Minnesota Ground Water Association
www.mgwa.org

Newsletter

25th Anniversary Issue
December 2007
Volume 26, Number 4

Featuring Our Past 25 Years:

- A Selection of Articles Appearing in Past Issues
- Companion Articles Enhancing and Projecting Our Understanding of the Issues Facing Minnesota's Ground Waters

Inside:

MGWA Members on 2003 Fall Field Trip

Corporate Contributors

Barr Engineering Company

Matrix Environmental LLC

Geomatrix Consultants Inc

ENSR Corporation

Pace Analytical Services

Liesch Associates

Individual Contributors

Anonymous

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Fletcher Driscoll

Mindy Erickson

Gil Gabanski

Sean Hunt

Jeanette Leete

Dale Setterholm

Harvey Thorleifson

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President's Letter

Shedding Light on the Uncertainties of Ground Water beneath Minnesota

By Jeff Stoner, MGWA President

Welcome to this special 25th anniversary volume of our Newsletter. I'm reminded of what some wise mentors have said throughout my career as a ground-water scientist—"It isn't science until it has been documented." A corollary I might add is "The data and analysis is not information until it is discussed and understood by the user." By this definition, our Association has done well in making a contribution to "information" about Minnesota ground water through 25 years of newsletters, conferences, special meetings, field trips and all of the associated networking.

A major portion of this 25th anniversary volume of MGWA Newsletter contains a sampling of articles from past newsletter authors who were solicited to compose commentaries on the current and projected future value of these topics. A comprehensive approach would have included all articles published in all newsletters to date, but that effort was deemed a little impractical for the volunteers involved. If you want ready recall of technical articles from past newsletters, check out the index in this issue. The selected papers have been organized under the broad themes of (1) Ground Water Conceptual Frameworks, (2) Tools and Data Sets, (3) Natural Contaminants and Monitoring, (4) Policies and Programs, (5) Remediation, and (6) Ground-Water History.

Also sprinkled through this volume are tabulations of charter members, officers, conferences, and field trips. Look for other facts and graphs about the brief history of the Association, views about ground-water consulting (past and future), evolution of the MGWA membership, and interesting stories that developed along the way. Enjoy photos selected from the files and from members. See a view of the "backyard" exhibit about ground water at the Science Museum of Minnesota sponsored by the MGWA Foundation. I hope you enjoy the read and the ensuing discussion about our future. Consider using this volume to educate non-members about our group of fine characters. It's a good time to thank the regular advertisers of the newsletter for their support of this and past volumes. Additionally note the contributors listed on the inside cover, who stepped up to provide additional resources to offset the cost of this thicker and bound volume of the newsletter.

This volume contains a scratching of the future. I believe that this special volume should represent a sampling of what we are as an association—therefore no picture of the president. If there were a mug shot, imagine the headwear as a miner's helmet complete with carbide lantern. This metaphor is to set an exploratory mood in dark places for which to shed light on the uncertainties of ground water. Through commentaries within this volume, several of our members have offered thoughtful insights about the future of ground water in Minnesota. Below I offer my unsolicited visions for Minnesota ground water by the year 2032, the time when my new grandson should be 25 years old. By some definitions, that time would be a generation from now. In geologic time, that's just a blip for natural changes in climate and ground water. In human time, technological changes could be significant over 25 years. In the context of societal change, advances and setbacks may cancel each other out. You will notice that these visions will not be tagged with caveats, assumptions, or uncertainty statistics commonly associated with predictions from a ground-water model. Rather, these are offered optimistically for the intent of inspiring imagination, raising eyebrows, and inducing some scoffing. After all, these ideas are based on one person's experiences and observations of current trends that have not been discussed and likely will be misunderstood—therefore of limited information. So let the discussions continue.

By the year 2032:

- Water-well logs (including some geophysical) will be georeferenced (vertically and horizontally) and available with aquifer attributes and readily available to the public for all wells older than one year.
- Virtual three-dimensional depictions of all major aquifers used in Minnesota will be readily available to ground-water practitioners.
- Simulation models of ground-water flow and some solutes will be readily available to water managers of major aquifers serving communities with populations exceeding 100,000.
- The relations between ground water and biogeochemical cycles will be as well understood as

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MGWA Web Page

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Newsletter Deadlines

Issue	Due to Editor
March '08	02/08/2008
June '08	05/09/2008
September '08	08/08/2008
December '08	11/07/2008

The primary objectives of the MGWA are:

- Promote and encourage scientific and public policy aspects of ground water as an information provider;
- Protect public health and safety through continuing education for ground water professionals;
- Establish a common forum for scientists, engineers, planners, educators, attorneys, and other persons concerned with ground water;
- Educate the general public regarding ground water resources; and
- Disseminate information on ground water.

President's Letter, cont.

today's understanding of relations between surface waters and biogeochemical cycles.
- How and where ground water moves through major secondary permeability regimes of fractures and solution openings, will be less of a predictive mystery in some locations.
- The importance of ground water to society will be taught in all Minnesota secondary schools. Teachers will be able to show maps of Minnesota aquifers, areas ground-water seepage to selected Minnesota streams, and distribution of ground-water age for major Minnesota aquifers.
- Communications between state legislators and practitioners of ground water will be improved by 49 percent.
- A statewide network of monitoring wells will be established to track climate change with summary information viewable from most homes.
- Several planning and engineering measures will be needed to sustain water storage of some aquifers associated with intense population and (or) industrial pressures.
- At least 500 additional chemicals will be quantified in ground water at trace levels. A few of these chemicals will even have MCLs for drinking water or standards for aquatic health.
- Nonpoint chemical loading to many surficial aquifers will be well understood.
- Several instruments, such as the "magneplas," will be available to remotely measure hydraulic properties of aquifers and to track specific contamination plumes.
- Many people will claim that fiscal resources are insufficient to conduct the necessary research to fully understand and manage all ground waters beneath Minnesota at the scale of interest.
- MGWA annual dues will be less than $100 (in today's dollars), a remarkable value for the benefits!
- Most of the MGWA members will be different than the members of 2007, but will continue to have this uncanny sense of enthusiasm for our purpose—ground water in Minnesota.
- The newsletter, conferences, field trips and other outreach events of MGWA will continue to complement peer-reviewed science of ground water as a forum for emerging ideas and information about ground water in Minnesota.

That's enough myopic visioning for one article. If I'm still around in 2032, direct the laughter to me, not to my innocent grandson. What's in your future for Minnesota Ground Water? You'll have your chance if you participate in the MGWA Fall Conference, "Assessing Ground-Water Issues for the Next Generation." If you can't make that, chew on the contents of this volume and keep the discussion and subsequent information flowing.

I use this opportunity to thank the MGWA membership for the privilege to serve you this past year as your facilitator. It was indeed a fast and rewarding year for me. My duties were made easy through association with exceptionally ambitious and enthusiastic people serving as MGWA Board members, newsletter editors, special 25th anniversary volume committee members, MGWA management and publications, advertising manager, numerous volunteers, and the MGWA Foundation. Be sure to personally thank these folks for their extra efforts when you see them.

If you have not gone beyond being a dues-paying member, consider serving the Association in any small or large way during the next generation. If history is any indication, the MGWA will contribute useful information that benefits the future of ground water in Minnesota. You'll want to be a part of that enlightenment.

Prologue

The "Big Backyard" ground water exhibit was sponsored in part by the Minnesota Ground Water Association Foundation.

A Look Back

Editor's Note: Your newsletter team recently asked former MGWA President Ray Wuolo, a consulting Geologist for Barr Engineering Co., to discuss how the business of ground water consulting has changed in the last 15 years or so. Ray took us up on the challenge and here is his response:

Well, it's the Millennium (±1 year, which is only an error of 0.1 %), and everyone is a historian or a futurist. MGWA has availed me of the opportunity to join in by posing me with a question: How has ground water consulting changed in my 15 or so years of practice? The answer, of course, is graph paper – I don't use graph paper anymore. There was a time, not so long ago (really!) when I couldn't get enough of the stuff; semi-log paper, log-log paper, probability paper, ternary diagrams. Now, I use the pre-printed grid on my computation pad to constrain my doodles while I wait for the lawyer on the other end of the phone to get to the point. I wonder, what's changed for that guy?

— Mike Liljegren, MN DNR Waters, demonstrates his water level measuring technique at the 'Outdoor Action Conference', Spring 2000.

The tools I use have certainly changed but the concepts (and the problems) that I work with are about the same. We contour (now we use Surfer), we draw maps (now we use ArcView), we perform pumping tests (now we use pressure transducers and data loggers), we collect ground water samples (now I have someone else do that for me). I'm still trying to answer the same questions that were posed when I first started in this business – where is ground water flowing and what will happen to the contaminants?

But, oh those tools! I occasionally hear one of my colleagues say something to the effect that it's all eye candy and no substance. Sometimes it is only eye candy, but most of the advances of the past two decades have added substantially to our ability to both understand ground water flow/contaminant transport and to convey that information to a broader audience. So, here's my top-ten list (in no particular order) of the most significant changes of the past twenty years.

1. Push-point sampling (e.g., GeoProbe) and mobile labs. What a wonderful luxury to mobilize a drilling crew and obtain ten or twenty samples and water-level measurements in a single day! In many settings, GeoProbe will never substitute for more permanent monitoring wells but they have provided us with the ability to quickly collect a large amount of high-quality data and at substantially lower cost than drilling.

2. Computer contouring and geostatistics. For a long time, computerized contouring was looked down upon because it ignored the interpretations of the geologist. True enough, but sometimes that's not such a bad thing. The widespread use of contouring programs and the knowledgeable application of geostatistical methods, such as kriging, are now common place. For my money, Surfer is one of the best and most versatile programs I've ever used.

3. Desktop GIS. Of course, I'm talking about ArcView. What started out as a cool way to create pretty maps has become a vehicle for understanding the spatial relationships of different types of data and for managing large data sets. Along with 3-D visualization and animation, GIS represents a powerful tool for conveying complex hydrogeologic information to non-scientists (a skill we could all use help with).

4. GUIs (a.k.a Graphical User Interfaces). Excuse me! Human beings are visual creatures – just ask Bill Gates – he made 80 billion dollars because he understood this. Digital ground water flow models have been around for over 30 years but they were inaccessible to anyone without a strong foundation in FORTRAN programming. The advent of the GUI, which allowed model data and model results to be entered and evaluated visually (and quickly) made ground water flow modeling almost commonplace (which it should be). Credit Otto Strack for much of this – SLAEM was about the first model to take this approach and much of its success can be attributed to a GUI that was well ahead of its time.

5. State-wide databases. I have had the fortune to practice hydrogeology in several states. Nowhere is there more high-quality, user-friendly electronic data than in the Land of 10,000 Lakes. It continually amazes me how much GIS-compatible data can be downloaded from the Internet (often for free). Foremost in my mind is the County Well Index database. Michigan is the only other State I can think of that has something comparable.

6. DNAPL. The concept of Dense Non-Aqueous Phase Liquid as a source of ground water contamination is only about 15 years old, yet it completely transformed our understanding of the appropriateness of the most common ground water remedy – pump-and-treat systems. From the concept of DNAPL came a new management strategy for some ground water contamination sites – contain the plume because removing

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A Look Back, cont.

the source was not technically feasible. The first question to ask is: Is it a sinker?

7. Natural attenuation. Natural attenuation (a.k.a. intrinsic bioremediation) used to be called “the no-action alternative.” The widespread recognition that organic contaminants can breakdown naturally in the ground water to less-toxic forms has made the no-action alternative a more palatable option. In a way, it’s nature’s answer to pump-and-treat hydraulic containment – only cheaper. The plume must be allowed to spread out some in order for biodegradation to keep pace with the source. Part and parcel with natural attenuation is the concept of risk-based approaches to remediation, which provides the regulatory framework for the acceptability of intrinsic bioremediation. Unfortunately Minnesota has something called Rule 7060, which seems to prohibit the degradation of Waters of the State and does not allow natural attenuation the space it needs to do its thing.

8. Automated parameter estimation. For my money, this is one of the most important methods to come about in the last 20 years and a tool we are only beginning to scratch the surface with. In a nutshell, automated parameter estimation allows us to calibrate models to an extent unthinkable only five years ago. The method frees the hydrogeologist from the mundane task of trial-and-error testing and lets him/her become the evaluator of concepts and hypotheses.

9. VIC/Brownfields. What a concept! Instead of spending millions of dollars on legal fees, why don’t we use the money to clean up properties and put them back on the tax roll? Voluntary Investigation and Cleanup is helping to make partners of business and government. Now, I know not everybody likes that idea but what is the alternative?

10. Spreadsheets. It never ceases to amaze me what I can do with a spreadsheet program. The macro languages in these programs are extremely powerful (and very foreign to anyone who cut their teeth on FORTRAN). Without a spreadsheet, I would feel like I was armed with stone tools and bear claws.

Of course most of the above changes would not have occurred had it not been for the explosive advance of higher speed, higher memory PCs. The PC and the Internet have changed the hydrogeologist’s world forever and I have no doubt they will continue to be the drivers for the next 20 years. Look for even more complex ground water models (maybe not always a great idea) that coupled stream flow, unsaturated flow, solute transport, GIS, and real-time global positioning. In the next few years, I believe we will see a low-priced *in situ* method for treating BTEX and chlorinated solvents to below detection limits quickly and permanently. And we will see a new dawn, as the world comes to embrace a yet unborn application for my graph paper – perhaps on Antiques Roadshow.

— We almost lost 1993 field trip participant Ruth-Ann Rhoads in the LaBrea Clay Pits (Ochs Morton Clay Pit) - we think Kelton Barr is offering a hand, but the second rescuer will remain anonymous until further notice.

Commentary on "A Look Back (Ground-Water Consulting Over the Past 15 years)"

By Ray Wuolo, Barr Engineering Co.

Well, only 6-1/2 years have past since my millennial look back at what had changed in my professional life as a ground-water scientist. What has changed the most in the interim is that 6-1/2 years goes by a whole lot quicker than it used to. What has not changed much is my list of significant changes. Those ten items, not in any particular order, continue to dominate the lives of hydrogeologists. Newly minted ground-water scientists take them for granted and look upon me with humor and pity when I start talking about how things used to be before GeoProbe, Surfer, ArcView (now ArcMap), and the assumed ability to be able to instantly download anything at anytime from anywhere. I'm sure I must be sounding like the loony great uncle that the family occasionally brings down from the attic for holiday gatherings.

I'm having a bit of trouble adding new tools to the list and that gives me some pause for concern. It occurs to me that in the past 20 years, we have lived through one of those watershed moments in history when everything seemed to changed permanently overnight and what went on before hovers like the shadows of ghosts behind a gauzy set of living room drapes. The PC completely remade our world and it completely changed the field of ground-water hydrology. Hydrogeology has always been about collecting, managing, and manipulating data from diverse sources. Is it any wonder that putting that data in digital form would change everything?

There are, however, a few new trends in "this thing of ours,", as Tony Soprano might say, that I think are worth taking note of. In no particular order they are:

1. A focus on quantifying recharge. Recharge has always been recognized as the primary source for ground water but we have generally been satisfied with bracketing its range at something between 2 and 12 inches per year. We know it can't be less than zero (but it can, when evapotranspiration is factored in) and we know it can't be greater than annual precipitation. As issues of ground-water sustainability become ever more important, the ability to better estimate recharge becomes crucial. Think of it this way: if the annual recharge rate for the Twin Cities area is 4 inches per year instead of 8 inches per year, the amount of available water that can be sustainably withdrawn is halved. Several methods for quantifying recharge in Minnesota are currently being evaluated. Quantifying recharge in terms of soil type, topography, land use, and climate is going to be key to reducing the uncertainty in future predictions. Issues of climate change loom over any discussion of recharge.

2. Biofuels and power. Ethanol production is focused primarily outside of the Twin Cities area and outside the area of productive bedrock aquifers. New coal- and gas-fired power plant siting is also in outstate Minnesota or in neighboring states. The water demands of these energy endeavors are huge – some easily on the

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A Look Back, cont.

scale of a mid-sized Twin Cities suburb. Ground water or ground water-fed rivers are the only available source of water for the majority of these facilities, which many deem to be crucial to the energy future of this country. As hydrogeologists, we are engaged in a delicate act of balancing two precious resources: energy for our homes and water for drinking and natural resources. We need to be clear-eyed in our consulting and regulation.

3. Wrestling with uncertainty. Uncertainty is the 800-pound gorilla that sits next to my desk and drinks coffee all day. I would love to ignore him but he's such a messy office mate. As ground-water professionals, we have always known that our work product is inherently infused with uncertainty. How could it not be? Typically, we are asked to make predictions, design facilities, and render judgments on a resource we can't see and can only measure indirectly. When it comes to ground water, there are no unique solutions – only a continuum of possibilities. New methods in ground-water modeling, such as predictive analysis, help us quantify the uncertainty of our predictions. What we typically find is that the uncertainty is huge and reducing the uncertainty to any degree is not just impractical, it's impossible. Making decisions about ground-water use in the face of this uncertainty is an unenviable position to be in. I sympathize with the spot that our colleagues at the DNR are placed in on a daily basis.

4. Limitations in Twin Cities ground-water supplies. Even six years ago, I had difficulty subscribing to the notion that the aquifer systems in the Twin Cities were not capable of meeting projected growth. Yes, there were areas where contamination or natural resources protection limited a community's well locations but by and large, the overall picture was one of abundant supply. I now think this notion needs re-evaluation. I am concerned that there is a tipping point, beyond which pumping exceeds recharge and water is mined locally from storage. When this tipping point is reached, wells that never had yield problems may suddenly lose specific capacity and the storage in the aquifer system that buffers fluctuating seasonal demand is gone for good. It could happen in one summer – it could happen in a month. It sometimes keeps me up at night.

5. Aquifer storage and recovery. Aquifer storage and recovery (ASR) is an approach to water supply problems that needs to be embraced by all of us in Minnesota because I believe it is an important part of our future. For better or worse, the water supply in the metro area is predominantly ground water from community-based well systems that are poorly interconnected. Some of these systems are doing just fine but some are reaching limitations – particularly during peak summer demand periods. Using aquifer systems as underground storage reservoirs is a practice widely seen in other parts of the country. Elk River is an ASR pioneer in Minnesota, with the primary motivation of conserving capital spent on treatment and storage during peak demand. Some communities, in the future, may need to go further by capturing spring freshet and injecting treated surface water into an aquifer system.

So, that's what I see in my crystal ball. It's really not about contamination anymore – it's about water supply. We can have great debates about the risk of drinking water with low levels of this "ane" or that "ic" but the consequences of not having enough water are indisputable. Maybe it's climate change or maybe it's just "something in the water." As ground-water professionals, we have the crucial role to play in understanding the nature of the problems our communities face, accepting uncertainty and the setbacks that are inevitable with an imperfect knowledge, and helping find solutions that in ten-years time, I can look back again and say, "Wow! What a decade to be a hydrogeologist."

News That's Fit to Print: 25 Years of MGWA Newsletter Milestones

> *"The Minnesota Ground Water Association is unlike any other professional society in the state. The Association focuses not on one profession, but on one basic resource—ground water." Minnesota Ground Water Association Newsletter, top of page 1, Volume 1, Number 1, October 1982.*

And with these words, written by newly minted association president Gil Gabanski, the Minnesota Ground Water Association came to be. It's a mission statement of daunting simplicity: We don't focus on professions, we don't lobby for jobs, and we don't regulate our members. We do one thing, and that is "focus on ground water." We are several hundred of the best hydrogeologic minds in the state, and we share our intense interest and concern for the resource that is ground water. It's a tortuous course that we've sailed from high head to low head for a quarter of a century, and it's a course that has served the association well.

Not everyone witnessed the beginning. Luckily we still have most of the first members around to tell stories of those earliest days, but memories fade or get inadvertently over-written during a defrag maneuver, so it sure is nice that history is preserved in the nearly 100 MGWA newsletter issues published over the past 25 years. The newsletter is a diary of association history, and like the rock record, maybe it needs a little boiling down and interpretation to be fully understood. So let me share some of what I've learned, scrounging around MGWA's attic.

Perusing early newsletter issues, it's clear that the need for this association was palpable, even urgent. I reminded myself that in 1982 there was no Internet, no e-mail, and no World Wide Web. Yes, there was the telephone, but that device was impractical for communicating with groups. It was possible there was someone across town, or even next door, who studied the same problem as you, and you would never know about it. Even those who frequently went to conferences found it difficult to connect with local scientists who shared common interests. Face time was scarce. And in the early 1980s, large numbers of geologists and ground water scientists were bursting out of school, ready to recharge the work force.

For these reasons, a charming aspect of the early newsletters is the set of abstracts members sent in to communicate the work they were doing (Table 1). Many were in graduate school then, and many are still active in ground water today. How young and eager they were!

In those early days, there was a lot of business to tend to. How should the organization be run? A board of directors was se-

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Table 1: "Current Ground Water Research in Minnesota"
(MGWA Newsletter volume 1, number 3, April 1983; and volume 1, number 4, July 1983)

Author	Abstract Title
Paul R. Book	Hydrologic Studies, Winona County, Minnesota
Chuck Clanton	Use of NTRM Model in Land Application of Wastewater
Janet Dalgleish	Dye Tracing at a Proposed Landfill Site, Winona County, Minnesota
Paul R. Goudreault	Computer Model of the Ogallala-Sand Hills Aquifer, South-Central South Dakota
Sheila Grow	Water Quality Variations of a Southeastern Minnesota Karst Basin
Roman Kanivetsky and Marc Hoyer	Determination of Hydraulic Parameters at the Thermal Energy Storage Project
Roman Kanivetsky and Barbara Palen	Ground Water Recharge Rates in Minnesota as Related to Precipitation
Patricia Leonard-Mayer	Development and Use of Azimuthal Resistivity Surveys for Jointed Formations
Amy J. Loiselle	Chemistry of Interstitial Waters in Red Lake Peatland, Minnesota
Eric Mohring	Subsurface Water Flow in a Southeastern Minnesota Karst Drainage Basin
Robert D. Schmidt, Steve Follin, Kent Peterson	Computer and Laboratory Simulation of Insitu Uranium Leaching
John Seaberg	Geohydrologic Interpretation of Glacial Geology Near Williams Lake, Central Minnesota
Donald Slack	Predicting Direct Recharge of Surficial Aquifers
O.D.L. Strack and H.M. Haitjema	The Analytic Element Method
O.D.L. Strack	Groundwater Flow Modeling Near the Divide-Cut Section of the Tennessee Tombigbee Waterway
G. Heitzman	Analytic Modeling of Multi-Layered Aquifer Flow
G.D. Keil	A Dupuit Analysis for Leaky Unconfined Aquifers
H.M Haitjema	An Initial Study of Thermal Energy Storage in Unconfined Aquifers
Jim Almendinger	Paleohydrology of the Holocene in West-Central Minnesota
Patricia Bloomgren	Accelerated Ground Water Management Program

News That's Fit to Print, cont.

lected, helmed by President Gabanski (who declared martial law and served an initial four-year term). Rounding out the first board were Dennis Woodward (vice president), Kelton Barr (secretary), Kent Peterson (treasurer), and Tom Clark (membership chair).

Other urgent business included setting and collecting annual dues ($10 per year, $5 per year for students), organizing the first public education committee (chaired by Pat Leonard- Mayer), and arranging the first of many meetings. The meeting notice included a map showing where the event was to be held (Figure 1). At that first meeting, on November 11, 1983, seventy-two people gathered at William Mitchell College of Law to hear Tom Johnson of the Illinois Geological Survey speak on "Waste Disposal and Ground Water Contamination". His message surely rattled some (remember, this was the early 1980s):

- Long-term waste isolation is not possible; and
- Costs are higher than anyone thought (especially due to litigation).

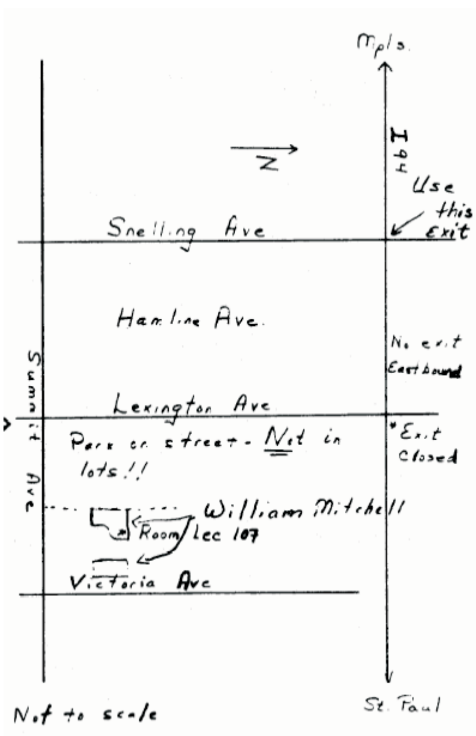

Figure 1. Map showing location of the first MGWA conference

In the first of several MGWA surveys (Figure 2), conducted in summer 1982, most responders claimed to be hydrologists, hydrogeologists, geologists, and engineers, and the survey revealed support for the envisioned newsletter and field trips. One interesting find was that out of nearly 100 responders, just two reported ground water modeling as an area of professional interest. It was a different world back then.

As the hard work of that first organizational year began to pay off, prospective members lined up outside Treasurer Kent Peterson's office to pay their $10 membership fee. Figure 3 shows (heavy blue line) the trend in membership over 25 years. According to Sean Hunt (who provided this chart), data collected after 1992 are probably more reliable than earlier data, but the early

Profession

26 Hydro/Hydrogeologist
23 Engineer
12 Geologist
8 Lawyer
2 Biologist
2 Professor
2 Soil Scientist
3 Geophysicist/Math.
1 Environ. Cont.
1 Water Well Cont.
1 Chemist
1 Geographer
1 Regulatory Spec.

The Assn. should have:

45 Newsletter
37 Annual field trip
35 Legislative monitoring
27 Study groups
20 Student section

What areas would you work in:

31 Program development
17 Field trip
16 Legislative monitoring
10 Newsletter
6 Membership
1 Legal

Areas of Professional Interest

44 Water quality
42 Waste disposal
36 Water supply
35 Geology
34 Monitoring
26 Engineering
22 Water law
16 Geophysics
14 Mining hydrology
2 Ground water modeling
2 Dewatering
1 Law and code enforcement

Figure 2. Excerpt from the initial MGWA survey results (volume 1, number 1, October 1982).

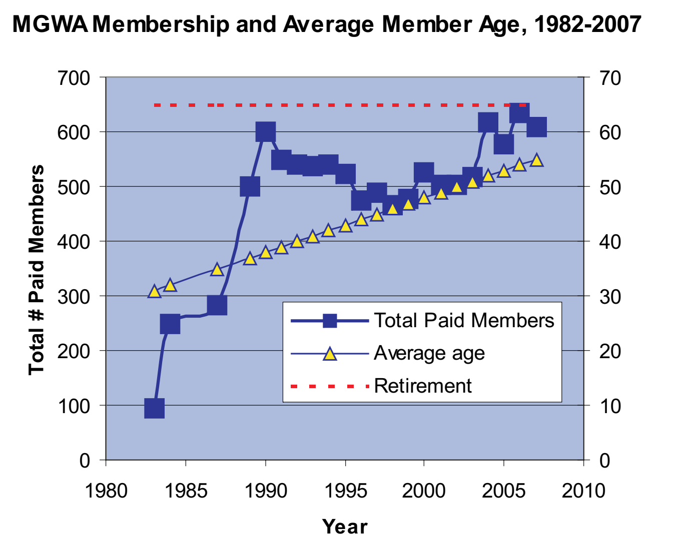

Figure 3. Total number of MGWA members and average age dur-

enthusiasm as reflected in membership totals is clearly evident. I suspect the steep trend of the line through 1990 reflects the passage of the 1989 Ground Water Protection Act (known to some as the "Hydrologist Employment Act of 1989"). Since then, membership has hovered above 450, and a gentle upward trend since 1998 has propelled the 2007 membership total above 600.

Figure 3 also shows the upward trend in average age of MGWA members during the same time period. Note the remarkable linear correlation coefficient of R^2= 1.0. After I made this data up, I realized how well it demonstrates the possibility that we will eventually see membership attrition due to a so far insignificant force: retirement. In fact, extending the trend line, we see that the entire membership is obliterated (statistically speaking) by retirement around 2015. To avoid this fate, MGWA needs to aggressively poach colleges and universities for fresh, unsuspecting new ~~victims~~ members.

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News That's Fit to Print, cont.

Returning to 1983, new members were not the only ones who noticed the shiny newMGWA. Both Governor Al Quie and state Senator Jack Davies sent their best wishes (vol. 1, no.2, February 1983). Governor Quie wrote:

> "… it is my hope that all Minnesotans will benefit from the comprehensive approach to the science of ground water hydrology which is afforded by the variety of professions represented in your membership…"

And Senator Davies:

> "…Congratulations on tackling a difficult but significant public service. It looks to me like your organization is going about its work in a sensible way."

That February 1983 issue (volume 1, number 2) holds other historical gems as well. It contains the first appearance of the now familiar (but uncredited) MGWA "drawdown logo" (Figure 4).

MINNESOTA GROUND WATER ASSOCIATION

NEWSLETTER v. 1, n. 2 February, 1983

Figure 4. The MGWA "chunky drawdown" logo first appears (volume 1, number 2, February 1983).

Also in February 1983, the association issued its first financial report (including a net worth of $527.05). Other newsletter firsts that appeared that month were the first newsletter article about ambient ground water quality (by Tom Clark and Dale Trippler), and the first guide to Minnesota ground water programs (by Linda Bruemmer). Contrast the Clark/Trippler report to the datasets generated only a few years later by the Ground Water Monitoring and Assessment Program (www.pca.state.mn.us/water/groundwater/gwmap/index.html). And contrast the original ground water programs list in 1983 to today's version (www.mgwa.org/gwig/index.html).

- The span of 1985-1987 brought more newsletter firsts: First publication of the membership list (volume 4, number 1, Fall 1985);
- First report of members' median ($32,000), maximum ($48,000) and minimum salary ($16,000) (volume 5, number 1, January 1986);
- First evidence of typesetting software (volume 5, number 1, January 1986);
- First mention of MGWA logo redesign (volume 5, number 4, December 1986). A logo redesign contest was anticipated, but I found no record of a winner. Then, a "slenderized" drawdown logo appeared in 1987 (Figure 5);
- First published photograph (volume 6, number 3, October 1987). The photograph could be celebrating the delayed arrival of split-spoon sampler technology on the prairie, and the nearby text hints at this. However the grainy photo quality obscures the object's true identity, casting doubt (Figure 6). It might be a musical instrument of some kind.And then, right on the President's page (volume 6, number 1, May 1987), Rick Johnston raised for the first time in the newsletter the inevitable question that has taunted MGWA and the entire profession ever since: Is it "groundwater" or is it "ground water"? (A recent attempt by the newsletter editors to re-stir this pot produced what may be the final word on the topic, submitted by Mike Trojan: "yes").

Figure 5. The "slenderized" MGWA logo, as it appeared in October 1987 (volume 6, number 3).

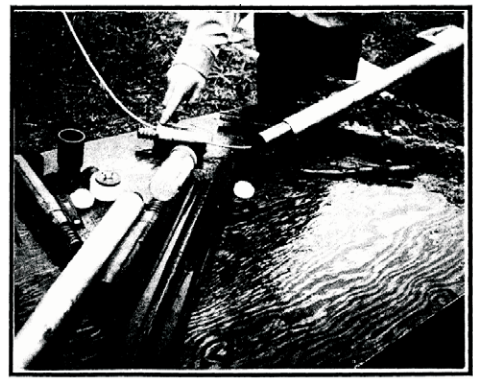

Figure 6. Mystery object, pictured in the first photograph published in the newsletter, October 1987.

As I perused ancient newsletter issues, I tracked the number of pages published each year (Figure 7). The chart shows that the annual total number of pages published has steadily increased along a bumpy curve approximated by a best-fit line with a respectable correlation coefficient of $R^2 = 0.6818$. The marginally

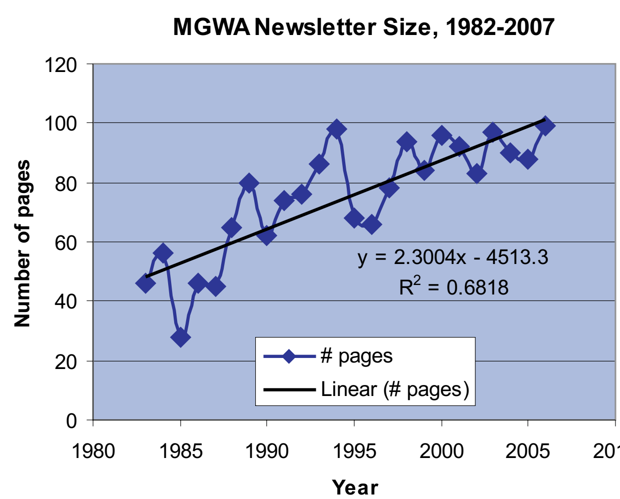

Figure 7. Number of pages published annually by the MGWA newsletter, 1982-2007.

— *continued on page 15*

News That's Fit to Print, cont.

impressive trend loses luster when you realize keeping the word count constant but gradually increasing the font size could have accomplished it. "Senior" members with feeble eyesight would hardly have noticed.

The newsletter also preserves the upward trend of annual membership dues since 1982 (Figure 8). Originally, dues were $10 per year ($5 per year for students), but they have crept steadily to current levels ($30 per year, $15 per year for full-time students). To demonstrate that this is still a really good deal, Figure 8 compares MGWA annual membership dues to the cost for bread and gasoline over the time period of 1982-2007.

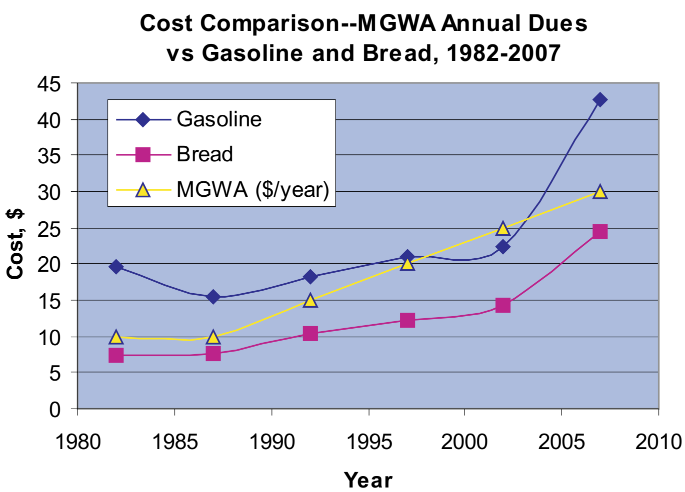

Figure 8. MGWA annual dues keep pace with inflation, as measured against gasoline and bread. The chart shows: 1) gasoline costs in dollars per tank, assuming a 14-gallon tank (blue line); and 2) bread costs in dollars per week, assuming two teenagers living at home and vigorously playing sports (pink line). Note how MGWA costs (yellow) slice right through the gasoline curve, but not the bread curve, adding mileage to the argument the MGWA membership is an incredibly good deal.

Finally, perhaps most importantly, it is worth mentioning the generosity of the MGWA membership. MGWA first sponsored student scholarships in 1992, and these were in the amount of $200 each to support hydrogeological field trips for undergraduates. Over the years since then, the ability of MGWA members to support student activities, and other public educational needs, has grown. The Minnesota Ground Water Foundation (MGWAF) now holds an endowment worth over $60,000, more than two orders of magnitude larger than the net worth reported in the first financial report in 1983 (see above). The 2006 interest from the endowment was approximately $2000, and that amount was donated to support:

- Children's Metro Water Festival ($1000)
- Ground water field projects by the Minnehaha Creek Watershed, Science Museum of Minnesota, and other volunteer events ($800)
- MGWA conference registration for college and university students ($800)

All the accomplishments archived in the newsletter over the past two and a half decades are noteworthy; yet it is all still just a start. As MGWA grows in membership, assets, energy, and vision, we have reason to be confident the next 25 years will continue to bring significant accomplishments—and that these will be archived in our newsletter (in whatever form it eventually takes). The very first page of the very first newsletter contains words that can still guide the MGWA, so let's take a cue from them as we enter a second quarter-century:

> *The Minnesota Ground Water Association invites—and challenges—you to work to solve Minnesota's ground water problems. Bring to the Association your experience and professional pride, but not your prejudices. Be generous enough to teach but willing still to learn and listen. LET'S GET STARTED. Minnesota Ground Water Association Newsletter, bottom of page 1, Volume 1, Number 1, October 1982.*

— Prepared by Jim Lundy, MGWA Newsletter Team

Original Advertisers

Volume 1, Number 1, October 1982

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Geotechnical Engineering Corporation

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Minnesota Ground Water Association—The First 25 Years

1982:

The Minnesota Ground Water Association is incorporated as a public benefit non-profit in September and publishes its first newsletter in October. The first Board of Directors includes Gil Gabanski, Minnesota DNR, President; Dennis Woodward, US Geological Survey, Vice President; Kelton Barr, Barr Engineering Co., Secretary; Kent Peterson, US Bureau of Mines, Treasurer; Tom Clark, Minnesota PCA, Membership Chairman; Pat Leonard-Mayer, US Bureau of Mines, Newsletter Editor. The MGWA Fall Meeting is held at William Mitchell College of Law and features Tom Johnson of the Illinois Geological Survey discussing “Waste Disposal and Ground Water Contamination”.

