 Plume Geothermal, CPG) provide carbon-neutral and carbon-negative, respectively, energy options that can help prevent the worst consequences of climate change. Until recently, estimates of geothermal heat flow in the state of Minnesota have been low (approximately 40 mW/m2), partly because these estimates were based on four measurements obtained over a limited sampling area with likely measurement bias. Recently, a coordinated, state-wide effort to obtain new measurements of geothermal heat flow, rock thermal conductivity, and radioactive content has yielded revised heat flow estimates as well as new knowledge regarding the state's prospects for geothermal energy ([Klenner et al. (2011) GRC Trans.: 425-430]). Here, we present recent heat flow measurements obtained around the state as well as an updated Minnesota geothermal heat flow map. Estimates of mean heat flux for the state has increased 12% to 45 mWm-2 and researchers calculate that the geothermal potential (district heat + electric power) in Minnesota is three times greater than previously estimated in a nationwide survey. Although the depth to the 150°C isotherm over much of the state is currently greater than the maximum drilling depth for geothermal wells, predicted advancements in technology indicate that EGS or CPG power sources installed across Minnesota could produce enough electricity to meet statewide demands.

Abstracts

Groundwater Quality – II: Nitrogen (Melinda Erickson and Bill Simpkins, co-chairs)

Central Sands Private Well Network 2011 Nitrate-N Results Summary

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Concerns about high nitrate-nitrogen concentrations in private wells across Minnesota led to the development of the Central Sands Private Well Monitoring Network. The first goal, which is completed, was to determine current nitrate concentrations in private wells in Central Minnesota. The second goal is the development of a long-term private well network that will establish long-term nitrate concentration trends. In 2011, the Minnesota Department of Agriculture, with Clean Water Funding, coordinated the random sampling and analysis of 1,555 private drinking water wells from 14 counties in Central Minnesota. Over 88.6 percent of the wells sampled had nitrate nitrogen concentrations less than 3 mg/L, 6.8 percent of the wells ranged from 3-10 mg/L and 4.6 percent were greater than 10 mg/L of nitrate as nitrogen. Analysis of the well owner surveys demonstrate that well construction, age and depth are important factors affecting the quality of water in private wells.

Where in Minnesota Can You Find 35,000 PPM Nitrate?

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The regulatory limit for nitrate-nitrogen in groundwater is 10 ppm (equal to 45 ppm nitrate) and amounts in excess of this are attributed to sources such as fertilizer, sewage contamination, and natural soil nitrification. However, there are some situations in Minnesota where nitrate accumulates to much higher concentrations under special conditions. Sediments were collected from nearly one hundred caves in the Upper Mississippi Valley, but mostly Minnesota, from a variety of rock types, and about two-thirds had elevated concentrations of nitrate. High nitrate concentrations, up to 35,000 ppm (3.5% dry weight), were widespread among caves along the dolomite cliffs surrounding Lake Pepin. By contrast, none of the surrounding surface control soils that were collected contained more than 10 ppm (dry weight) nitrate. Dual stable isotopic analysis of nitrogen and oxygen from nitrate in the cave sediment was used to exclude rainfall and fertilizer as potential sources for the accumulations, while other factors rule out the surrounding rock itself. The formation of high-nitrate cave sediments is surmised to result from animal traffic and plant debris, which provides nitrogenous organic matter that undergoes microbial nitrification, forming nitrate, which then accumulates because the cave roof protects the sediment from leaching and by shutting out sunlight permits this plant nutrient to remain in the sediment. No adverse environmental impacts are known to be associated with these very localized nitrate accumulations because the caves are not part of a hydrologically active karst and so from a management perspective they are not of concern.

Nitrate-N Loading Assessment and Remediation in a Shallow Unconfined Aquifer

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Following a wet climate shift in 1993, an estimated four million pounds of nitrate-N was leached to the Karlsruhe aquifer in Mclean County, North Dakota. A method was developed to estimate and monitor the total aquifer nitrate-N load and load changes in units familiar to production agriculture. An index called the Potential Mixed Concentration Index (PMCI) was used to provide a toxicological assessment for the stratified nitrate profile. Nitrogen dissipation was affected through natural denitrification, discharge to a local river, and extraction wells. After six years of monitoring about 40% of the nitrate had been removed.

Modeling the Electron Donor Contributions to Aquifer Denitrification, Karlsruhe, ND

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In situ aquifer denitrification was monitored at two sites in the Karlsruhe aquifer in north-central North Dakota. At the site with the higher denitrification rates, geochemical modeling was performed to estimate the contributions of organic carbon (as CH2O), pyrite (FeS2), and ferrous iron [Fe(II)] minerals for the denitrification measured. Fe (II) was modeled as hornblende and as a ‘mixed-Fe; amphibole to provide a reasonable range for minimized and maximized sources of Fe(II), both being constrained by analytical results of the groundwater evolution during denitrification and Mössbauer spectroscopy. The results indicated that the denitrification observed could not be explained by contributions from organic carbon and pyrite alone; non-pyrite Fe(II) minerals also needed to be involved. Depending on the sample date, 43-92% of the denitrification was caused by organic C, 4-18% by pyrite, and 2-43% from non-pyrite Fe(II).

Abstracts

Groundwater Quality – III: Geochemistry, Age, and Residence Times (Melinda Erickson and Bill Simpins, co-chairs)

Hydrogeologic Evidence of Preferential Pathways Near Municipal Supply Wells

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Recent work in southern Wisconsin demonstrates that rapid subsurface transport pathways move human enteric viruses from leaky sanitary sewers to deeply cased municipal wells. Human enteric viruses are excellent indicators of wastewater in groundwater systems because virus presence can be detected at very low concentrations. The virus detection data indicate that leaky sanitary sewers are a widespread, non-point source of groundwater pollution in urban areas.

Our efforts to characterize the viral transport pathways to deep supply wells included drilling monitoring wells within 75 feet of three supply wells. Early project results include digital images and borehole flow logs collected in these monitoring wells. These provide spectacular, direct observations of subsurface conditions adjacent to high capacity wells. At two of the three sites, flow is dominated by horizontal fractures in a sandstone formation. Measured flow in discrete fractures exceeded 300 gallons per minute while pumping from the adjacent supply well. While the supply well was shut off, flow decreased to about 50 gallons per minute, driven by the large hydraulic gradients in this heavily-pumped, regional aquifer. The large fracture apertures may be a result of pumping from the adjacent production wells for more than 50 years.

These findings are potentially significant in several respects. Flow measurements of 100s of gallons per minute along a discrete fracture in a sandstone aquifer suggest a substantially different capture zone than that delineated under an assumption of porous media, radial flow to the well. Travel time from the near subsurface to the well is much faster than that predicted based on porous media flow, thus explaining the presence of viruses in deeply cased wells. These observations demonstrate the vulnerability of deep aquifers to pathogen contamination from leaky sewers and illustrate the necessity of disinfection of groundwater supplies in sewered areas.

The Minnesota Pollution Control Agency's Statewide Ambient Groundwater Monitoring Network

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The Minnesota Pollution Control Agency (MPCA) maintains an Ambient Groundwater Monitoring Network to describe the current condition of the State's groundwater resources and track any changes in its quality. The MPCA uses this network to monitor for the presence of non-agricultural chemicals in Minnesotaís groundwater to meet its water quality protection and restoration goals. The current network has been in place since 2004 and was established using existing wells to minimize costs. Due to coverage gaps in the existing network, additional funding was secured from the State's Clean Water Legacy Act Amendment to install new wells since 2010.

The network is designed to provide an early warning of groundwater contamination and a first indication of any changes in its quality. To achieve this goal, the network primarily monitors two aquifers that may contain human-caused contamination: the unconsolidated sand and gravel aquifers and the Prairie du Chien-Jordan, both of which are near the surface. A network of wells that tap the water table in the sand and gravel aquifers also is monitored to identify the key factors affecting groundwater contamination, such as land use and geology. The monitored land use settings include:

1. sewered urban residential,
2. urban residential areas served by individual sewage treatment systems (ISTS),
3. commercial/industrial, and
4. undeveloped.