1983

MGWA’s Winter Meeting expands to a half-day seminar on the “Legal and Regulatory Aspects of Ground Water Contamination in Minnesota” at the Earle Brown Center on the St. Paul campus of the U of M. Dr. Mary Anderson of the University of Wisconsin is the featured speaker of the Spring Meeting. Her talk is: “Ground Water Modeling: Is It True the Emperor Has No Clothes?” A summer meeting is held at Johnson Screens in New Brighton on the topic, “Drilling, Sampling and Monitoring Well Installation” and includes an afternoon of drilling and sampling equipment demonstrations. MGWA's new Public Education Committee is led by Pat Leonard-Mayer and Linda Bruemmer.

1984:

Gretchen Sabel of Minnesota PCA is elected as Treasurer and Tom Clark is re-elected as Membership Chairman. The January newsletter includes a summary of some of the early hydrogeological work of Thomas C. Chamberlin of the US Geological Survey from the mid-1880’s. Association meetings for the year include “The Professional as an Expert Witness”, “Modeling Aquifer Thermal Energy Storage”, and “Use of Microcomputers for Ground Water Modeling”. The April newsletter has a feature on the certification and registration of ground water professionals. The July newsletter solicits nominations for President, Vice President and Secretary of MGWA, as required by the by-laws.

1985:

Gil Gabanski is re-elected MGWA President, joined by Jerry Rick, Soil Exploration Co. as Vice President and Jim Stark, US Geological Survey as Secretary. Kevin Powers of Leggette, Brashears and Graham takes over as Newsletter Editor. The January newsletter has a feature on the emerging issue of LUST—leaking underground storage tanks. The MGWA financial statement shows a cash balance of $993 as of December 31, 1984. Updated by-laws are published in the October newsletter. The MGWA hosts the hospitality suite at the Midwest Ground Water Conference, held in St. Paul in October. Kevin Kessler of Wisconsin Department of Natural Resources is the guest speaker at MGWA’s winter meeting discussing “Implementation of Wisconsin’s Ground Water Law”.

1986:

Gil Gabanski steps down as MGWA President and is thanked by the Board for his vision in being one of the founders of the association and his hard work to make it a success. Jerry Rick takes over as President and the membership is now about 250. Dues are $10 for professionals and $5 for students. The January newsletter has an article about Minnesota DNR’s plans to purchase Mystery Cave. The January association meeting is held at MPCA where about 75 attend to hear presentations on the topic of ground water quality data analysis. The fall meeting, co-sponsored with the University of Minnesota, Duluth is held at the Life Science Building on campus and features Dr. John Cherry, noted Professor at the University of Waterloo, Canada, and co-author of the pre-eminent hydrogeology textbook of the time.

1987:

Rick Johnston, Minnesota PCA is elected President and Pat Bloomgren, Minnesota DNR takes over as Treasurer, which has been combined with the position of Membership Chairman. Lee Trotta, US Geological Survey, takes over as newsletter editor. Senator David Durenberger announces proposal of a Ground Water Protection Act at a public meeting in Southeastern Minnesota. The May newsletter discusses how the ground water field is booming and hydrogeologists are in demand, especially in the cleanup and remediation areas. Ron Nargang is new Director of the Minnesota DNR Division of Waters and Priscilla Grew is named to head the Minnesota Geological Survey. The fall conference is a seminar devoted to nitrate. The October newsletter has a fresh look as the publisher transitions from Microsoft Word to a new VENTURA desktop publishing system.

1988:

Linda Lehman, L. Lehman and Associates, is elected President and Gordy Hess, Sunde Engineering is the new Secretary. The spring meeting, held at Winona State University with the Minnesota Chapter of the American Water Resources Association, is titled, “Radium in Ground Water: Origin, Occurrence, Treatment and Health Effects”. The drought of 1988 is a hot topic among hydrologists. The MPCA’s Ground Water Protection Strategy is featured in the October newsletter. The St. Anthony Falls Hydraulic Lab celebrates its 50th anniversary.

1989:

Bob Karls, Delta Environmental Consultants is the new MGWA President and Don Jakes, Minnesota PCA, the new Treasurer. Passage of the 1989 Ground Water Protection Act is the topic of several newsletter articles and MGWA’s fall conference. The Property Transfer Program is gathering momentum at the Minnesota PCA. The by-laws are revised for the first time since 1985, establishing a three-tier progression of President-Elect, President and Past-President, all of whom serve on the Board. Attorney General Hubert (Skip) Humphrey III is named to a national task force to speed environmental cleanups at federal facilities.

1990:

Gordy Hess, ERM-North Central, is MGWA’s first President-Elect and Bob Beltrame, Donohue and Associates, becomes Secretary. Jan Falteisek, Minnesota DNR becomes newsletter editor when Lee Trotta transfers to Reston for USGS. Cost-share grant programs for well sealing become popular. The spring conference revisits “Field Techniques and Interpretation”, while the fall conference tackles “Risk Assessment” for the first time. A featured panelist is Dr. Jay Lehr of the National Water Well Association. The MGWA publishes its first comprehensive membership directory, which includes listing of members alphabetically and by affiliation, as well as an information

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MGWA History, cont.

referral index to services of government agencies.

1991:

Gordy Hess becomes President, Sheila Grow, Minnesota Department of Agriculture, is the President-Elect, and Susan Price, HDR Engineering is elected Treasurer. Watershed Research, Inc. assumes responsibility for business management and publications for the association. At the beginning of the year, MGWA's total budget is $19,463. The Spring Conference topic is "Remediation Technologies for the Unsaturated Zone". In June, MGWA joins Twin Cities Geologists and the Minnesota Chapter of AIPG for a hog roast at Bruce Bloomgren's Bar-Nothing Ranch. Fall brings the first annual field trip co-sponsored by MGWA and the Minnesota AIPG Chapter to parts of southwest Wisconsin and southeast Minnesota. By year's end, storm clouds gather over the future of the Minnesota Geological Survey as Governor Carlson has vetoed a line-item of the University of Minnesota budget that contains funding for MGS.

1992:

New officers are: Sheila Grow, President; Larry Johnson, Dames and Moore, President-Elect; and Bruce Olsen, Minnesota Department of Health, Secretary. MGWA celebrates its tenth anniversary. The spring meeting features "Innovations and Updates on Drilling and Well Construction". The Minnesota District Office of USGS moves from downtown St. Paul to Mounds View. The fall field trip travels to northeast Minnesota in September and stops at the Highway 61 Silver Cliff Tunnel, under construction.

1993:

Larry Johnson becomes President and Doug Connell, Barr Engineering is President-Elect. Rita O'Connell, MPCA, is Treasurer. The Association provides six scholarships of $300 each to institutes of higher education in Minnesota. The new Director of the State Health Department's Division of Environmental Health is Pat Bloomgren. The spring conference features applications of geographic information systems (GIS) in solving ground water problems. Technical articles in the newsletter address use of chlorofluorocarbons (CFCs) as ground water tracers and discuss the operation and status of MPCA's Voluntary Investigation and Cleanup (VIC) program. The fall field trip features southwest Minnesota, including Redwood Falls and New Ulm.

1994:

Doug Connell assumes the presidency, Cathy O'Dell of Geraghty and Miller is President-Elect and Rich Soule, Minnesota Department of Health, is elected Secretary. Health Risk Limits (HRLs) for 89 ground water contaminants are adopted as rules by MDH. The spring conference looks at the health effects of landfill gases. The annual Treasurer's Report indicates that total income for the association is $23,106.67. Dr. David Southwick becomes the eighth director of the Minnesota Geological Survey. The Ad Hoc Committee on Professional Practice for Geologists is gearing up to reintroduce a licensing bill for the 1995 legislative session.

1995:

Cathy O'Dell is President, Gretchen Sabel of MPCA is President-Elect, and the new Treasurer is Paul Putzier of RETEC. Tom Clark, MPCA, takes over from Jan Falteisek as newsletter editor. The spring conference topic is Technical Communication with the Public—Ground Rules for Scientists. The fall conference is a short course on isotope hydrology, featuring Drs. Carol Kendall of USGS and Calvin Alexander of the U of M's Department of Geology and Geophysics. Field trippers enjoy perfect fall weather in a two-day trip to the Iron Range. Technical articles in the newsletter feature the Twin Cities Area Groundwater Model, the Ground Water Clearinghouse at the Land Management Information Center, and use and application of HRLs.

1996:

Ray Wuolo, Barr Engineering, is President-Elect and Jan Falteisek takes over as Secretary. The unelected position of Advertising Manager is established (formerly part of the newsletter editor's duties) and is filled by Jim Almendinger, St. Croix Watershed Research Station. The spring conference looks at "Applied Ground Water Management: Wellhead Protection and Beyond." There are 791 members in the MGWA database. Technical articles feature DNR's program to locate and seal abandoned wells on state lands and MPCA's ground water monitoring and assessment program. The fall field trip looks at the diverse hydrogeologic issues of the Twin Cities Metro Area.

1997:

Paula Berger, Environmental Strategies Corporation is President-Elect and Paul Bulger, MPCA is Treasurer. Under Gretchen Sabel's leadership, MGWA has its first open house for legislators and their staff to raise awareness of the need for ground water protection in the Land of 10,000 Lakes. Technical articles feature springs of the Twin Cities and Winona County sinkholes. The spring conference is an update on the state licensing program for geoscientists, and the fall field trip fills two buses for a tour through the karst country of southeast Minnesota. A team approach is adopted for production of the quarterly newsletter and Leigh Harrod is the new Advertising Manager.

1998:

Jim Piegat, Hennepin Conservation District is President-Elect and Jan Falteisek is re-elected Secretary. The DNR-MGS County Atlas and Regional Hydrogeologic Assessment Program continues to make steady progress in assessing and mapping the state's hydrogeologic resources, and is featured in several newsletter articles. The spring conference focuses on brownfields redevelopment, the fall conference tackles emerging technologies in ground water remediation, and the fall field trip plays "glacial roulette" in east-central Minnesota and northwest Wisconsin. MGWA is one of 30 co-sponsors of the Children's Water Festival, which has now become an annual event.

1999:

Jim Lundy, MPCA, is the new President-Elect and Lee Trotta, US Filter, is the Treasurer. A possible link between ground water and Minnesota's malformed frogs is a hot research topic as is the link between naturally-occurring arsenic in west-central Minnesota ground water and human health effects. Consumer confidence reports for drinking water supplies become mandatory under amendments to the Safe Drinking Water Act. The fall field trip is popular as it heads to the North Shore and Gunflint Trail. The Midwest Ground Water Conference returns to Minnesota for the first time since 1985 and draws 270 to St. Paul for two days of technical presentations and a half-day field trip along the Mississippi River corridor from St. Paul to Minneapolis.

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MGWA History, cont.

2000:

Keeping in the "Jim" tradition of the previous two years, Jim Stark of the USGS is President-Elect. Jan Falteisek is elected to another term as Secretary. The newsletter features articles as diverse as program evolution at the Minnesota Geological Survey to the emergence of MTBE as a ground water contaminant of concern. Jim Lundy, MGWA President, testifies before the House Subcommittee on Ground Water, which is considering possible amendments to the 1989 Ground Water Protection Act. Several local hydrogeologists receive considerable media coverage as a result of the great MSP airport dewatering controversy. The real story is told in several newsletter articles and a Capillary Fringe column. The fall conference considers fine tuning the Ground Water Protection Act and plays to a full house at Earle Brown Center. The fall field trip returns to the Minnesota River Valley for the first time since 1993. Jim Aiken of North Jackson Company takes over as Advertising Manager.

2001:

Rob Caho of Bergerson-Caswell is President-Elect and Eric Hansen, Pinnacle Engineering becomes Treasurer. Over 200 pack the Earle Brown Center for the spring conference, the largest attendance ever for a MGWA-sponsored event. The MGWA Foundation, Ground Water Education and Membership Committees broaden the scope of Association activities and involve more members. John Pollock, Frontline Environmental joins the newsletter team from the private sector. Plans are under way for the fall field trip to the Brainerd lakes area and Cuyuna Range, co-sponsored with the Minnesota Chapter of AIPG. The trip will be held in conjunction with the national meeting of the American Institute of Hydrology, to be held in Bloomington in October.

2002:

Marty Bonnell of DPRA becomes President-Elect. Under Rob Caho's leadership as President, the Spring Conference is held outdoors at Johnson Screens in New Brighton and includes a full range of drilling and well installation technology. Dr. Matt Walton, Director of the Minnesota Geological Survey from 1973-1986 is presented with the first MGWA Outstanding Service Award. Norm Mofjeld takes over the position of newsletter editor and the first steps are taken to transition the newsletter to electronic format and distribution to minimize costs of postage and paper. The fall conference on ground water supply issues facing small communities is well-attended by ground water professionals and representatives of local units of government.

2003:

Chris Elvrum, a Water Supply Planner for the Metropolitan Council is President-Elect. The March newsletter debuts the new enhanced PDF format and electronic distribution system. The spring conference focuses on ground water-surface water interactions and is dedicated to the memory of Dave Ford, a hydrologist who worked for DNR Waters for 25 years. Harvey Thorliefson is the new director of the MGS. The Baytown Township TCE contamination plume is in the news and the MPCA embarks on a major effort to sample 320 wells in the area. The fall conference addresses topics in water conservation and over 90 attend the fall field trip to learn about the hydrogeology of the St. Croix River Valley, with stops in both Minnesota and Wisconsin.

2004:

Laurel Reeves, DNR hydrogeologist is President-Elect, John Pollock is elected to another two-year term as Secretary, and Kurt Schroeder of MPCA joins the newsletter team. Kathy Villas-Horns, Chris Elvrum and Gil Gabanski spearhead efforts to get a ground water exhibit as a part of the new outdoor Science Park at the Minnesota Science Museum. Technical articles in the newsletter address the oldest measured age of ground water in Minnesota and the distribution of naturally occurring arsenic in ground water in the upper Midwest. MPCA Commissioner Sheryl Corrigan is the keynote speaker at the spring conference which highlights the "State of the State" in Minnesota ground water contamination and cleanup efforts. MGWA membership is approximately 600.

2005:

Dale Setterholm of MGS is President-Elect and Craig Kurtz of SEH, Inc. is the new Treasurer. A new flowing well is installed at the Science Museum as the first step in developing a public ground water display. The spring conference features the topic of ground water sustainability and Dr. Hans-Olaf Pfannkuch of the University of Minnesota Department of Geology and Geophysics is presented with MGWA's Outstanding Service Award. The fall conference details geochemical tools that can be used in ground water investigations. The 50th annual Midwest Ground Water Conference is held in Illinois. As 2005 concludes, the MDH and MDA move to their new building south of the capitol. The facility includes state-of-the-art laboratory services to serve the two departments.

2006:

Jeff Stoner, director of the USGS Minnesota Water Science Center is the President-Elect and Jon Pollock begins his third term as Secretary. Based on reader input, the newsletter debuts a new format with an open, cleaner look and more use of color. The first in a four-part series on use of the Minnesota Ground Water Information Guide is published in the newsletter. The spring conference focuses on better ground water by design and repair of the Dancing Waters Sinkhole in Woodbury is a topic of interest for local hydrogeologists. The fall conference discusses data, tools and techniques for ground water management. The MGWA Foundation raises its profile and now has a page in the newsletter dedicated to its activities. The Foundation endowment fund now exceeds $50,000. MGWA's first president Gil Gabanski heads the Foundation.

2007:

Stu Grubb, hydrogeologist with Emmons and Olivier is the new President-Elect and Craig Kurtz, now a financial risk analyst for 3M is re-elected as Treasurer. Concern over a continuing drought over parts of Minnesota is reflected in several newsletter articles. The spring conference identifies methods for solving complex ground water problems. The new outdoor ground water exhibit opens at the Science Museum of Minnesota. A newsletter article features the seven geologic wonders of Minnesota and Greg Brick's always entertaining Ground Water History column remains a popular feature. MGWA membership prepares for a 25th anniversary retrospective with the fall conference and social event, as well as a special edition of the December newsletter to take a look back at the past 25 years of ground water in Minnesota.

This retrospective was prepared by Tom Clark, MGWA Newsletter Team and Charter Member.

Ground Water Conceptual Frameworks

COMMENTARY

Hydrostratigraphy of Paleozoic Bedrock, Southeastern Minnesota

Commentary by Anthony C. Runkel, Minnesota Geological Survey

As discussed in the conclusions to this 1998 article, its objective was to outline a rigorous approach to characterizing Paleozoic hydrogeologic units in southeastern Minnesota, with the hope that such an approach would advance our understanding of groundwater conditions, and better serve the needs of environmental managers and researchers. The hydrogeologic framework illustrated in the article was referred to as a "cartoon" because at that time it was inadequately supported by hydrostratigraphically-based research. Five years later, the publication of Minnesota Geological Survey Report of Investigations 61 (MGS RI 61)(Runkel and others, 2003) represented the transition from a "cartoon" to what the authors believe is a rigorously supported, comprehensive hydrogeologic framework. MGS RI 61and subsequent publications documented significant progress in a number of topics touched upon in the 1998 MGWA newsletter article, among them characterizing fracture flow in Paleozoic bedrock—not only in carbonate aquifers, where fractures were long regarded as hydraulically important, but also in some of the most widely used sandstone aquifers, and in aquitards as well. Additionally, we have better quantified the hydraulic properties of hydrogeologic units, and demonstrated that fracture networks are commonly stratigraphically controlled and thus predictable enough that they can be mapped. Key to this progress has been the routine use by MGS of downhole geophysical tools that allow us to recognize hydraulically significant fractures, determine their stratigraphic position, and quantify their hydraulic properties.

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Volume 17, Number 2: June, 1998

Hydrostratigraphy of Paleozoic Bedrock, Southeastern Minnesota

By Anthony C. Runkel

Aquifers and confining beds are bodies of rock. Porosity and permeability fundamentally control groundwater flow in rocks. Characterization of aquifers and confining beds, depicted in what is called a hydrogeologic framework, should therefore be based on the porosity and permeability of rock bodies. The commonly accepted hydrogeologic framework for the most widely used aquifers in the state, the sandstone, carbonate and shale of Paleozoic age in southeastern Minnesota, is not based on this fundamental principle. As a result its continued use has seriously hindered groundwater management practices and scientific investigations. It is time to construct a new hydrogeologic framework that is based on the water-bearing characteristics of strata; this approach is called a hydrostratigraphic approach.

Commonly Accepted Framework

<u>Background</u> The commonly accepted, or "classic" hydrogeologic framework for the bedrock of southeastern Minnesota (Fig. 1) is based largely on the first state hydrogeologic map (Kanivetsky and Walton, 1979). Paleozoic lithostratigraphic formations from an earlier bedrock map were grouped by Kanivetsky and Walton (1979) into five aquifers and four confining beds. They conducted their study using the premise that lithostratigraphic units more or less correspond to hydrogeologic units at the regional scale of their map. Characterization of individual hydrogeologic units was based largely on the compilation of previous work, most conducted by the US Geological Survey in the Twin Cities metro area (e.g. Norvitch and others, 1973). The classic hydrogeologic framework, with minor revisions, has been widely used by environmental managers and scientific investigators over the past 19 years to depict groundwater conditions at all scales and depths across southeastern Minnesota.

<u>Limitations</u> How would you classify the following two bedrock layers in a hydrogeologic framework? 1) A fractured, karsted carbonate rock layer that has solution features large enough to walk through, and 2) A 100 ft thick layer of very fine grained sandstone and shale that has a vertical conductivity of 10^{-4} ft/day, and that hydraulically separates more permeable layers above from those below. On nearly all hydrogeologic maps, computer models, and sensitivity to pollution maps published in the past two decades the karsted carbonate rock layer (Platteville Formation) is depicted as a confining bed, and the shaly layer (part of Franconia Formation) is depicted as an aquifer.

These are only two of many examples that demonstrate the failure of the classic hydrogeologic framework to provide an accurate depiction of groundwater conditions in southeastern Minnesota. The classic approach has suffered from three fundamental

—continued on page 2

— George Mickelson's license plate (September 2003)

Commentary, cont.

A measure of the success of any idea is the degree to which it is ultimately accepted and used. By this measure the hydrostratigraphic approach described in the 1998 MGWA newsletter article appears to have been successful. The hydrogeologic framework based on this approach (originally presented in MGS RI 61) is routinely used by a number of Minnesota organizations that deal with environmental management, including the Department of Natural Resources in the production of hydrogeologic plates for the County Geologic Atlas mapping program; the Department of Health in well management functions; the Pollution Control Agency in site investigations; and by consultants for uses that range from optimum construction of high capacity wells to county-scale and larger scope groundwater models. I therefore believe we have made a substantive contribution that has facilitated environmental management and research over the past nine years. That said, my opinion of where we now stand in our understanding of the groundwater system of southeastern Minnesota compared against today's needs of environmental managers leads to a sense of frustration over the many profound gaps in our knowledge that remain. Particularly noteworthy in this regard is our limited understanding of vertical fractures and their function in the hydrologic system, and an overall dearth of quality information on the properties of aquitards. The statement from the 1998 MGWA article that "We are in the early stages of a re-evaluation of the hydrogeologic properties of Paleozoic rocks, and recognize that much more fundamental information is needed" therefore, is apropos today. Ideally, we hope to target and close these significant gaps in our knowledge, at a faster pace than the previous nine years, with the ultimate objective of producing a "Hydrogeology of southeastern Minnesota: second edition" that is vastly improved over the original.

Runkel, A.C., Tipping, R.G., Alexander, E.C., Jr., Green, J.A., Mossler, J.H., and Alexander, S.C., 2003, Hydrogeology of the Paleozoic bedrock in southeastern Minnesota: Minnesota Geological Survey Report of Investigations 61, 105 p., 2 pls.

Paleozoic Hydrostratigraphy, cont.

problems: 1) It is based on the incorrect assumption that lithostratigraphic units are equivalent to hydrogeologic units; 2) It fails to address the important fact that individual lithostratigraphic units that are fractured and karsted in their "near-surface" extent, may have very different hydrogeologic properties in deeper subsurface settings; and 3) Hydraulic conditions within the framework are based chiefly on potentiometric maps that fail to delineate important confining beds.

The purported hydrogeologic units mapped by Kanivetsky and Walton (1979) are not hydrogeologic units at all, they are lithostratigraphic units with terms such as formation simply replaced with the terms aquifer or confining bed. These lithostratigraphic units were developed (e.g. Mossler, 1987) with *no regard* for hydrogeologic properties. The characterization and classification of these ersatz hydrogeologic units as aquifers and confining beds is based on scattered observations of local hydrologic conditions (mostly in the metro area) extrapolated to each individual unit across all of its extent and at all depths in southeastern Minnesota.

Individual hydrogeologic units in the classic framework are commonly depicted as having more or less the same hydrogeologic properties in deep settings as they do in shallower near-surface settings (Kanivetsky and Walton, 1979). We now recognize that bedrock in outcrops and in quarries is ubiquitously fractured, commonly to depths of more than 100 ft below the bedrock surface, and that solution features are common in carbonate rocks (e.g. Alexander and others, 1996). Cores collected from greater depths below the bedrock surface have fewer and generally smaller fractures and solution features. Carbonate rock layers best reflect this relationship: individual units can be karstic and have high conductivity in near-surface settings (e.g. Alexander and others, 1996), but have relatively low conductivity and consequently act as confining beds where they are covered by hundreds of feet of younger bedrock and secondary porosity is not well developed (e.g. Nicholas and others, 1984; Libra and Hallberg, 1985, Visocky and others, 1985).

Large-scale potentiometric maps (1:100,000 and greater) used to depict the hydraulic conditions in the classic hydrogeologic framework (e.g. Delin and Woodward, 1984; Kanivetsky, 1988) have inherent limitations related to scale and methods of study that have obscured recognition of important, regional-scale, confining beds. The scale of these maps relative to the number of data points, the sources of error in determining potentiometric elevations, and the poor internal stratigraphic control preclude the recognition and accurate contouring of small (ft) vertical differences in potentiometric head within individual aquifers. Where such differences *have been* noted across adjacent units within an individual aquifer they are most commonly dismissed as "local" or "small" by investigators operating with the incorrect premise that an apparent similarity in heads across the same units elsewhere is by itself proof of good hydraulic connection. Rigorous, stratigraphically controlled hydrogeologic testing commonly does not support the depiction of internal hydraulic connection within many of the supposed single aquifers of the classic framework. For example, site-specific studies demonstrate that the fine clastics in the lower Franconia Formation hydraulically confine the underlying coarse clastics of the Ironton Sandstone, even in a fractured setting (e.g. Miller and Delin, 1993: Delta Environmental Consultants, Inc., 1992; Wenck and Associates, Inc., 1997). Similarly, the "upper carbonate aquifer" of the classic hydrogeologic framework has been shown to contain at least two internal confining beds in northern Iowa and in southern Minnesota (Libra and others, 1984, Libra and Hallberg 1985: Green and others, 1997; Mossler, in press; Tipping, in prep). Varied hydrologic evidence including potentiometric data (e.g. Donahue and Associates, 1991), pumping tests (e.g. Barr Engineering, 1996), and groundwater chemistry (e.g. Alexander, 1990; Setterholm and others, 1991; Wall and Regan 1994) also indicates that the

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MGWA Newsletter, June 1998

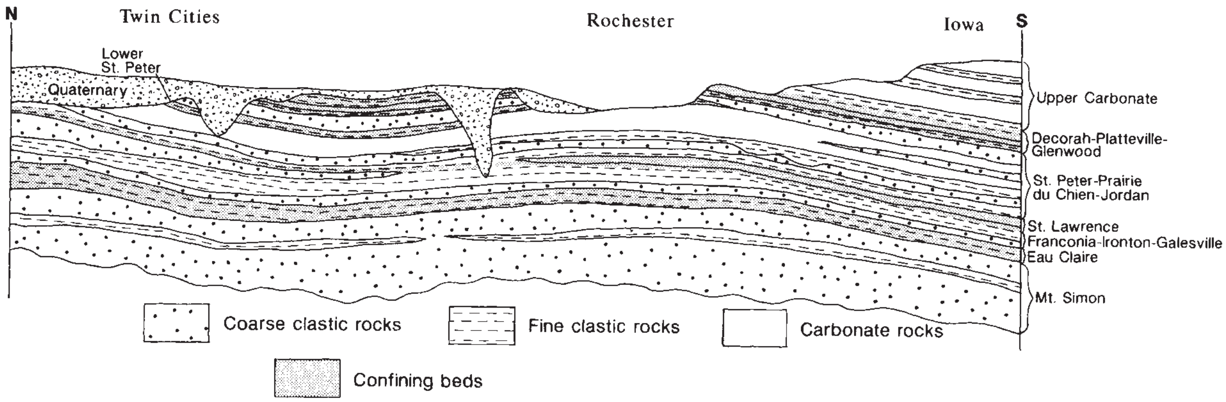

Fig. 1 Highly schematic cross section (not to scale) of Paleozoic strata across southeastern Minnesota showing commonly used hydrogeologic framework superimposed on three principal rock types. Unshaded areas are aquifers

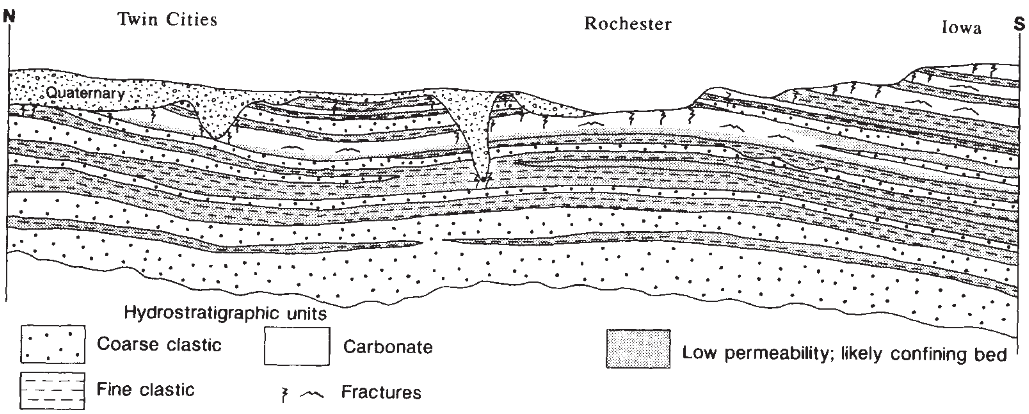

Fig. 2 Highly schematic cross section (not to scale) of Paleozoic strata across southeastern Minnesota showing hydrogeologic framework based on distribution of three principal hydrostratigraphic units. Only regionally extensive, relatively thick aquifers (unshaded) and confining beds (shaded) are shown. On a local scale, individual confining beds can have major groundwater conduits within them, and aquifers will contain internal confining beds.

3

— These photos date from the 1999 Karst Owrkshop in May 1999, held at the Spring Valley Cavern karst preserve. It was not actually an MGWA event, yet many MGWA members were involved. A microgravity survey has already been conducted over a possible buried sinkhole, and the backhow is digging for proof. Not everyone involved in the geophysics knew that a backhow was going to show up, so that explains some of the apprehension in the faces of the crowd. We can identify Calvin Alexander, Ross Dunsmore, and Eric Porcher.

Paleozoic Hydrostratigraphy, cont.

karsted carbonate rock of the Prairie du Chien Group is hydraulically separated from the coarse clastics of the Jordan Sandstone by fine clastic strata and unfractured carbonate rock. Seven of the nine geologic atlases completed for southeastern Minnesota counties note "local" differences in potentiometric head between the Prairie du Chien and Jordan (e.g. Kanivetsky, 1988). The results of these studies raise important questions about the accuracy and usefulness of large-scale potentiometric and transmissivity maps that depict hydraulic characteristics within the classic framework.

Hydrostratigraphic Approach

A hydrogeologic framework should be based on hydrostratigraphic units. Hydrostratigraphic units are defined to distinguish bodies of rock that may be similar in other material categories on the basis of content or physical limits, but differ in the properties of their water bearing interstices (Seaber, 1988). Therefore they are based on features that control groundwater flow. Such units may or may not correspond to lithostratigraphic units.

Hydrostratigraphic components Hydrostratigraphic procedures are flexible and applicable to any scale of investigation. A few hydrostratigraphic components can be defined and mapped for investigations at regional scale, or dozens of individual components can be delineated for site specific studies. On a regional scale the Paleozoic strata in southeastern Minnesota can be divided into three distinct hydrostratigraphic components (Fig. 2, Table 1). The components are: 1) fine clastic rock; 2) coarse clastic rock; and 3) carbonate rock. The fine clastic component consists of moderately to strongly cemented very fine grained sandstone, siltstone and shale that has low to very low relative permeability. The coarse clastic component is a moderately sorted to well-sorted, fine- to coarse-grained sandstone composed of about 98 percent quartz that has a high to very high permeability and porosity. The carbonate rock component consists mostly of limestone or dolostone with negligible matrix porosity and permeability. Values for porosity and permeability within the carbonate rocks vary markedly depending on the degree of development of fractures and solution features, and the scale of the method used to determine them. Permeability varies from extremely high where such features are well developed and interconnected, to very low, even on a large scale, where minimally developed (e.g. Nicholas and others, 1984; Libra and Hallberg, 1985; Visocky and others, 1985).

Lateral and vertical variability in the frequency and interconnectivity of fractures and solution features can markedly affect the hydrogeologic character of the three components described above. Such features are most abundant and best interconnected in the 100 ft below the land or subcrop surface (Fig. 2). In such a setting, the fine clastic component, which has low to very low intergranular permeability, may be orders of magnitude higher in conductivity because there is a substantial component of flow along fractures (Wenck and Associates, Inc., 1997). Conversely, the carbonate units, which are karstic in near-surface settings, may have a relatively low conductivity and act as confining beds where they are covered by younger bedrock because their secondary porosity is not well developed (e.g.Nicholas and others, 1984; Libra and Hallberg, 1985; Visocky and others, 1985). Additionally, fracture flow may be dominant even in the coarse clastic component, which has a high intergranular permeability, where it lies near the surface. Additional work is needed in near surface, fracture-dominated settings (e.g Alexander and others, 1996; Gianniny and others, 1996) to define and characterize hydrostratigraphic units.

Revised Classification of Aquifers and Confining Beds The revised classification of Paleozoic aquifers and confining beds shown in Figure 2 is based on standard hydrologic data such as potentiometric levels, distribution of springs, pump tests, and water chemistry that can be confidently constrained within the context of the hydrostratigraphic framework. The carbonate rock (where dissolved/fractured) and coarse clastic components are aquifers that contribute most of the yield to water wells developed in Paleozoic strata. The fine clastic component can potentially yield moderate quantities of water, in particular where it is highly fractured, but more

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Table 1. Characteristics of three principal hydrostratigraphic components that compose the Paleozoic rocks of southeastern Minnesota. Data from Norvitch and others (1973), Libra and others (1984), Setterholm and others (1991), Miller and Delin (1993), and unpublished data from Minneapolis Gas Co. records stored at the Minnesota Geological Survey. *1-centimeter-scale permeability.

Hydrostrat component	Character of porosity and permeability	Plug sample permeability (md)*1	Pump test hydraulic conduct.
Coarse clastic	Intergranular	>3000 (HIGH)	Kh= 2-20 ft/day (MOD to HIGH)
Fine clastic	Intergranular	10^{-5} to 100 (vertical) (horizontal) (V.LOW-LOW)	Kh= 10^{-2} ft/day Kv= 10^{-4} ft/day (LOW)
Carbonate	Fractures/ sol'n features	10^{-2} to10^{-5} (V. LOW)	Kh= 1-40 ft day (MOD. to HIGH)

importantly it serves as confining units that separate coarse clastic and carbonate aquifers (e.g. Wenck and Associates, Inc., 1997). Carbonate rock can also serve as confining beds where it is unfractured (e.g. Nicholas and others, 1984; Visocky and others, 1985).

The revised hydrogeologic framework (Fig. 2) includes changes to the boundaries and internal attributes of nearly every hydrogeologic unit of the classic framework (Fig. 1). A notable example is that the Franconia-Ironton-Galesville aquifer of the classic framework is not a single, hydraulically connected aquifer as commonly supposed (e.g. Kanivetsky and Walton 1979). Pumping tests (e.g. Miller and Delin, 1993) and stratigraphically well-constrained local static water level measurements (Delta Environmental Consultants, Inc., 1992; Wenck and Associates, Inc., 1997) clearly demonstrate that the fine clastic component of the lower Franconia hydraulically separates groundwater in more permeable strata above and below. This lower Franconia aquitard is as thick and laterally extensive as any confining bed in the Paleozoic section of southeastern Minnesota, and has hydrogeologic properties nearly identical to those in the well-known Eau Claire confining unit (Miller and Delin, 1993); recognition of these features has been obscured by the long-standing adherence to the classic framework.

Recognition of the lower Franconia confining bed is one of many examples of the advantages of the hydrostratigraphic approach in constructing a hydrogeologic framework. Another is that the approach makes a distinction, albeit highly generalized at this time, between near-surface fractured conditions versus deeper confined conditions; it shows for example that the "Platteville confining bed" of the classic framework is more accurately depicted as a karstic aquifer in subcrop and outcrop (e.g. Spong, 1980; Lindgren, 1994; Hoffman and Alexander, 1998). Another major advantage is that a hydrostratigraphically based framework better depicts the fundamental lithologic controls on groundwater movement. For example, the lithologic controls on transmissivity and the distribution of nitrates in the widely used "Jordan Aquifer" were elucidated through a hydrostratigraphic approach whereas the classic framework simply did not provide the information necessary to make such determinations (Setterholm and others, 1991; Runkel, 1996). Perhaps more importantly, the hydrostratigraphic framework provides a high degree of predictability of hydrogeologic conditions because individual hydrostratigraphic units by definition have the same water-bearing characteristics wherever they occur. In contrast, lithostratigraphic units vary markedly from place to place in their water-bearing properties.

A much better understanding of groundwater conditions is gained when it is not assumed that the classic, lithostratigraphically based hydrogeologic framework is applicable to a given area of study. Some examples include the Aquifer Thermal Energy Storage (ATES) project (e.g. Miller and Delin, 1993), which remains the best hydrogeologic study of confined siliciclastic bedrock in Minnesota; the Oronoco Landfill study of the groundwater movement in the Prairie du Chien Group and Jordan Sandstone (Donahue and Associates, 1991); and investigations of carbonate-dominated, karsted strata south of Rochester (Libra and others, 1984; Alexander and others, 1996; Green and others, 1997) and in Wisconsin (e.g. Gianniny and others, 1996). Even though these studies do not strictly follow hydrostratigraphic procedures, they contain the data necessary to construct such a framework and therefore the results can be confidently extrapolated elsewhere. Much of Figure 2 is based on the results of these studies.

The hydrogeologic framework shown in Figure 2 is a schematic, highly generalized depiction of regional groundwater conditions, not a citable model. We are in the early stages of a reevaluation of the hydrogeologic properties of Paleozoic rocks, and recognize that much more fundamental information is needed. For example, we know little about the position of confined conduits in deeply buried carbonate units, and about the interplay between intergranular and fracture flow in siliciclastic units that are near the land surface. Variability in cementation of the siliciclastic units also is poorly understood. The construction of a new hydrogeologic framework is essentially a mapping exercise and as such we must first define map units and test their usefulness. Some will fail to be useful and be abandoned, others will be added. Eventually, well constrained local studies can be compiled into a regional scale framework, and the hydrogeologic units can be formally named.

Conclusion

The primary objective of this article is not to gain acceptance of the cartoon framework shown in Fig. 2. Rather, the objective is to spur a reevaluation of the manner whereby we classify and characterize hydrogeologic units in southeastern Minnesota. Critical evaluation of the fundamental scientific data, methods and principles that support the commonly accepted hydrogeologic framework shows that it is substantially inaccurate and inconsistent at all scales. It is time to adopt a more rigorous approach to hydrogeologic characterization in southeastern Minnesota. Hydrologic data should be collected and interpreted within the context of hydrostratigraphic components, rather than lithostratigraphic units. Until we do so we will continue to hinder advancement in understanding groundwater conditions.

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Shallow Buried Aquifers of Murray County, Minnesota

James A. Berg, Minnesota DNR Waters

Introduction and Purpose

Southwestern Minnesota is a region of limited ground-water resources. A consortium of ground-water appropriators, with assistance from a geological consulting company, is exploring for buried aquifers in Murray County to establish a new well field for regional water distribution. This group consists of Lincoln-Pipestone Rural Water (LPRW), Red Rock Rural Water, and the City of Worthington. The Minnesota Department of Natural Resources, Division of Waters (DNR Waters), has provided technical advice to this group since the beginning of this project in the summer of 2000. DNR Waters believes that a better understanding of aquifer distribution will help appropriators achieve their resource needs and help avoid future resource conflicts. The purpose of the project was to better define some of the limited extent glacial drift sand aquifers in the area. Murray County is underlain by clayey drift overlying Cretaceous and Precambrian bedrock. The glacial drift and Cretaceous bedrock contain limited extent sand and sandstone aquifers, respectively. This mapping project has shown that Murray County, centrally located within the region, may have better buried glacial ground-water supplies than some other counties in the region

Methods

The basic data used in this study consist of a surface geology map, a regional Quaternary stratigraphy framework, and a database of accurately located and interpreted water-well construction logs (drillers' well logs) in the County Well Index (CWI). All of these elements were compiled for the Southwestern Minnesota Regional Hydrogeologic Assessment (Setterholm, 1995). This information represents the minimum data required for a first approximation of buried aquifer boundaries within the study area. These data were used to produce an extensive network of correlated geologic cross sections that is an essential part of this study. Two cross sections from this cross-section network were selected for presentation in this article (Figure 1).

The main purpose of establishing the cross-section network was to identify glacial till units and sand and gravel outwash units with a common geologic history that could be mapped across most of the area. Three key assumptions were used to define the geologic boundaries shown on the cross sections. First, buried oxidized till (yellow to brownish color) indicates ancient land surfaces. This till existed at or near the surface long enough for oxygen-rich water to chemically change the minor amounts of iron-containing minerals to an oxidized state. These horizons are minor unconformities and can be used to define till units deposited by a single glacial ice advance. Second, sand and gravel layers mostly occur on the top of geologically related till units and were deposited as outwash by the receding glacier that had deposited the underlying till unit. Third, glacial sand and till units can be defined within similar elevation ranges or regionally sloping elevation ranges.

After the cross sections were produced and correlated, well logs from the study area CWI database were examined within ArcView for the presence of sand and gravel. These sand and gravel records were given unit designations based on the unit boundaries from the nearest cross-section segment. The sand and gravel thickness and elevation per well, for each mapped unit, were then plotted by ArcView and contoured by hand. The result was a draft paper map of sand and gravel distribution in the study area. Finally, the paper map boundaries were digitized with ArcView to create a shapefile.

Maps of sand and gravel distribution were produced with an outwash channel depositional model in mind. The main channel orientations were probably parallel or subparallel to the ice margins, and outwash sediment was contained within linear depressions between higher land to the southwest and the ice to the northeast (Southwick and others, 1993). Only the Unit 1 sand and gravel distribution map is shown in this article. A map of the Verdi Unit sand and gravel distribution is included in the full report. The Unit 1 map has only one contour indicating sand thickness greater than 20 feet. This simple representation is mostly due to the limits of the CWI data. The data density was usually not sufficient to predict sand thickness with any greater detail. Also, most of the well logs end within a sand layer rather than at the bottom of the layer in a clay or bedrock layer. Presumably this method of well development was a cost-saving measure by the drillers whose goal was to find a minimum sand thickness for a well screen. Unfortunately, this method results in an incomplete picture of true aquifer thickness in many areas.

Area Stratigraphy and Bedrock Structure

Six glacial till units were identified within the study area. This finding is similar to interpretations in this same area by Carrie Patterson, a co-author of the Southwestern Minnesota Regional Hydrogeologic Assessment (Setterholm, 1995). Five of the six glacial till units are shown on cross-section S-S'. The study area is generally underlain by two Late Wisconsin till units associated with ice advances that created the Bemis and Verdi moraines. In many locations, the boundary between these two till units is indistinct due to a lack of oxidized till surfaces. However, enough oxidized till layers and other unit boundaries were identified to allow mapping of sand and gravel associated with the recession of the Verdi ice (map not shown).

The first till and outwash unit beneath the Late Wisconsin glacial sediment is named Unit 1. The relative abundance of oxidized till and sand at this interface makes it a very distinctive marker bed and key datum. Cross-section S-S' illustrates how widespread and useful this layer is in determining the area stratigraphy. Possibly the thickest and most laterally extensive aquifers in the area are associated with this layer. Some of the thickest sand and gravel

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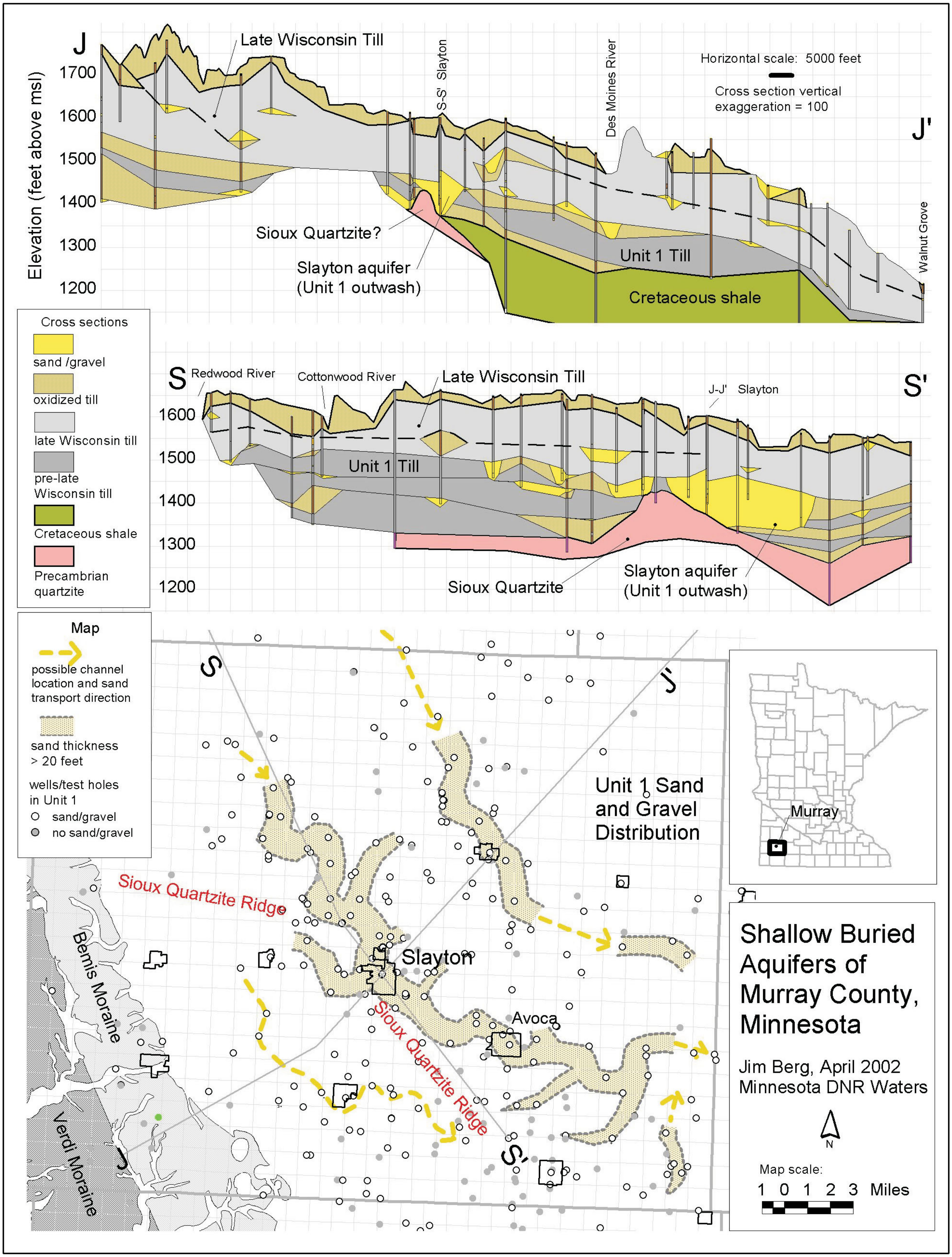
J
J'
Late Wisconsin Till
S-S' Slayton
Des Moines River
Horizontal scale: 5000 feet
Cross section vertical exaggeration = 100
Elevation (feet above msl)
1700
1600
1500
1400
1300
1200
Sioux Quartzite?
Slayton aquifer (Unit 1 outwash)
Unit 1 Till
Cretaceous shale
Walnut Grove
Cross sections
sand /gravel
oxidized till
late Wisconsin till
pre-late Wisconsin till
Cretaceous shale
Precambrian quartzite
S
S'
Redwood River
Cottonwood River
Late Wisconsin Till
J-J' Slayton
Unit 1 Till
Sioux Quartzite
Slayton aquifer (Unit 1 outwash)
Map
possible channel location and sand transport direction
sand thickness > 20 feet
wells/test holes in Unit 1
sand/gravel
no sand/gravel
Unit 1 Sand and Gravel Distribution
Sioux Quartzite Ridge
Bemis Moraine
Verdi Moraine
Slayton
Avoca
Sioux Quartzite Ridge
Murray
Shallow Buried Aquifers of Murray County, Minnesota
Jim Berg, April 2002
Minnesota DNR Waters
N
Map scale:
1 0 1 2 3 Miles

Murray County, cont.

occurrences associated with this layer are shown on cross-section S-S' in the Slayton area.

The deposition of the Unit 1 sand appears to have been controlled by the structure of the underlying Sioux Quartzite. Two major buried bedrock ridges run northwest to southeast in southern Murray County. The crests of the ridges are labeled on the Unit 1 sand distribution map. The cross sections show that this ridge was exposed or possibly influenced the area topography during the deposition of the Unit 1 sand. The Unit 1 sand was commonly found from 150 to 200 feet below land surface in the area. The elevations of the sand channels ranged from 1300 to 1550 feet above sea level. Some of the other underlying units are also associated with thick sand layers, but sand distribution maps for these deeper units have not been created because of inadequate density of well data.

Conclusions and Future Work

Some unique geological circumstances may have created the opportunity for ground-water resources in Murray County that are not generally available in other parts of the region. For instance, the Sioux Quartzite ridge appears to have been an important depositional control for the Unit 1 sand; however, similar bedrock control structures do not appear to have influenced sand deposition in Rock, Pipestone, or Nobles counties (Berg, 1997).

This project represents a first effort to define, in detail, some significant ground-water resource potential in the area. Due to the incomplete nature of the lithology log data, a great deal of uncertainty still exists regarding the locations of the very thickest portions of these aquifers. The reliability of channel boundaries is especially poor southeast of Avoca since many of the wells were too shallow to penetrate the entire thickness of the Unit 1 sand. We are planning to drill 2 test holes in this area this year to help define the southeastern extent of this Slayton aquifer.

We have also submitted a proposal to the Legislative Commission on Minnesota Resources (LCMR) to complete a more intensive exploration project in the county. Other research in the future should include aquifer tests and some kind of recharge analysis since little is known about the capacity of area aquifers to sustain large-capacity pumping. . With increasing interest in biodiesel, ethanol, and other uses of agricultural products, all of which require water to process, new and better information about possible water sources in the region is especially important now.

The report titled Shallow Buried Aquifers of Murray County, Minnesota, Technical Paper 12, became available this spring. The paper is available at http://www.dnr.state.mn.us/publications/waters/index.html

A limited number of paper copies are available from the author: James A. Berg, DNR Waters, Ground Water Unit, 500 Lafayette Road, St. Paul MN 55155-4032.

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COMMENTARY

Thoughts about "Shallow Buried Aquifers of Murray County, Minnesota"

By Jim Berg, DNR Waters

Sometimes it seems the essence of geological investigation is the ability to make highly qualified conclusions based on limited and incomplete evidence followed by the inevitable plea for more data. Trying to unravel the leftovers, and eroded remnants of leftovers, from the glaciers that kept coming and going, can seem like an almost foolish thing to attempt. But the dots can be connected once the data are organized in cross section and map layouts with the help of a computer, some creative use of GIS software, and our geological brains.

We never did get any funding for follow-up work for this county or anywhere else in the region despite three proposal attempts (as I write this we are in the middle of preparing a fourth proposal) and stable funding for these types of investigations continues to decline even though the challenges presented by biofuels industrial development and the need for regional water supply thinking have grown dramatically since this article was published. However, we are still at it and our methods continue to improve. Since this article was published, we (DNR Waters), have added buried and gravel maps to the geologic picture in an Otter Tail Regional Assessment (2002) and in southern Pine County (2004) using the same Murray County approach. In the past two years (2005 and 2006) other maps, using a newer closely spaced cross section method, have been completed in the Fargo-Moorhead region (DNR Waters and Minnesota Geological Survey – MGS), and Pope County (DNR Waters). By the end of this year (2007) there will have been a relative "big bang" of atlases or atlas supplements with buried sand/gravel aquifer maps including Stearns and Crow Wing Counties from DNR Waters; and Todd and Scott counties from the MGS.

The future will include learning more about ground water recharge in the places where these buried sand layers are connected to other sand layers and the surface. We should also be able to connect maps of sand bodies across county boundaries and begin to create a regional understanding of these systems. Finally, of course, we will need more data.

Ground Water/Surface Water Interaction - A Graphic Display

Pomme de Terre River, Swift County

By Eric Mohring, Senior Hydrogeologist with the ground water unit of the DNR, Waters Division.

It is convenient to treat ground water and surface water as separate entities, and to overlook their interaction. However if we look closely, mother nature is continually reminding us that ground water and surface water are part of one interrelated system.

We all have heard that lakes and wetlands can be thought of as outcrops of ground water , or places where the water table is above the land surface. Long-term fluctuations in the levels of lakes and wetlands are usually tied to ground water level fluctuations.

Ground water also plays an important role in the flow of rivers and streams. Baseflow - the portion of the flow which is not directly attributable to overland runoff - comes from the input of ground water. Baseflow is of course the reason rivers and streams can continue to flow for weeks or months after the last rainfall. Long-term average river discharges will correspond to long-term ground water level fluctuations, especially in baseflow-dominated rivers.

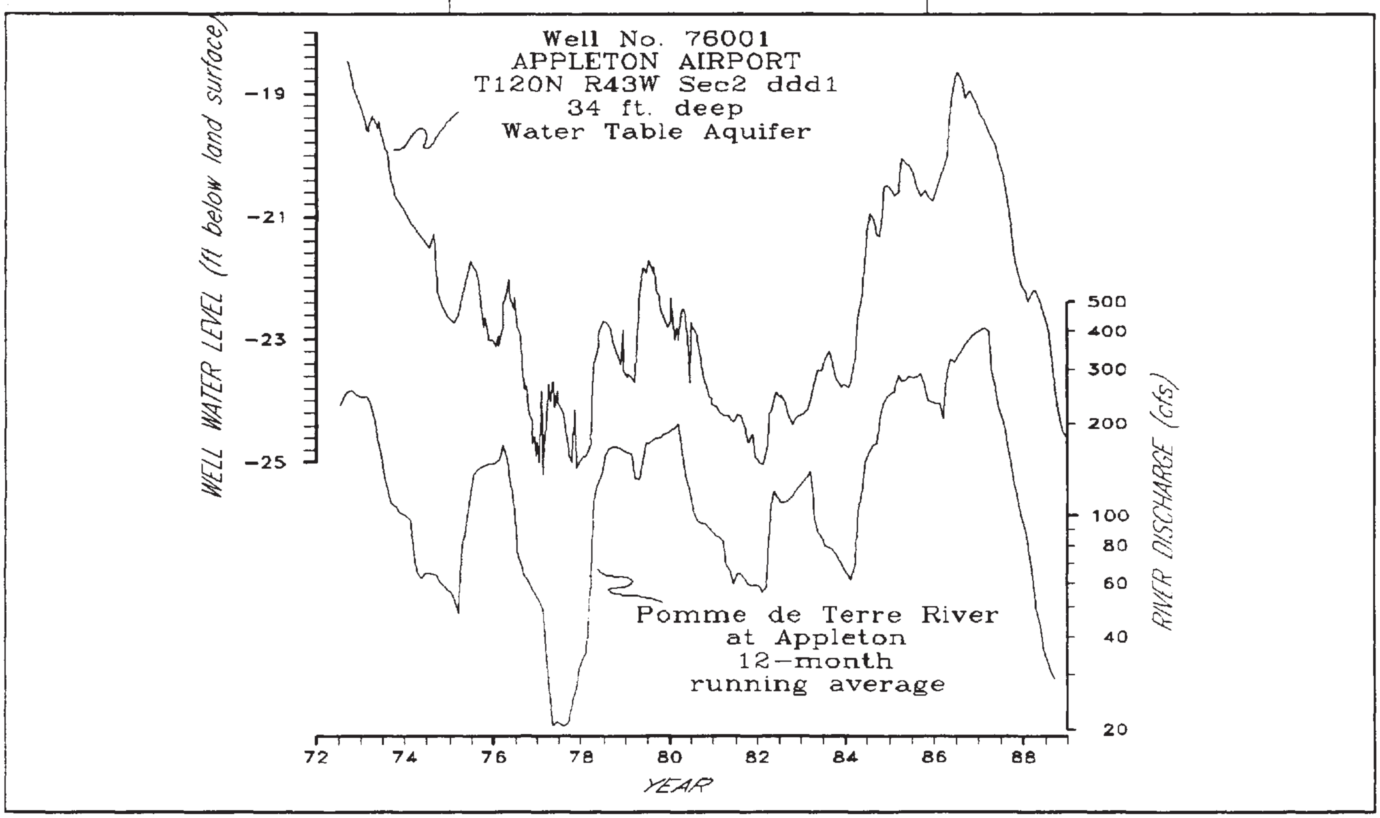
This correspondence is convincingly demonstrated by data from the Pomme de Terre River Valley near Appleton, in west-central Minnesota. Sand and gravel deposits in the valley comprise a major surficial aquifer system. The baseflow of the river is sustained by discharge from the aquifer.

The accompanying graph shows river discharge data from the Pomme de Terre River plotted on the same time scale as water level data from a nearby observation well in the surficial aquifer. The discharge data are plotted as a 12-month running average - each data point is the average of the preceding 12 months' mean monthly discharge values. This tends to smooth out short-term fluctuations, making the long-term trends more evident. The data are plotted on a logarithmic scale to accentuate the correspondence with the ground water level data. Notice the remarkable match!

The aquifer is pumped extensively by high capacity wells for agricultural irrigation and by smaller wells for domestic water supplies. There is concern that pumping from the high capacity wells has the potential for causing significant reductions in streamflow. A modeling study conducted by the U.S. Geological Survey (Soukup et al., 1984)[1] suggested that pumping during a drought year from wells along the Pomme de Terre River could reduce streamflow to near zero when only baseflow is present. During the summer of 1988, the river was reduced to zero flow on several occasions, and ground water pumping was felt to be partially responsible.

These data provide an interesting picture of the close relationship between surface and ground water. Clearly it is important to understand this relationship for better management of our water resources.

[1]W.G. Soukup, D.C. Gilles, and C.F. Myette, 1984. Appraisal of the Surficial Aquifers in the Pomme de Terre and Chippewa River Valleys, Western Minnesota. U.S. Geological Survey Water-Resources Investigations Report 84-4086.



Ground Water/Surface Water Interaction

Review by Eric Mohring, BWSR with input from Jim Stark, USGS

My initial impression on re-reading the article is that the author had a firm grasp of the obvious, and convincingly overstated it. It shouldn't have been surprising to readers of the MGWA newsletter that water levels in a water-table aquifer would track climatic fluctuations. On the other hand, sometimes the obvious can do with a little overstating. I recall having this graphic posted on the outside of my cubicle at the Minnesota Department of Natural Resources (DNR) Waters Division. It generated a steady stream of passersby who would pause, study the graphs, nod, and perhaps stop to discuss some aspect of ground water-surface water interaction. It was a conversation piece - simple, graphic presentation of an obvious, important link in the hydrologic cycle.

There was a research focus on ground water-surface water interaction during the 1970s and 1980s – locally, nationally, and internationally – for example the work of Tom Winter and colleagues on ground water-lake interaction and Dick Novitzki's work on wetland-ground water interaction.

On the Minnesota front, the DNR and the U.S. Geological Survey were conducting a study of ground-water and surface-water interactions in the Straight River watershed in Becker and Hubbard Counties, with funding through Legislative Commission on Minnesota Resources*. This cooperative effort was to assess potential effects of ground-water withdrawals for irrigation on streamflow and stream temperature in the river, a designated trout steam. The late 1980s was a time of drought. During the summer of 1988 the water table and the potentiometric surface of the uppermost confined-drift aquifer approached record low levels. Stream discharge indicated that the river was affected by irrigation pumping. Ground-water model simulations were evaluated by matching model-calculated streamflow and simulated ground-water levels with measured data from 1988. Simulations indicated that continuous irrigation, at rates comparable to 1988, could result in ground-water level declines ranging from 0 to 10 feet in the surficial aquifer and from 0 to 15 feet in the uppermost confined-drift aquifer. The lowering of the water table and the potentiometric surface was simulated to reduce the base flow of the river by 34 percent compared to conditions where there was no ground-water withdrawal for irrigation. Results from an associated stream-temperature model indicated that daily changes in stream temperature were influenced by solar radiation, wind speed, stream depth and ground-water inflow. Further results from simulations, iterating between the ground-water flow and stream-temperature models, indicated that reductions in stream discharge from irrigation withdrawals could result in increased stream temperature from 0.5 to 1.5 degrees Celsius and that this increase could be a significant factor in the viability of trout in the river. Ground-water use and level data and streamflow information collected since the time of the study, recent advances in our understanding of ground-water recharge, and advances in models that couple ground-water and river models, both hydraulically and thermally, would now allow for a more detailed analysis the effect of drought on the Straight River.

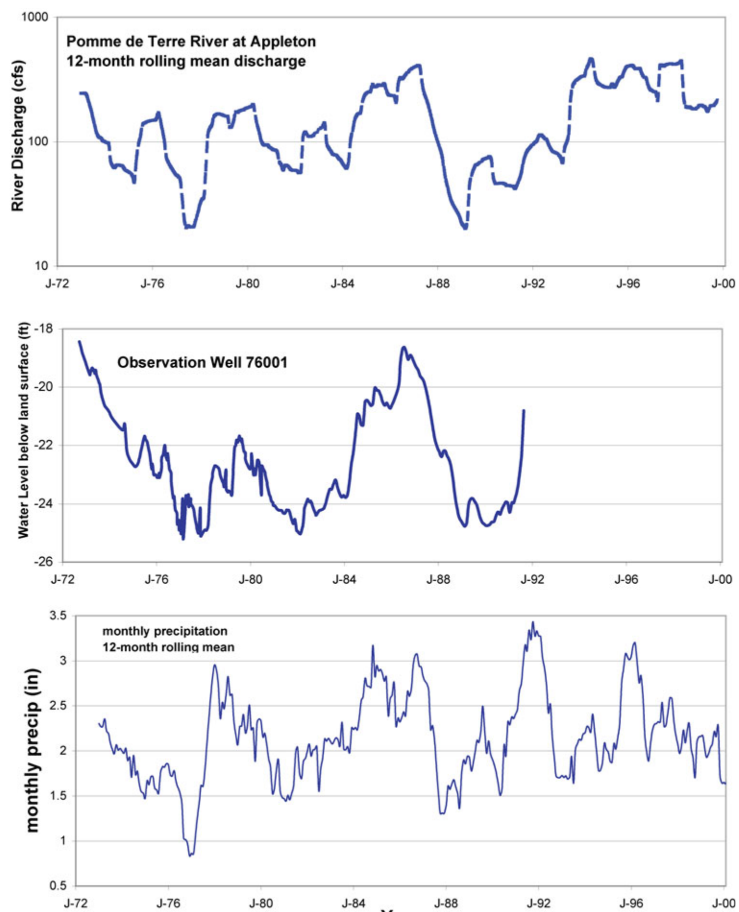
In the regulatory and policy arenas ground water – surface water interaction was also often the "topic-du-jour." The 1970s and 80s saw hydrologic extremes: a major drought in 1976, undesirably high lake levels in the mid 80s, another major drought in 1988. The interplay of ground water and surface water resources played a major role in the human response to these challenges. The talk was all about water allocation, safe yield, well interference, in-stream flow needs, competing uses, as well as recharge areas and ground water sensitivity. Concern for ground water contributions to wetlands increased as protection efforts escalated. So though the little MGWA newsletter article overstated the obvious, it was at least timely.

The type of simple analysis used is still a bread-and-butter item in the toolbox. Hydrologists, especially those involved in wetland hydrology, need to be able to put observations and data obtained during a given (usually too short) time period into climatic context. We often find ourselves in the business of assessing "antecedent conditions." Water level data from observation wells are a key tool - ground water levels are a good integrator of shorter-term hydrologic fluctuations. Precipitation and river discharge data are also essential tools, and "rolling-mean" analyses of these data greatly help in their interpretation.

The moral of the story: sometimes the simplest tools in the toolbox are the most useful.

Out of curiosity I put together a somewhat updated version of the graphic, adding a rolling-mean graph of precipitation.

*Stark, J. R., Armstrong, D. A., and Zwilling D. R., 1994, Stream-aquifer interactions in the Straight River Area, Becker and Hubbard Counties, Minnesota, U. S. Geological Survey Water-Resources Investigations Report 94-4009



Innovative Approach to Fen Protection - Irrigate!

By Jeanette Leete and Tom Gullett, DNR-Waters

An interagency team of DNR-Waters and Minnesota Pollution Control Agency (PCA) staff is working together with the Metropolitan Waste Control Commission (MWCC) to prevent damage to a rare Minnesota habitat: the Nicols Meadow calcareous fen. The Seneca Wastewater Treatment Plant expansion and upgrade poses a potential threat to the nearby fen (see Site Map) if the flow of ground water to the fen is disrupted. Flow disruption is likely because construction plans include excavation and dewatering of a large area to facilitate construction of the expansion.

Calcareous fens are rare peatlands. Nicols Meadow fen is an example of the Minnesota River Valley fen type; only 4 areas of this type of wetland complex have survived. The three other fens in the river valley are Black Dog Fen, Savage Fen and Fort Snelling Fen. They occur at the base of north-facing bluffs where a constant flow of cold, calcium-rich ground water makes its way toward the surface. Calcareous fens once stretched for miles along the Minnesota River valley until human activities such as road construction, ditching, and fire prevention caused widespread degradation.

Calcareous fens have been designated as Outstanding Resource Value Waters by the PCA. This classification means that state government must use all practical means and measures to preserve them.

The ground water regime which supports the remaining calcareous fens has been stable for several thousand years, relict plant species of early post-glacial climatic periods have survived in them. Other plant species cannot invade an undisturbed fen because they cannot tolerate the unfriendly conditions: cool temperatures and constantly wet oxygen-poor peat soil.

Nicols Meadow fen has rare plant populations of state-wide significance; sterile sedge *(Carex sterilis)*, valerian *(Valeriana edulis)*, and three kinds of lady slippers grow there. These plants are protected under Minnesota's Endangered Species Act.

The treatment plant upgrade and expansion is also environmentally significant. The plant is being changed so that the discharged treated water will meet the standards of the Federal Clean Water Act.

Site preparation for the planned construction was started in late winter 1988. When impacts of the dewatering near the fen were recognized, the DNR Waters staff directed the installation, at MWCC expense, of two sets of water level observation wells. Each set has one shallow well and one deep well. Nested wells can reveal the vertical direction of ground water movement.

Water level measurements in these wells were first taken in early June, 1989. Initial ground water conditions were typical of a fen: ground water was moving upward (discharging or upwelling conditions). This was observed by comparing the water levels in the nested pairs of wells. If the water level in a deep well is higher than in a shallow well at the same site, water is moving upward.

As pumping at the Seneca site continued and pumping volumes were increased, the observation wells near the fen revealed a transition to recharging or downward movement of ground water (see Figure 2). Kennealy Creek, a trout stream between the fen and the Seneca site, was also apparently affected by dewatering. Compared to Harnack Creek, which is fed by a spring less than one-half mile to the west, flow in Kennealy creek decreased more rapidly during the early summer and ceased flowing altogether in late July.

Water levels in another fen in the Minnesota River Valley, Savage Fen, were monitored in order to have a comparison to a fen which was not affected by ground water withdrawals. In addition, peat water level monitoring wells were installed in the interior of Nicols fen. This comparison led to the conclusion that water levels in the fen

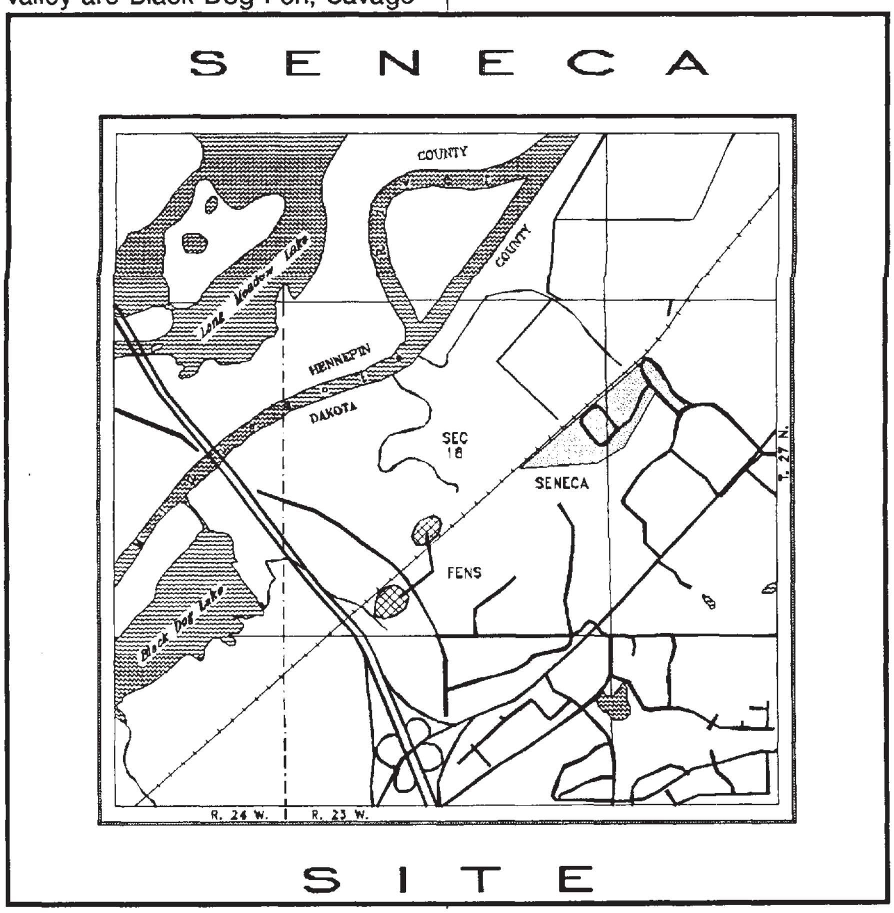
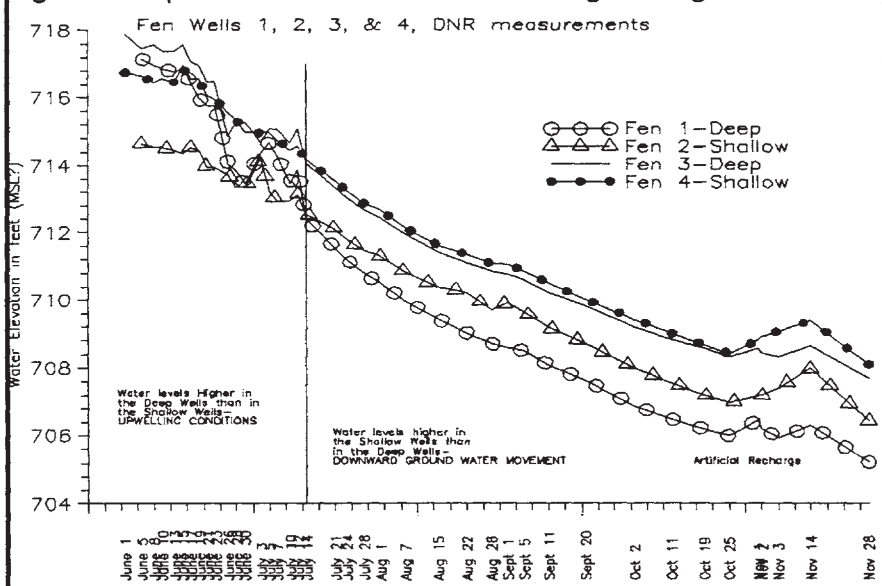


Figure 2: Response of Nested Wells to Dewatering and Irrigation.



at the end of the 1989 growing season were at least 4 feet lower than the DNR's estimate of seasonal norms.

Given the low water conditions, the roots of the fen plants were in an unsaturated soil zone and would be exposed to winter temperatures and humidities without the protection of water. If sufficient moisture was not available prior to winter freeze-up, the roots might "freeze dry". This situation was deemed to be a serious threat to the native fen species. In addition, the landowner and adjacent property owners had expressed concern that fire danger might be heightened and that ground subsidence in the fen might result from long-term dewatering.

DNR, PCA, and MWCC staff agreed that a temporary watering program should be carried out to irrigate the surface of the fen with ground water (pumped out of the ground at the construction site). The goal was to saturate the peat before frost. To avoid compaction and other physical damage to the fen, the irrigation guns were to be placed along the railroad right-of-way.

In less than two weeks from conception to first application of water:

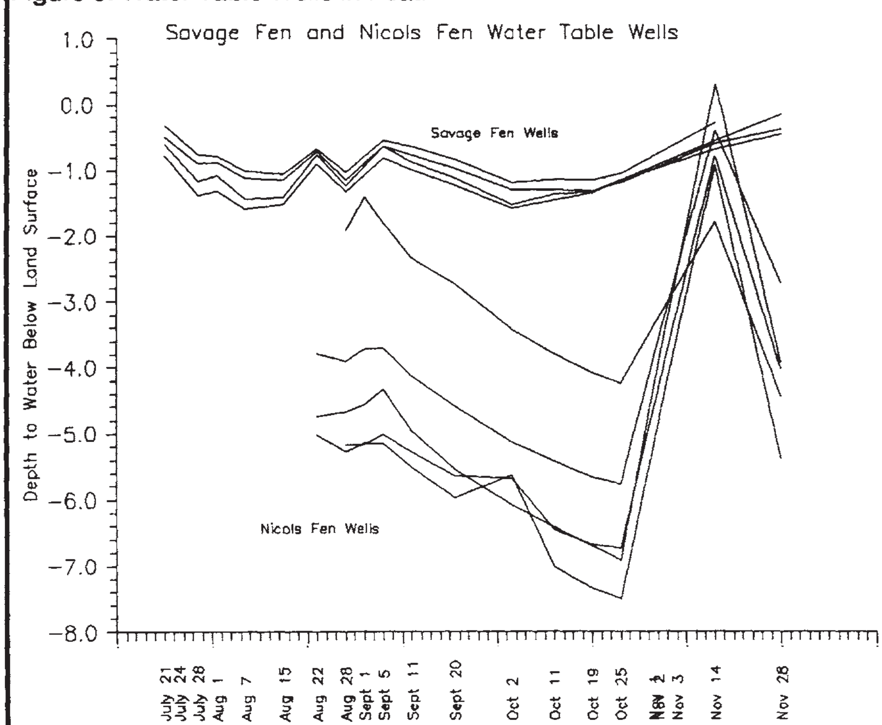
- PCA staff effected a change in the dewatering project's National Pollutant Discharge Elimination System permit to allow water to be sprayed on the fen,
- MWCC staff negotiated an access agreement with the Chicago and Northwestern Railroad and obtained and installed the irrigation equipment,
- and DNR staff helped design the irrigation system, obtained the permission of the concerned landowner, Joseph Kennealy, assisted with fine-tuning of the spray pattern, and began to monitor the response to irrigation in the wells (see Figure 3).