Each of these land use settings are monitored in sand and gravel aquifers composed of siliceous and calcareous glacial deposits. The data collected from the Ambient Groundwater Monitoring Network has refined assessments of anthropogenic and natural groundwater quality conditions in the State. The enhanced monitoring network has been used since 2010 to assess the occurrence and distribution of contaminants of emerging concern (CECs) in the State's groundwater. This one-time sampling indicated that CECs were present in about one-third of the monitored wells and were detected more frequently in residential areas served by ISTS. The enhanced network also was used to assess the effect of various urban land uses on chloride concentrations and the effect of surficial geology on phosphorus concentrations.

Groundwater Age and Quality, Papio-Missouri River Natural Resources District, Eastern Nebraska

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To assess groundwater age and quality in the Papio-Missouri Natural Resources District (PMRNRD), groundwater samples were collected from a total of 217 wells from 1992 to 2009 for analysis of various analytes. Groundwater samples were analyzed for age-dating analytes (chlorofluorocarbons), dissolved gases, major ions, trace elements, nutrients, stable isotope ratios, pesticides and pesticide degradates, volatile organic compounds, explosives, and 222radon. Apparent groundwater-recharge dates ranged from older than 1940 in the Missouri River Valley alluvial aquifer to the early 1980s in the Dakota aquifer. Dissolved concentrations of major ions in the most recent sample per well indicate that the predominant water type was calcium bicarbonate. Eighteen of the 21 trace elements analyzed have enforceable or non-enforceable U.S. Environmental Protection Agency (USEPA) drinking-water standards. Sixteen of the trace elements with USEPA standards were detected in the selected samples; only arsenic concentrations exceeded an enforceable USEPA standard – arsenic concen-

Groundwater Quality – III: Geochemistry, Age, and Residence Times (Melinda Erickson and Bill Simpins, co-chairs)

trations exceeded the USEPA Maximum Contaminant Level in 4 percent of the samples. The concentration of nitrate plus nitrite as nitrogen in the most recent nutrient samples collected from the network wells (irrigation, public supply, stock, industrial, and domestic) and from one randomly selected well in the well nests [2 to 3 short-screened monitoring wells in each well nest; these monitoring wells are screened just below the water table, in the middle of the aquifer (optional), and just above the aquifer base] from 1992 to 2009 for most wells ranged from less than 0.06 to 8.55 micrograms per liter (mg/L), with a median value of 0.12 mg/L. Of the 61 pesticides or pesticide degradates analyzed from 2007 to 2009, 21 were detected. Three of the 21 pesticides detected (alachlor, atrazine, and metolachlor) have established, health-based criteria; all detections of these compounds were at concentrations less than their USEPA drinking-water standards.

Using Cuttings to Identify Arsenic Risk During Well Construction in Unconsolidated Aquifers

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High amounts of arsenic in groundwater poses a health risk in parts of Minnesota. The relationship between arsenic concentration and aquifer material is not well understood. Research on this relationship has been limited to drill core rather than the easier to obtain drill cuttings. This study examines cuttings from five sand and gravel wells and arsenic concentrations in water from the aquifers tapped by these wells. The cuttings were examined, photographed, and classified using a grain count system similar to Hobbs (1998). The preliminary results obtained from this study suggest a correlation between lithic sand and arsenic concentration. While additional research is necessary to confirm these results, it appears possible to use cuttings to identify high-arsenic aquifers during well construction where local aquifer As-concentrations are known. When a new well is constructed, water quality testing typically occurs after the well is completed. Often the presence of arsenic in concentrations that exceed the maximum contaminant level (MCL) of 0.01mg/L comes as a surprise to the well owner. Identifying aquifers with high arsenic concentration during construction would provide the well owner with the opportunity to change the design of the well or the water system before the system is operational, mitigating the risk of arsenic exposure and/or the cost of water treatment.

Groundwater Modeling – II: (Madeline Gotkowitz, David Steward, and Otto D.L. Strack, co-chairs)

Application of a "Semi-Structured" Approach with MODFLOW-USG to Address Local Groundwater/ Surface-Water Interactions at the Regional Scale

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On the horizon is the transformation of MODFLOW from a structured finite-difference code (fixed row and column dimensions) to an unstructured code with flexible gridding - MODFLOW-USG. This reformulation of the equations in MODFLOW dramatically extends its power. Among the options - a domain can be discretized into cells of different sizes and shapes, allowing any number of nested grids, including vertical sub-discretization within layers. A preliminary version of this code has been used to test its power to simulate local groundwater/surface-water interactions over a large area. A 20-layer model of shallow and deep groundwater flow in the Lake Michigan Basin with cells 5000 ft on a side has been converted into a 4-layer model of the same lateral and vertical extent, but with cell sizes varying by layer. In this "semi-structured" approach, the top layer is more finely discretized than underlying layers: it is composed of cells 500 ft on a side, thereby allowing much more accurate simulation of exchanges with the surface-water network than with the original model but at a great savings in model size (34 million structured cells at the 500 ft scale is reduced to 9 million cells with unstructured gridding).The availability of a regional model with capabilities for simulating local flow opens the way to a research strategy for statistically testing the importance of stream depletion as a source of water to shallow wells. Using the flexible grid structure, it is possible to simulate thousands of realizations of the systemís response to pumping from a network of wells with a single simulation. By then employing Bayesian networks to analyze the relations between surface-water depletion as the dependent variable and local factors (for example minimum distance from wells to surface water and density of local surface water) as independent variables, we are constructing transfer functions that will allow managers to balance well withdrawals and protection of surface water by considering local conditions only - without the need to construct, calibrate, and apply a site-specific numerical flow model.

Emulating a Regional Groundwater Model with a Bayesian Decision Network for Efficient Decision Support

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Outside the groundwater community, Bayesian decision networks (BDN) have a long history in decision support in systems considering uncertainty. Previous applications range from medical diagnostics to terrorism threat assessment. In

Groundwater Modeling – II:
(Madeline Gotkowitz, David Steward, and Otto D.L. Strack, co-chairs)

the context of groundwater modeling, BDNs use the system variability provided by the natural world to synthesize a range of hydrogeologic situations within a single model run. Moreover, BDNs explicitly incorporate the uncertainty of the system, thus provide outputs in terms of probabilities – a metric well understood by decision-makers. BDNs, therefore, can serve as an efficient alternative to other uncertainty methods such as computational demanding Monte Carlo analyses and others methods restricted to linear models. We present an application of the BDN to groundwater modeling analyses. A simple spreadsheet of model output realizations is constructed using the variability encompassed by the model domain. In the Lake Michigan Basin (LMB), a regional unstructured-grid MODFLOW-USG model allowed analysis of stream capture and diversion resulting from new pumping. The depletion/diversion can be related to model variables, including: well/stream proximity and local stream density; pumping rate; and local recharge and transmissivity. Two models, each with 1,000 synthetic pumping wells scattered throughout the domain, are summarized to build the BDN. The BDN operates as a transfer function to predict stream depletion conditional upon proposed well location conditions (distance to streams, depth, etc) and trained by sampling across the Lake Michigan regional model. The goal is to apply this understanding to similar settings encompassed by the Glacial Aquifer System outside the LMB model domain. The use of MODFLOW-USG with BDNs provides decision makers a distilled understanding of the system with the associated uncertainty. This information, in turn, can provide a science-based foundation for water-resource management without the necessity of simulating every potential new situation.