Water was first sprayed on the fen on October 30. Water levels in the peat recovered rapidly and similar increases in water levels were seen in the nested wells. On November 14th irrigation had to be discontinued because of deteriorating weather conditions. Temperatures were predicted to be near or below freezing and the system could not be allowed to freeze with water in it.

After irrigation was stopped, water levels in all the wells declined (see Figure 2). DNR staff believe that the peat was at or near field capacity when it froze and that the goal of the irrigation project was accomplished.

Construction dewatering will continue into 1992, and some dewatering will also be required during the operation of the new plant. MWCC's consultant, HDR Engineering, is in the process of evaluating long-term mitigative measures to protect the fen. HDR's initial proposal includes a recommendation to recharge the ground water between the fen and the dewatering site with reinjection wells. The goal will be to allow ground water conditions under the fen to return to normal by the start of the 1990 growing season.

Figure 3: Water Table Wells in Peat.



Graphics by Jerry Johnson and Jay Frischman

Innovative Fen Protection - Irrigate!

Commentary by Jeanette Leete, MN DNR Waters

Status of Nicols Fen

The 1989 article is an account of an emergency action undertaken to save a calcareous fen from a short-term activity that would have severely degraded it. The context of the Seneca Waste Water Treatment Plant expansion was (in informal terms) that a lawsuit against Minnesota had been filed by the State of Wisconsin. Wisconsin claimed Minnesota was not adequately treating wastewater before discharging it to the Mississippi. If memory serves, Minnesota was being fined $20,000 per day for non-compliance. Compliance meant getting this wastewater treatment plant running!

The immediate intervention that kept the calcareous fen wet during construction dewatering was successful, yet that was not the end of the insults suffered by this calcareous fen, which consists of a segment owned by the US Fish and Wildlife Service and a segment that is part of Fort Snelling State Park.

- The permanent underdrain system at the Seneca Plant has not allowed heads in the fen to return to pre-construction levels, contrary to the consultant’s predictions.
- During powerline maintenance, a crew drove heavy vehicles over the fen, getting their trucks stuck and carving ruts into the peat through some of the areas where the best calcareous fen vegetation had been.
- The upgrade to the treatment plant led to the construction of a new sewage siphon between the two remaining segments of the Nicols fen across the river to bring more raw sewage to the plant.
- Increased development atop the bluff led to increased stormwater discharge through a storm sewer that discharged into the fen, carving a gully along the edge of the fen and allowing water to drain from the peat into the new channel.

At each step of the way, mitigation, restoration or repair has been effected, with local government leading the effort. It is clear that only the vigilance possible through local monitoring can hope to ensure the sustainability of calcareous fens in urbanizing settings.

Legal Framework

Since 1988, significant progress has been made to achieve overall protection of calcareous fens through additional statutory protections.

The Wetland Conservation Act was first passed in 1991 as Minnesota Laws Chapter 354, as amended (Minnesota Statutes, 103G.222-.2373 and in other scattered sections). Rules were promulgated by the Minnesota Board of Water and Soil Resources in Minnesota Rules, chapter 8420, as amended (Rules).

The significance of this act in general was its intent to achieve no net loss of wetlands in the State of Minnesota. With respect to calcareous fens, the Act was very specific that no exemptions from the Act’s no net loss goals would apply.

*“**103G.223 CALCAREOUS FENS.***
Calcareous fens, as identified by the commissioner by written order published in the State Register, may not be filled, drained, or otherwise degraded, wholly or partially, by any activity, unless the commissioner, under an approved management plan, decides some alteration is necessary. Identifications made by the commissioner are not subject to the rulemaking provisions of chapter 14 ...“

In the Rules, the Department of Natural Resources is established as the approving authority for projects involving calcareous fens, and procedures for listing and identifying calcareous fens are established.

In addition, off-road vehicle traffic is prohibited in calcareous fens (MS 84.773). Since the passage of this regulation, a vehicle was impounded after the owners were caught in the act of destroying calcareous fen vegetation.

A technical committee established guidelines for identification of calcareous fens, and these guidelines were tested using data gathered through projects funded by the Metropolitan Waste Control Commission (now Metropolitan Council Environmental Services), by USWest (now Qwest), by DNR Parks, by the US Environmental Protection Agency, and by the School Trust Fund.

Irrigation Technique Used to Protect Ottawa Fen

Where dewatering is going to be short-term, and where it is expected that ground water levels will shortly return to normal after dewatering ceases, DNR concluded that temporary irrigation is a plausible method to prevent damage to organic soils and calcareous fen vegetation. When DNR learned that Ottawa Fen, another Minnesota Valley calcareous fen, would be impacted by dewatering from an adjacent sand mine (Figure 1), and the mine’s consultants predicted there would be no postmining water level impacts, the mine operator agreed to irrigate the fen as a way to avoid limitations on their dewatering permit.

Figure 1: Sand Mine near Ottawa, Minnesota

This calcareous fen is in private ownership, and the owner had been a long-term cooperator in other ongoing studies. With the owner's permission, the mitigation measures were undertaken and studies of water levels in monitoring wells renewed.
The irrigation project was diligently carried out by mine staff who drove a tractor pulling a water tank to a location above the

— *continued on page 34*

Figure 2: Water in transit to a location above the calcareous fen near Ottawa.

fen (Figure 2), connected a hose to the sprinkler system, and let it spray (Figure 3).

Several years post-mining, the project appears to have been successful. The diversity of the calcareous fen vegetation has been preserved, and though there are residual, likely permanent, drawdowns, the peat soils are expected to equilibrate with the new water levels.

Figure 3: Irrigation at Ottawa Fen.

Educational Efforts

After completion of this baseline work, funded primarily by co-operators, staff and funding resources at the Department of Natural Resources were not adequate to provide direct assistance with calcareous fen management at the local level. DNR staff decided to do what we could do to provide local government and consultants with the information necessary to take on calcareous fen management on a site-by-site basis.

Two workshops have been held (both sponsored or co-sponsored by MGWA) during which research results, restoration practices, and technical guidelines were provided and experiences with calcareous fen management issues were shared.

The sustainability of individual calcareous fens into the future rests in the hands of the local community, and in the cases of some of the smaller calcareous fens, the hands of an individual owner.

Proactive Local Management of Calcareous Fens

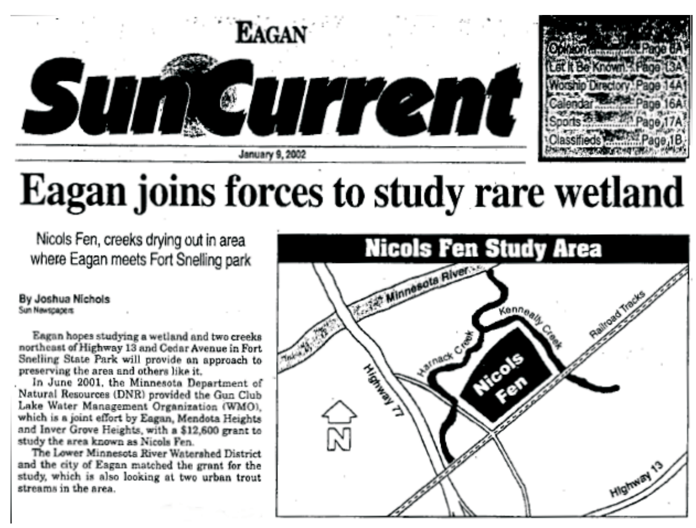
Several Minnesota communities have taken on the challenge in ways that are instructive to the rest of us who would hope to preserve ground water dependent calcareous fens. Three brief examples follow:

The City of Chanhassen has been working on this issue since 1994 when Chanhassen city planners listed the fen's watershed as an environmental and recreational resource. They set a goal of acquiring land adjacent to the creek, and they contacted the DNR for help in forming a natural resources plan. DNR staff couldn't work full-time on the project, but Hannah Texler, a DNR ecologist, served as DNR's representative on the steering committee, helping the group define "best outcomes" for the watershed and develop a watershed management plan that became part of the comprehensive plan for the city. The watershed is managed with the intent of preserving its natural features.

The City of Rochester has begun the process of developing calcareous fen management plans to guide restorative activities in calcareous fens for which it has responsibility. Barb Huberty, Environmental and Regulatory Compliance Coordinator, Rochester Public Works has completed the first such plan and it has been approved by DNR. Two others are in draft stages. A local developer, Dick Argue, was one of the first to embrace the idea that a calcareous fen's presence near his Stonehedge development could give his project a marketing advantage. He worked with state and local staff to design it with an eye toward sustainability of the fen, and work has been done to restore portions of the fen that were impacted by agricultural practices of former years.

The City of Eagan has actively worked to reverse some of the negative impacts of development and has rerouted the storm sewer discharge that had caused problems. The City's water resources staff guided a study (Figure 4) that began long-term collaboration between the City, the local Watershed Management Organization, the Minnesota Department of Transportation, the US Fish and Wildlife Service and Fort Snelling State Park.

The City of Eagan intends to positively influence the sustainability of Nicols Fen.



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Eagan joins forces to study rare wetland

Nicols Fen, creeks drying out in area where Eagan meets Fort Snelling park

By Joshua Nichols
Sun Newspapers

Eagan hopes studying a wetland and two creeks northeast of Highway 13 and Cedar Avenue in Fort Snelling State Park will provide an approach to preserving the area and others like it.

In June 2001, the Minnesota Department of Natural Resources (DNR) provided the Gun Club Lake Water Management Organization (WMO), which is a joint effort by Eagan, Mendota Heights and Inver Grove Heights, with a $12,600 grant to study the area known as Nicols Fen.

The Lower Minnesota River Watershed District and the city of Eagan matched the grant for the study, which is also looking at two urban trout streams in the area.

Figure 4: Media attention paid to Eagan's planning effort.

Tools and Datasets

Minnesota Ground Water Association

Volume 16, Number 4: December, 1997

COMMENTARY

Managing Subsurface Geologic Information in Minnesota

Update of a 25 year Status Report Published in 1997

By Dale Setterholm

In the 10 years since this article was published, the demand for subsurface geologic information has increased as more geologists became aware of the data, and the need for water management has become more acute. As noted in the original article, there was a time when limits on the quantity of water available in Minnesota weren't thought to be an important issue. That perception has changed as the demand for ground water has grown and the availability of ground water has become an economic issue in some communities. There is also a growing awareness that the protection and wise use of ground water requires an understanding of aquifer distribution, size, confinement, and hydrologic characteristics. Geologic mapping based largely on subsurface geologic information is an essential element in establishing that framework.

Web-based access and the use of geographic information systems have changed how users obtain and apply the data. The web-based access to County Well Index (CWI) provided by the Minnesota Department of Health (www.health.state.mn.us/divs/eh/cwi/) allows users to efficiently search and retrieve subsurface geologic information. The digital format also makes it much easier to capture, store, and apply the

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Managing Subsurface Geologic Information In Minnesota — A 25-Year Status Report

— G.B. Morey, Dale R Setterholm, and Robert G. Tipping, Minnesota Geological Survey

Twenty-five years ago Minnesota was in the midst of planning a statewide ground-water quality information system. The lead author of this article represented the Minnesota Geological Survey through much of that planning process (Morey, 1973). Although I am no longer directly involved with the program, I have had the opportunity to observe how it has grown over the past 25 years. Today my co-authors, Dale Setterholm and Bob Tipping, have management responsibilities for various parts of the program.

Those attending a conference convened by the Water Resources Research Center in August 1972 (Walton, 1973) recognized that Minnesota had a large ground-water resource. Consequently, ground-water exploration was not thought to be an important issue. The management plan that evolved from the conference focused on two issues:

(1) How to match the ground-water needs of specific users with available resources, in terms of both quality and quantity, and

(2) how to protect the ground-water resources from pollution. The first issue received little subsequent attention, but the state has worked very hard to prevent degradation of its existing resources.

Looking back, we now recognize the importance of the 1972 conference in that it was formally recognized there, perhaps for the first time in the state, that the quantity and quality of any ground-water regime are governed by two related but distinct systems. The geologic system is relatively static, at least within a time scale of years to hundreds of years, whereas the subsurface fluid system is dynamic and changes over time. The geologic system provides a fixed datum within which the subsurface fluid system operates. The importance of understanding the geologic framework cannot be overemphasized if the distribution, quantity, and quality of ground water are to be understood. The geologic framework was poorly defined and even more poorly understood in much of Minnesota 25 years ago. This was true for several reasons:

(1) Geologists and others did not always know what subsurface data existed;

(2) the data that did exist were not always available in a usable form;

(3) data were sparse, particularly in out-state areas; and

(4) there was no readily acceptable way to distinguish good data from bad.

At the time of the conference the Minnesota Geological Survey had already begun to address the first two issues with the development of an electronic data storage and retrieval system for geologic information, which was described in Minnesota Geological Survey Information Circular 9 (Mossler et al., 1971).

The scarcity and uneven distribution of valid geologic data were not easily solvable problems. In May of 1972, there were only 750 sets of well cuttings housed at the Minnesota Geological Survey. Two hundred and seventy-five of those sets were from the Seven County Metropolitan Area; 19 counties lacked any data. Those numbers contrasted with North Dakota, Iowa, and Wisconsin, where 10,000, 23,000, and 16,000 sets of well cuttings, respectively, were available. At the same time, the Survey had only several hundred drillers' logs in its files, many of which were compromised by inaccurate locations. Thus, in 1973 it was generally agreed that the subsurface geologic data base in Minnesota was totally inadequate for planning and management purposes, and that the state must expand its efforts to collect subsurface geologic data.

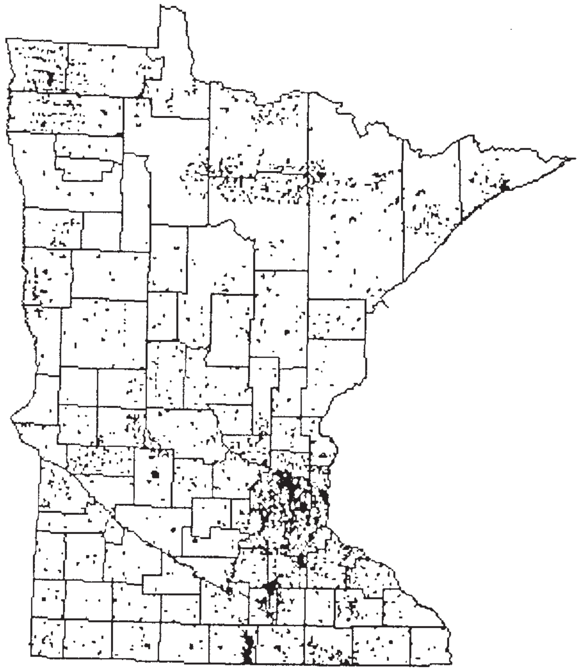

Figure 1. Locations of water wells having cuttings stored at the Minnesota Geological Survey.

How well have we done in the intervening 25 years? Programs such as the Water Well Contractors Licensing Act of 1971 have made it much easier to systematically collect cuttings, cores, and other data. As of March 30 of this year, the survey had 3,800 sets of water-well cuttings in its files. All but two counties now have at least one set of cuttings (Fig. 1). However, much of the collection is still focused on the Seven County Metropolitan Area and on southeastern Minnesota, where a variety of geologic studies has been completed. Other than selected areas in northwestern Minnesota in the Red River lowland, and in northeastern Minnesota along the north shore of Lake Superior, the cuttings collection in out-state areas remains inadequate for modern geologic interpretations.

The lack of an adequate collection of cuttings has been mitigated somewhat by the availability of other kinds of data, most importantly down-hole geophysical logs. As of March 30, the Survey had approximately 3,250 geophysical records in its files (Fig. 2). Of those, 1,184 records were derived from wells where cuttings also are

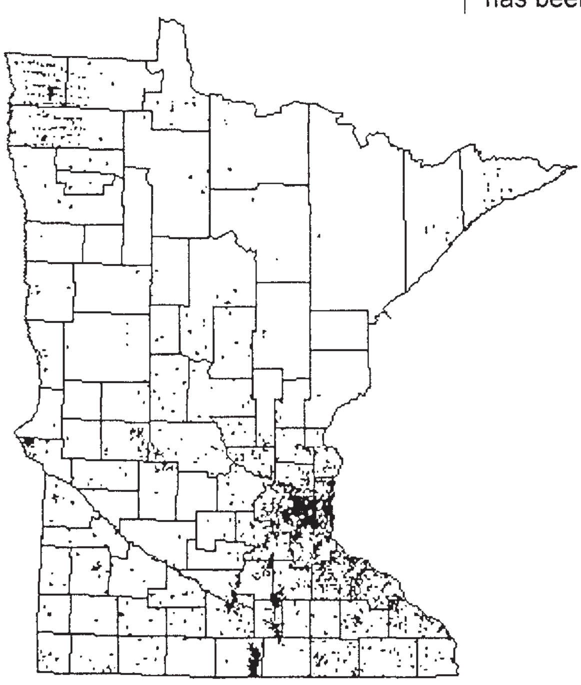

Figure 2. Locations of water wells having down-hole geophysical logs in the files of the Minnesota Geological Survey.

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Update of Subsurface Geologic Mapping, cont.

data. Geographic information systems allow users to take advantage of the locational aspects of the data and to automate the construction of maps, cross-sections, models, and 3-dimensional illustrations. As an example, these techniques have enabled improvements in the products of the County Geologic Atlas program, particularly in the mapping of glacial aquifers.

The amount of readily available subsurface data has grown significantly. The table on page 37 shows the magnitude of the changes and the growth rates. Much of the backlog of historical subsurface information that existed before CWI was created has been entered in the system, and new data are being entered soon after they are submitted. As an average, the well records entered in 1997 were for wells drilled in 1981. In 2006 the average date of drilling for wells entered in CWI was 2002. The entry of historical data is often stimulated by MGS mapping projects, and this causes the average age of the wells being entered to be slightly behind the current year.

Downhole geophysical logging data are growing in volume and in the types of data generated. Natural gamma data are still the most common type collected because they are useful for establishing lithology and stratigraphy. MGS now commonly runs a multitool that records natural gamma and fluid properties, including resistivity and temperature, simultaneously. In this way we are linking conditions that can be expected to change over time in the fluids, and conditions that are static in the bedrock or sediment that hosts the water. MGS is also collecting downhole data with an electromagnetic flowmeter in an effort to characterize aquifer properties.

As we look ahead, accurate location information, including an elevation for wells and borings, remains a challenge. It is expensive and time consuming to visit well locations, and in the case of borings there is commonly no permanent feature to visit. Locations recorded with global positioning satellite systems are

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MGS Subsurface Data, cont.

available. Geophysical logs are important because they record actual physical measurements rather than subjective descriptions skewed by observer bias. The geophysical logs provide points of high-quality stratigraphic information that enhance the value of lower-resolution drillers' logs by serving as a guide when interpreting nearby well logs.

The importance of geophysically logged holes as stratigraphic control for interpreting well records that lack both geophysical logs and cuttings is underscored by the raw numbers. As of March 30, 1997, our County Well Index (CWI) contained the records of approximately 228,000 drill holes. We do not have the time, money, or staff to locate all of the drillers' logs submitted to us, consequently, the backlog of unlocated logs continues to grow. Of those in the system, approximately 83,000 logs contain interpreted geologic information and are located to within the area of a 2.5-acre or smaller cell. Approximately 38,000 of the located and interpreted wells are finished in bedrock (Fig. 3), and 45,000 are finished in glacial materials (Fig. 4). The remainder are so-called unlocated logs that are in the descriptive language of the driller and have not been verified as to geographic location.

CWI records are derived from copies of drillers' logs submitted to the Minnesota Department of Health as part of a reporting protocol mandated by the Licensing Act of 1971. At the Minnesota Geological Survey we enter the drillers' logs into a desk-top computational system that facilitates the storage, retrieval, and manipulation of the contained information (Wahl and Tipping, 1991). As an organization, we are concerned with locating and interpreting the logs so that they can be used in geologic studies. Today, much of that work is done as part of our portion of the County Atlas Program and other mapping activities.

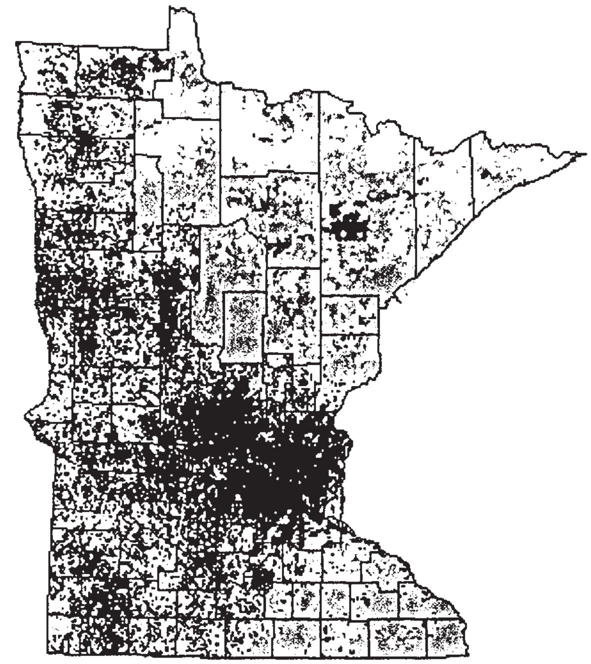

Figure 4. Location of water wells and other kinds of holes recorded in CWI (County Well Index) that are finished in Quaternary material. Black, located; gray, unlocated or wells that have less than four quarter-section letters (2.5-acre cells).

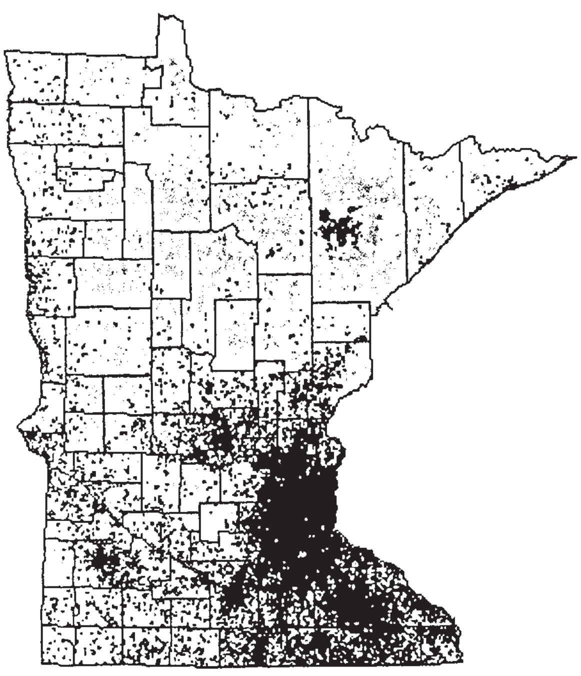

Figure 3. Location of water wells and other kinds of holes recorded in CWI (County Well Index) that are finished in bedrock. Black, located; gray, unlocated or wells that have less than four quarter-section letters (2.5-acre cell).

What difference does it make to planners and resource managers that drillers' logs are located and interpreted professionally? Today the state is engaged in developing a comprehensive geographic information system that starts with a well-constrained georeferenced base. Adding digital locations to well data allows users to compare geologic or hydrologic attributes with other kinds of data generated for public-health, land-use, or planning purposes. These comparisons increase the value of all sets of data. Additionally, geologic data obtained from drillers' logs represent the foundation upon which hydrogeologic interpretations are built. Competently interpreted well records build a useful geologic framework by providing a transition from point data to mappable geologic units. The delineation of carefully defined geologic and hydrogeologic units is the essential first step in understanding the availability of ground-water, mechanisms of contaminant transport, changes in the physical parameters that define an aquifer, and many other attributes that are important in managing the resource.

Experience over the years has taught us that some well records lack validity, but distinguishing the good from the bad logs is not always easy. This judgment is best made in the context of preparing a map, where the individual logs are integrated into geologic syntheses or "working models" that are continually modified as new data are added. Questions continually arise about the validity of individual data points, especially those that depart from the synthesis provided by the model. Should the model be modified to reflect the discordant data or should the data be disregarded? Clearly the experiences and the bias of the geologist making such decisions are important factors in deciding which approach to follow. Regardless, poorly located or inaccurate data cast doubt on the reliability of

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MGS Subsurface Data, cont.

any geologic synthesis to a point where it becomes unbelievable.

Although we have learned how to use drillers' logs effectively, an evolving problem of considerable significance remains to be solved. (Figs. 3-4) Approximately 135,000 or 59 percent of the wells recorded in CWI are unlocated according to currently accepted standards, or they lack geologic interpretation. Furthermore, over the past 3 years an average of 14,900 new well records per year was received by the Survey. We have been able to locate and interpret only 3,500 of these wells each year. Consequently, our backlog of unlocated and uninterpreted logs grows larger and larger. The state, counties, and the other planning districts, as well as the community of earth science professionals, must recognize that it is not enough just to have the original data. We must all assume some of the responsibility in data management for the common good. As a first step, we should critically ask if the Minnesota Geological Survey is the appropriate place to store drillers' records electronically or manually? Should we store all of the data or focus on the geologic logs? Should all of the data be located to currently acceptable standards? Do all of the water wells need a geologic interpretation beyond the descriptions provided by the drillers? If the answer to either of the last two questions is no, what criteria should be used to determine which wells are located and interpreted? Regardless of specific answers to these and similar questions, it is clear that we have a massive task ahead of us. If we do nothing or continue along the same path, the problems will only get worse with time. Now is the time to implement changes that will move the geologic information system 25 years into the 21st century.

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Update of Subsurface Geologic Mapping, cont.

likely to become part of the answer to this problem. We are also looking for ways to record transient subsurface data. For example, a new road cut, excavation or quarry may expose geologic contacts that are only visible for a short time. Photos are useful, but it would be more useful to store the contact as a linear feature with x, y and z (elevation) coordinates. Because subsurface data are commonly used to map geologic contacts (surfaces) we are interested in developing methods of updating those surfaces efficiently as new data become available. MGS also would like to develop resources and methods to enable us to capture shallow subsurface data such as boring records and geophysical surveys.

Table 1: County Well Index Statistics and Growth over the Past Decade

CWI	1997	2007	Growth %
Total	228,000	416,968	83
Location verified	83,000	175,880	112
Geologic interpretations	83,000	122,914	48
With cuttings	3,800	4,543	20
Geophysical logs	3,250	5,013	54

1999 Field trip leader Bob Tipping, Minnesota Geological Survey at the Cross River gravel pit. Photo by Tom Clark.

Metro Groundwater Model — Site Applications

By Andrew Streitz, John Seaberg and Doug Hansen, Minnesota Pollution Control Agency

Introduction

It has been four years since staff at the Minnesota Pollution Control Agency (MPCA) reported on the Metropolitan Area Groundwater Model (Metro Model) project in a MGWA article (see MGWA Newsletter, Vol. 14, number 4, December 1995). At that time we stated that our original goals were to assemble databases, develop a conceptual model, and build a regional groundwater flow model encompassing the Twin Cities seven-county Metropolitan area. Further, we wanted to pursue these goals so that the Metro Model was accepted and used by the environmental and groundwater modeling community.

In 1999, our original goals have been met, and it is time to set new ones. The most dramatic shift is toward use of this tool by the Agency, and we believe that the project can also provide support to many different types of hydrogeologic investigations, ranging from relatively simple reviews of geology to more complicated drawdown analyses. A large storehouse of shape files, maps and database files is available to all interested parties including unified Minnesota Geological Survey (MGS) Twin Cities bedrock coverages (Figure 1), geostatistically filtered calibration datasets, Quaternary sand-content maps, and stream discharge measurements. These databases can be used to solve hydrogeologic problems that do not require the building of a groundwater model.

If a model is required however, regional groundwater models covering the glacial drift to the Mt. Simon/Hinckley aquifers are ready for use as well. The Metro Model provides a platform from which expansion or development of other subregional models may be developed. And by collecting and reviewing the incremental changes made to the Metro Model, improvements can be shared with all participants. Though originally designed with groundwater contamination in mind, other uses that the Model can be put to include analyzing groundwater management issues such as sustainable development of groundwater, and delineating wellhead protection areas. Within the last year, the team has been working with a number of parties to apply the Metro Model and/or its databases to various groundwater modeling projects. To demonstrate the utility of this new strategy, this article will present two examples of modifications of the Metro Model to build local-scale groundwater models, following a brief review of the Metro Model effort.

The Metro Model—A Brief Review

The Metro Model is a regional groundwater flow model encompassing the Twin Cities seven-county Metropolitan area. The Metro Model provides the regional boundary conditions so that an end-user can insert local detail, thereby creating a more robust site-specific model in a shorter time than was previously possible.

The computer model simulates multi-aquifer groundwater flow and is based on a conceptual model that consists of five aquifer layers, four of which represent bedrock units, and one representing a glacial drift aquifer. Separate groundwater simulations now exist for all five layers and all three hydrologic provinces, metropolitan regions divided by the Minnesota and Mississippi Rivers. The software used is the Multi-Layer Analytic Element Model (MLAEM), based on the analytic element method pioneered by Professor Otto D.L. Strack of the University of Minnesota

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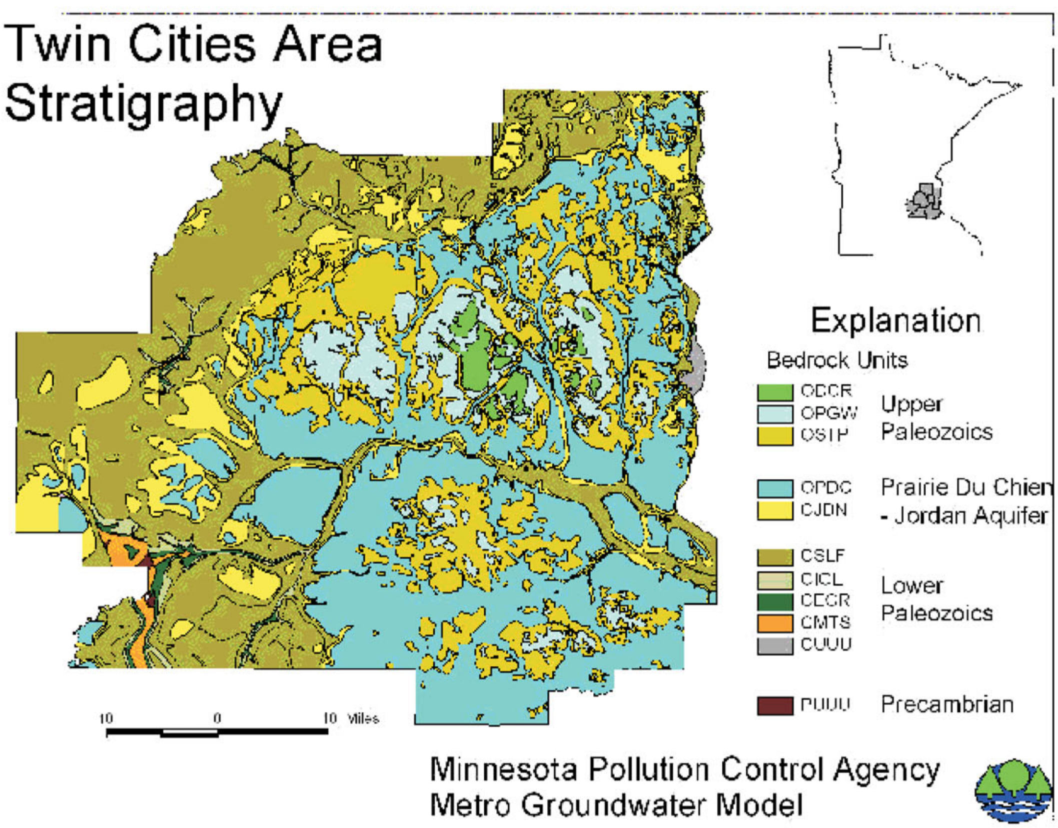

Figure 1

Civil Engineering Department. Improvements in modeling techniques are incorporated into the effort as they are developed to ensure that the Metro Model provides the best technical tool possible for groundwater management issues.

Site Use of the Metro Model

The most exciting new development in the Metro Model project has been the adaptation of the model for use on two local-scale sites. One was performed under contract to the Metro Model project, and the second was completed by an independent consultant for a third party client enrolled in the MPCA's Voluntary Investigation and Cleanup (VIC) program. Both local-scale models were developed in close cooperation with the Metro Model team. In each case the Metro Model and its supporting databases were easily converted to the needs of the smaller-scale models as described in the two sections below. More detailed information on all aspects of the Metro Model and the local-scale models is available upon request. Contacts are provided at the end of this article. Relevant geologic information from these local-scale models will be eventually incorporated back into the Metro Model, strengthening its simulation in these areas.

Reilly Superfund Site

The Reilly Tar & Chemical Superfund site was modeled to test the project strategy of applying the regional-scale Metro Model to local-scale sites. Kelton Barr of Kelton Barr Consulting, working with MPCA hydrologists and project staff, modified the Metro Model to meet the local site needs, adding detail in the form of model elements and calibration points where needed while the project team analyzed the use of the Metro Model with the goal to simplify the process.

The Reilly Tar & Chemical Site, in the Twin Cities suburb of St. Louis Park, was selected because of the lateral and vertical extent of groundwater contamination found at that location. The Reilly site is contaminated with coal tar compounds, which are found in the glacial drift and several underlying Paleozoic aquifers. The goals of the exercise:

- Adapt the Metro Model's northwest hydrologic province model,
- Determine if contaminated groundwater in the glacial drift and Platteville aquifers is effectively intercepted by the extraction wells in each aquifer, and
- Determine if the extraction wells are preventing contaminated groundwater from entering the bedrock valley to the east of the site and affecting the St. Peter aquifer.

The Platteville Limestone and Glenwood Shale are absent in an erosional valley southeast of the site that is a tributary valley to the larger buried bedrock valley that underlies the Minneapolis chain of lakes. The head of the valley is subdivided into at least two prongs extending generally to the northwest toward the site. The valley

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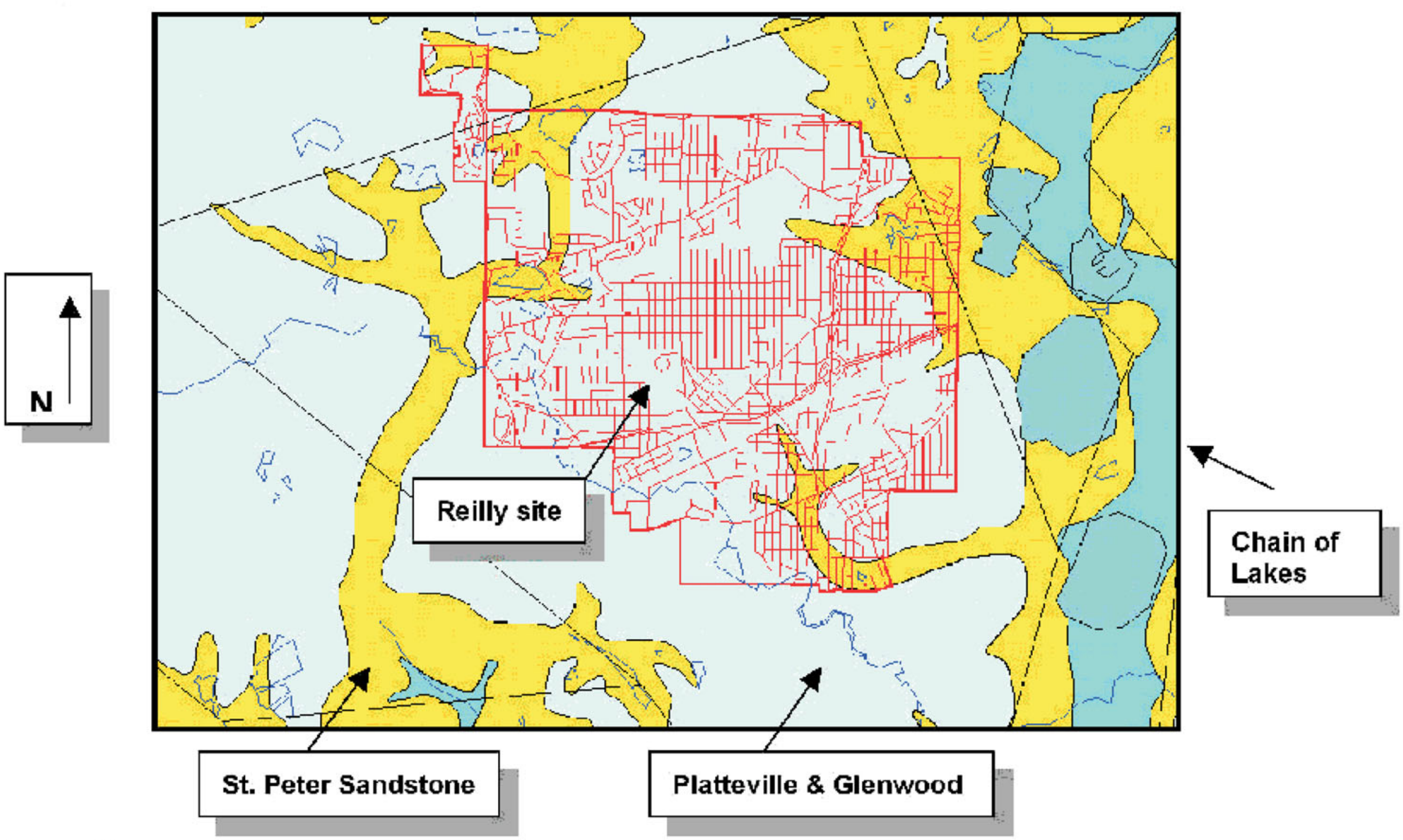

Figure 2

extends generally to the east (see Figure 2).

The groundwater flow in both the drift and Platteville aquifers is generally to the east. Flow in both aquifers is influenced by Minnehaha Creek, which meanders to the southeast in the area directly south of the site. The groundwater flow directions are also influenced by the occurrence of valleys eroded into the upper bedrock and long since filled in. This includes both the buried bedrock valley described above and another, less developed valley to the northeast of the site. An additional bedrock valley also is located to the west of the site, but does not likely exert much influence on local flow.

The general setting of the Reilly site is shown in Figure 2. Also included in the figure are the site location, the St. Louis Park street system, and Minnehaha Creek. Modeling based on these and other local-scale conditions led to the following conclusions:

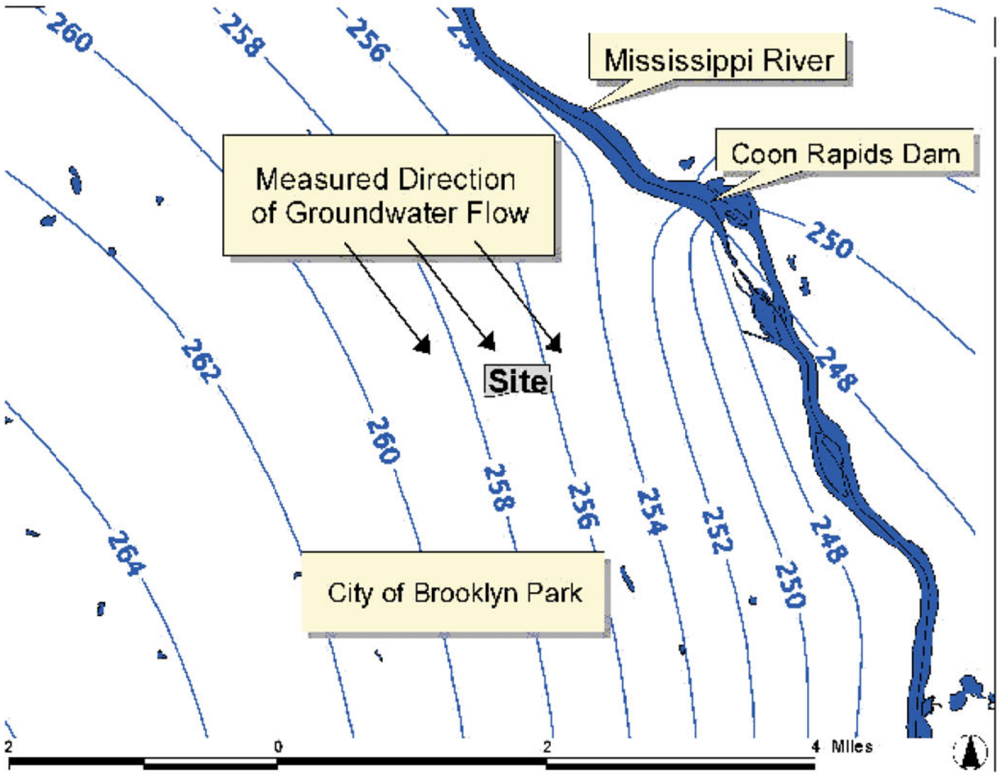

Figure 3

- The potentiometric surfaces of the Glacial drift and Platteville aquifer are reasonably simulated in the model developed for the Reilly site. The Metro Model's northwest province model was effective with minor modifications,
- The extraction wells in the Platteville Aquifer appear to effectively capture groundwater from the site vicinity. Moreover, it appears that these wells are effective in preventing contamination from reaching the tributary bedrock valley.
- Dissolved contamination either originating within the Platteville or migrating from the overlying drift into the Platteville within the site vicinity appears to be effectively contained by the extraction wells.

This local-scale model is currently being updated and will be used in future remedial decisions by the MPCA.

Voluntary Investigation and Cleanup Site Application

Richard Pennings of GME Consultants, Inc. (GME) recently applied a portion of the Metro Model to a hydrogeologic assessment of a site approximately 0.5 square mile in an area located in Brooklyn Park. The identity of the site is being withheld for proprietary reasons. It is a former industrial site contaminated with solvents and heavy metals, and is enrolled in the VIC program at the MPCA.

A local-scale model, based on the Metro Model, is being used to evaluate site conditions and to evaluate hydraulic control options. At GME's request, Metro Model staff provided the glacial drift aquifer portion (Layer 1) of the Northwest Province of the Metro Model, as well as head calibration data. Additionally, hydrogeologic data, including US Geological Survey topographic and MGS bedrock maps, provided on a database CD-ROM prepared by the Metro Model team were readily incorporated by GME into the analysis using ArcView Geographic Information System (GIS) software.

The aquifer that was modeled consists primarily of Quaternary sands overlying the St. Lawrence Formation, interpreted to be the aquifer base. Because the Metro Model is regional in nature, the first step was to tailor it to fit local site conditions. GME staff used 14 monitoring wells to help define local groundwater conditions. Further adjustments were made to simulate the phreatic aquifer, and to simplify the far-field conditions to allow for faster calculations. Although the model predicted a similar hydraulic gradient, the predicted direction of groundwater flow (easterly) differed from the observed direction (southeasterly), as shown in Figure 3.

Using ArcView GIS, the Graphical User Interface (GUI) in MLAEM, and the digital coverages that the Metro Model project team provided, GME inserted the appropriate local-scale features near the site, including wells, surface waters, and areal inhomogeneities. However, the model still did not reflect the local southeasterly flow direction. Further analysis using the MGS bedrock geology coverage, revealed a locally occurring

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but significant outlier of Jordan Sandstone above the St. Lawrence Formation. Insertion of an inhomogeneity representing decreased hydraulic conductivity for this portion of the aquifer influenced by the Jordan Sandstone (Figure 4) produced groundwater flow directions and gradients that were reasonably consistent with what has been observed at the site for the past couple years.

GME found that, because the Metro Model contained sufficient global detail and was regionally calibrated, they could use it as a basis from which they could construct a site-specific groundwater model. By using the Metro Model and its supporting databases, GME did not have to spend extensive time on the initial start-up and construction of their groundwater model. Future work by GME may include splitting the model into two layers, the first representing continuous Quaternary deposits above the Jordan Sandstone, and the second representing both the Quaternary deposits and Jordan Sandstone immediately above the St. Lawrence Formation.

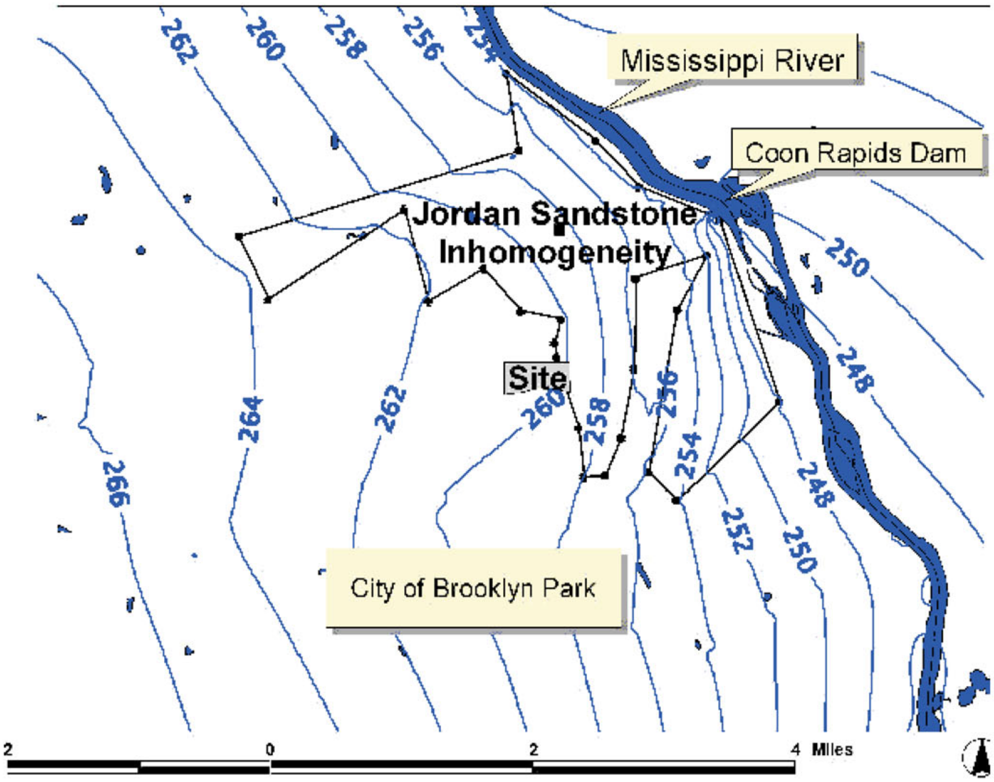

Figure 4

Other Uses of the Metro Model and its Supporting Databases

Examples of the use of the Metro Model include three recent Requests-for-Proposal issued by the Ramsey County Soil & Water Conservation District and the Minnesota Department of Health for the construction of regional models to be applied to problems of wellhead protection and groundwater management. All three stipulated extensive use of the Metro Model and its supporting databases as a necessary starting point for the consultants picked for the contracts. Additionally, the St. Croix Watershed Research Station of the Science Museum of Minnesota used the Metro Model and supporting databases on their 1997 Legislative Commission on Minnesota Resources project, Watershed Science: Integrated Research And Education Program.

Summary

After spending four years engaged primarily in the development of the Metro Model and its associated databases, project team members are shifting the emphasis towards its direct use in site remediation. Initial applications of the Metro Model project resources indicate that they can be used effectively as a tool in the support of groundwater management decisions. Project team members will now spend more time on applying the Metro Model to projects both within the MPCA and also outside, including providing assistance to private parties. However, they will also continue to refine and improve the existing project as new information, data, and modeling techniques become available. And they will bring lessons learned and resources to bear on MPCA projects in Greater Minnesota.

Contacts:

If you would like more information or think that the Metro Model project team can provide you with resources you need for your project, please contact the following:

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Web site
http://www.pca.state.mn.us/water/groundwater/metromodel.html

Acknowledgements

The authors wish to thank the following individuals for supplying information used in this article: Richard Pennings and Mark Millsop of GME Consultants, Inc., Kelton Barr of Kelton Barr Consulting, and Paul Bulger of the MPCA.

Footnote: *The Metro Model was initially supported from 1995 through 1999 by the Legislative Commission on Minnesota Resources, with additional support coming from the US Environmental Protection Agency and the MPCA. As of July 1, 1999, the project has become a permanent part of the MPCA's Environmental Outcomes Division.*

Update to "Metro Groundwater Model – Site Applications"

Update by Andrew Streitz, Minnesota Pollution Control Agency

Looking back at the Metro Model some ten years later, several things stand out clearly. First that the Metro Model is best understood as a process more than as a product. Many of the original Model solutions themselves are not used in their original state, but many of the conceptual models, supporting datasets and summary reports continue to be used by modelers using different modeling software. These include detailed descriptions of aquifers, Paleozoic and Quaternary GIS coverages, calibration datasets, and perhaps most important, a legacy of open discussion about the construction and use of ground water models within the State.

Did we get anything wrong? Well, it would be hard to call our use of Analytic modeling code a mistake, but it is clear that numerical modeling techniques have been in ascendancy in the years since we began our project. The combination of cheap computer power and broad acceptance of the USGS open code across the world means that improvements and refinements are being made daily, conveying a huge advantage to modelers using this software.

Given all this, it is appropriate that the Metropolitan Council is currently in the process of updating and replacing the Metro Model throughout the seven county area within a MODFLOW format, incorporating additional model layers to reflect the improved understanding of hydraulic variability within geologic units, and implementing an automated inverse optimization method for model calibration. The project is expected to be complete by the end of 2007. More information on the Met Council Metro Model will become available at that time.

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Update to "Analytic Element Modeling of Hennepin County Aquifers with a Geographic Information System"

Update by James Piegat

This model was perhaps the first analytic element model (AEM) prepared with a geographic information system (GIS) or even a graphic user interface (GUI). As I was becoming familiar with Dr. Strack's AEM and with other modelers who were using it, I was struck by the amount of time and effort needed to manage all of the input and output files required by the code. All of this work was done by looking for a few numbers among many on printed pages, using digitizing pads, word processors, spreadsheets, and more. However, all of this changed for me once I taught the GIS to create input files and to read output files. I ran three versions per day, one started in the morning, one in the afternoon, and one at the end of the day. I could literally see the results, make decisions on changes that I wanted to made, generate new input files, and start another run in a matter of minutes. The remainder of time was spent watching a 486 computer run the model.

The GIS allowed me to quickly and easily create the model. For example, irregular quadrilaterals were used to model infiltration into the aquifer; all that was needed was a shape, a resistance to vertical flow, and a head in the overlying material for each quadrilateral. I decided to determine the resistance to vertical flow by considering the material that was directly on top of the aquifer. I had the GIS look for all wells that penetrated to the Prairie du Chien, and then look at those logs to determine the material immediately above. The routine also looked at the thickness of the material to insure that it was thick enough to either limit flow in the case of material that would be modeled as an aquitard or to transmit significant water in the case of material that would be modeled as an aquifer. This work would have been monumental had I been required to use the 15,000 paper well logs then available in Hennepin County, plot them on a base map, and then create a "worm's eye view" geologic/hydrogeologic map. With the GIS, it took a short afternoon. The GIS also allowed me to find and fix errors. If the model crashed because of a problem with a particular element, I could quickly see on a map which element was causing the problem and figure out how to solve that problem.

This work was done in the days before PEST (a model-independent parameter optimization program). Because I could rely on the mapping created with the GIS, I decided to assign the same parameter values to all elements of a kind that had the same geologic or hydrologic basis. Exactly what those values would be were determined during calibration. The uncertainty of the model is displayed when calculated water levels are compared to measured levels. Hence, the uncertainty of the model is directly related to my uncertainty about the nature and distribution of geologic features that affect ground water flow in the aquifer. Had I used a PEST-like technique, at least some of the uncertainty of the model would have been hidden in the model itself, specifically in elements that represented similar geologic features but with different parameter values that were assigned not because I knew what those values are in reality, but because the "overall" calibration was "improved" as a result.

Todd Petersen, Minnesota DNR Waters Division, comes prepared to hit the field.

Analytic Element Modeling of Hennepin County Aquifers with a Geographic Information System

—Leigh Harrod and James Piegat, Hennepin Conservation District.

In November, 1993, staff from the Minnesota Department of Health (MDH) and the Hennepin Conservation District (HCD) began informal discussions about wellhead protection for public water supply wells in Hennepin County. Those discussions resulted in a joint project that merges geographic information system (GIS) technology with analytical element modeling to develop a ground-water model for two major aquifers.

The Hennepin County Ground Water Plan written by HCD offered GIS mapping of preliminary wellhead protection areas on parcel maps for all cities in the county. MDH is the lead agency for wellhead protection in Minnesota.

Initially, HCD hydrogeologists had considered the WHPA model developed by the U.S. EPA for delineating wellhead protection areas (WHPA). However, seasonal variations in pumping in many community and high capacity wells can cause changes in the direction of ground-water flow which the WHPA model does not address. HCD and MDH determined that a regional model could be used as the basis for more refined WHPA delineations. A regional ground-water flow model could address seasonal pumping conditions, infiltration, boundary conditions and aquifer facies changes.

Analytical element modeling (AEM) developed at the University of Minnesota was selected for the Hennepin County model because it offers the ability to calibrate ground-water flow at a scale which utilizes much of the information already contained in the Hennepin County Geologic Atlas. AEM allows for the subsequent addition of detailed geologic information, pumping rates and surface hydrology for specific areas without the need for recalibration. Furthermore, AEM data files can be easily exported for use by others.

Finite-element models such as MODFLOW can account for transient pumping, but require explicit boundary conditions. Furthermore, there is a practical limit to the level of detail in a model of a large area. While AEM does not handle transient pumping easily, neither does it require knowledge about boundary conditions. The project team decided that the effects of transient pumping can be addressed later in greater detail by using AEM to set boundary conditions for MODFLOW models of selected smaller areas.

MDH and HCD hydrogeologists decided to develop separate AEM models for the water table and the Prairie du Chien-Jordan aquifers. These two aquifers are most commonly used for community water supply wells in Hennepin County. After each aquifer is modeled separately, the layers will be combined into a multiple-layer model and recalibrated. This approach anticipates that it would be simpler to model, find errors and calibrate each layer individually before combining them into a multiple-layer AEM model.

General Description of an AEM Model

An analytical element model uses points, lines and areas to simulate the hydrologic setting. Mathematical solutions for each element are calculated and superimposed to predict the response of an aquifer system to various forces, such as pumping, rainfall or discharge. The solution can be output either numerically or displayed graphically as flow paths.

Four-sided area elements are used to model extraction or infiltration distributed over an area. These area elements can represent rainfall or irrigation and can simulate lakes or wide rivers. Area elements can model aquitards between aquifers in multiple-layer models. Inhomogeneities within an aquifer are modeled with multiple-sided polygons called doublets. Line segments (line sinks) represent rivers, streams, or other linear features. Wells are modeled as points.

The AEM — GIS Connection

There are several reasons why using GIS technology as a pre-processor and post-processor can make analytical element modeling easier, faster, and more accurate. The simplicity of the graphic items used by an analytical element model makes them easy to identify, draw, and edit electronically. The freedom to draw elements in their natural locations without constraint by a grid allows the user to easily superimpose AEM elements over features as they appear in geo-

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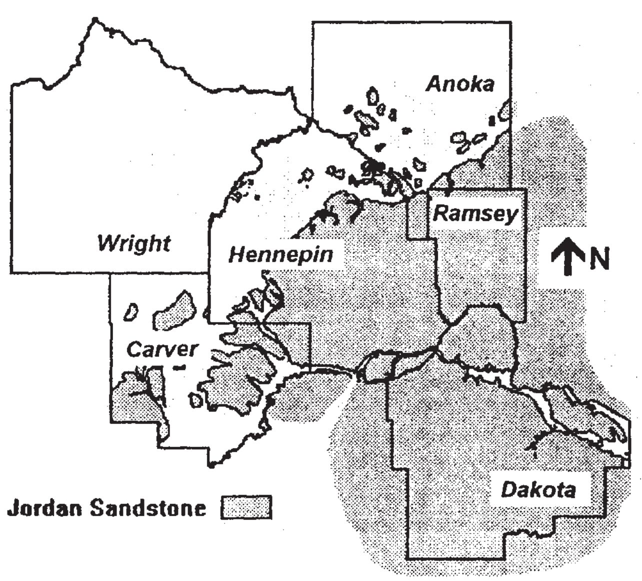

Subcrop of Jordan Sandstone underlying Hennepin County and adjacent counties logic and hydrologic maps already stored in the GIS. A map view of the modeling results displayed by GIS allows the modeler to quickly identify problems and calibrate the model.

A GIS can quickly generate detailed and accurate data files for an AEM. Drawing elements on a computer monitor using an existing GIS base map and executing routines which capture information from graphic items and data files replaces the time-consuming tasks of mapping and digitizing from paper maps and manually coding data files that traditionally accompany AEM modeling. (Using GIS was an obvious choice because of the experience at HCD in geology, hydrogeology and GIS management). HCD's graphic database includes bedrock geology, depth to bedrock, surficial geology, well locations and logs, land cover, surface hydrology and locations of potential contamination sources. These data can be viewed simultaneously or selectively from a metro-wide scale to the parcel level.

Base Maps and Data Sources

Climatological data was acquired from the State Climatologist. Well data was obtained from the County Well Index (CWI) for Hennepin County and the surrounding counties: Carver, Anoka, Ramsey, Dakota, Wright, and Scott. Pumping data was obtained from the State Water Use Data System (SWUDS) and city records. Water level information from the HCD observation well network, two synoptic well measurements, other state agency sources and county geologic atlases were used for data entry and model calibration.

The base map for all HCD graphic data is the Hennepin County parcel map developed by the Hennepin County Surveyor. Section corner locations were obtained from the surveyors of Anoka, Carver, Dakota, and Ramsey counties to provide additional location control. Bedrock geology maps of Anoka and Carver counties were automated by HCD. Electronic maps of bedrock geology for Dakota and Ramsey counties were obtained from the Dakota County Surveyor and the U.S. Geological Survey, respectively. Locations of significant streams and lakes in Carver County were digitized from topographic maps.

Conceptual Model for the Prairie Du Chien-Jordan Aquifer

The conceptual model treats the Prairie du Chien-Jordan (OPCJ) as an inhomogeneity within glacial material. Variations in aquifer thickness and bedrock valleys that cut through the Jordan are modeled. Area elements assigned a head and resistance are used to model vertical flux into the aquifer. The Minnesota, Mississippi and St. Croix rivers and their associated floodplains are treated as resistance area elements everywhere except north of the Jordan subcrop where the Mississippi river is represented as a line sink. The Crow River is represented by a line sink. Elements are broken at every dam. No other surface water features are represented in the bedrock model.

All elements were drawn directly in GIS while viewing bedrock contacts, major valley walls, and terrace boundaries. Bedrock contacts and isopachs were used to model inhomogeneities. Heads for constant-head and resistance elements were obtained from U.S. Geological Survey (USGS) topographic maps, county geologic atlases and head values in the St. Peter Sandstone generated by a SURFER model. Values of resistance for resistance elements were taken from the literature.

The Water Table Model

The conceptual model for the water table (QWTA) treats drift deposits as a composite of relatively low permeability with areas of higher permeability in outwash and along river terraces. The water table is in till in the western part of

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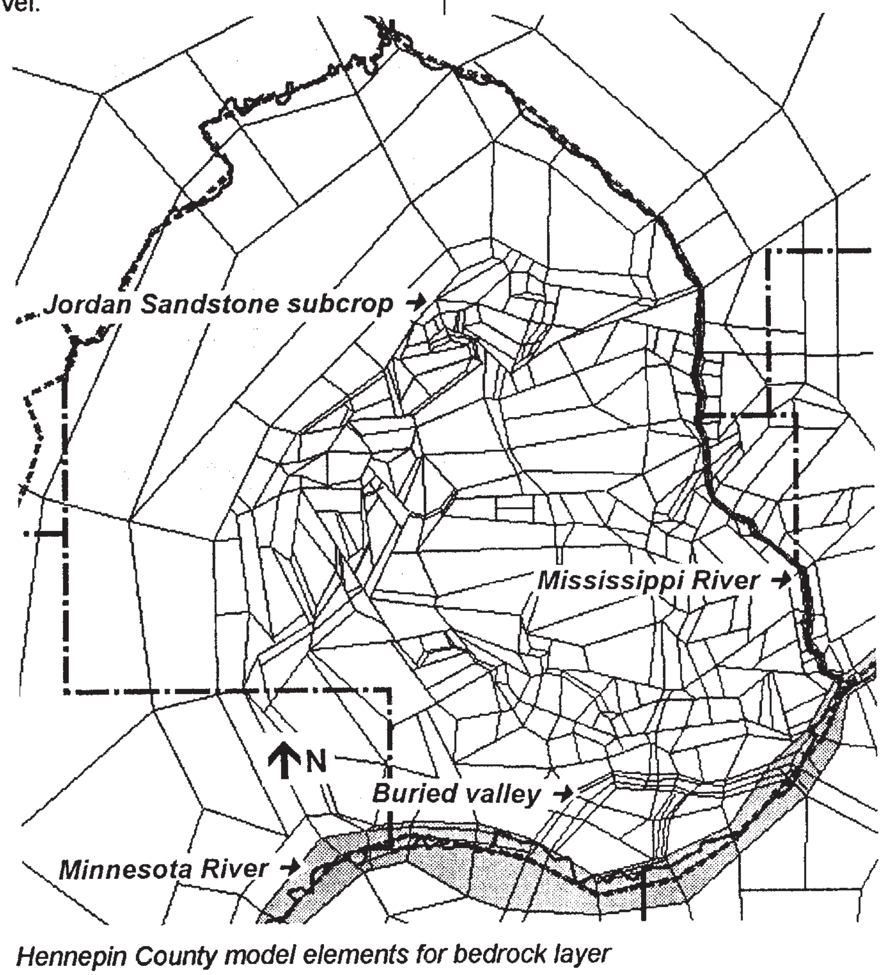

Hennepin County model elements for bedrock layer the county and in outwash in the east. Near the Minnesota River, the water table is in the St. Peter Sandstone and Plattville Formation. Significant public water supplies are developed in unconfined valley fill and kame materials.

A buried drift aquifer in western Hennepin County, and its hydrologic connection to other hydrologic units, poses an interesting problem. For example, is the buried drift aquifer continuous or is it a composite of smaller, unconnected buried aquifers scattered throughout the till? The problem of the buried drift aquifer will be addressed in the second phase of this modeling project, beginning in April 1995.

A GIS routine evaluated bulk hydraulic conductivity from well log data and plotted wells color-coded according to texture, either mostly till or mostly sand and gravel. The plot was too general to conclusively identify boundaries of inhomogeneities, so forty cross sections were generated at MDH using a geologic logging software program (STRATIFACT) and imported into GIS. The initial conceptual model was then modified to assume sand and gravel everywhere and treat clay-rich till as inhomogeneities. Inhomogeneity boundaries were drawn in GIS while viewing well logs from on-screen cross sections.

Stream elevations are used as the expression of the water table rather than static water levels in the western area above the buried drift aquifer. Linesinks were drawn by following river and stream lines; each line segment was annotated with beginning- and end-point elevations obtained from USGS topographic maps. Annual reports for watershed districts and water management organizations were reviewed for stream-flow data, which was generally lacking.

Databases of water levels in lakes were acquired. Lakes listed as protected waters by the Minnesota Department of Natural Resources were treated as area elements and assigned an elevation from USGS topographic maps. A decision has not been made about how major wetlands will be addressed in the model.

The water table model will be less detailed than the bedrock model. Although the drift is geologically more complex than the bedrock aquifers, the available data do not allow accurate three-dimensional mapping of the drift. However, it is anticipated that certain areas will be identified where recharge to the bedrock from drift deposits is by a more rapid path.

Both models will be extended into Carver County because the Carver-Hennepin political boundary is not a river system. Detailed work in Hennepin County will focus on areas where municipalities have public supply wells in Quaternary deposits. GIS automation of topographic relief is being considered. Impervious cover created by high-density development and its effect on recharge may be an aspect of planning that the model can address because land cover is part of the existing GIS graphics data base.

Checking Model Results with the Real World

Currently, the bedrock model is being calibrated and elements for the water table model are still being drawn in GIS. Flow values from gaging stations on the major rivers and observation wells will be used to refine the models. Two synoptic water level measurements were taken in 1994 as part of the project: one mass measurement was conducted in February under winter pumping conditions and a second measurement in August to reflect summer usage. More than 165 wells were measured each time within a 5-day period. Several municipalities agreed to measure their own wells. The remainder of the synoptic well measurements were taken by HCD staff and summer interns.

Equipment and Software

GIS is used to draw model elements on screen while viewing various maps, such as bedrock contact, which act as a guide to the modeler. GIS routines generate the AEM data files and plot model results on a parcel base map. HCD used Ultimap GIS software on the Hewlett Packard 425 workstation.

The GIS workstations do not actually run the AEM software to solve for the model. Data files generated in GIS are exported as ASCII files using PCTCP to a 486DX2 PC. The model generates ASCII check files for calibration and flow paths for each well using 10-year and 25-year time-of-travel criteria which are then exported back to GIS. Wellhead protection area boundaries are automated in GIS by plotting the coordinate points of the flow paths generated by AEM and then drawing an envelope around them. The WHPA boundaries can then be viewed on a parcel base map with any combination of property lines, streets, waterways, and potential contamination sites.

Two Hennepin County cities, Minnetonka and Eden Prairie, agreed to serve as pilot communities for the project. The two cities have adjoining jurisdictions and both pump their municipal supply from the Prairie du Chien-Jordan aquifer. HCD completed an initial contaminant source inventory and well inventory for each city. Each city has informally agreed to continue the project and participate in development of a Wellhead Protection Plan in 1995. The intent is to make model results and data files available to the public at project completion.

For questions, comments or suggestions about this project, please call MN Dept. of Health, Special Services, (612)623-5167, or the Hennepin Conservation District, (612)544-8572.

Near-Surface Geophysics: A Tool for the Hydrogeologist

Introduction

Near-surface geophysics can be used to determine many things from the location of buried trash to the subsurface geologic conditions. Surveys are conducted to find buried metal and tanks, ground water contamination and plumes, the bedrock subcrop (elevation and lithology), and sink holes and voids and to investigate stratigraphy (both glacial and bedrock).

Both environmental investigations and engineering projects begin with an assessment of the conditions at the work site. Near surface geophysics can be very valuable during this initial assessment phase. The first priority on an environmental site is to find out what is on the site and where it is located. Without this information, a cleanup plan can't be made.

Site assessment is also the first phase of an engineering survey. The geotechnical parameters, such as the soil conditions, depth to bedrock, and depth to ground water need to be determined prior to the design phase.

Near surface geophysics is one of the quickest and least expensive options for site assessment. Its noninvasive character helps prevent the spread of contamination and keeps the cost low. It produces accurate results without digging or drilling.

There are many types of near surface geophysical surveys. Some of the most common surveys include seismic refraction and reflection, electromagnetic (EM), resistivity, and ground penetrating radar (GPR). This report will discuss the seismic refraction and reflection techniques. Other techniques will be discussed in a future article.

Seismic Refraction Primer

The seismic refraction technique measures changes in the velocity of geologic materials with depth. This method assumes that

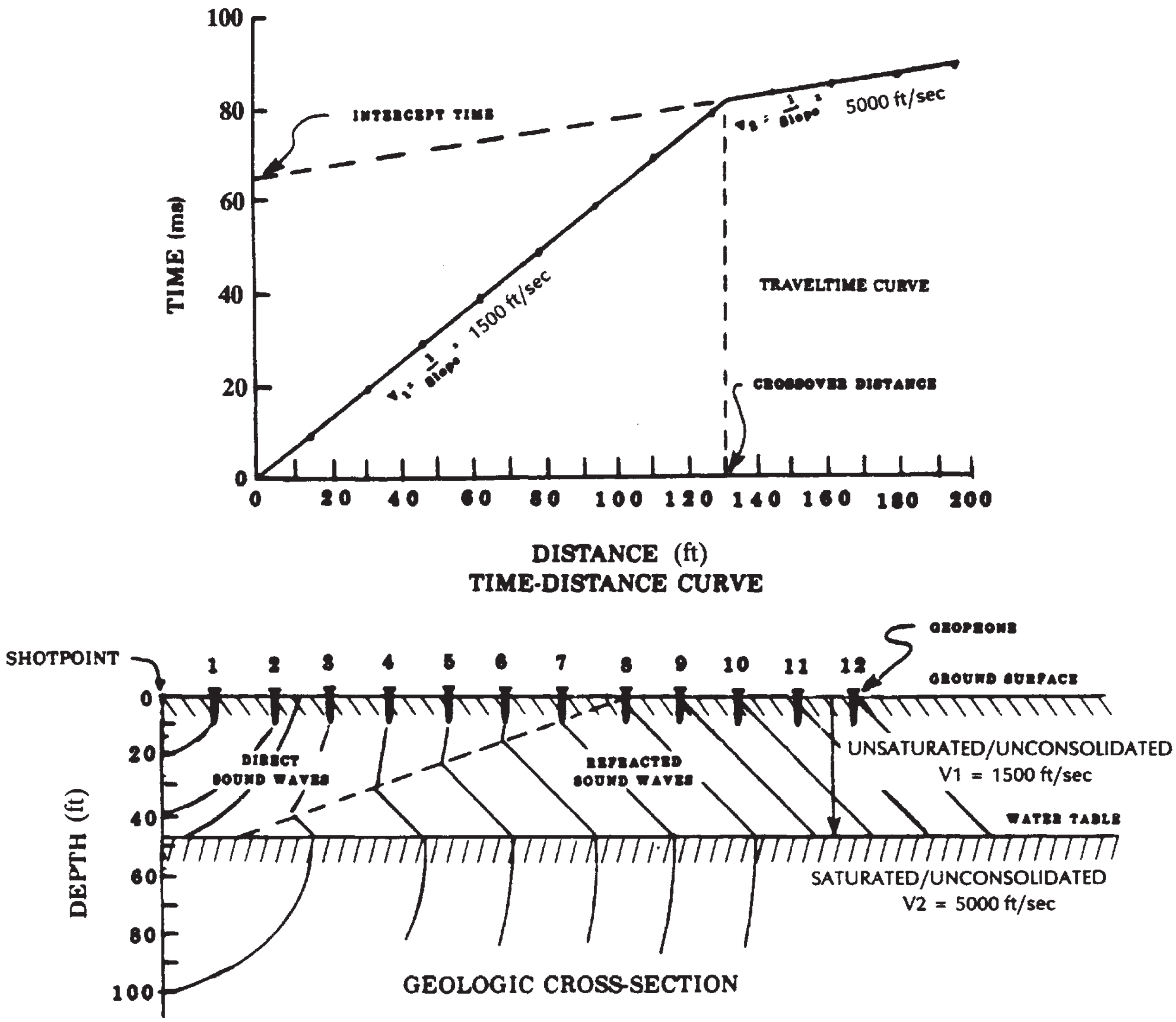

Figure 1: Diagrammatic geologic cross-section and resulting time distance curve using the seismic refraction method. (Modified from Haeni, 1986.)

the earth consists of a series of layers, and that deeper layers have a higher velocity than shallower layers. Resolution is limited to three or four velocity layers. Small velocity changes either vertically or laterally are not distinguishable.

Applied to common engineering and environmental problems, seismic refraction surveys will typically resolve three layers: the unsaturated/unconsolidated zone above the water table, the saturated/unconsolidated zone below the water table, and the top of bedrock. The thickness of the first two zones and the seismic velocity of all three zones can be determined.

Seismic surveys require an acoustic (sound) wave source, a line of geophone sensors, and a seismograph to record the data. A sound wave is input at the shot point: usually with a sledge hammer, or larger weight drop, pipe gun, or explosive. This sound wave propagates from the shot point to the line of geophones.

The seismic refraction method is based on Snell's Law, which describes the bending of a ray path across an interface where the wave propagation velocity changes. If a seismic wave travels into a layer of higher sound velocity, the ray path will be bent away from the normal (an imaginary line at 90° to the interface). At some critical angle, the ray path will be bent 90° from the normal and will travel along the interface as a head wave or refraction wave (see Figure 1). These refraction waves will be produced at all geologic boundaries where the seismic velocity of the lower layer is significantly larger than the layer immediately above it. The head wave continually leaks energy back to the surface, these refracted sound waves are then observed by the geophones.

The seismic refraction method uses only the first arrivals (the first seismic energy to reach the geophones). First arrivals are formed by the direct wave and by refracted head waves (see Figure 1). The direct wave is the first arrival for the geophones nearest the source. Refracted arrivals form the first arrival for geophones farther out. On Figure 1, the direct arrival is the first arrival for geophones 1 through 7 and the refracted arrival from the water table is the first arrival for geophones 8 through 12.

When the first arrival data are plotted as arrival time versus geophone-source distance, the first arrivals lie along a line for each geologic layer; the slope of the line will decrease with each deeper layer.

The inverse slope of these lines is equal to the velocity of the geologic medium where the wave is propagating. For example, for geophones 1-7, the inverse slope of the first arrival times is equal to the velocity in the unsaturated zone, and the inverse slope of the first arrival times for geophones 8-12 is equal to the velocity of the saturated zone. If the geophone spread is long enough, any deeper layers, that have a higher velocity, will show up. For example, an arrival from the bedrock would be the first arrival for geophones at some larger distance beyond geophone 12. While there is no theoretical limit to the number of layers visible with seismic refraction, the practical limit is three or four layers.

Seismic velocity values provide good information on lithology and water saturation. Typical seismic velocities are given in Table 1. Unconsolidated sediments have velocities ranging from 1000 to 8000 ft/sec. If they are saturated with water, their velocity will be at least 5000 ft/sec. Bedrock typically has higher velocities than unconsolidated sediments. Sandstone velocities range from 4600 to 14200 ft/sec, limestone velocities range from 5600 to 20000 ft/sec and igneous/metamorphic rocks have velocities which typically range from 15000 to 28000 ft/sec. Velocities also vary considerably with porosity, fracturing and percent saturation, but these are good general guidelines.

Many parts of Minnesota are ideal for investigations using seismic refraction. Most of the state has a blanket of glacial material overlying igneous/metamorphic bedrock. This produces a very high velocity contrast and makes the determination of depth to bedrock relatively easy.