Fully Three-dimensional Poroelastic Model Simulating Reverse Groundwater Fluctuations During Aquifer Pumping

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Conventional groundwater flow models consider fluid movement through non- deforming porous media. Groundwater flow can be more completely described when accounting for three-dimensional matrix deformation of the porous media in response to pumping-induced changes in effective stress. During groundwater pumping, aquifer consolidation can lead to temporary groundwater rise (Noordbergum effect), especially in low hydraulic conductivity (K) units. Previous models considered water level rise in only laterally continuous low K zones or layered aquitards. The purpose of this study is to construct a three-dimensional coupled consolidation-fluid flow model with completely independent heterogeneities. This allows for modeling poroelastic behavior of low K "mudballs" of various geometries and depths. These geometries represent realistic geologies such as clay lenses from ox-bow lakes or the edges of layered aquitards. The finite element analysis software package ABAQUS is used to build the model. The model domain is cylindrical with radius equal to 100 meters and depth of 10 meters. A well is in the center of the domain with radius of 0.1 m. It is fully penetrating to the bottom of the domain and is screened over the entire aquifer length. The well is pumped at a constant rate of about 38,000 gallons per day (1.67 x 10-3 m3/s) for a total of three days. After verifying the model with a comparison to the Theis solution for drawdown in an infinitely confined aquifer, we model three different subsurface geometries: layered aquitards above and below the aquifer, a low K material in an arc, representing ox-bow lake sediment, and an eroded aquitard with the edge starting some distance away from the pumping well. All three models show Noordbergum effect at early times in low K zones, not just in continuous layers. When the Noordbergum effect is seen in a pumping test, it indicates heterogeneity. The observation well has been placed in a low conductivity zone relative to the conductivity around the pumping well.

Mapping Flow Path Uncertainty with an Analytic Element Model and Monte Carlo Techniques

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The Lac du Flambeau Band of Lake Superior Chippewa Indians and the Indian Health Service are concerned about the fate of effluent that infiltrates from wastewater treatment lagoons on the reservation. Of particular concern is the potential for capture of effluent by drinking-water supply wells or short circuiting to a lake given current and possible alternative management scenarios for handling disposal of the wastewater. Groundwater flow and effluent movement from the wastewater treatment lagoons were simulated using the analytic element groundwater flow model, GFLOW, and calibrated using the parameter estimation program, PEST. Uncertainty in the extent of the simulated wastewater plumes as related to calibrated parameter values was evaluated using Monte Carlo techniques and the parameter posterior covariance computed by PEST during model calibration. A grid of particles was simulated with backward tracking from the bottom of the aquifer to the point of recharge. Determining which particles originally recharged as wastewater was done using a novel algorithm based on vector geometry and Voroni Tesselation. A Latin Hypercube algorithm was used to generate 1,000 candidate parameter combinations that each honored the correlation and uncertainty structure of the parameters estimated using PEST. Combining the results of the parameter candidates, the probability that individual particles originated as wastewater was calculated and used for generating maps of plume extent probability. Results were displayed as color-flood maps of probability, allowing the Tribe and Indian Health Services to evaluate risk of plume migration for multiple scenarios.

Abstracts

Karst – II: Karst Groundwater Resource Characterization (Jeff Green and Calvin Alexander, co-chairs)

Viruses in Groundwater: From Disease Outbreaks to Sporadic Illness

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Numerous studies have documented the presence of human gastrointestinal viruses in groundwater wells used for drinking water, but the effects on human health are not fully understood. This presentation will discuss two studies on exposure to groundwater-borne viruses and human health risk. The first was an investigation of an outbreak of acute gastrointestinal illness (AGI) among patrons of a restaurant located in Door County, Wisconsin. Groundwater supplies for this region are from a densely fractured dolomite aquifer characterized by rapid groundwater flow. An interdisciplinary approach relying on epidemiological, microbiological, and hydrological methods determined the outbreak source was the restaurant well contaminated from a nearby septic system.

The second study examined the relationship between community rates of sporadic AGI and levels of viruses in the municipal drinking water of 14 Wisconsin communities that do not disinfect their groundwater supplies. Three measures of virus contamination level, mean concentration, maximum concentration, and the proportion of virus-positive samples, were significantly associated with AGI incidence rates in these communities. Despite nearly 40 years of regulatory efforts to reduce waterborne disease in the USA, groundwater in particular remains vulnerable to pathogen contamination and a source of disease transmission.

Deep Time in the Upper Mississippi Valley Karst

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In the Upper Mississippi Valley (UMV) Karst, the routine appearance of new surficial karst features, groundwater flow velocities of km/day, and highly variable water quality parameters are unambiguous evidence that these karsts are currently active and evolving on human time-scales. However, the underlying karst aquifers have been developing multi-porosity conduit flow systems since the initial deposition of the carbonates in the Lower Paleozoic. The existence of syndepositional interstratal karst unconformities between the Oneota and Shakopee Formations and the Shakopee and St. Peter Formations were recognized in the 1800s. The karst porosity and permeability near the Oneota/Shakopee contact is a major, regional high transmissivity zone for ground water. Brannon et al. (2012) recently reported Alleghenian (270 My) ages for sphalerites in the UMV. This UMV Pb/Zn mineralization was deposited in preexisting solution enlarged joints, bedding planes and caves. The UMV has been above sea level since the Cretaceous and huge volumes of fresh water have flowed through these rocks. The regional flow systems have changed from east to west in the Cenozoic to north to south in or before the Pleistocene. The incision of the Mississippi and its tributaries has and is profoundly rearranging the ground water flow systems as it varies the regional base levels during glacial cycles. Caves high in the remnants of the Cretaceous weathering surface have speleothems that are >300 ka old The Pleistocene glacial cycles have removed or covered many of the surficial karst features and buried even more of them under glacial sediments. High erosion rates from row crop agriculture between the 1850s and 1930s filled many of the conduit systems with top soil. The three-generational soil conservation efforts have significantly reduced the flux of mobilized soil into the conduits and they are currently flushing much of that stored soils out of their spring outlets. Finally, the increased frequency and intensity of major storm events caused by global climate warming is reactivating conduit segments that have clogged and inactive for millions of years. The currently active conduit flow systems in the UMV karst aquifer are, in many cases, rejuvenated conduit networks initially formed 100s of millions of years ago.

Flexible Liner Special Utility for Karst Formations

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Karst formations present special difficulties for site characterization. The high flow rates, large open flow channels, and the difficulty of grouting casing are only a few of the problems. The relatively new use of flexible liners for sealing of boreholes, measurement of flow paths intersecting the boreholes, and multi-level sampling and head measurements takes advantage of a unique set of liner attributes. The first advantage is the use of the continuous liner to seal the entire borehole instead of discrete packers, a sealing grout, or other fill outside of a traditional casing. A second advantage is the ability to measure the transmissivity distribution of very fast flowing boreholes while installing a sealing liner in order to prevent contamination propagation due to an open borehole. Another advantage is the fact that all the water in the borehole is inside the liner and the multi-level samples are drawn directly from the formation. These characteristics have been tested in a wide variety of karst sites in the USA, Canada and Denmark. Those experiences have been very useful to refinements of the flexible liner methods in design and procedures to deal with the extremes of karst situations. Those refinements are stronger fabrics, eversion aids through caverns, high volume water flow controls for transmissivity profiling, formation head data collection after transmissivity profiling, and sometimes a grout fill of the liner after an installation of a multi-level system. Whereas sealing liners and multi level systems are practical in holes with more than 100 gallons/min. vertical flow rates, transmissivity profiling in such high flow conditions has limited resolution. Details of that experience and the refinements are presented in this paper. The problem of drilling of the initial borehole still remains.

Abstracts

Karst – II: Karst Groundwater Resource Characterization (Jeff Green and Calvin Alexander, co-chairs)

Karst Hydrogeology Investigations in the Cambrian St. Lawrence Aquitard

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The Cambrian St. Lawrence formation contains beds of siltstone, fine-grained sandstone and dolostone. It historically has been considered an aquitard. This view of the St. Lawrence as an aquitard has been accepted even though it has been known for many years that numerous springs in the karstlands of southeast Minnesota emanate from it. In the last five years, field investigations in southeast Minnesota have located more than twelve streams that sink into the upper St. Lawrence. Dye traces have been conducted at seven of these sites. At all of the sites, dye was recovered at springs discharging from the base of the St. Lawrence Formation. Breakthrough travel velocities from the sinks to the springs are 35-750 meters/day but the breakthrough curves have tails that continue for months to over a year. Locating these sinking streams is a challenge in the rugged topography of southeast Minnesota. Some valleys have roads which go through them, in those cases the streams can be checked directly. Most valleys, though, do not have roads. We have used LiDAR and aerial photography to do initial reconnaissance of many valleys. A wide variety of aerial photographs are available for southeast Minnesota; the most effective for locating sinking streams has been high resolution color infrared (CIR). The water in the streams shows as black lines; the streambeds are littered with dolostone cobbles and boulders so when the streams sink it is quite visible. LiDAR imagery has also been very useful. The point at which the streams sink into the St. Lawrence is quite visible on the one and three meter LiDAR hillshade coverage. The St. Lawrence stream sinks are pools; on the LiDAR coverage the terminal sinking points are visible as incised features; at the downstream end of these pools the stream channel becomes much less distinct and the valley surface becomes smooth. Our field investigation techniques for the St. Lawrence flow system have evolved over a four-year span and are based on correlating the LiDAR and CIR imagery with our field observations. The first dye traces were run from sinking streams identified by local citizens. From those sites, we began to investigate valleys with road access. The consistent air photo and LiDAR characteristics at those sites are now being used to locate additional streams to investigate.

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Joanna N. Thamke[1], Andrew J. Long[2], Larry D. Putnam[2], Gary D. LeCain[3], Derek W. Ryter[4], Timothy T. Bartos[5], Roy Sando[1], Kyle W. Davis[2], Adel E. Haj[2], Katherine R. Aurand[2], Jonathan D.R.G. Mckaskey[2], Jennifer M. Bednar[2], Diane K. Rauch[1], and Jeremy M. Vinton[6]
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Case Study: Arsenic in domestic wells west of Carlton County 2 Sanitary Landfill

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Minnesota Groundwater Level Observation Well Inventory Update

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A multi-year project to find, survey, and test Minnesota's groundwater level monitoring observation wells and update the inventory of such wells statewide is drawing to a successful close. The new inventory will advise repair and replacement activities and provide a sound basis for gap analysis that will lead to the build-out of Minnesota's groundwater level monitoring network over the next 20 years.

Monitoring the Recharge Edge of the Mt. Simon Aquifer

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The deepest bedrock aquifer of southeastern Minnesota is the thick (50 to >200 feet) Cambrian Mt. Simon sandstone aquifer. This aquifer supplies water to over one million Minnesotans. Water levels in this aquifer have been declining in the Mankato area (locally) and Minneapolis/St. Paul metropolitan area (locally and regionally) from municipal and industrial use. To help determine recharge pathways and sustainable limits for this aquifer, the western recharge edge was investigated by installing observation wells at 24 sites; measuring static water levels in the wells; analyzing groundwater chemistry including stable isotopes, ^{14}C, and tritium; and testing aquifer capacity. In south-central Minnesota the youngest Mt. Simon aquifer groundwater (7,000-8,000 years before present) indicates the aquifer is very slowly recharged from a large source area located south of the Minnesota River. Along the northwestern extent of the aquifer, ^{14}C residence time values less than 1,000 years before present indicate more rapid recharge through scattered occurrences of focused recharge. Planned long-term water-level monitoring of the wells installed by this investigation will help hydrogeologists and resource managers evaluate the local and regional effects of current and future Mt. Simon aquifer groundwater use.

Buried Sand and Gravel Aquifers of The Breckenridge/Wahpeton Area, Minnesota and North Dakota

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Located on the border between North Dakota and Minnesota, the communities of Wahpeton, North Dakota and Breckenridge, Minnesota share buried sand and gravel and sandstone aquifers that straddle the border. Management of these limited cross-border resources has been a contentious issue between local and state government entities in the past and could be again in the future. Due to these concerns, the North Dakota State Water Commission (NDSWC), Minnesota Department of Natural Resources (MNDNR), and Wilkin County Environmental Services collaborated from 1995 through 1998 on an area groundwater investigation that included: Collection of groundwater samples from 42 wells in Richland (North Dakota) and Wilkin (Minnesota) counties analyzed for stable isotopic analysis of 18O and deuterium, and general chemistry; drilling through the entire glacial section into Cretaceous bedrock at 11 locations in Minnesota with North Dakota drilling equipment and staff; and completion of water-level synoptic measurement events in June and October of 1995. Closely-spaced hydrogeologic cross sections of the area illustrating the distribution of stable isotopic groundwater types in buried sand aquifers suggest hydraulic connections to surficial recharge water are common. Widespread occurrences of groundwater with a mixed-warm stable isotopic type and gradually rising water levels in several observation wells indicate active recharge of area aquifers. The relatively open nature of the area aquifers suggests that water usage in this area appears sustainable at current water usage rates and quantities of precipitation. Should water usage or precipitation change significantly, the sustainability of aquifer usage in the area would need to be reevaluated. Long-term monitoring of the groundwater resources in this area should be continued.

A Simple, Low-Cost Downhole Flow Logging System

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Measurements of fluid flow in a well or borehole provide valuable information about the adjacent formations, including the presence of permeable features such as fractures, the presence of aquitards, and whether flow is upward or downward. Borehole flow data in groundwater wells are typically collected with mechanical spinner, heat pulse, or electromagnetic flow meters. These instruments provide excellent data, but can be expensive to purchase, and in the case of the spinner flow meter, can require significant data analysis.

We have developed a simple, economical method for measuring flow in groundwater wells. The equipment consists of an electric heater that induces a heat pulse into the water column, and a submersible temperature measurement device. The heater consists of a 2000 watt cartridge heater, shrouded in a perforated steel housing, and attached to electrical cable. The heater runs on a 2000 watt generator. Temperature measurements can be made with a variety of instruments designed to measure water temperature. We used a combined water level, temperature, and conductivity meter with a flat tape to measure depths. The total cost of the heater was $639 and the cost of our water level/temperature/conductivity meter was $1,361 for a total cost of $2,000.

The method consists of setting the temperature measurement device in the well at a known distance from the heat source and measuring the time required for the heated water to reach the measurement point. The elapsed time between onset of heating and the first measured temperature change at the temperature device is used to calculate fluid velocity in the well.

We tested the equipment and the method in a previously-studied well and found the results to be in good agreement with previous flow measurements at the site. Laboratory tests were conducted to determine practical upper and lower limits of effective flow measurement using this system. The simple design, ease of analysis, and low cost and availability of components make this system an effective and economical tool for measuring fluid flow in wells and boreholes.

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Practical Use of Flexible Liner Transmissivity Profiling Results

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The FLUTe hydraulic covnductivity profiling technique first published in 2004* has now been used in over 250 boreholes at 53 sites under a wide variety of conditions. Most applications have been at chlorinated solvent sites in fractured rock where detailed information on transport paths is especially useful for a wide range of remediation and monitoring designs. The method uses a flexible borehole liner to map the transmissivity distribution of the formation intersected by an open borehole. There have been many refinements in the method in the last 8 years. However, a common problem still is the general understanding of the advantages and application of the results. A simple graphical technique makes the results directly comparable to straddle packer measurements and more useful in numerical modeling. Use of the results is explained.