Table 1: Ranges for seismic velocities in various geologic materials.

Geologic Material	Range of Seismic Velocities (ft/sec)
Unconsolidated Sediments	1000 - 8000
Sandstones	4600 - 14200
Limestones	5600 - 20000
Igneous/metamorphic	15000 to 28000

Table 2: Comparison of seismic reflection and refraction.

Seismic Reflection	Seismic Refraction
Deeper penetration	Shallow penetration
Better resolution	Maximum resolution 3 or 4 layers
Allows horizontal changes	Assume layers horizontally consistent (only vertical changes)

Although much of Minnesota has a relatively flat topographic surface, there is often a very irregular bedrock surface underlying glacial deposits. The irregular thickness of the glacial blanket is not always easy to determine from surface observations alone. Thus geophysical information can be very useful. Some of the common geologic problems which can be solved with seismic refraction are the location of buried valleys (common in southeast Minnesota), the delineation of granite knobs (in central Minnesota) and the depth to the water table in unconsolidated sediments.

By defining aquifer boundaries, such as the depth to the water table and to bedrock, this method is very useful to the hydrogeologist.

Seismic Reflection Primer

The seismic reflection technique also measures changes in the velocity of geologic materials with depth. Data are collected in a similar manner to seismic refraction, in fact they can be collected at the same time. Seismic reflection surveys for typical engineering or environmental site investigations usually use 12 to 24 geophones, the larger the number the better.

The major difference between reflection and refraction is that reflection uses the entire seismic waveform. This waveform (which is a plot of ground motion as a function of time) is plotted as a trace for each geophone, and each geophone trace is plotted relative to its absolute surface location. This gives a distance versus time plot (similar to the refraction plot) which can be interpreted for depth. The seismic refraction technique uses only the first arrivals from this plot. Another major difference is that the geophones are spaced more closely (10'-15') for reflection than for refraction (10' to 30'). Because of these differences, seismic reflection has a deeper penetration and better resolution than seismic refraction. Table 2 summarizes these differences.

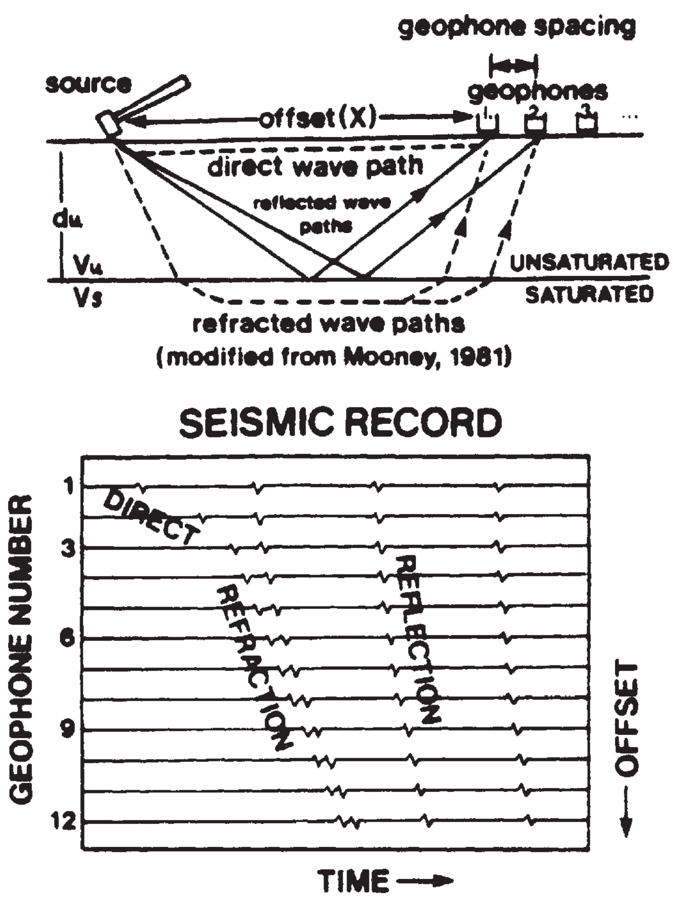

Figure 2: Idealized cross section of direct, refracted and reflected wave paths from seismic source to geophones and idealized seismic record. (Modified from Mooney, 1981.)

The data is processed to focus on the reflected wave paths (Figure 2). Sound waves will reflect off any interface with an impedance contrast, that is, a change in velocity or density. Because of this, the seismic reflection method is not limited to areas where the velocity increases with depth, as is refraction.

Seismic reflection is a very good tool for stratigraphic studies. Intraglacial stratigraphy, which is not definable through refraction, because velocity does not increase with depth, is possible with seismic reflection. The bedrock stratigraphy of southeast Minnesota is also much easier to resolve with reflection.

Defining the intraglacial stratigraphy of Minnesota is very useful from a number of perspectives. It is very helpful in defining the water resources in confined drift aquifers in western Minnesota. It is very useful in mineral exploration. It is also potentially very useful in Quaternary mapping.

Seismic reflection will help better define the bedrock stratigraphy of southeast Minnesota, by extrapolating information on bedrock strata beyond wells and outcrops. It will be possible to map the edges of confining beds and aquifers. This will improve the boundary conditions for ground water models and studies. It is a good technique to better image the hidden subsurface geology.

Equipment needed

Seismic studies require an engineering seismograph, marine batteries for power, a set of 12 or 24 geophones, and cables to connect them, a seismic source (such as a sledge hammer or dynamite), and a computer (to download data from the seismograph and to process the data). This equipment is relatively expensive, especially for seismic reflection work, which requires more complex switching equipment and a seismograph capable of finer resolution.

Data reduction

Data reduction for seismic refraction is typically done by computer program. The programs available vary in their assumptions from those that assume all layers are planer, to more complex ones, that allow for the natural rugosity or "bumpiness" of geologic interfaces. Seismic reflection processing requires an even more complex computer program, which includes the capability of time signal analysis.

As with any specialized field, it is imperative to hire staff people who are well acquainted with the seismic technique to do the field work and to process the data. If staff and equipment are not available it would be prudent to subcontract this work to a specialist, who can get good results for a reasonable cost in both time and money.

– Todd Petersen, Minnesota Department of Natural Resources, Division of Waters

Minnesota DNR Geophysical Capabilities

The Minnesota DNR has three geophysicists on staff in the geophysics group. The primary responsibility for the group is to conduct various geophysical surveys to support water resource investigations by State and Federal Governmental Agencies. The group also does research in the application of the seismic reflection technique in glacial terrain for aquifer definition, mineral potential, and Quaternary mapping. A secondary responsibility is to review geophysical reports submitted to the State of Minnesota.

Further reading on the topic of geophysical methods.

Dobrin, M. B., and others, 1988, Introduction to Geophysical Prospecting, Fourth edition, McGraw-Hill, Inc., 867 p.

Haeni, F. P., 1986, Application of Seismic Refraction Methods in Groundwater Modeling Studies in New England, Geophysics, Vol. 51, No. 2, 236-249.

Mooney, H. M., 1981, Handbook of Engineering Geophysics: Bison Instruments Inc., 191 p.

— Sue Magdalene explains her research to an interested group, photo by Kelton Barr.

COMMENTARY

"Near-Surface Geophysics: A Tool for the Hydrogeologist"

Commentary by Todd Petersen, MN DNR Waters

Major changes have occurred in near-surface geophysical techniques since this article was written in 1991, largely because of greatly improved electronics in the recording instruments and in computer processing power.

The seismic refraction and reflection techniques for shallow environmental and ground water exploration have not changed a lot. However, the recording equipment and computer processing power have greatly improved. The best engineering seismographs in 1991 had 16-bit analog to digital (A/D) converters that allowed an amplitude ratio from the highest to the lowest of about 65 thousand to one. New seismographs have 24-bit A/D converters that allow an amplitude ratio of about 16.8 million to one. The new seismographs can record all relevant amplitudes generated during a seismic survey and allow much better interpretation of low amplitude signals. This allows more accurate interpretation of data that is very deep (greater than a few hundred feet below land surface). The new laptop computers have much greater processing and storage capability and can now process the largest surveys conceivable for engineering and ground water applications. Reflection surveys collected in 1991 created so much data that it was difficult to store on media available at the time. One reflection line required many boxes of high-density (1.44 kb) diskettes. Today, even more data is collected, but it easily fits on the hard disk inside the seismograph or on backup CDs.

Resistivity surveys (only briefly mentioned in the introduction) have also greatly improved since 1991. In 1991, resistivity data were either collected as vertical soundings or horizontal profiling. The data collected for a vertical sounding usually consisted of tens of data points (20 to 50) and were compared to a forward model of a simple layered earth (usually 3 or 4 layers). Horizontal profiling was used to qualitatively map horizontal changes in the area of interest. Today, computerized resistivity meters automatically collect hundreds of readings per line and powerful inversion software converts the raw data to 2-D and 3-D representations of resistivity versus depth.

The basic physics behind these techniques is unchanged, but major advances have occurred in both geophysical instrumentation and computer processing capability. These changes mean that geophysics data can be collected and processed more efficiently today and the interpretation often has greater certainty than in 1991.

Use of Chemical and Isotopic Data for Wellhead Protection Area Delineation in Fractured Aquifers

— James Walsh, Minnesota Department of Health

Groundwater flow in fractured aquifers is poorly understood. As a result, wellhead protection area delineations for fractured aquifers that are based solely on groundwater flow modeling are accompanied by considerable uncertainty. Chemical and isotopic data may be useful in some instances to minimize this uncertainty.

The chemical and isotopic characteristics of well water reflect sources of recharge. If a well captures water from two sources, such as groundwater and surface water, water from that well will plot along a line connecting water from those sources for any pair of conservative constituents, such as oxygen-18, deuterium or chloride. A tie-line connecting the two end-member sources can be scaled off and the percentage of each source present in the mixture determined (Figure 1). This is the basis for the mass balance approach to mixing (Dysart, 1988). This technique is only applicable if 1) there is a significant difference in the initial end-member compositions and 2) compositional variations in the end-members are known.

Case Study

National Steel Pellet Company is located adjacent to the city of Keewatin on the Mesabi Iron Range in northeastern Minnesota. Both National Steel Pellet Company and the city of Keewatin derive their drinking water from wells completed in the Biwabik Iron Formation, a middle Precambrian sedimentary unit consisting primarily of fine-grained silica and iron oxide minerals. Permeability within the Biwabik Iron Formation is thought to be limited primarily to fractures.

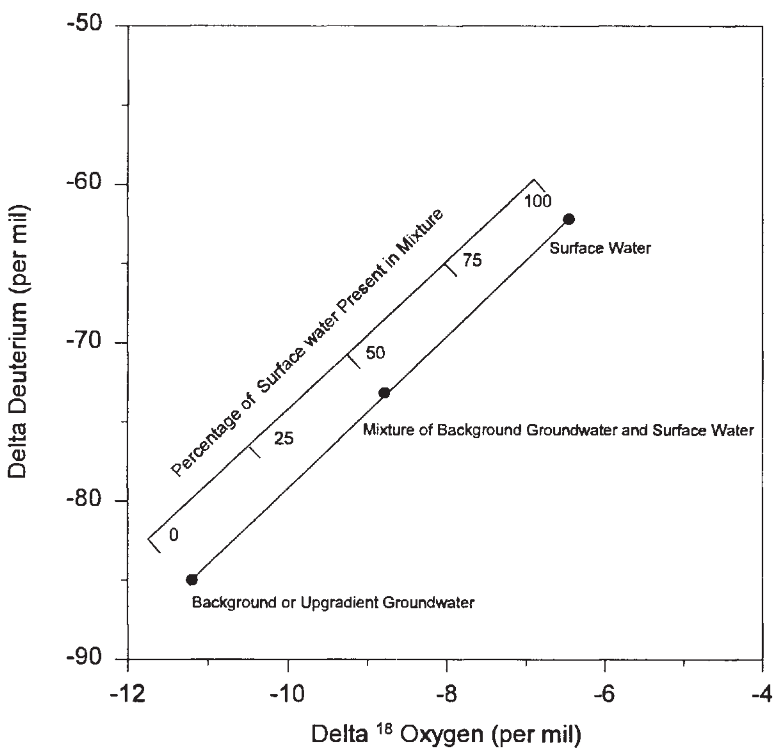

Figure 1: Example of mass balance approach to water mixing using oxygen-18 and deuterium. This figure shows that the mixed sample contains roughly equal parts of surface water and background ground water.

Mining in the Keewatin area has created a number of deep pits in the Biwabik Iron Formation. Some of the mine pits are dewatered and are actively being mined, others have not been mined for 30 to 40 years and are mostly water-filled. Water levels in the dewatered mine pits are 100 to 200 feet lower than the water-filled pits, suggesting that these are major sinks in the local groundwater flow system.

In an effort to characterize sources of recharge to National Steel Pellet Company and Keewatin wells, the wells and nearby mine pits were sampled in February and August of 1996 for major element chemistry, oxygen-18, deuterium and tritium. Oxygen-18 and deuterium proved particularly useful because these isotopes are concentrated in surface water exposed to evaporation, such as lakes. The Keewatin #1 well and some of the dewatered mine pits plot on the meteoric water line, indicating recharge from unevaporated precipitation, whereas the water-filled pits fall well off this line due to evaporation (Figure 2). These groupings constitute end-member sources whose mixing along groundwater flow paths creates intermediate compositions, such as those seen at Keewatin #2 well and the National Steel Pellet wells. Further analysis of the major element chemistry of the pit waters indicated that a single water-filled pit, the Carlz, contributes 35% to 50% of the water drawn from Keewatin well #2 and the National Steel Pellet Company main well (Figure 3).

The chemical and isotopic information described above was used to construct and calibrate a simple analytic element groundwater flow model for the purpose of defining the wellhead protection areas for the National Steel Pellet Company and Keewatin wells away from the Carlz pit hydrologic boundary. The Carlz pit was simulated as an areal element with given head and resistance. Resistance to flow through the base of the pit was adjusted until approximately 50% of the particle trace pathlines generated from the

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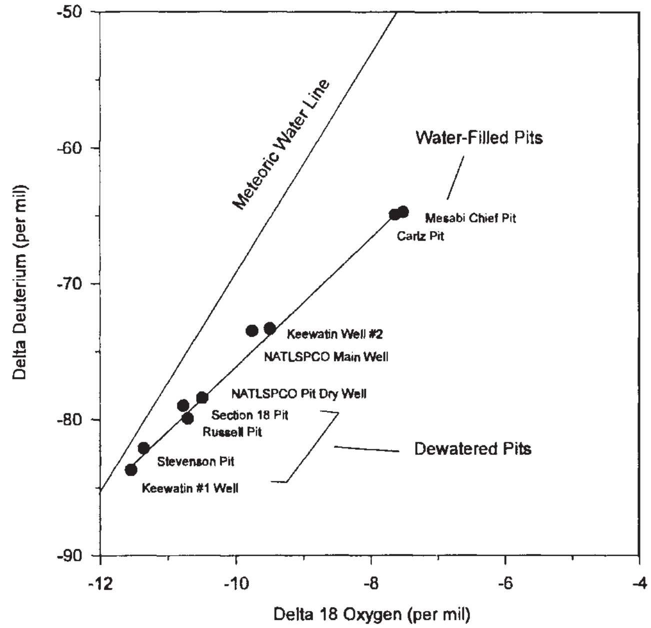

Figure 2. Deuterium and oxygen-18 results from February, 1996.

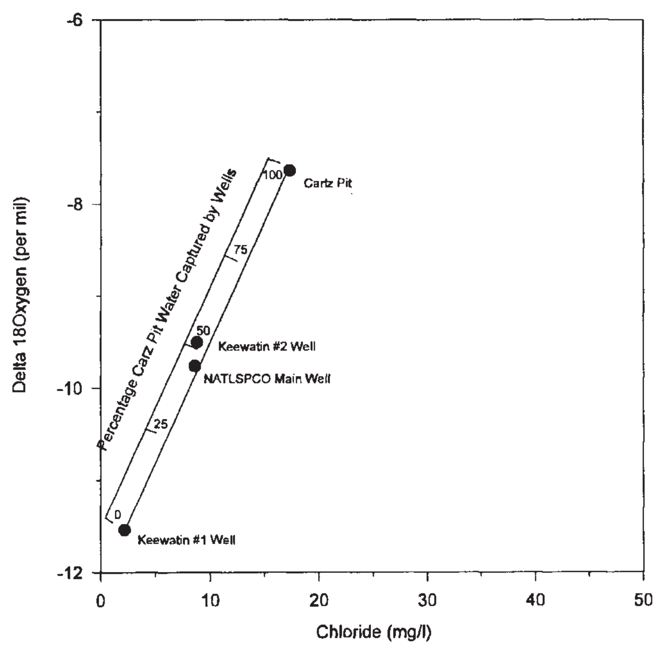

Figure 3. Mass balance mixing analysis based on oxygen-18 and chloride from February, 1996.

Wellhead Protection, cont.

Keewatin #2 well and National Steel Pellet Company office well terminated at that pit.

The final step in determining the wellhead protection areas for the the Keewatin #2 well and National Steel Pellet Company main well was to include the watershed of the Carlz pit. It is important to include watershed boundaries whenever a surface water feature can be demonstrated to recharge that portion of the aquifer within the delineated wellhead protection area.

Reference:

Dysart, J.E., 1988, Use of Oxygen-18 and Deuterium Mass-Balance Analysis to Evaluate Induced Recharge to Stratified-Drift Aquifers. American Water Resources Assoc., Monograph Series 11.

COMMENTARY

Update to "Use of Chemical and Isotopic Data for Wellhead Protection Area Delineation in Fractured Aquifers"

By James Walsh, Minnesota Department of Health

Changes since original article was published:

Since the time the original article was published, we have become increasingly reliant on the use of chemical and isotopic data for solving problems related to wellhead protection. This is particularly true in fractured or karst aquifer settings, where an unusually high degree of uncertainty is associated with standard well capture zone delineation techniques. However, these tools have also found increasing use in porous-media settings, particularly where nearby surface water bodies may function as hydrologic boundaries. Aside from the fingerprinting of well recharge areas in both fractured bedrock and porous-media settings, chemical and isotopic data are now routinely used for 1) general aquifer characterization, 2) assessing the vulnerability of wells and aquifers to contamination, 3) recognition of well construction problems (leaky well casings), 4) contaminant source identification (especially nitrogen and carbon isotope forensics), and 5) determination of mixing ratios within wells that are open to more than one aquifer or productive conduit/fracture. Chemical and isotopic data are also increasingly being paired with borehole geophysical data to more accurately discern zones of preferential flow within wells and the aquifers they tap.

Anticipated changes in the future:

As technological advances occur in analytical methods, reductions in detection limits and analytical costs should follow. This should allow for routine inclusion of chemical and isotopic data in a wide range of hydrogeologic investigations, including those dealing with wellhead protection area delineation. As an example, the MDH lab now offers analysis of both

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Update on Isotopic Data for WPA Delineation, cont.

bromide and chloride for relatively low cost ($24) and at reasonably low detection limits (0.005 mg/l for Br and 0.5 mg/l for Cl) using ion chromatography. As a result of this recent development, many samples collected for wellhead protection projects that had previously been analyzed only for chloride are now routinely analyzed for both components. The additional information derived from analysis of the ratios of these solutes can provide useful insights into the sources of salinity within a well capture zone. This information in turn can be used to verify wellhead protection delineations. In addition, tools developed or advanced at research institutions such as universities and the USGS should continue to trickle down to general practitioners at the state government and private consulting levels. Isotopic methods that were once perceived as exotic, such as tritium and the stable isotopes of water, are now routinely used by groundwater investigators. This trend should continue with other tools, such as sulfur hexafluoride (SF_6) for age-dating and strontium isotopes for tracing flow paths and source areas.

— Bob Beltrame, 1993 Field Trip guide, speaks to the group at the Morton Quarry.

— Chris Elvrum envelopes a student in a big bubble at the 2004 Metro Children's Water Festival.

— MGWA President Laurel Reeves presents the MGWA Outstanding Service Award to Dr. Hans-Olaf Pfannkuch. The text on the plaque can be read in the inset at right.

Natural Contaminants and Monitoring

Radium in Drinking Water

by L. Lehman & Assoc.

The water supply of the City of Savage has been found to contain a higher level of the element radium than is allowed by National Drinking Water Standards. The City of Savage is now taking the steps necessary to comply with the Standard.

Radium in water supply wells is a problem that is not unique to Minnesota. The U.S. Environmental Protected Agency (EPA) (1984) states that of 59,872 community drinking water supplies in the United States, from 2,500 to 5,000 may exceed the radium standard. In order to make the safest and most cost effective decision on lowering the radium concentrations, several questions must be addressed:

- What is radium?
- Where does it come from?
- How does it get in the water?
- How can we get rid of it?
- What are the health risks?

WHAT IS RADIUM AND WHERE DOES IT COME FROM?

Radium is a naturally occuring element that is formed from the radioactive decay of uranium. There are two (2) isotopes of concern; radium 226 and radium 228. Radium 226 has the longest half-life which is 1,620 years. A half-life is the time it takes for an isotope to decay to one-half the initial amountl. Uranium occurs widely throughout the geologic environment although usually in minute quantities. The age and type of rock generally influence the amount of radium and uranium. The highest concentrations are usually associated with very old granitic rocks and sandstones formed from granitic rocks.

Occurences of higher than normal concentrations have been reported in Wisconsin, Illinois and Iowa in the Great Lakes/Midwest region. Other states with reported high concentrations are North Carolina and Maine; areas which are also underlain by old granitic-type rocks. Since radium is a product of the decay of uranium, older rocks will generally contain higher concentrations of radium. A map published in 1961 by the United States Geological Survey (USGS) shows the location of areas containing high radium (Figure 1). The large area of high uranium in the Great Lakes region should now be expanded further into Minnesota.

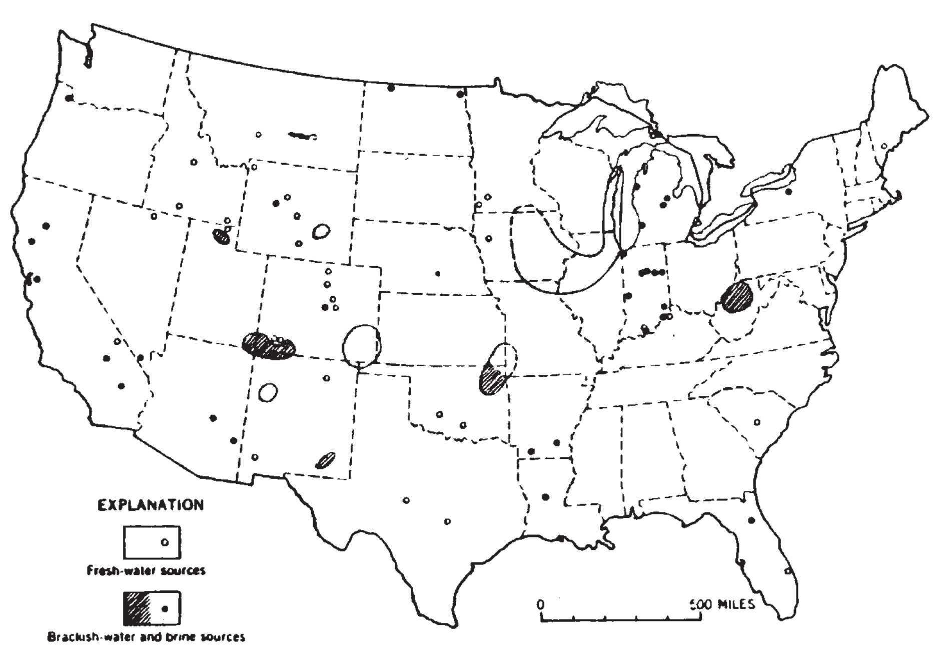

Figure 1 -Location of ground-water sources containing high concentrations of radium.

HOW DOES RADIUM GET IN OUR WATER?

The City of Savage gets its water from three (3) wells drilled deep into the bedrock. The geologic column in Figure 2 depicts the geologic formations that underlie Savage. Two of the City's wells are drilled into the Jordan formation, and the third is drilled into the Mt. Simon-Hinckley formation.

Both the Jordan and the Mt. Simon-Hinckley formations are predominantly sandstones that are quite old in terms of geologic time. They are of Cambrian Period, i.e., older than 485 million years. It is most likely radium is somewhat concentrated within these units, and is therefore leaching into the water drawn from the wells.

HOW CAN RADIUM BE REMOVED FROM THE WATER?

There are several options the City is considering. These options are as follows:

- Replace water supplies with new wells.
- Correct supply within existing wells.
- Treatment.
- Some combination of the above.

Water Supply Replacement

New wells could be drilled into more shallow formations which do not contain as much radium. Care must be taken in locating shallower wells since the pollution potential from surface contaminants is greater than for deep wells, especially from nitrates.

Correct problem at existing wells

This option involves pulling out the existing pump and utilizing special well logging techniques to locate high radium zones within the well. The precise levels where radium occurs are determined by a series of highly sophisticated testing devices which are further verified by down-hole videotaping. Once the high radium zones are located, it may be possible to block them off and only draw water from less radioactive units within the well. This method has been successfully utilized in Wisconsin.

Water Treatment

Processes that are effective in removing radium from drinking water include lime softening, cation exchange, reverse osmosis and selective adsorption.

Lime softening is best suited for large capacity plants. This process requires more complicated equipment and demands more operating supervision.

Cation exchange to replace calcium and magnesium ions with sodium ions to soften water is a widely practiced technology. If radium is present in the water, it will be removed with the hardness since radium is similar in chemistry to calcium and magnesium. The problem with this process is it adds to the sodium content of the water. This could be a potential problem for people with restricted diets and hypertension. Potassium chloride could be used as a substitute for the sodium chloride, but costs approximately five (5) times as much.

Reverse osmosis is a relatively new technology, and is commonly used in areas where water has a high total dissolved solids content (or high salinity). This process utilizes a membrane which allows the passage of the water, but not the dissolved salts. Pressure is required to force the water through the membrane. Compared to other treatment techniques, reverse osmosis is relatively expensive to operate due to high energy requirements for pressure pumps.

Removal processes via adsorption, although in the development stages, should be given consideration due to their potential to remove radium. One of the adsorption processes utilizes the capabilities of manganese dioxide to adsorb metal ions. The drawback to treatment is the need to dispose of the various residues. If the plant removes the radium from the drinking water, radium will accumulate to relatively high levels at the plant. Sewer disposal of these residues may be possible if concentrations are kept below levels specified by the U.S. Nuclear Regulatory Commission for hospital wastes. The allowable levels for sewer disposal within the State are not currently defined for naturally occuring radiation.

WHAT ARE THE HEALTH RISKS?

The Safe Drinking Water Act specifies five (5) picocuries per liter of radium is the allowable limit for drinking water supplies. The average amount in the three (3) Savage wells is 9.3 (pCi/liter). A picocurie is one trillionth or 1/1,000,000,000,000 or a curie.

What we know of the carcinogenic effects of radium comes primarily from two group studies: 1) several thousand German patients who received injections of radium as therapy for tuberculosis, and 2) about 2,000 Amercian watch-dial painters who ingested as much as 2,000 micro curies (1/1,000,000 curies). These luminous watch-dial painters ingested the radium by "tipping" the paint brush in their mouths in order to keep a fine point on the brush.

Because of its similarity to calcium, nearly 90% of the naturally occuring radim contained in the body resides in the bones. Consequently the primary risk from radium ingestion is cancer of the bone, or of the tissues within the sinus cavities of the bone. Cancer caused by radium ingestion does not occur in every person who has been exposed, nor does it appear until many years after ingestion.

Cancer risk is quantified by first determining the dose to the bone from continuous ingestion of radium. If a person drinks two liters of water a day containing 5 pCi/liter over a 70 year period, the result would be a lifetime dose of 6,440 millirems (mR) to the skeleton. By comparison, we would receive a lifetime dose of about 5,600 millirems from cosmic rays and other external naturally occuring background radioactive materials.

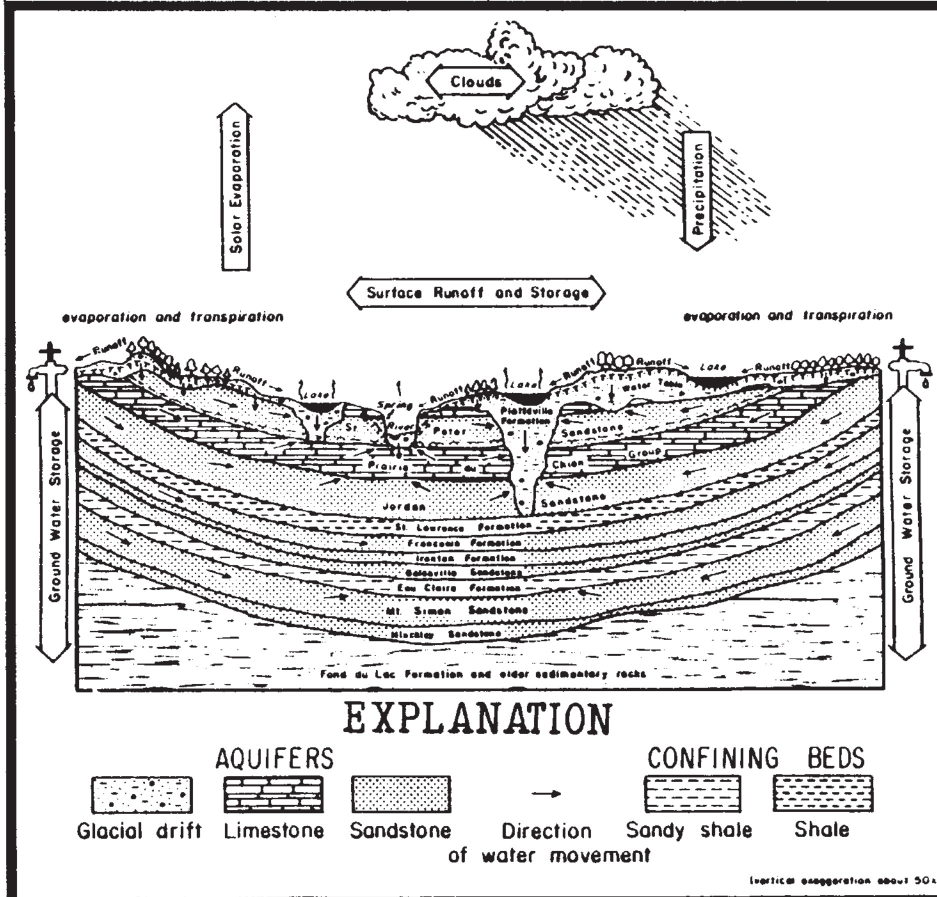

Figure 2 Diagrammatic section through Twin City basin showing probable direction of water movement.

The lowest known intake of radium to cause a tumor is about 9 microcuries. The body is though to retain only 20% of the radium ingested. From this basis, we can calculate how long it would take to accumulate 9 microcuries in our bodies from drinking Savage municipal water. Another assumption is we consume two liters of water daily.

The calculation is as follows:
2 liters/day X 9.3 pCi/liter = 18.6 pCi/day
18.6 pCi/day X 20% ingestion = 3.72 pCi/day
9 microcuries = 9,000,000 pCi divided by 3.72 pCi/day = 2,419,355 days divided by 365 days/year = 6,628 years

It is doubtful any of us will live this long.

No immediate health effects are known to result from low levels of radium ingestion. The risks of genetic effects in subsequent generations are also thought to be much lower than general cancer risks. The EPA has calculated a population consuming water at the Safe Drinking Water Act limits would have a death rate per lifetime of 44 deaths per million. Translated to a community of 10,000 people at the concentrations we are drinking, this is approximately equivalent to 1 death every 80 years.

WHAT CAN WE DO UNTIL THE CITY CORRECTS THE PROBLEM?

A residential water softener which removes calcium and magnesium will also remove radium. To bring the concentrations to within the Safe Drinking Water Standard, you will need to dilute the unsoftened tap water by half. If you have a water softener, you can mix the softened water (usually the hot water tap) half and half with the cold tap water. However, this process raises the level of sodium in the water. Persons on sodium restricted diets should be aware of this. If you personally feel the need to take additional measures, buy distilled water for consumption, or mix distilled water half and half with cold tap water

FOR MORE INFORMATION:

Attend the Spring Meeting, announced elsewhere in this newsletter.

Updating Our Understanding of Radium in Minnesota Groundwater

By Jim Lundy, Minnesota Department of Health

Since Linda Lehman's review of radium in Minnesota's drinking water appeared in 1988, Minnesota groundwater scientists have focused attention on anthropogenic pollutants. A smaller, but significant effort has been expended toward the understanding and regulation of naturally occurring contaminants in groundwater, including radium. One result of this effort was a data-rich 1992 Minnesota Geological Survey publication entitled "Radium in the Mt. Simon-Hinckley Aquifer, East-Central and Southeastern Minnesota" (Lively, et al., 1992), and this study has formed a solid foundation for further inquiry into radionuclides in Minnesota groundwater.

A driving force behind the need for further inquiry is the finalized the "Radionuclides Rule" (66 FR 76708; December 7, 2000, vol. 65, no. 236), which hovered over public water suppliers in interim form since 1977, with the Maximum Contaminant Levels (MCLs) listed in Table 1. Further information on the Rule is located at www.epa.gov/safewater/radionuclides/regulation.html.

Anticipating rule finalization, studies performed in New Jersey, North Carolina, New Mexico, Wisconsin, and elsewhere further defined conditions in which naturally occurring radium in groundwater is expected. Hydrogeochemical conditions emerged as important controls on radium occurrence in groundwater, because studies showed that reducing conditions—conditions typical of Minnesota's confined aquifers—favor the release of radium to solution.

However, Lively, et al. (1992) found radium to be distributed non-uniformly across Minnesota's most notorious radium-producing aquifer, the Mt. Simon Sandstone. The non-uniform radium distribution would be expected if hydrogeochemistry is the major control on radium occurrence, and if hydrogeochemical conditions within Minnesota's aquifers vary similarly to those under study elsewhere in the nation.

However, the pH range of Minnesota's confined aquifers is generally narrower (7.0 < pH < 8.0) than those reported elsewhere (4.0 < pH < 10.0), and dissolved oxygen is generally low (< 1.0 mg/L). The variable radium distribution within relatively uniform, consistently reducing hydrogeochemical conditions points to the possible existence of yet unidentified controls on radium occurrence.

The Minnesota Department of Health (MDH) is using data from Lively, et al. (1992) combined with more recent public water supply well data and other recent sampling data to help constrain conditions under which municipalities can expect to encounter radium in ground water at emission rates exceeding the federal MCL for public drinking water. So far, the following activities have been completed or are underway:

- Define patterns of radium occurrence in Paleozoic aquifers beneath the Twin Cities and southern Minnesota. The pattern of radium occurrence within groundwater of the Mt. Simon Aquifer beneath the Twin Cities Metro Area (TCMA) has been defined (Minnesota Department of Health, 2007). Additional mapping is planned to include younger aquifers (e.g., the Franconia-Ironton-Galesville, Jordan) in the larger area of Paleozoic subcrop beneath southeastern Minnesota.
- Identify potential indicator analytes for radium occurrence. Analytical costs for radium (^{226}Ra + ^{228}Ra) are high, driving the search for cost-effective surrogate analytes. Over 20 analytes and other factors were assessed for their utility in predicting radium occurrence.
- Determine the pumping time-dependence of radium measurements. For some infrequently pumped wells, samples collected a short time after pump activation had higher radium levels than subsequently collected samples. Therefore, in 2006 MDH conducted time-series sampling tests at six public water supply wells. Four were conducted at wells completed in the Mt. Simon aquifer and two were conducted at wells completed in the Jordan aquifer, over time intervals ranging from two to over 1000 hours.
- Determine vertical (stratigraphic) distribution of radium on grains of various aquifers. A methodology was developed whereby emission rates of radium daughter product radon ^{222}Rn (conveniently measured in the office using available equipment) are measured. Because ^{222}Rn is produced only by ^{226}Ra, ^{222}Rn emission rates are sensitive to the amount of ^{226}Ra present on sand grains recovered from specific intervals of the Mt. Simon sandstone. The results may help define stratigraphic zones where high radium levels are expected.
- Short-half life radium isotopes in the Mt. Simon Aquifer. A study of short half-life radium isotopes (including the "radium quartet" of ^{223}Ra, ^{224}Ra, ^{226}Ra, and ^{228}Ra) in groundwater from selected Mt. Simon aquifer public water supply wells was performed in 2007 with Duke University. The findings are expected to improve understanding of the transfer mechanism of radium into groundwater.