(*Method developed and patented by FLUTe: no. 6910374 and 7281422)

Characterizing the Platteville Aquitard as a "Hybrid" Hydrogeologic Unit

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The Ordovician Platteville aquitard in the Twin Cities Metropolitan area of Minnesota is a shallowly buried, extensively fractured carbonate rock in an urban setting, and therefore vulnerable to contaminants. A large number and wide variety of geomechanical and hydrogeologic studies over the past few decades have yielded a wealth of data that combined with our own borehole geophysics and outcrop observations, has led to a more comprehensive understanding of the Platteville. Key information acquired includes borehole flowmeter logs in ambient and stressed conditions, discrete interval packer tests, multiple head measurements from individual boreholes, long duration "aquifer" tests, spring hydrostratigraphy, vertical fracture characterization based on mechanical stratigraphic analysis of outcrops, and observations of subsurface fractures in underground excavations. These data are brought together within detailed stratigraphic context using natural gamma logs collected from both outcrops and boreholes. The combination of data from all of these efforts collectively leads to a characterization of the Platteville as a complex, "hybrid" hydrogeologic unit. From one perspective it can serve as an important aquitard that limits vertical flow, while from another perspective, it is best considered a karstic aquifer with well-developed bedding-plane parallel conduit systems of very high hydraulic conductivity that permit rapid flow of large volumes of water. Further, thin stratigraphic intervals of a few feet or less appear to contain both the highest hydraulically conductive bedding-plane parallel conduits as well as the key aquitards. Despite this complexity there is strong stratigraphic control in the vertical and bedding-plane parallel fracture patterns, and thus the potential for a strong degree of predictability in flow path geometries.

Groundwater availability in the Williston and Powder River basins, North and South Dakota, Montana, Wyoming, Saskatchewan, and Manitoba

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The recent explosion of oil and gas development in the Williston structural basin (containing the Bakken Formation) in the Dakotas, Montana, Saskatchewan, and Manitoba and Powder River structural basin in Montana and Wyoming provides a critical opportunity to study the water-energy nexus within a groundwater context. Large amounts of water for energy development in these basins are withdrawn from the hydraulically-connected bedrock aquifers in the regional lower Tertiary and Upper Cretaceous aquifer system. In some parts of the Powder River structural basin, these aquifers are removed (or stripped) to mine coal for use in the U.S. and Far East. These aquifers are often the shallowest, most accessible, and in some cases, the only potable aquifers within the northern Great Plains.

In the future, groundwater and energy will continue to be important resources in these structural basins. To effectively develop energy resources it is critical to understand the potable groundwater resources in the bedrock aquifer systems in these basins, evaluate how these resources have changed over time, and provide tools to better understand system response to future anthropogenic demands and environmental stress.

This work is part of the U.S. Geological Survey's Groundwater Resources Program to improve understanding of groundwater availability in major aquifers across the Nation (http://water.usgs.gov/ogw/gwrp/). Additional details about this work are available on the project web page: http://mt.water.usgs.gov/projects/WaPR/

Analytic Element Modeling of the High Plains Aquifer: Parameter Estimation of Groundwater-Surface Water Interaction Rates

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This presentation studies the impact of a sloping aquifer base on a large aquifer. Our case study is the High Plains Aquifer in the central plains of the USA. Modeling of groundwater is accomplished through the use of numeric and analytic techniques. MODFLOW, the most widely used numeric model, has been utilized to model the High Plains Aquifer, but problems often arise in the models due to steep slopes, small saturated thicknesses, and high hydraulic conductivities. These aquifer properties frequently result in cells going dry unexpectedly, as well as failure to meet model convergence criteria. The sloping base model is an Analytic Element Method that has also been used to simulate groundwater flow in the High Plains in previous studies by the authors. This approach breaks the aquifer into a set of rectangular cells, solves for the 1-D flow, and iterates across cells. The initial solution is achieved without taking into account groundwater-surface water interactions resulting in large errors in the final results. An optimization algorithm is then used to locate and quantify groundwater-surface water interaction rates which minimize error in the model. Results are shown for the two modeling approaches, and the strengths of each are illustrated.

Identifying Controls on Infiltration Capacity to Predict Recharge

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Infiltration measurements on a hillslope scale are used to identify controls on infiltration capacity. The infiltration data is used to supplement the soil survey. Soil surveys provide soil hydraulic properties for soil mapping units, but the properties can vary within soil mapping units due to land use, land management, or topographic position. By using the water balance method, soil surveys combined with weather data and land cover data are used to determine groundwater recharge. Measuring infiltration on a field scale enables us to identify the controls on infiltration capacity and provides a supplement to the soil survey data. The results are a higher spatial resolution of for infiltration capacity and potential groundwater recharge. To measure infiltration on a hillslope scale, Automated Mini-Disk Infiltrometers (AMDIs) were deployed on ten sites within a watershed at Konza Prairie in order to determine the effect of landscape position on infiltration. AMDIs allow for multiple rapid measurements of infiltration in the field creating a higher spatial resolution of soil hydraulic properties than provided by a soil survey. The results of the measurements show significant differences in infiltration capacity along an assumed homogeneous landscape.

The Simple Script Wrapper for OpenMI: Enabling Interdisciplinary Water Studies

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The management of large-scale water resources impacts both societies and ecologies and balancing these competing needs requires an understanding of the interplay between processes across domain boundaries. The emerging field of multidisciplinary integrated modeling that bridges traditionally isolated domains is uniquely suited to inform this understanding. It is necessary for such initiatives as the European Union Water Framework Directive and studies envisioned by the Consortium of Universities for the Advancement of Hydrologic Science (CUASHI). The Open Modeling Interface (OpenMI) was created to provide a standardized mechanism to link models together and we have found it to be an effective means to integrating interdisciplinary models in earlier work. What this study addresses is a current challenge in implementing OpenMI strategies; scripting languages such as MATLAB, Scilab, and Python are commonly used by scientists for modeling yet require considerable effort to use with the OpenMI. We present the design of a software component called the Simple Script Wrapper (SSW) that facilitates the linking of scripted models to OpenMI components. The simplicity afforded by our solution is presented in a case study set in the context of irrigated agriculture that illustrates the importance of integrated modeling.

Using a numerical model to assess groundwater remediation effectiveness at a former manufactured gas plant site

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Numerical models of groundwater flow and contaminant fate and transport can provide a cost-effective alternative to extensive data collection and oversimplification of system operation as part of an evaluation of remediation effectiveness. When calibrated to monitoring data, a model provides a more complete representation of the remediation processes than can be interpreted from the monitoring data alone, thereby reducing ambiguity in the monitoring data, providing insights into aspects of treatment operations, and facilitating straightforward computation of remediation effectiveness metrics, e.g., mass reduction. We have applied a three-dimensional numerical model of groundwater flow and contaminant fate and transport to simulate the operation of a treatment cell-based groundwater extraction-reinjection remedial system at a former MGP site in Waukegan, Illinois. The model was initially developed to assess remedial options and design of the extraction-reinjection system and was subsequently modified to simulate full-scale operation. As part of detailed monitoring to demonstrate effectiveness of the cell-based groundwater remediation, nested monitoring wells were installed in one of the full-scale treatment cells, which was operated early in the treatment program. To accurately simulate operation of the treatment system, the model was updated with pre-remediation groundwater concentration data and pumping rates measured during cell operation and then calibrated to concentration data from the monitored cell by adjusting hydraulic and contaminant transport parameter values. A primary use of the calibrated model was to quantify mass reduction in the cell, which was a critical piece of information for the evaluation of groundwater remediation effectiveness that could not be accurately calculated from available monitoring data. The combination of model results and monitoring data has proven to be a useful tool in evaluating and demonstrating the effectiveness of groundwater remediation at the site.

Predicting Groundwater TCE Plume Migration at the Paducah Gaseous Diffusion Plant, Kentucky

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The Paducah Gaseous Diffusion Plant is an active uranium-enrichment facility owned by the U.S. Department of Energy. It is located in the Jackson Purchase region of western Kentucky, approximately 16.1 km west of Paducah and 6.5 km south of the Ohio River. Historic activities have released hazardous, nonhazardous, and radioactive wastes to the

environment, including PCBs, trichloroethene (TCE), uranium, and technetium-99. The plant is listed by the U.S. Environmental Protection Agency as a National Priority List Superfund site. TCE, a chlorinated solvent, is the most widespread groundwater contaminant associated with the plant. TCE occurs as dense nonaqueous phase liquid in shallow silts and clays and in the regional gravel aquifer. It is estimated that about one million kg of TCE are present in the subsurface. TCE contamination has resulted in multiple dissolved phase plumes in groundwater that migrate from the plant toward the Ohio River.