MDH reports the following summarized conclusions from the above activities:

- Patterns of radium occurrence. Similar to Lively, et al. (1992), radium is present in the Mt. Simon beneath the TCMA at or above the MCL in most locations. Some wells completed across several aquifers have anomalously low radium levels, attributable to dilution. The pattern of radium occurrence in wells open only to the Mt. Simon sandstone suggests a connection with 1) structure, 2) upward groundwater recharge, or 3) both.
- Potential indicator analytes. Most indicators assessed showed little promise as predictors of radium

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Table 1: Maximum Contaminant Levels (MCLs)

Analyte	Maximum Contaminant Level (MCL)
Beta/photon emissions	4 mrem/yr
Gross alpha particle emissions	15 pCi/L
Combined radium 226 and radium 228	5 pCi/L
Uranium	30 ug/L

Updating Our Understanding of Radium, cont.

occurrence or concentration. Although more study is needed, one or more of the following general conditions may favor elevated radium occurrence:

Gross alpha activity above 5 picocuries/L;

Boron concentration above 100 ug/L;

Strontium-magnesium ratio less than 0.10;

Chloride-bromide ratio significantly different than that for rainwater (180:1);

Bromide concentration above a threshold level close to 50 ug/L;

Chloride concentration above background (2 mg/L), or major ion chemistry composed of greater than 20% chloride;

Groundwater major ion chemistry composed of less than 50% calcium;

Groundwater major ion chemistry composed of greater than 10% sodium + potassium.

- Time-series measurements. Many of the time-series measurements indicated that radium and gross alpha generally decline over the first 15-30 minutes of pumping. Major ion measurements were not sensitive to pumped time. Filtered and total samples indicate that much of the excess radium measured initially was due to the presence of mobile solid material upon which the radium is attached. These solids dissipate with pumping time, resulting in decreased radium content. Pumping a well for 15-30 minutes prior to sampling will usually avoid an abnormally high radium result, and will produce a sample representative of the long-term drinking water quality.
- Stratigraphic distribution of radium. The results are preliminary. Cutting samples from the uppermost and lowermost Mt. Simon transferred approximately half the radon content to water as those collected from the middle portion.
- Short-half life radium isotopes. We have received the data from this sampling effort and are working with Duke University to interpret it.

Most of the recently collected evidence supports a conceptual model first outlined in Lively, et al. (1992):

- Mt. Simon Aquifer groundwater acquires radium from aquifer solids.
- The distribution of radium and parent isotopes on solid aquifer material could be either primary or secondary, or possibly both.

If primary, the distribution of radium and parent isotopes on solid aquifer material may be related to sediment source zones (granitic highlands or sediments eroded from them) during the early Paleozoic. Areal and stratigraphic expected patterns of radium occurrence (on aquifer solids and in groundwater) might be related to grain size and maturity.

If secondary, brines originating at depth and occupying pore space prior to a post-Pleistocene melt-water flush could have mobilized radium into the Mt. Simon from deeper zones. Expected patterns of radium occurrence (on aquifer solids and in groundwater) would be irregular but concentrated near sub-vertical fault zones that penetrate the deeper, radium-rich zones.

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— 1993 field trip participant Jay Frischman takes yet another specimen home. Nice hat, Jay!

Minnesota Ground Water Association

www.mgwa.org

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COMMENTARY

Research on Arsenic in Minnesota Ground Water

By Mindy Erickson, Minnesota Pollution Control Agency

In the early 1990s, the U.S. Environmental Protection Agency was reviewing the 50 micrograms per liter (ug/l) arsenic Maximum Contaminant Level (MCL) and considering lowering it. In Minnesota during the same period, regional and statewide ground water studies revealed that west-central Minnesota had elevated concentrations of arsenic in ground water in buried drift aquifers. The early arsenic findings and the expected MCL revision prompted the Minnesota Department of Health (MDH) to conduct the Minnesota Arsenic Study (MARS) during 1998-2000. MARS was a large study of

1) the occurrence of arsenic in west-central Minnesota ground water; and

2) effect biomarkers in people exposed to elevated arsenic from their drinking water.

As described in the December 2000 MGWA newsletter article "The Minnesota Arsenic Study (MARS): Mechanism and Occurrence of Arsenic in Western Minnesota Drinking Water," primary MARS arsenic occurrence results were:

1. the association of elevated arsenic concentrations with the Lower Goose River Group till unit,

2. the geochemical arsenic redistribution and concentration mechanism of a pyrite roll-front, and

3. the variability of arsenic concentrations in small geographic areas within the same aquifer.

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The Minnesota Arsenic Study (MARS): Mechanism and Occurrence of Arsenic in Western Minnesota Drinking Water

— *Michael E. Berndt[1], Richard G. Soule[2], and Melinda L. Erickson[3]*

Abstract

Many groundwaters from glacial aquifers in Minnesota have arsenic concentrations significantly above current and proposed EPA drinking water standards. Evaluating the source and occurrence of this arsenic is obviously a high priority for communities and households both in and outside of Minnesota, where drinking water is supplied from glacial aquifers. To better understand the distribution and origin of this arsenic, approximately 900 wells in a known arsenic "hot-spot" region in west-central Minnesota were sampled and analyzed for arsenic and other parameters during the Minnesota Arsenic Study (MARS). Study wells producing waters with the highest arsenic concentrations tended to be completed down-gradient from surficial regional aquifer recharge features in deep sand units (approximately 100-200 ft in depth), although many wells completed in the same strata produced waters containing little or no arsenic. This distribution and a close association of arsenic with sulfidic groundwaters, together with preliminary evidence for pyrite dissolution and precipitation processes occurring within affected aquifers, suggests that high arsenic in the study area may be a by-product of a pyrite roll-front system advancing through the inter-till aquifer network. Further study is needed, however, to evaluate whether this interpretation is accurate and, if so, to determine the current shape and distributions of these roll-fronts.

Introduction

The EPA recently proposed a lowering of the federal drinking water standard (the Maximum Contaminant Level or "MCL") for arsenic from 50 µg/l to 5 µg/l. This proposed change is of particular significance to Minnesotans because a number of private wells have naturally-occurring arsenic concentrations above the current MCL, and many more, including almost 20% of municipal water supplies, have levels above the proposed MCL. Figure 1 shows the distribution of arsenic in Minnesota groundwater (Minnesota Pollution Control Agency, 1998 and Minnesota Department of Health data).

Unquestionably, the most significant occurrences of high arsenic in Minnesota groundwaters are those produced from inter-till sandy aquifers in Des Moines lobe glacial sediments (Kanivetsky, 2000). This high arsenic led the Minnesota Department of Health to conduct a major study, referred to as the Minnesota Arsenic Study (MARS; Messing *et al.*, 2000). This study was designed to gain a better understanding of the geologic and hydrologic processes responsible for the occurrence of the arsenic in glacial aquifers and to assess human

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MARS Study, cont.

exposure to drinking water containing greater than 50 µg/l arsenic. Water samples were collected from approximately 900 wells in a selected nine-county area and analyzed for arsenic and approximately 30 other key elements and compounds.

Results indicate that arsenic may be elevated as a by-product of an extensive pyrite roll-front system that is actively penetrating into glacial sediments in the study area. This article briefly describes the distribution of arsenic, and provides preliminary evidence that leads to a conceptual model for a possible roll-front system in Minnesota glacial sediments. The human exposure/risk portion of MARS is not addressed here, but is available in Messing (2000).

Arsenic distribution:

Arsenic distribution in the MARS study area revealed a close correlation between high arsenic and the subcropping of stagnation moraines of the Lower Goose River Group glacial unit within the Des Moines lobe glacial complex (Figure 2). In addition, it was found that most high-arsenic samples came from relatively deep, artesian wells rather than from relatively shallow wells. Approximately 7.5% of the samples had arsenic concentrations exceeding 50 µg/l, the current federal drinking water standard set by the US Environmental Protection Agency (EPA), while 65% of samples had arsenic greater than 5 µg/l, the recently proposed and lowered EPA drinking water standard.

While our findings were broadly similar to those of Kanivetsky (2000), who believed that the high arsenic occurs where pH and redox conditions at depth in

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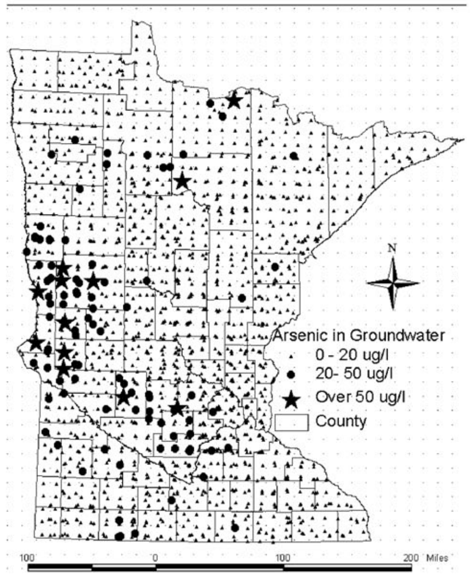

Figure 1: Distribution of arsenic in Minnesota groundwater from MPCA (1998), Ground Water Monitoring and Assessment Program, and MDH data.

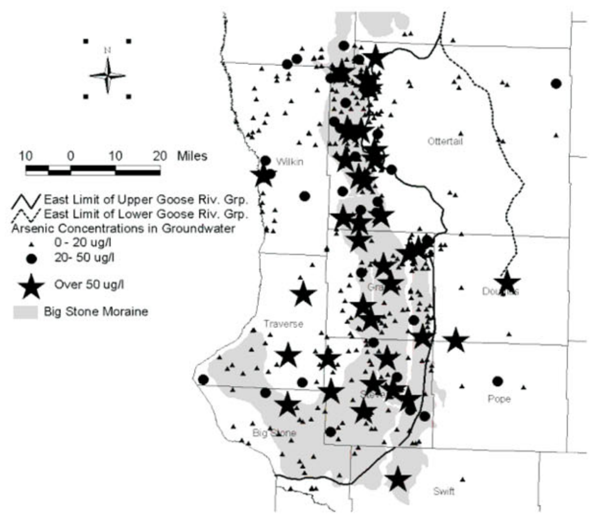

***Figure 2:** Distribution of arsenic in the nine-county area studied in the MARS Study (Messing, 2000). Arsenic correlates well with the occurrence of the Goose River Group of the Des Moines lobe, which, owing to its variable topography and bimodal permeability (tills vs. sand), serves as a recharge area to sandy intertill aquifers beneath. The distribution of high and low arsenic waters in MARS samples is highly complex. However, 7.5% of the MARS wells had arsenic exceeding the current MCL for drinking water (50 µg/l), and 65% had arsenic exceeding the proposed MCL (5 µg/l).*

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Arsenic in Minnesota Ground Water, cont.

Follow-up arsenic research was conducted during 2002-2003 with financial support from MDH, the U.S. Geological Survey, and the University of Minnesota. The follow-up research focused on MDH's need to effectively respond to the new 10 ug/L MCL. Results were presented in the March 2004 MGWA newsletter article "Arsenic in Ground Water: Recent Research and Implications for Minnesota."

Some of the follow-up research questions of particular interest to the Minnesota Department of Health, and the answers included:

1. Does ground water arsenic concentration directly relate to sediment arsenic concentration?

No. Aquifer type and confining layer type are more directly related.

2. Will the arsenic concentration in a newly-drilled well increase or decrease over time?

Neither. Arsenic concentrations in newly-drilled wells remained consistent from drilling date to one year after drilling.

3. What well construction factor most influences arsenic concentration?

Well screen length and its placement relative to the confining unit.

4. How variable are arsenic concentrations over time?

In some cases highly variable over both short time periods and long time periods; it depends on the well. Arsenic concentration variability can have a significant impact on public water systems' compliance with the 10 ug/L MCL.

— Sarah Tufford, MN DNR Waters, now retired. December 2006.

MARS Study, cont.

some glacial aquifers were ideally poised to promote desorption of the element from iron oxides and oxyhydroxides, some of the detailed systematics of the arsenic distributions remained puzzling and difficult to explain by this type of model. In particular, extremely large ranges were found in the concentrations of arsenic from groundwaters with nearly the same chemistry and collected from the same stratigraphic unit. If a simple adsorption/desorption model were responsible for all of the high arsenic, we would expect good correlation between high arsenic and the primary adsorption parameters, pH and Eh, but no clear correlation was found. In effect, the occurrence of both high and low arsenic in the same system suggests that another mechanism, capable of enriching arsenic in some portions of sandy aquifers while depleting others, is affecting arsenic distribution in the MARS study region.

Pyrite dissolution and precipitation in Minnesota aquifers?

Pyrite, a mineral often enriched in arsenic, is common in many Des Moines lobe tills because the Pierre Shale, a geologic unit containing pyrite, was an important source rock for some of the glacial deposits (Schultz et al., 1980). Pyrite in tills is potentially of great significance because this mineral often contains arsenic, and it, like many other sulfide minerals, is rapidly oxidized and easily dissolved when exposed to aerated water. Thus, one mechanism to account for high arsenic in groundwater is by the aggressive dissolution and preferential release of arsenic from pyrite in the glacial tills. In fact, dissolved sulfate is commonly present at high concentrations in groundwaters throughout the region, and the sulfur in dissolved sulfate was found to have very negative sulfur isotope ratios, consistent with derivation by oxidation of a pyritic source rock (Berndt and Soule, 1999).

However, high arsenic in Minnesota groundwaters appears to involve a much more complicated process than simple dissolution of arsenic-rich pyrite. In particular, if this were the only process accounting for high arsenic, there should be a strong correlation between the concentrations of arsenic and dissolved sulfate. No such correlation exists; some waters have high sulfate and low arsenic while others have low sulfate and high arsenic. Furthermore, if pyrite dissolution were the only source of arsenic in groundwaters, then the highest arsenic concentrations should be found in the areas where pyrite is exposed to oxygen. This is the opposite of what is observed; most high arsenic concentrations are found in deeper portions of the aquifers where little or no dissolved oxygen is present to oxidize the sulfide minerals. Arsenic concentrations in the shallower portions of the aquifer systems are generally low, even when sulfate concentrations are high. Therefore, the high arsenic in groundwaters is currently being released into the groundwater relatively deep within the aquifer.

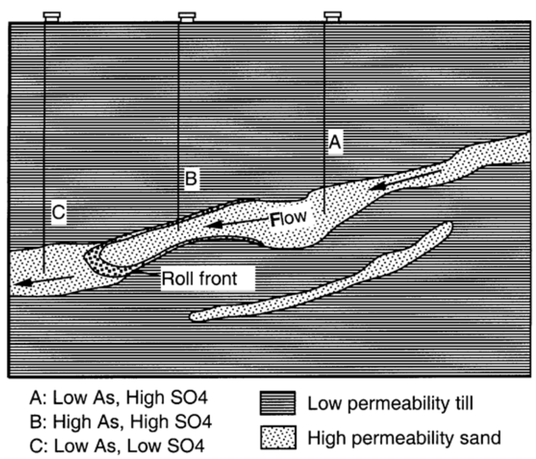

Figure 3: *Conceptual "roll front" model to account for high arsenic in intertill aquifers. Well A is located in a region where sulfate ($SO_4^=$) and iron concentrations are high, but where conditions are not sufficiently reducing to permit desorption of arsenic from the surfaces of iron-oxides. Well B is in the high arsenic region immediately behind the roll-front and is more likely to have high arsenic concentrations owing to dissolution of pyrite from past roll-front deposits. Well C has low arsenic because any arsenic that was in the water at the location of Well B is trapped in pyrite when the water passes through the roll-front. Arsenic accumulates at the roll-front as it migrates down the hydraulic gradient with time.*

In response to the observations discussed above, a pyrite "roll-front" model (Fig. 3) was developed to account for the relative distributions of arsenic and dissolved sulfate. The roll-front forms at a chemical redox boundary in response to chemical changes taking place within the aquifer. By this model, sulfate derived from oxidation of pyrite in surface recharge areas is reduced to sulfide at the chemical boundary. This sulfide combines with dissolved iron at depth to precipitate pyrite at the roll-front. As this chemical boundary moves downward through the system with passage of time, the roll-front moves with it.

If such a system is active in western Minnesota aquifers, it will have a profound influence on the distribution of arsenic in associated groundwaters. Not only does arsenic have a strong affinity to precipitate within the pyrite framework but the conditions needed to maximize arsenic release from the surface of iron oxides and hydroxides occurs right at the geochemical conditions where this mineral begins to precipitate. Thus, in a system dominated by flow of sulfate-rich waters into a reduced portion of the aquifer, arsenic is first released from iron oxides and then transported to the roll-front, where it may be trapped within the framework of precipitating pyrite. Through time, as more oxidizing conditions penetrate progressively deeper into the system, the roll-front also migrates deeper and the arsenic will continue to be collected and accumulated at this boundary.

A key point is that when this roll-front moves, the arsenic-enriched pyrite that was deposited at the previous position of the roll-front becomes unstable and can redissolve, potentially releasing large amounts of arsenic into the surrounding groundwater. This roll-front mechanism may

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MARS Study, cont.

explain why some waters in Minnesota aquifers have been found with more than 150 µg of dissolved arsenic. Indeed, pyrite has been identified as the major culprit for trapping and then releasing arsenic into waters in a number of other environments (Thornton, 1996; Bhattacharya *et al.*, 1997).

Several pieces of evidence support a roll-front model for high arsenic in western Minnesota groundwaters. These include: (1) the presence of a strong sulfide odor in many water samples collected from the region, indicative of conditions appropriate for conversion of sulfate to sulfide at depth within at least some portions of the aquifer system; (2) actual observation of scant pyrite within rotosonic drill core from a sandy interval that appeared to correlate stratigraphically with a high arsenic aquifer (Berndt and Soule, 1999); (3) a general regional pattern for redox-sensitive elements (U, As, and SO_4) suggesting that the oxidizing conditions in the recharge areas upgradient of the arsenic-rich zones give way to much more reducing conditions downgradient within the system (see appendix G in Messing, 2000).

Roll-front models have been used to account for the occurrences and distributions of uranium ore deposits in the western US (Reynolds and Goldhaber, 1978; Miller et al., 1984). In those settings, the primary target element, U, is released in the oxidized portions of an aquifer system and redeposited at positions in the aquifer where conditions become reducing. Arsenic enriched pyrite is commonly associated with these deposits. It is possible, therefore, that these deposits may provide an excellent analogue for high arsenic zones in western Minnesota glacial aquifers.

At this time, arsenic distributions in Minnesota groundwaters have yet to be unequivocally linked to pyrite in the host aquifer groundmass, and sufficient data has still not been collected which can prove the existence of a an active pyrite roll-front system in glacial sediments. However, research is currently in the planning stages to study one or more of the western Minnesota high-arsenic areas in more detail. This research will be specifically focused on determining the subsurface distributions of pyrite and arsenic (dissolved, absorbed, or sulfide related) as well as identifying potential chemical reductants (e.g., buried organic matter). It is hoped that this work will help better determine whether a roll-front mechanism is responsible for high arsenic in Minnesota groundwaters, and if so, refine our understanding of how it operates. More experience with these systems will help geologists and hydrologists to make better predictions of where high arsenic wells are likely to be located, and will also provide a clearer means to determine how human activities may alter the present distribution of arsenic in groundwaters either to the betterment or detriment of existing or planned water supply systems.

Acknowledgements:

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— Dr. Calvin Alexander at the discharge point for Fountain Big Spring, Fillmore Couny. Photo: Sean Hunt.

Hastings Area Nitrate Study: Preliminary Results

Jill Trescott, Dakota County

The City of Hastings is a historic Mississippi River town, about twenty miles downstream from St. Paul. Hastings is in the northeast corner of Dakota County, of which it is the county seat. The City's population of 18,000 and the 2,000 residents of the surrounding townships rely on groundwater for their drinking water. Dakota County's Environmental Management Department has been conducting a Clean Water Partnership study, funded through the Minnesota Pollution Control Agency (MPCA), to investigate the sources of nitrate in the drinking water in the Hastings area and develop approaches for reducing the levels of nitrate. Additional funding and technical assistance have come from the Minnesota Department of Health (MDH), Minnesota Department of Agriculture (MDA), Minnesota Department of Natural Resources (DNR), the City of Hastings, the Dakota County Soil and Water Conservation District (SWCD), and the Metropolitan Council.

Project Background

Over the past few years, both the City and private well owners have had problems with increasing levels of nitrate in the drinking water. When the City started the siting process for a new municipal well in 1997, both test wells, completed in the Jordan aquifer, showed levels of nitrate at approximately 8 mg/L. The city tested five private wells within the search area for the new municipal well and found elevated nitrate levels ranging from 12 to 16 mg/L. In May 1999, the MDH closed Hastings Municipal Well #6 for several weeks, after samples contained average nitrate concentrations of 10.5 mg/L. Existing municipal wells in Hastings are also showing increasing levels of nitrate: although nitrate levels are below the recommended Health Risk Limits (HRLs), over the last ten years all of the wells producing out of the Prairie du Chien and Jordan aquifers have shown increases of 1 to 2 mg/L of nitrate.

In addition, Dakota County, MDA, and MDH have cooperated to conduct free nitrate testing clinics for Dakota County residents. Through these clinics (1997-1999), 387 samples from private wells have been analyzed for nitrate; of these, 17.5% contained nitrate concentrations greater than 10 mg/L (1997-1999 results). Consequently, water resource managers, planners, and elected officials at county and local levels of government are concerned about the continued health and safety of the water supply as a result of this apparent trend toward increasing nitrate levels in the groundwater.

The study is intended to evaluate the extent of the area's nitrate problem, sources of nitrate, groundwater flow patterns, and interactions between the Vermillion River and the groundwater. While the results are still being analyzed, the preliminary results are discussed below.

Bedrock Geology (Mossler, 1990)

The underlying geology consists of a thin layer of outwash on top of the Prairie du Chien and Jordan Formations, but the bedrock is criss-crossed by two notable features, as can be seen in Figure 1. The buried valley of an ancient precursor to the Mississippi River cuts through the Prairie du Chien and Jordan Formations, crossing the area from the northwest to the southeast, so that the City of Hastings sits on

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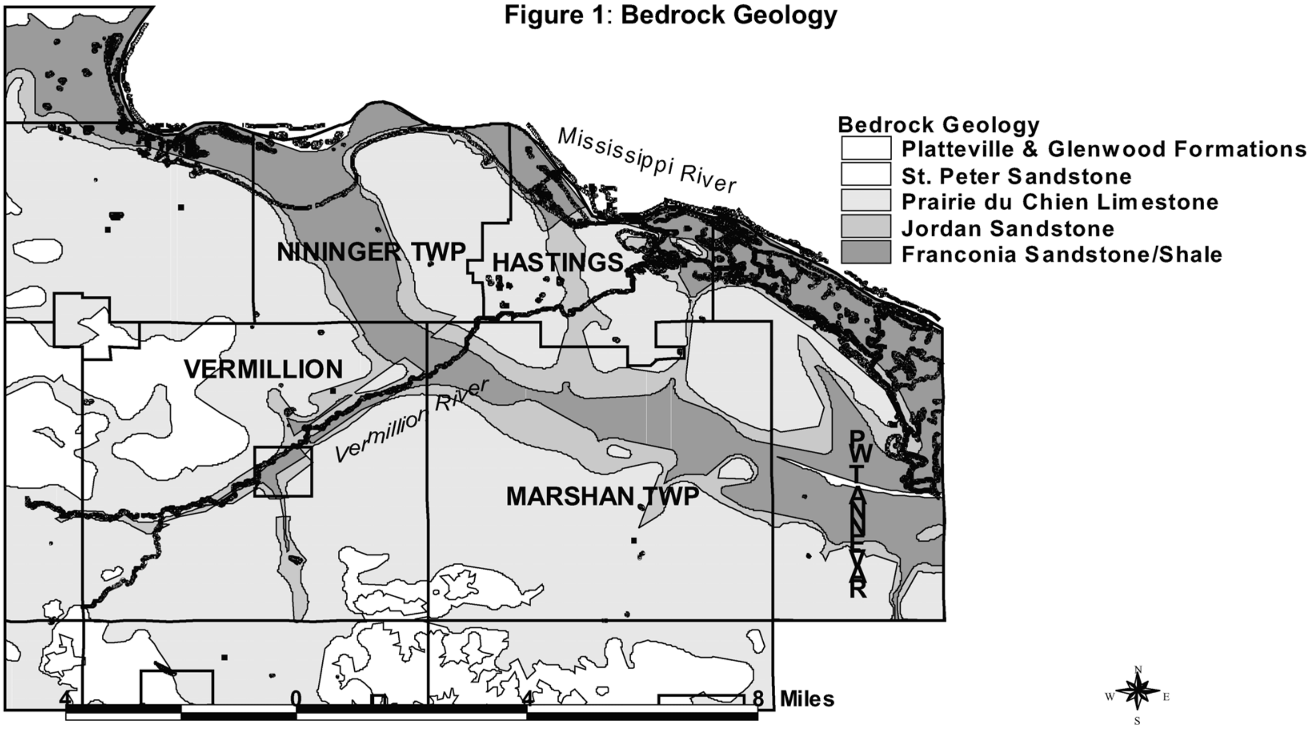
Figure 1: **Bedrock Geology**



Hastings Nitrate Study, cont.

three bedrock "islands." The buried valley, which is filled with mixed outwash from the St. Croix moraine, has depths-to-bedrock of more than 500 feet, compared to less than 50 feet in the areas outside the buried valley. The Empire Fault of the Mid-Continental Rift System cuts across the area from the southwest to the northeast. The bedrock north of the Empire Fault is about 100 feet higher than the bedrock south of the fault.

Quaternary Geology (Hobbs et al, 1990)

The oldest glaciers for which there is evidence within the study area originated in the Keewatin ice center to the northwest; they advanced and receded during the pre-Wisconsinan period, leaving "Old Gray" tills on top of the northernmost of the bedrock "islands" in what is now Nininger Township and western Hastings. After a long period of weathering and erosion, the Labradorean Superior lobe advanced from the northeast into Dakota County during the Illinoian glaciation, depositing reddish till and sediments of the River Falls formation, some of which remains near the surface in Nininger Township and Hastings. The Superior lobe advanced to cover much of Dakota County during the late Wisconsinan period, retreated, then advanced to an equilibrium position where melting of the ice front kept pace with the flow of ice, building the extensive St. Croix moraine, the southern tip of which covered northern Dakota County. Layers of outwash from the St. Croix moraine formed the Rosemount outwash plain, which buried the bedrock valley in the eastern part of the County.

Later, the Des Moines lobe of Keewatin ice advanced from the northwest, reaching its equilibrium point in western Dakota County. As it melted, the meltwater cut into the Superior lobe sediment and laid down new layers of outwash, forming the modern valley of the Vermillion River in the center of the County and the Rich Valley, through the Rosemount outwash plain, further north. These two streams of Des Moines outwash met and completed the filling of the bedrock valley in the Hastings area, covering most of the southern bedrock "island," about half of the middle "island", but little of the northernmost "island." Well drilling restrictions apply to most of the project area because the Prairie du Chien is so near the surface, with only a thin layer of coarse material over it.

Vermillion River

The Vermillion River flows through the study area from the southwest to the northeast, crossing over the buried bedrock valley. The river follows the path of the Empire Fault for much of its course, but bends southward of the Fault where the underlying geology changes as it enters the City of Hastings. There are sinkholes near the river within Hastings. According to the Dakota County Groundwater Model, the general direction of groundwater flow in the area is parallel to the flow of the Vermillion.

In 1990 and 1991, the USGS conducted a study to explore the relationship between the hydrology and the water quality in the Vermillion River watershed (Almendinger and Mitton, 1995). This study showed a reduction of stream flow east of the City of Vermillion, indicating that surface water was discharging into the surficial and bedrock formations in this area. The USGS study also concluded that there might be a relationship between groundwater quality and water quality in the Vermillion River.

In November 2000, Dakota County Environmental Management installed three sets of monitoring wells along the Vermillion River: one set just downstream of the City of Vermillion, a second set in the center of the buried bedrock valley, and a third on the other side of the buried bedrock valley, just within the Hastings city limits. The results from these wells are sketched in Figure 2. The data indicate the Vermillion has a gaining reach upstream of the bedrock valley, where the water table intersects the river. As the river crosses the bedrock valley, the river is perched above the water table, with little interaction between the river and the water table 60 feet below. At the monitoring wells within Hastings, the river loses water. A flow study is currently underway that will help map the gaining and losing stretches of the river in more detail. In addition, isotope analysis of water from the City of Hastings municipal wells will help quantify the contribution of river water to the drinking water supply.

Farm Nutrient Management Assessment Program (Bruening, 2001)

In conjunction with the Hastings Area Nitrate Study (HANS), the Minnesota Department of Agriculture conducted

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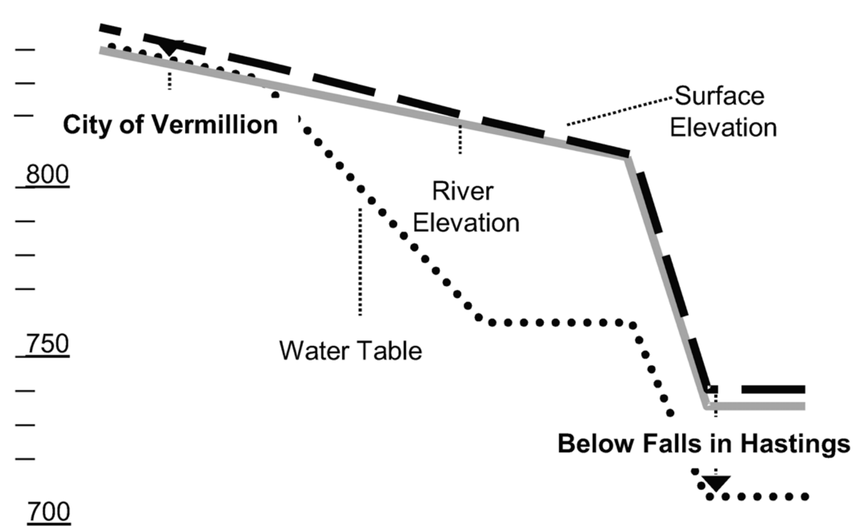
Figure 2 – Vermillion River and Water Table Levels in the Buried Bedrock Valley (not to scale)



Hastings Nitrate Study, cont.

a Farm Nutrient Management Assessment Program (FANMAP) survey in the study area. This MDA program evaluates the farming practices within a given area and compares them to Best Management Practices recommended by the University of Minnesota. Forty-two farm operators, representing about 25% of the acreage being farmed within the study area, participated in the FANMAP in July and August 2000; the results were released in June 2001. The FANMAP found strong evidence that producers in the study area are voluntarily adopting the educational materials and recommended nitrogen strategies developed by the University of Minnesota.

To summarize the report, field corn and soybeans were the dominant crops, with 69% of all acres planted with these crops. Irrigation was prevalent, with 63% of acres under irrigation. Forty-two percent of the crop acreage was planted with field corn; 68% of the 1,100,000 pounds of commercial nitrogen fertilizer was applied to those acres. Most of nitrogen fertilizer applied in the study area was applied as a spring preplant. Less than 1% of nitrogen was fall applied. Nitrogen inhibitors were applied with spring preplant applications of nitrogen and 44% of field corn applied with anhydrous ammonia used nitrogen inhibitors. While some livestock is raised in the area, the numbers are not large enough for manure to represent a significant source of nitrogen.

Pesticide use was prevalent in the study area, with 90% of all crop acres receiving herbicides, insecticides, and/or fungicides. Fifty-two separate compounds were used, totaling 37,000 pounds of active ingredient. Herbicide use was primarily on field corn, representing 47% of all active ingredients applied; atrazine was the most used herbicide compound. Potatoes received the most fungicides, with 99% of all active ingredients applied to potatoes; chlorothalonil was the most used fungicide compound. Potatoes also received the most insecticides, with 62% of all active ingredients applied to potatoes; phorate was the most used insecticide compound. It also appears that applications of pesticides are at or below recommended rates.

Nitrate Sampling

In September 2000, 20 representatives of Dakota County and its HANS partners sampled 146 domestic wells, plus five City of Hastings municipal supply wells. The Dakota County Well and Water Management System (adapted from the County Well Index, Wahl and Tipping, 1991) and Parcel Query database were searched to identify domestic wells for which the County had construction and geologic data, such as depth, static water level, year constructed, aquifer, and construction details. The Well and Water Management System has records for very few wells constructed prior to 1975, but the study area has been settled for 150 years (and is home to a number of "Century Farms" that have been farmed by the same family for at least one hundred years). Therefore, the wells sampled may generally be younger than the total population of wells in the area. Well owners were contacted beforehand for permission to sample, and after the sample analysis was completed, they were notified by letter of their results.

While the representatives were sampling, they drew sketches estimating the locations and separations of wells, septic systems, and structures at each site where such features could be seen. In most cases, the faucet was run for 15 minutes before the water sample was taken. All samples were analyzed for nitrate. Twenty percent (29) of the 151 wells were selected for additional analyses, including a time-series comparison of the number of minutes the faucet was run (5, 10, 15, and 20 minutes); caffeine; and pesticides. The 29 wells were selected to represent different aquifers, depths, and geographic (horizontal) locations.

Nitrate Results: Descriptive Statistics

The samples were analyzed for nitrate (as nitrogen) using a Hach DR 4000 photospectrometer, calibrated with 1.0 mg/L, 3.0 mg/L, and 7.0 mg/L standards to ± 0.5 mg/L accuracy. (Accuracy as stated applies to samples with nitrate-nitrogen concentrations as high as 10.4 mg/L. Samples with initial results of 10.4 mg/L or higher were diluted by a factor of ten and re-analyzed.) Of the 151 samples analyzed (from the 15-minute sampling interval), nitrate results ranged from zero to 40.0 mg/L. The median result was 3.70 mg/L; the mean 6.31 mg/L; and the standard deviation was 7.66. The results were skewed and not normally distributed

Table 1: Nitrate levels by classification (MDH, 1998):

Nitrate Level (mg/L)	Count	Percentage
Non-detect (0.0)	51	34%
Background (>0 and < 1.0)	10	7%
Transitional (>= 1.0 and < 3.0)	11	7%
Elevated (>= 3.0 and < 10.0)	40	26%
Exceeds standards (>= 10.0 mg/L)	39	26%
Total	151	100%

Table 2: Nitrate Results by Aquifer

AQUIFER	Number of Wells	Nitrate Results: Range	Nitrate Results: Median	Depth of well (feet bgs): Range	Total Depth of Well (feet bgs): Median
Quaternary	34	0-29.0 mg/L	8.7 mg/L	125-340	178.5
Prairie du Chien	13	0-40.0 mg/L	15.0 mg/L	125-321	200
Jordan	88	0-26.0	1.85 mg/L	180-500	320

Hastings Nitrate Study, cont.

(Shapiro-Wilk W = 0.8135, p <0.0001).

The samplers took samples at 5-, 10-, 15-, and 20-minute intervals from 29 of the wells. The nitrate results from the 29 wells in the multi-analysis subset were representative of those found in the full sample set. (Means, medians, and variances were not found to be unequal.) The amount of time the faucet had been run was not found to make a difference in the nitrate results for each well (Friedman's ANOVA (rank sum) $\times^2_r$ = 1.1304, p = 0.7697).

As shown in the table below, the results were significantly different between wells completed in unconsolidated materials, the Prairie du Chien, and Jordan aquifers (Kruskal-Wallis H = 31.72, p = 0.0000), but the highest results were from the Prairie du Chien. The buried bedrock valley in the study area complicates the relationship between the aquifer in which a well was completed and the depth of the well; because of the depth of unconsolidated material in the buried bedrock valley, the deepest Quaternary wells in the study area are deeper than the shallowest Jordan wells.

The major risk factors significantly associated with high nitrate results are the depth of the well (Spearman's rho = -0.4727, p = 0.0000), the age of the well (Spearman's rho = -0.4312, p = 0.0000), and the type of soil in which it is located (Kruskal-Wallis H = 4.3297, p = 0.0375). It should be noted that well depth and age are cross-correlated, since newer wells are also deeper wells. Nitrate results by depth interval, regardless of aquifer, are shown below.

The median nitrate result for wells in areas of loam or clay loam was 2.05 mg/L, while the median result in areas of sand or sandy loam was 4.65 mg/L. Once these factors are taken into account, there were no geographic areas within the study area that had higher or lower nitrate results than others. For instance, the results for wells constructed over the buried bedrock valley were not significantly different than the rest (Kruskal-Wallis H = 1.5319, p = 0.2158).

Caffeine Results

The 29 wells selected for the time-series comparison of nitrate results were also analyzed for caffeine (as a tracer for domestic wastewater) and pesticides (as a tracer for row crop agricultural impacts). Medallion Laboratories analyzed the samples for caffeine using a proprietary HPLC analytical method with a detection limit of 0.001 mg/kg. Low levels of caffeine were detected in 26 of the 29 samples (90%), with concentrations ranging from 0.001 mg/kg to 0.051 mg/kg. The median result was 0.005 mg/kg; the mean 0.007 mg/kg; and the results were not normally distributed (Shapiro-Wilk W = 0.5114, p < 0.0001).

The caffeine results were not significantly correlated with the nitrate results (Spearman's rho = -0.3311, p = 0.799); however, they were significantly correlated with the age of the well (Spearman's rho = 0.4770, p = 0.0126). Caffeine results were not significantly correlated with the aquifer of the well (Kruskal-Wallis H = 0.8670, p = 0.8334), the depth of the well (Spearman's rho = 0.2913, p = 0.1319), or the soil type (Kruskal-Wallis H = 3.1746, p = 0.0748)

Pesticide Results

Minnesota Valley Testing Laboratories analyzed the samples for Minnesota Department of Agriculture List 1 pesticides (reference method U.S. E.P.A. SW 846-8081-8141A-3510), with detection limits from 0.2-0.5 µg/L. The MDA List 1 includes the pesticides most commonly used in the corn-soybean crop rotation in Minnesota. Also, the pesticides found most frequently in groundwater in the United States Geological Survey's National Water Quality Assessment program (atrazine, deethylatrazine, simazine, metolachlor, and prometon) (Kolpin *et al*, 1998) are included in MDA List 1. From this initial sampling, a single sample contained a detectable quantity of atrazine (0.5 mg/L).