In this study, a 3-D groundwater flow and contaminant transport model was used to simulate migration of the TCE plumes for 100 years into the future under four potential response actions: (1) continuation of existing pump and treat action, (2) reduction of contamination for sources at the C-400 building, (3) reduction of contamination for all sources, and (4) reduction of contamination for all sources and a permeable treatment zone along the plant's security fence. Each response action was simulated for two scenarios: one for continued operation of the plant and the other for plant shutdown. The simulation results suggest that, under the continued operation scenario, even with the most aggressive action (response action 4), the plumes will still impact large areas between the Ohio River and the plant for more than 50 years. Under the plant shutdown scenario, only the response action 4 appears to be effective in preventing the plume migrating out of the plant site.

Understanding Long-Term Natural Attenuation of Crude Oil in the Subsurface

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Long-term multi-disciplinary investigations into the processes that limit the extent of subsurface hydrocarbon contamination have been conducted at a site near Bemidji, Minnesota, USA, where crude oil was spilled in 1979. Long-term trends in the concentrations of (1) benzene, toluene, ethylbenzene, and xylene (BTEX) in the source oil body and groundwater and (2) sediment Fe (III), a source of electron acceptors critical for hydrocarbon biodegradation, were examined. Groundwater and crude oil samples were collected periodically from 1987 through 2010 and analyzed for BTEX. Sediment samples were collected and analyzed for Fe (III) concentrations from 1993 through 1995 and again from 2006 through 2008. At most locations, benzene concentrations in both the oil body and near-source groundwater decreased between 1987 and 2010, whereas ethylbenzene concentrations remained consistent over this same time period. Ethylbenzene is less water-soluble than benzene, and hence a larger fraction remains in the oil despite similar exposure as benzene to recharge and groundwater. The dissolved benzene and ethylbenzene plumes have expanded at a rate of approximately 3 meters per year since 1995, extending to 105 meters down-gradient from the center of the oil body. Previous research at the site indicated that iron-reducing bacteria utilize iron oxyhydroxide coatings on the aquifer's sand and gravel sediments to oxidize the hydrocarbons. Since BTEX is still being supplied by the source oil, the plume continues to expand as this Fe (III) source is consumed. Between 1993 and 2006, Fe (III) decreased by an average of 20 micromoles per gram of sediment in the zone 60 to 120 meters down-gradient from the oil body. In general, when BTEX compounds remain in the source zone, contaminant plumes are prone to expansion because of depletion of electron acceptors inside the plume and limited mixing with dissolved electron acceptors outside the plume.

Assessing Iron Impacts on An Aquatic Ecosystem: a Relief Well System Example

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Excessive amounts of iron, in both dissolved and particulate forms, have the potential to negatively alter aquatic ecosystem structure, function, and ecosystem services. For example, iron in groundwater impacts thousands of Minnesotans across the state. While some iron-related impacts are simply due to natural conditions, human activities that alter the environment also have environmental consequences. A relevant example is a pumped storage energy facility operated by Xcel Energy. The project is comprised of upper and lower reservoirs formed by earthen dams; a power tunnel connecting the two reservoirs; a powerhouse with two reversible pump-turbine units producing 300 MW; and transformers and other appurtenant facilities. A relief well system has been constructed in the lower earthen dam, which contributes a pulsed discharge of water downstream to a trout stream. Trout populations were anecdotally reported to be undersized in the reach immediately downstream of facility.

Xcel conducted several studies to verify and assess potential ecological impacts of the facility on the trout population, including hydraulics, surface and groundwater quality, characterization of the macroinvertebrate communities, and fish population surveys. The studies showed that numbers of trout are unaffected, but verified the observations of the trout size. The discharge of the relief well system was shown to be rich in ferrous iron, which oxidizes and precipitates downstream of the facility. At low flow, the relief well pulsed discharge approximately doubles the magnitude of the base flow. Macroinvertebrate populations are stressed immediately below the facility. Thus, it appears the undersized trout are caused by the relief well discharge.

High iron concentrations increase the potential maintenance requirements for applying traditional methods of iron removal at this site, and more cost effective solutions are sought. An adaptive management plan is proposed, beginning with eliminating the pulsed discharge and additional characterization of the in situ iron oxidation process.

Poster Abstracts

Groundwater Monitoring of Liquid Manure Storage Structures in Iowa

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Concerns about the impacts of manure storage on groundwater quality were raised in the mid 1990's resulting in the initiation of new research efforts and the incorporation of monitoring requirements into state-issued permits for earthen manure storage (EMS) structures. In 2004, additional monitoring requirements went into effect for below-building pits associated with new construction of confinement animal feeding operations in karst areas. Required monitoring of wells (generally within 15 meters of the EMS structures) and perimeter tiles revealed chloride concentrations generally below 300 mg/L, nitrate-nitrogen (or nitrate-N plus nitrite-N) concentrations up to 140 mg/L, and ammonia-nitrogen concentrations below 3 mg/L with two exceptions at 11 and 160 mg/L. Required monitoring of perimeter tiles around confinements located in karst areas revealed some elevated ammonia-N concentrations (up to 11 mg/L with one exception at 88 mg/L), however, concentrations were highly variable and no clear trends were apparent. To assess the impacts of permitted earthen structures where only 2-3 years of quarterly data are available, these data were compared to data distributions and trends seen in the long-term records obtained from groundwater monitoring of two earthen manure storage (EMS) structures. Groundwater monitoring around three EMS structures located in western, north-central and eastern Iowa began in 1994. Monitoring at the western Iowa basin was discontinued in 1998 when no effects were seen on downgradient wells. The other two EMS site were monitored until 2005. These basins were constructed primarily in glacial till and designed to meet the maximum permitted seepage limit of 0.16 cm/day (1/16th inch per day). The results of long-term monitoring show that water resources located less than 45 meters (150 ft) downgradient of EMS structures are at risk for high nitrate concentrations (up to 150 mg/L) which can affect the health of humans, livestock, and aquatic organisms. The potential for greater transport in more permeable settings, and the potential for transport of other contaminants, such as viruses, cannot be evaluated from available data. The long-term records indicate that wide ranges of nitrate concentrations and/or median nitrate-N concentrations above 20 mg/L are indicative of more severe contamination, while narrow distributions with medians below 20 mg/L nitrate-N are typical of monitoring during the first five years after basin construction or for basins with little impact on surrounding groundwater. The results of short-term monitoring data must be interpreted cautiously, and may be complicated by upgradient feedlots, nearby manure application, or other activities.

Preliminary Assessment of Naturally-Occurring Manganese in Minnesota Groundwater

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Interest in naturally-occurring manganese as a chemical component of groundwater and drinking water is increasing. The United States Environmental Protection Agency (USEPA) National Secondary Drinking Water Regulations (NSDWR) standard for manganese is 50 ug/L, and the Minnesota Department of Health (MDH) Health Risk Limit (HRL) is 100 ug/L. Because of concerns related to source water used in infant formula, MDH may soon apply these drinking water quality standards more widely than in the past. The MDH Source Water Protection (SWP) program prepared a summary of the natural distribution of manganese in Minnesota groundwater, using data from various federal, state, and county sources.

The statewide distribution of 4339 data points had a lognormal frequency distribution, a median of 93 ug/L, and was strongly spatially correlated. The highest concentrations occurred in southwestern Minnesota and the lowest in southeastern Minnesota. Quaternary water table and buried artesian aquifer settings had the greatest median concentrations (155 and 160 ug/L, respectively), and the Paleozoic bedrock aquifers had the least (32 ug/L). Concentrations at 2123 wells (48.9%) exceeded the HRL (100 ug/L). Buried artesian aquifer settings had the greatest percentage of wells exceeding the HRL (63.0%) and the Paleozoic bedrock aquifer had the least (24.3%).

Median concentrations in plastic-cased wells were twice those in metal-cased wells, suggesting that casing material may affect concentration. Hydrogeologic setting or other factors related to well construction may also influence concentration, hypotheses that MDH intends to test. Several sampling efforts including manganese are in the planning stages or underway, ensuring that the manganese dataset continues to grow.

Case Study: Arsenic in domestic wells west of Carlton County 2 Sanitary Landfill

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The Carlton Cty 2 Sanitary Landfill (Landfill) started accepting waste in 1971. Characterization of the aquifer in the early 1970s was limited so that background water quality was not determined before waste was accepted at the Landfill. The monitoring system in place at closure was installed to reflect regional flow with wells on the north, east and south sides of the waste footprint. In addition, a one mile receptor survey was not completed.

Domestic wells are located 260 meters to the west and are installed in the Quaternary drift aquifer. Domestic wells were not sampled until 2003. Arsenic was detected above the Maximum Contaminant Level at one of the residences (which through expanded sampling includes 4 residences above the standards) but the origin of the arsenic was inconclusive because of limited previous studies.

Several phases of investigation in the drift were completed to determine the cause of elevated levels of arsenic in the domestic wells west and southwest of the Landfill. Phase 1 involved the installation of multichannel wells along the west side. Phase 2 was an upgrade of the monitoring system based on 5 years of data collected in the multichannel wells and reconnaissance of drainage channels from the landfill to the property west of the landfill. Phase 3 was the installation and sampling of temporary wells on the property west of the Landfill.

The results indicated that leachate travels to the west and southwest within sand and gravel layers within the drift. The results pared with geochemical studies at other closed landfills indicate that arsenic is released from the sediments because of the acidic leachate released from the site (the Landfill is unlined). Remediation of the impacted domestic wells is being implemented in late summer.

Identifying the Arsenic Source and Mobilization Mechanisms in Glacial Aquifers, west-central Minnesota, USA

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In Minnesota, elevated arsenic concentrations in groundwater are spatially correlated to the northwest-provenance Late-Wisconsinan (Keewatin) till. Wells open to glacial sediments and shallow bedrock overlain by this till are most affected by elevated arsenic concentrations. Evidence suggests that the distinct characteristics of the Keewatin till cause the geochemical conditions necessary to mobilize arsenic. This fine-grained, comparatively organic-rich, biologically-active sediment creates a geochemical environment favorable to a regional-scale mobilization of arsenic. X-ray absorption spectroscopy (XAS) and sequential extractions were used to identify and quantify different arsenic (As) species present in glacial sediments from west-central Minnesota. Sample locations were chosen based on proximity to domestic drinking water wells with arsenic concentrations exceeding the 10 ug/L maximum contaminant level for drinking water in the United States. Total arsenic concentrations of the glacial sediments are not unusually high relative to crustal average (1-1.8 mg/kg). However, the concentration of anion-exchangeable or labile species of arsenic is unusually high. In addition, the proportion of oxidized As (arsenate) was high in permeable glacial outwash, intermediate in low-permeability glacial till adjacent to outwash (the "contact" till), and low within non-contact glacial tills. Conversely, the proportion of reduced As (arsenopyrite) was low in glacial outwash, intermediate in the contact till, and high within the non-contact glacial tills. No changes in the proportion of As(III) species across the contact were observed. These results reveal an oxidation-reduction gradient in As across the contact till, and support the hypothesis that the till contact is an active zone of As release to groundwater.

Distribution of phosphorus in three hydrologic units of variable flow characteristics

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Agriculturally derived phosphorus (P) is the root cause of poor surface water quality in Midwestern watersheds. Phosphorus enhances phytoplankton growth in water, resulting in increased deposition of organic matter to deeper water. This in turn stimulates respiration, thereby increasing the consumption of oxygen, which leads to eutrophication of the water body. Today, many of Iowa's lakes no longer support their designated uses as a habitat for aquatic life and a recreational water body because of the eutrophication problem.

Abundance and mobility of P in three contrasting hydrologic environments were compared in this study. Silver Lake of northeast Iowa is characterized by cyanobacterial blooms in the summer with dissolved oxygen (DO) of less than 2.0 mg/L. Lake sediments show high levels of P with a concentration gradient in which P decreases with depth. The average P concentrations in the sediments are 848 µg/gm at 0-5 cm, 666 µg/gm at 10-15 cm, 420 µg/gm at 20-25 cm, and 293 µg/gm at 30-35 cm below sediment surface. Munns Creek watershed in north-central Iowa is well aerated with DO values ranging between 5.3 and 13.9 ppm. The average P concentration in surface soil is 30.2 µg/gm of soil. However, samples recovered from 6 inches below the surface have an average concentration of 57.6 µg/gm of soil. This increase in concentration is attributed to the high adsorption of P to the higher particle surface areas in deeper but still well oxygenated condition. On the other hand, the high level of P in Silver lake sediments is caused by its mobilization from particles in low oxygen condition and then accumulation in pore water for not having adequate escape routes. Dissolved P in standing water of an active wetland system in north-central Iowa, called the Beaver Valley Wetland, shows consistent decrease in concentration going from 12.3 µg/L in May to 5.7 µg/L in August and1.4 µg/L in November. It is evident from the above results that redox conditions play a very important role in determining the fate of P in shallow hydrologic environments. In all 3 systems P was found to be actively transporting within the system in response to the changes in unit characteristics.

Baseflow contribution to seasonal hypoxia, Clearwater River, Clearwater County, Minnesota

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The headwaters reach of the Clearwater River is seasonally impaired due to low dissolved oxygen. Physical and chemical hydrologic data were collected in the vicinity of Bagley, Minnesota from June to October, 2008. Data collected included: stream discharge measurements at 5 sites (2 on the Clearwater River and 3 on tributary streams); in situ measurements of water quality parameters at 10 Clearwater River sites, 3 tributary sites, and 10 observation wells installed in two transects within stream-margin fens. Hydraulic heads were also monitored in the observation wells. In situ chemical parameters analyzed included pH, temperature, RedOx, specific

conductivity, dissolved oxygen; Mg, Fe^{II}, total Fe, SO^4, NO^2, NO^3, PO^4, ATP, and chlorphophyll were evaluated in the laboratory. No consistent relationship was recognized between the chemical parameters and D.O. within the river.

Shallow groundwater in the stream margin fens was nearly always O^2 deficient. Hydraulic gradients within one fen indicate consistent groundwater discharge into the river; the other fen discharged into the river early in the study and underwent a flow reversal later due to persistently high stream stage. Stream gaging data indicate that the downstream discharge is greater than the upstream discharge plus the sum of tributary discharge about 88 percent of the time (N = 17). In some cases the difference is attributable to flow in intermittent tributaries after precipitation events but during periods of low river discharge, the high downstream discharge appears to be the result of baseflow contribution to the river. During periods of low river discharge, the influx of oxygen deficient baseflow from the fens appears to overwhelm the river's ability to absorb oxygen from the atmosphere.

Using a Physically Based, Coupled Surface Water/ Groundwater Model to Assess the Hydrologic Impacts of Tile Drainage in Iowa

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Recent large-scale flood events in Iowa demonstrate a need to understand how drainage alteration, specifically through tile drainage and ditches related to intensive agriculture, affect peak flow events and streamflow hydrology. We are investigating these relationships in the South Fork watershed in north-central Iowa using the physically based, coupled surface water/groundwater model, HydroGeoSphere. The model will represent all flow partitioning mechanisms, simulate the effect of agricultural drainage on peak flow events, and quantify spatial and temporal heterogeneous water fluxes by simultaneously solving the flow and transport equations in surface, tile drain, and groundwater flow pathways and the exchanged fluxes between these systems. In addition to more standard calibration techniques (i.e., hydraulic head, streamflow), stable isotopes of water (δ^2H and $\delta^{18}O$) will be used to estimate the contributions of tile drainage and groundwater to streamflow under varying flow conditions. Contributions to peak flow by tile drainage will be estimated by hydrograph separation using the simulated hydrographs produced by the model. Preliminary results for September 2011 to March 2012 suggest $\delta^{18}O$ ranges of -13.91‰ to -8.95‰ for tile drainage water, -10.20‰ to -7.09‰ for groundwater, and a mean precipitation value of -7.99‰. The slope of the local meteoric water line (LMWL) from precipitation is $\delta 2H = 7.85*\delta^{18}O + 6.21$. The drought of 2012 has also affected stream water isotopic composition. Samples from June and July 2012 trend away from the LMWL along a slope of 4.5 – indicative of evaporation. The goal of this research is to describe, through modeling of the watershed pre- and post-alteration of drainage, how the hydrologic behavior of the South Fork watershed has been altered by drainage systems. The results will inform water resource and land management practices and suggest potential control measures for future peak flow events.

Nitrate-Nitrogen in the Springs and Trout Streams of Southeast Minnesota

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The relationship between row crop land use and nitrate-nitrogen concentration in baseflow was evaluated for 100 trout stream watersheds in the karstlands of southeast Minnesota. The watersheds range in size from 9 to 831 km2 (a majority of the watersheds (82) range from 14 to 150 km2); the percentage of land in row crop (planted to corn or soybeans in 2009) varied from 1.4 to 73.2%. Mean baseflow nitrate-nitrogen ($NO^2 + NO^3$) concentrations ranged from 0.2 to 17.4 mg/l. Results indicate that nitrate-nitrogen concentrations are directly related to the percentage of row crop in the watershed ($r^2 = 0.68$). A linear regression showed a slope of 0.16. The strong correlation between nitrate-nitrogen concentrations in streams and watershed row crop percentage suggests that, in general, nitrogen application over a span of decades has impacted the condition of the underlying aquifers that are the source of these streams' baseflow.

To examine changes in nitrate-nitrogen concentrations over time, trend analyses were applied to data collected at two trout hatchery springs in southeast Minnesota: Lanesboro State Hatchery and Peterson State Hatchery. Statistically significant increasing trends in both nitrate-nitrogen concentration and load were documented at each location, for periods covering the last twenty years. Concentration trend statistics ranged from 0.01- 0.001, and load from 0.05 - 0.001.

The Combined Application of LiDAR, Aerial Photography and Pictometric Tools for Sinkhole Delineation

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The location of sinkholes in karst and silici-karst environments has taken on increasing importance in land use planning and zoning regulations across South East and East Central Minnesota. The delineation of sinkholes has traditionally depended on extensive field work, using topographic maps, intensive networking with local landowners, and the luck of the observer to spot a feature that is often rapidly filled or concealed within croplands.

The application of aerial tools now allows mappers to identify potential sinkholes and eliminate holes generated by other surficial processes. LiDAR mapping across Minnesota now allows high resolution imaging of very small depressions in Karst landscapes without interference from vegetation. These depressions can then be compared to aerial photography flown periodically by the USDA to verify persistence and/ or reappearance of features through time. Additionally, low angle, high resolution pictometric imagery allows overhead views from several angles to further identify and verify the genesis of a given depression. While field verification is still the ultimate standard many obvious sinkholes can be identified and numerous non-sinkhole depressions eliminated from consideration greatly reducing field time.

Poster Abstracts

Outdoor Ground Water Exhibit at the Science Museum of Minnesota: First of its Kind!

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The Minnesota Ground Water Association (MGWA) Foundation worked with the Science Museum of Minnesota (SMM) to design and develop an outdoor interactive ground water exhibit at the SMM Big Backyard (BBY). The exhibit opened in June 2007 and includes a 300 foot deep well, hand pumps, two sand box models, and various displays illustrating porosity and hydraulic conductivity. Kids can fill buckets of water from hand pumps and pour water on the displays; and much to the chagrin of parents, encouraged to just get wet!

The MGWA members and corporations donated over $20,000 for drilling and installing a flowing artesian well in the Jordan Sandstone as the first part of constructing the exhibit. After the well was completed, we discovered that a nearby high capacity well stopped the flow when this well was pumped during the summer months. We incorporated the well interference into the design of the surface pumps and one of sand box model displays. Groundwater can be obtained by either turning a handle of a pump and a drinking fountain when the well is flowing; or, by hand pumping a pitcher pump or the hand pump at the fountain when the well is not flowing.

The exhibit has two large sand tank type models. One shows the BBY site conditions by having a flowing well and a second well that can be pumped to demonstrate both how wells work and how pumping of one well can influence the groundwater conditions in a nearby well. Visitor turn a crank that begins to withdraws water from the second well and if they crank enough, they stop the flowing conditions in the other well. The other tank demonstrates water table conditions including a river and a shallow well.

Two large rocks are used to demonstrate primary (Jordan sandstone) and secondary porosity (Prairie du Chien limestone with solution channels). Visitors can fill buckets of water from the hand pumps and pour the water on the rocks to see how the water moves in the rocks. The limestone boulder was selected because water poured on its surface flows out in different spot with no visible connection between these two points. Plexiglas tubes holding different size particles (gravel, sand, silt, and clay) can be filled with water to compare the rate of flow through the tubes. There are educational placards that provide general on the bedrock formations and the flow of ground water.

The SMM BBY is open from Late May thru September. Come visit the display next year and just try not to get wet!

Ground Water Tracing Information Database for Minnesota

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The Legislative-Citizen Commission on Minnesota Resources (LCCMR), other governmental agencies and private entities have supported ground water tracing studies over three decades. Fluorescent dyes have been the most common tracers but a wide variety of tracers have been used. Many of the hundreds of traces conducted to date were conducted to answer site specific questions. Such traces answered questions about the speed and direction of contaminant movement, for example. The LCCMR supported work has focused on mapping the subsurface springsheds of the source water springs for Minnesota state fish hatcheries and designated trout streams. Those waters are important economic resources to the state.

The traces also generate fundamental hydrogeologic information about the speed and direction of Minnesota groundwater flows. That more basic information is critical for the realistic modeling necessary to sustainably manage Minnesota groundwater resources – but has remained largely inaccessible to the modeling and management communities. Only a fraction of these tracer results have been formally published. Too much of the data is essentially lost to most potential users. A centralized repository of the accumulated groundwater tracing results is needed.

In the context of a current LCCMR funded project we are developing a database of all the historical groundwater tracing work that we can access. The goal is to make the database web-accessible to all interested workers. We invite everyone who knows of any groundwater tracing work in the state of Minnesota to share that data with us and it will be added to the database. It is our goal to make the water tracing database as comprehensive as possible, so that it can be used to its fullest potential. This presentation will outline the current status of the database. Suggestions of what features will be important to future users of the database are welcome.

Integration of Water Tracing and Structural Geology for the Delineation of Springsheds

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Fountain, Fillmore County, Minnesota, a small town self-identified as "The Sinkhole Capitol of the U.S.A.," is located on a large sinkhole plain in the Upper Ordovician Galena Group. Recent mapping of the structural setting in the Fountain area provides new constraints for the interpretations of flow paths in springsheds defined by three decades of dye traces (Runkel, 2012, private communication). The strata of the Galena Group are deformed into a low-angle, asymmetric syncline that is plunging northwest. The Fountain East dye traces, initiated in May 2012, were designed to further refine springshed boundaries on the northern edge of the sinkhole plain and to delineate source areas for cold-water springs that feed Minnesota designated trout streams in the area, particularly Rice Creek. Two major springsheds were previously mapped in the Fountain East area: the Fountain Springshed, which drains northwest and forms the headwaters for Rice Creek and the Mahoney Springshed that drains southeast to form the headwaters for Mahoney Creek. The newest tracing efforts begin to document a new springshed to the northeast of Fountain feeding Klomp's Spring and ultimately Rice Creek. The integration of dye trace data, structural contours, and ArcGIS imagery contextualizes the regional subsurface flow and further supports evidence for the delineation of the Fountain, Mahoney and Klomp Springsheds. Knowledge of the structural setting of the Fountain East trace area is a significant step in answering broader questions regarding the hydrogeologic behavior of the Galena Group karst system and its role in the productivity of designated trout streams.