When the Minnesota Pollution Control Agency studied groundwater quality in Cottage Grove, which is adjacent to the Hastings study area, their pesticide analysis was done with lower detection limits than above and they analyzed for pesticide degradates as well as parent compounds (MPCA, 2000). In order to have the Hastings study results be comparable to the Cottage Grove results, in August 2001 Dakota County re-sampled 27 of the wells above, as well as three additional wells. (The wells were re-sampled for nitrate at the same time; the 2001 results were not significantly different from the 2000 results, t = -0.22, p = 0.8279.) The United States Geological Survey's Organic Geochemistry

Table 3: Nitrate Results by Depth of Well

WELL DEPTH INTERVAL (feet below ground surface)	Number of Wells Sampled	Nitrate Results: Range (mg/L)	% Background	Nitrate Results: Median (mg/L)	% Over Drinking Water Standard
120-159	14	0.0 – 40.0	14%	16	57%
160-199	22	0.0 – 27.0	18%	11.2	55%
200-239	14	0.0 – 18.0	29%	6.1	21%
240-279	20	0.0 -- 26	35%	4.3	25%
280-319	21	0.0 – 18.0	48%	3.3	19%
320-359	36	0.0 – 19.0	64%	0.1	11%
360-399	11	0.0 – 17.0	55%	0	9%
400+	7	0.0 – 3.8	57%	0	0%

Hastings Nitrate Study, cont.

Research Laboratory analyzed the samples for low levels of herbicides using GC/MS and herbicide breakdown products using HPLC/MS, with a detection limit of 0.05 μg/l. Herbicides or their degradates were detected in 22 (73%) of the wells, and 20 wells (67%) had multiple herbicides detected. The most frequently detected compounds were Alachlor and Alachlor degradates (16 wells, or 53%) and metolachlor and metolachlor degradates (16 wells, 53%). The MDH recommends that, when a pesticide and/or its degradates are detected in a water sample, the mass of that family of compounds be summed for comparison to the HRL. Two wells exceeded the 4.0 μg/L HRL for Alachlor, with combined quantities of 9.50 μg/L and 7.19 μg/L, respectively. Atrazine and atrazine degradates were detected in 12 wells (40%). Acetochlor was introduced to the market in 1994; Acetochlor or acetochlor breakdown products were detected in 8 wells (27%); Dimethenamid was introduced in 1993, and a dimethenamid breakdown product was detected in one well.

The low-level herbicide results (summed mass of all herbicides and degradates in μg/L) were highly correlated to nitrate results (Spearman's rho = 0.793, p = 0.0000). However, the herbicide results were not significantly correlated to the aquifer of the well (Kruskal Wallis H = 2.6333, p = 0.4517), the depth of the well (Spearman's rho = -0.3073, p = 0.1050), the age of the well (Spearman's rho = -0.3337, p = 0.0771), or the soil type (Kruskal Wallis H = 0.1419, p = 0.7064). The herbicide results were also not correlated to the caffeine results (Spearman's rho = -0.3311, p = 0.0799). It should be noted, however, that of the 27 wells that were analyzed for both caffeine and low-level herbicides, 16 (59%) had detectable levels of both caffeine and herbicides; 8 (30%) had detectable levels of caffeine but not herbicides; and 3 (11%) had detectable levels of herbicides but not caffeine. Every well had something.

Pending Data and Analyses

In August 2001, six wells within the study area were sampled for helium and tritium isotopes, and an additional four wells were sampled for tritium alone. Results of this analysis are currently being used to calibrate the groundwater flow model, estimating the groundwater flow paths within the study area. Additional wells in the vicinity of the Vermillion River have been sampled for oxygen isotopes, to determine the proportion of river water within the groundwater at those locations. These results are pending. In addition, the data for pesticide detections in the groundwater were quite different from the FANMAP information on pesticide use in the area, so this will bear further investigation.

Conclusions

The nitrate sampling conducted for this study confirms that nitrate is a problem in the area's drinking water supplies, with one-fourth of the samples exceeding the drinking water standard and another one-fourth showing elevated levels of nitrate. However, the higher nitrate is found in shallower groundwater (the surficial aquifer and the Prairie du Chien) and in older (less well constructed) wells. Once the modeling of the groundwater flows in the area has been calibrated, a better understanding will be developed of how elevated nitrate might affect the Jordan aquifer and deeper groundwater resources in the future.

While surface water resources have been examined for multiple human impacts through programs such as the National Ambient Water Quality Study, the Hastings Area Nitrate Study is one of the first to analyze groundwater for the non-point source pollution represented by caffeine and pesticides and to examine their relationship to elevated nitrate. Caffeine detections were ubiquitous, but the statistical relationship between nitrate and pesticide levels was very strong, and the relationship between nitrate and caffeine was not. While the presence of both caffeine and pesticides suggest both domestic wastewater and row crop agriculture as sources, it is difficult to quantify their relative contribution of nitrate to the groundwater. However, the strong statistical relationship of pesticides to nitrate suggests that row crop agriculture is the dominant contributor.

Acknowledgments

Funding for the Hastings Area Nitrate Study has been provided by a Clean Water Partnership grant through the MPCA. Additional funding and technical assistance have come from the Minnesota Department of Health, the Minnesota Department of Agriculture, the Minnesota Department of Natural Resources, the City of Hastings, the Dakota County Soil and Water Conservation District, and the Metropolitan Council.

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New health-risk information on alachlor ethane sulfonic acid (alachlor ESA):

As this issue of the MGWA newletter was going to press, new health-risk information related to alachlor ESA became available. This information may be important relative to the accompanying article on the Hastings Area Nitrate (HAN) Study.

In mid-February the Minnesota Department of Health issued a memorandum to the Minnesota Department of Agriculture providing a Health Based Value (HBV) for alachlor ESA of 100 μg/L. The HBV, an unpromulgated exposure value, serves as interim advice to protect the health of individuals potentially exposed through drinking water where a contaminant has been detected. The HBV does not serve to protect the groundwater resource.

An analysis of HAN Study pesticide health-risk data using the alachlor ESA HBV of 100 μg/L is being undertaken by the study's author and will be included in the final report. For more information on the alachlor ESA HBV, contact the Health Risk Assessment Unit of the Minnesota Department of Health. For more information on the HAN study final report, contact author Jill Trescott.

Hastings Nitrate Study, cont.

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COMMENTARY

The Response to the Hastings Area Nitrate Study

By Dan Stoddard, PG and Brian Williams, CCA Minnesota Department of Agriculture

In September 2000, Dakota County conducted the first Hastings Area Nitrate Study (HANS 1) and reported the results in the March 2002 Minnesota Groundwater Association Newsletter. Since then, Dakota County and the Minnesota Department of Agriculture (MDA) worked with other cooperators to develop a coordinated response to groundwater problems identified in the study. In this article we describe a general response strategy for nitrates in groundwater and use the response to the nitrate problems identified in HANS 1 as an example of implementing this strategy.

As the MGWA Newsletter article indicated, eastern Dakota County has a considerable amount of row crop agriculture and is highly vulnerable to groundwater contamination. In areas with these characteristics it is, unfortunately, not unusual to find elevated levels of nitrates in vulnerable groundwater. Groundwater may become contaminated with nitrates even when farmers follow recommended Best Management Practices (BMPs) for nitrogen fertilizer. This is the case in Dakota County.

Herbicides in Groundwater

Groundwater sampling in Dakota County also identified low levels of several herbicides in vulnerable aquifers. Herbicides, such as atrazine, are frequently found at low levels, well below the health standards, in vulnerable groundwater in agricultural areas of Minnesota. However, sampling in Dakota County identified degradates of cyanazine, a corn herbicide that is no longer registered for use in Minnesota, at concentrations above the health advisory value in several wells. It is highly unusual to find a pesticide at a concentration that exceeds a health standard from a non-point source in Minnesota. Fortunately, the concentrations of these degradates appears to be dropping. The MDA along with the University of Minnesota and other cooperators has developed and is promoting BMPs for common herbicides. The MDA also has an ongoing statewide groundwater monitoring program to evaluate long term trends in groundwater quality. Although this article will focus on the response efforts for nitrates, pesticide BMPs are also being promoted concurrently with nitrogen fertilizer BMPs in Dakota County.

General Response to Nitrates in Groundwater

In Dakota County, as in many rural counties, contamination from nitrates poses one of the greatest health concerns in vulnerable groundwater. Common sources of nitrates in groundwater may include septic systems, manure and nitrogen fertilizer. The MDA is the lead state agency responsible for addressing the impacts of nitrogen fertilizer in groundwater. A Task Force that included multiple state agencies and interest groups developed a general approach to responding to nitrates from fertilizer in groundwater, and this approach is outlined in a Nitrogen Fertilizer Management Plan. The approach consists of three phases: (1) Promotion of the Nitrogen BMPs; (2) Evaluation of BMP adoption and effectiveness; and (3) Response to the evaluation phase. The key prevention component in this plan is the promotion and adoption of voluntary BMPs that are appropriate to the unique conditions and agricultural practices in the area.

When dealing with a problem as complex as nitrate contamination in groundwater, it is essential to put together an effective project team. The MDA sees one of its primary roles as assembling and supporting a cooperative response effort. In the case of Dakota County the cooperation has been excellent. Dakota County has provided strong local leadership, including financial support, and local farmers have demonstrated a sincere interest and commitment to working on viable long-term solutions. In addition, numerous other organizations have contributed staff time and resources to the effort.

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Hastings Nitrate Study Response, cont.

Cooperators for any given response may include some combination of the University of Minnesota, University of Minnesota Extension, U.S. Department of Agriculture Natural Resource Conservation Service (NRCS), U.S. Department of Agriculture Agricultural Resource Service (ARS), local Soil and Water Conservation Districts (SWCDs), county, township and city governments, agricultural suppliers, agricultural consultants, the Minnesota Department of Health, the Minnesota Pollution Control Agency; farm organizations and, of course, local farmers. Each of these groups contributes unique knowledge, skills and resources. Stakeholder participation is critical to obtain the necessary technical skills and resources needed for long term success. Especially important is effective local leadership and the participation of local farmers, retailers and agricultural consultants. An effective team will mobilize resources to focus on the specific issues in their area. An ineffective team is not likely to have a significant impact on the problem, and may discourage farmers and other groups from participating in current or future efforts.

Assessing Agricultural Practices

An early step in a response effort is to evaluate current agricultural practices at the site. To accomplish this, MDA developed a diagnostic tool called FArm Nutrient Management Assessment Process (FANMAP) to gain a clear understanding of existing farm practices regarding agricultural inputs for nitrogen fertilizer, manure and pesticides. Timing, rates, form, and methods of application were collected for all nitrogen sources (fertilizers, manures and legumes); and soil and manure testing results were compiled when available. Farmers in the HANS area were interviewed in July and August 2000 and the findings determined that Dakota County farmers generally followed the University of Minnesota's nutrient recommendations and BMPs for the application of nitrogen fertilizer.

Conducting a FANMAP survey of farm practices provides real data that yield a number of benefits. FANMAP data can:

1. Help the project team to focus its efforts on promoting the specific practices that yield the greatest environmental return. It may identify practices that could be easily adopted (the low hanging fruit) and those that could yield the greatest environment protection.

2. Increase the opportunity for supplemental funding. When a project team can demonstrate in a grant proposal that there is a specific activity that should be improved to address a known problem, they tend to be much more successful in obtaining funding.

3. Be used to measure and evaluate changing behaviors and BMP adoption over time.

4. Enhance the opportunity for building positive relationships. As the saying goes, without data all you have are opinions. Some opinions regarding the use of manure and fertilizer can be quite inaccurate and can lead to distrust and conflict. Having real data provides the opportunity to focus on finding solutions rather than fixing blame. It should be noted that capable leadership is also needed to ensure the team interacts in a positive and supporting manner.

Nitrogen Fertilizer BMPs

The next step in responding to a local nitrate problem is to promote the BMPs for nitrogen fertilizer. The University of Minnesota developed BMPs for nitrogen use and first distributed them in 1993. The University is now updating them. By statute, BMPs are intended to prevent degradation of Minnesota's water resources by efficiently managing inputs while maintaining farm profitability. The BMPs are presented using a three-tier approach for application statewide, by geographic regions, and in special situations.

The University of Minnesota established new nitrogen guidelines for corn in January 2006. This process was the product of a seven-state effort, (Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin) to use a similar regional philosophy/approach to determine nitrogen rate guidelines for corn. Data used in the project were from research conducted since 1989 and involved more than 700 locations in the corn belt. Additional data are needed to validate the BMPs in certain special conditions including coarse-textured irrigated soils in Dakota County. Considerations used for the new guidelines include soil productivity, price/value ratio, (corn vs. nitrogen price) and previous crop. Farmers in Dakota County and across Minnesota are still becoming familiar with and evaluating these new rate guidelines for their farming operations.

Promotion and Evaluation of Fertilizer BMPs

In a typical nitrate response situation like Dakota County, certain BMPs may be particularly important given the environmental characteristics of the area and common agricultural practices on local farms. Ideally, the BMPs should be promoted through one-on-one contacts between the farmer and a qualified agricultural consultant. BMP demonstration projects should be established to evaluate and promote locally important practices. It is also important to involve local fertilizer retailers, certified crop advisors and agricultural consultants as these professionals advise farmers on fertilizer application rates and practices, and they must be convinced themselves before they will advise farmers to adopt any specific practice.

Following BMP promotion, the BMPs must be evaluated on two criteria: implementation of the practices in a voluntary system, and effects on nitrate contamination of water resources.

If farmers are not adopting the BMPs, the team needs to evaluate the obstacles to their adoption. Potential barriers to BMP adoption could result from inadequate awareness of the BMPs, direct costs for implementation or concern of a potential economic loss from adoption. There also may be a tendency to continue practices that the farmer has found to be successful. In some cases a change in crops or practices may require a significant capital investment in equipment or for changes on the land, and the farmer may not be able to afford such an investment. It also takes time to learn how to apply a new practice, and most farmers will want to experiment on a few fields before taking the risk of adopting the changes on a large scale. Many farmers in Dakota County have already made significant changes with the timing and application methods of fertilizer. For example, some farmers have increased the number of fertilizer applications to as many as six applications per growing season. This provides nitrogen as the

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crop needs it and reduces the risk of leaching any excess nitrogen.

Given the many potential barriers, the team will need to be flexible in offering solutions to help local farmers overcome the barriers to BMP adoption. Funding is frequently a key issue and the NRCS, MDA, local government or others may be able to help with grants or loans to cover implementation costs and to insure against economic loss from BMP adoption. On farm demonstration projects such as the Nutrient Management Initiative, which is funded by the NRCS and implemented by the MDA, are especially effective in encouraging farmers to test recommended rates on their own operation.

It is equally important to confirm that the BMPs actually help reduce nitrate levels in groundwater. Any specific BMP may provide varying nitrate reductions from year to year depending on the timing and amount of fertilizer applied verses the timing and volume of rainfall (or irrigation water), the conditions for optimal crop growth (and fertilizer uptake) and other factors. It may take several years to evaluate the effectiveness of a specific BMP in a specific setting because these factors can vary dramatically year to year. Environmental variables and other variables may be simulated in plot work but cannot be simulated in field-scale studies. The MDA and others are also engaged in computer modeling to evaluate these practices but such efforts still require validation with actual field data.

Specific Response Actions

BMPs that may help reduce nitrate losses to groundwater include changing the amount, timing or method of fertilizer application; rotating crops; planting alternative varieties; irrigation management; and, the use of nitrification inhibitors and new technology timed release fertilizers. In addition to BMPs, it may be desirable in some cases to promote alternative crops, accept a lower yield due to reduced inputs or to take land in highly sensitive areas out of row crop production and compensate the farmer(s) for economic losses.

A variety of activities have been conducted to promote and evaluate nitrate fertilizer BMPs in Dakota County. These include:

1. One-on-one meetings with farmers and retailers to discuss groundwater concerns and the BMPs;

2. Preparation of handouts, fact sheets and informational mailings;

3. Meetings, tours and field days that involve local farmers and agricultural consultants;

4. A mail survey conducted by University of Minnesota Extension on nutrient management, tillage and other crop management practices;

5. Demonstration projects on several local farms to evaluate the new nitrogen rate guidelines including the installation of lysimeters to evaluate losses through the root zone;

6. Research sites established by the University of Minnesota for nitrogen rate evaluations under coarse textured irrigated sands, with extensive monitoring on two sites through lysimeters;

7. Free irrigation water testing to ensure proper nitrate crediting from irrigation water;

8. Several multi-participant grant proposals including a grant from the US EPA provided under section 319 of the Federal Clean Water Act for the phase two study that resulted in hiring a half-time Extension Educator to provide county-wide educational efforts, coordination between stakeholders and technical assistance through direct one-on-one contacts with farmers;

9. A standing advisory board with a local ag-retail supplier, a local crop consultant, a township officer, two farmers, the City of Hastings Public Works Superintendent, and representatives from Dakota County SWCD, Dakota County Water Resources Department, University of Minnesota Extension, and USDA-NRCS;

10. Contacts with producers and suppliers to promote the use of a new technology timed release polymer coated urea fertilizer (ESN) (all the potatoes that were grown in Dakota county in 2007 used this fertilizer product);

11. Numerous free nitrate water-testing clinics for testing of well-water samples;

12. Field locations identified to conduct a field demonstration project in cooperation with USDA-ARS phytofiltration research; and

13. Continued monitoring of ground and surface waters in the county by the SWCD, MDA, Dakota County Environmental Services, and Vermillion River Watershed.

A Long Term Focus is Required

It may take years to improve water quality in an aquifer that is contaminated from an agricultural source. It likely will take several field seasons for farmers to adopt, evaluate and refine the use of the current BMPs in their operations. At the same time, the BMPs themselves need to be evaluated for effectiveness in a local situation and they may need to be refined. This evaluation process may also take several field seasons. In some areas with highly vulnerable groundwater, adoption of the current BMPs may not provide adequate protection of water resources and local modifications of the BMPs or alternative strategies will be needed. Further, over time the BMPs will need to be reviewed and updated to address new research and technology, such as new varieties of seed, and possibly changing climatic conditions. The BMP evaluation, refinement and demonstration process needs to be an ongoing cycle if it is to be effective in the long term. Finally and perhaps most importantly, groundwater in a porous aquifer flows slowly and it may take years for the concentration of nitrates in an aquifer to drop after the sources are reduced or even eliminated. For these reasons the project team must have a long-term focus and presence if they are to implement a permanent change in water quality.

Conclusion

The partnership between Dakota County, the MDA and numerous other cooperators has been very effective in responding to the nitrate problems observed in Dakota County. Considerable work has been undertaken to promote and evaluate nitrogen fertilizer BMPs to area farmers. The area farmers have demonstrated a sincere interest in protecting groundwater. It may take several years for these activities to have a positive impact on groundwater quality, but the process for change is well underway. What is required now is a long-term commitment to continue the effort in order to produce the desired permanent improvement in groundwater quality.

Lasting Effects of the Hastings Area Nitrate Study

By Jill V. Trescott, Dakota County Water Resources Department

Dakota County conducted Phase I of its Clean Water Partnership project, the Hastings Area Nitrate Study (HANS I), from 1999 until 2003, but the project has had lasting effects on how the County addresses water quality issues. With funding from the Minnesota Pollution Control Agency, Dakota County partnered with the City of Hastings, the Minnesota Department of Health (MDH), the Minnesota Department of Agriculture (MDA), the Dakota County Soil and Water Conservation District (SWCD), and the Metropolitan Council to determine the cause and extent of nitrate contamination in the Jordan and Prairie du Chien aquifers in Hastings and the surrounding townships (Figure 1). The project also developed an implementation plan to reverse the trend in nitrate contamination and restore water quality through a combination of education, management practices, and other activities. The National Groundwater Association recognized HANS I as its Outstanding Project in Groundwater Protection in 2003.

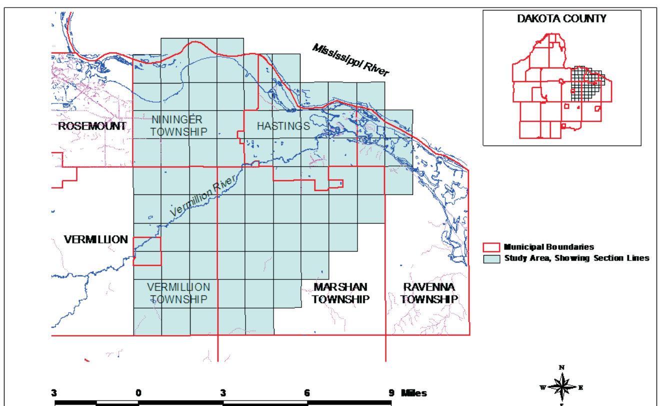

Figure 1: Hastings Nitrate Study Area

The lasting effects of HANS I have stemmed from:

- The nitrate findings;
- The relationship found between nitrate and pesticides associated with corn and soybean farming, determining that, in this area, the predominant source of nitrate contamination in groundwater is row-crop agriculture;
- The pesticide results;
- The caffeine results;
- The enhanced understanding of groundwater/surface water interactions within the Vermillion River Watershed;
- The results showing the effectiveness of the County's Delegated Well Program; and
- The cooperative relationships established with other agencies.

The project has demonstrated that combining the County's own expertise, data, and resources with those of other agencies to address water quality problems enables us to achieve better, faster, and more creative solutions than would be accomplished if the various stakeholders attempted the work separately.

Nitrate Results and the Relationship between Nitrate and Agricultural Pesticides

HANS I brought together information in a way that allowed the numerous stakeholders to work together on positive solutions.

1) Nitrate testing of private wells showed the extent of the nitrate problem in the study area's groundwater: a quarter of the wells tested had nitrate over the Health Risk Limit of 10 mg/L, and another quarter of the wells had "elevated" nitrate between 3 and 10 mg/L.

2) Testing for pesticides (and degradates) associated with corn and soybean farming, through the United States Geological Survey (USGS), showed not only that numerous wells had detectable levels of pesticides or their degradates, but also that the correlation between nitrate levels and pesticide levels in a given well was very high (79%, shown in Figure 2).

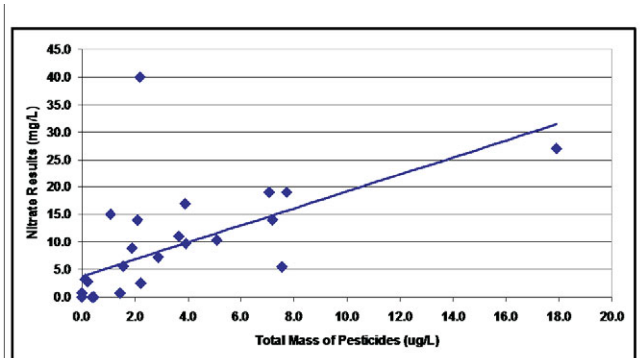

Figure 2: HANS I Correlation of Nitrate and Pesticide Results

3) MDA's **Fa**rm **N**utrient **M**anagement **A**ssessment **P**rogram (FaNMAP) indicated that farmers in the study area were, for the most part, following University of Minnesota guidelines for fertilizer and pesticide application.

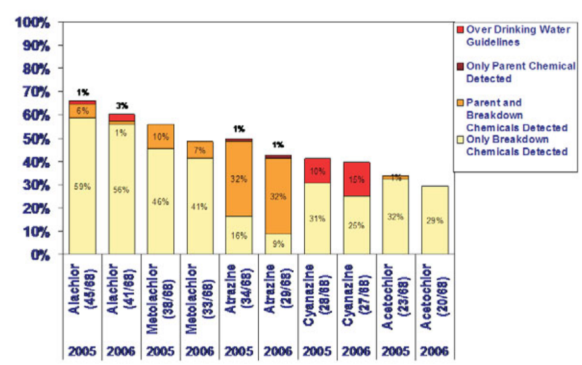

Figure 3: AGQS Pesticide Results (Private Wells) 2005-2005

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Lasting Effects of the Hastings Nitrate Study, cont.

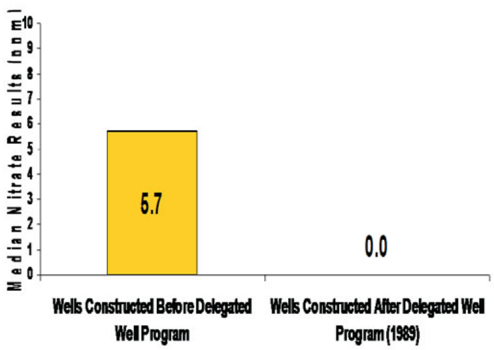

Figure 4: Impact of Delegated Well Program on Drinking Water Quality

These findings might appear somewhat contradictory, but the combination has actually helped the stakeholders look beyond "who's to blame" and understand that the soils and geology of the area are extremely susceptible to groundwater contamination. The underlying conditions include sandy, coarse-textured soils; a deep, buried bedrock valley without confining layers; faulted, fractured bedrock; and the Vermillion River, the gaining reaches of which apparently transport nitrate to its losing reaches downstream.

While HANS I was being completed, the University of Minnesota (UM) and other Midwestern universities radically changed their recommended method for calculating nitrogen fertilizer rates. The new recommended Best Management Practices, which maximize economic returns rather than crop yields, produce much lower recommendations for nitrogen fertilizer application rates in conditions such as those found in the geologically sensitive areas of Dakota County. With funding from HANS Phase II and the Vermillion River Watershed Joint Powers Organization (VRWJPO), the UM is conducting research in Dakota County to verify that the new recommended fertilizer rates are appropriate.

Pesticide Results

Because of the high number of private drinking water wells from HANS I (22 out of 30, or 73%) that had detectable levels of pesticides or degradates, and the number of wells (20 out of 30, or 67%) that contained multiple pesticides, Dakota County added pesticide and degradate analysis to its ongoing sampling program, the Ambient Groundwater Quality Study (AGQS). In the AGQS, the County annually samples a set of 68 private drinking water wells that were selected to be geographically and geologically representative across the County. The pesticide results from the AGQS have been comparable to those of HANS I: from one year to the next, approximately three-fourths of the wells tested have had detectable levels of pesticides and degradates, and the correlation coefficient between total pesticide compound concentrations in a well and its nitrate levels has been around 80%.

However, in 2004, the County began using a different analytical method with the USGS than what was used during HANS I. In 2004, 25 Quaternary wells were tested using this different method; cyanazine breakdown products were detected in 16 wells, with five wells exceeding the cyanazine Health Based Value (HBV). Cyanazine (Bladex) was not produced after 1999, and was banned from sale or use after 2002. In 2005-2007, all 68 AGQS wells (Quaternary, Prairie du Chien, and Jordan aquifer wells) were tested using this method. In 2005, 28 wells had detectable cyanazine chemicals, with seven exceeding the HBV. In 2006, 27 wells had detectable cyanazine chemicals, with ten exceeding the HBV. Despite the increase in the number of exceedences from 2005 to 2006, the wells with the highest levels in 2004 are showing decreases in the concentrations from one year to the next, although the decrease has not yet been statistically significant. (2007 results not yet available.)

Because of the frequent detections of nitrate and pesticide compounds in private drinking water wells in these studies and in the County's Water Testing Service results, in July 2006, the County mailed a brochure describing the issues, availability of testing, and treatment options to the 8,000 households that rely on private wells in the County.

Caffeine Results

The same private wells in the study that were analyzed by the USGS for pesticides and degradates were also analyzed by Medallion Labs for caffeine, as an "indicator compound" for potential wastewater contamination from septic systems. Caffeine was detected in 89% of the samples, which received a lot of public attention at the time, but there was no statistical relationship between the caffeine levels in a well and its nitrate levels. Because reaches of the Vermillion River are impaired for coliform bacteria, in addition to the HANS caffeine findings, the County and the SWCD are implementing an EPA 319 Grant-supported program to inspect all septic systems in the Vermillion River (and Chubb Creek) Shoreland and Floodplain areas and require the owners to replace those that are not compliant with current standards. This program may be extended to the whole Vermillion River watershed.

The AGQS wells were subsequently analyzed for caffeine and none was detected. However, the County plans to have the AGQS wells sampled for a broad array of organic wastewater components when funds are available.

Groundwater/Surface Water Interactions

Previous work had shown that the Vermillion River had gaining reaches in its upper areas and losing reaches closer to Hastings. As discussed in the March 2002 MGWA Newsletter, monitoring wells installed as part of HANS I helped identify where the water table in the vicinity of the river changes from above the level of the river upstream of the buried bedrock valley to below the river level as it crosses the buried bedrock valley (Figures 5 and 6). As a result, any contamination such as nitrate that enters the upstream portions of the river has the potential to flow into the groundwater along the downstream portions. The MDH has been conducting isotope tests of the City of Hastings municipal wells and the Vermillion River to quantify the proportion of the Vermillion's contribution to the city's drinking water supply. Results are pending.

The Empire Wastewater Treatment Plant contributes nitrate to the Vermillion River, just downstream from Farmington. Metropolitan Council Environmental Services is currently constructing

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Lasting Effects of the Hastings Nitrate Study, cont.

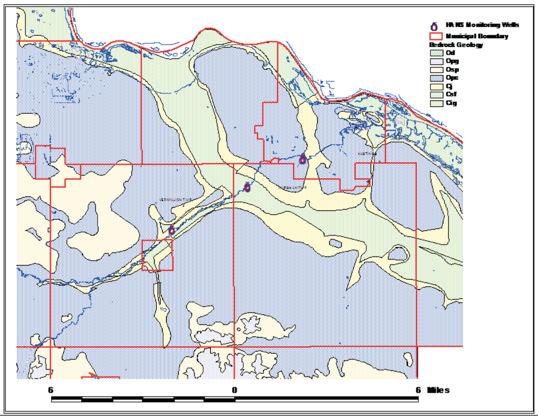

Figure 5: Vermillion River Monitoring Wells and Bedrock Geology

an outfall pipe that will redirect the treated effluent from the Empire Plant from the Vermillion to the Mississippi River at Rosemount, diverting this source of nitrate away from the Vermillion River. This project is scheduled for completion in 2008.

At the time Dakota County was conducting HANS I, the administration of the Vermillion River Watershed was being reorganized, from a Watershed Management Organization to a Joint Powers Organization managed by Dakota and Scott Counties. The new VRWJPO completed its updated Watershed Plan in 2005. The watershed process for planning and establishing standards incorporated the HANS I findings and the VRWJPO is working with MDA and the County to address the groundwater issues within the watershed.

Documented effectiveness of delegated well program

The HANS I results showed that the County's Delegated Well Program, through which it regulates the construction and sealing of domestic wells, has been effective at protecting residents' drinking water. The County has had its Well Program, delegated to it from the MDH, since 1989. In the HANS nitrate results, wells that were constructed prior to 1989 had median nitrate results of 5.7 mg/L, but wells constructed later than 1989 had median results of zero nitrate (Figure 4).

Established positive multi-agency cooperation that has continued to expand and improve

Many agencies were involved with HANS: the City of Hastings, the Dakota County SWCD, the Metropolitan Council, MDA, MDH, DNR, and USGS. These partnerships proved to be very fruitful; many of these partners are also participating in the implementation phase of the projects, the EPA 319 Grant-supported HANS Phase II. In addition, University of Minnesota Extension (UM Extension), USDA-Natural Resources Conservation Service, and USDA-Agricultural Research Service, which were not involved in the initial effort, are active participants in Phase II.

Because of the issues raised by HANS I and the AGQS, Dakota County, MDA, and MDH formed a working group that has met

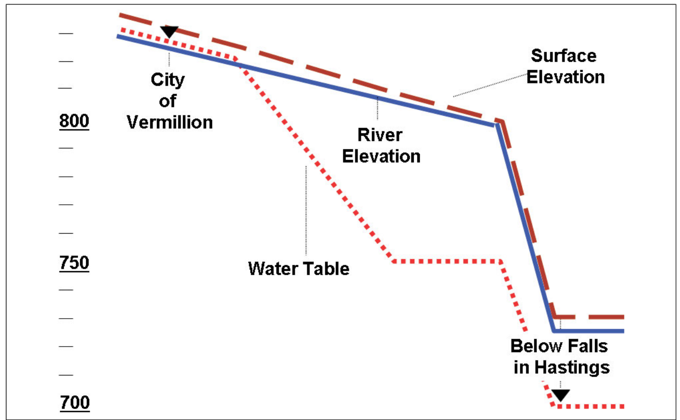

Figure 6: Surface Water and Groundwater Cross Section

as needed to discuss issues and strategies, exchange ideas, and coordinate activities. MDA, which bears statutory responsibility for responding to groundwater contamination from nitrogen fertilizers and pesticides statewide, was involved with HANS I from the beginning. In response to HANS I, and in cooperation with Dakota County and the VRWJPO, MDA is implementing a five-year plan to address agricultural chemicals in Dakota County groundwater.

Dakota County's HANS II project and MDA's efforts in the County are closely coordinated and include numerous other partners. With funding from the HANS II grant, UM Extension has hired a part-time Extension Educator dedicated to Agricultural Production and Water Quality Outreach in Dakota County. The County, the UM Extension Educator, MDA, and other agencies have worked together on outreach activities:

- Surveying farmers regarding their current practices and attitudes;
- Presenting classes and Field Days on nutrient and irrigation management for farmers and other agricultural professionals in Dakota County;
- Creating and distributing a Nitrogen Management newsletter that explains the new recommendations for fertilizer applications on corn;
- Recruiting farmers to participate in MDA's Nutrient Management Initiative (NMI) or a UM research project study nitrogen fertilizer rates for corn on coarse-textured soils; and
- Monitoring and analyzing the progress and results from the NMI and UM research sites.

Conclusions

The Hastings Area Nitrate Study demonstrated that the people of Dakota County are well served by the County's capacity to investigate and address drinking water quality issues in collaboration with other agencies. Cooperative efforts require patience and respect, but in the long term the efficiencies and innovations that such efforts can produce are well worth the investment. The HANS results laid the groundwork for the County's long-term efforts to work with its multiple stakeholders to address agricultural chemicals in its drinking water supply and to protect the Vermillion River.

Policies and Programs

A CONSUMER'S GUIDE TO MINNESOTA'S GROUND WATER PROGRAMS

Linda Bruemmer, Water Planning Board

At times, trying to find out which state agency gathers what ground water data and performs what services, is like being trapped in a maze. But, armed with a.) a reasonable amount of patience, b.) an appreciation for the complexity of ground water resources/ the state bureaucracy/your question, and c.) the following guide to state programs, you will probably be able to obtain the information that you need.

General Rule: The state's ground water programs fall within three agencies: the Department of Natural Resources (DNR); the Pollution Control Agency (PCA); and the Department of Health (MDH).

A.) Ground water quantity matters such as appropriation permits, recorded water use, pumping tests, resolution of well interference complaints, and hydrologic studies are handled by the DNR's Division of Waters. (296-4800)

B.) Water quality data for public water supplies falls under the auspices of the Safe Drinking Water program at the MDH. Public water supply data describe the finished water quality, i.e. water quality after treatment and often after waters from several sources are mixed. Questions about the health effects from chemical constituents in drinking water supplies can also be answered by this staff. (296-5330)

C.) Water well, exploratory well, and monitoring well construction, inspection, and logs are overseen by the MDH. (296-5338) This same program includes licensing of drillers.

D.) Ground water monitoring and sampling involves the greatest number of agencies. Water levels are monitored under a DNR-U.S. Geological Survey Cooperative program. The PCA carries out a ground water quality monitoring program which tracks the ambient quality at over 300 sites in the state.

Residential private well sampling is the responsibility of each county's community health service. Problems with water quality in a public water supply system should be referred directly to the municipal utility.

Operators of Grade A dairy farms must submit periodic water quality data to the State Department of Agriculture.

E.) Most ground water quality problems are handled by the PCA. The PCA's ground water programs fall within the Division of Solid and Hazardous Waste. (296-2735, Director) The organizational approach is set up according to land-use activity and its impact on ground water. The PCA also has an emergency response unit for spills and a site response unit to investigate toxic waste contamination. The MDH houses the laboratory where the majority of these analyses are done.

F.) Geological information and well logs can be obtained from the Minnesota Geological Survey at the University of Minnesota. (373-3372)

G.) The Land Management Information Center (LMIC, 296-1211) at the Department of Energy, Planning, and Development has developed a catalog of water information systems. This catalog may be obtained in hard copy or through a public-access computer program. A more specialized summary of ground water data is currently being developed through Systems for Water Information Management (SWIM) at LMIC. This includes a list of ground water staff and the programs they operate.

Of course, if you're really in doubt as to where to begin, your state-employed MGWA officers--Gil Gabanski (DNR), 296-0431, and Tom Clark (PCA), 297-3362, will gladly assist you.

— from Volume 1, Number 2

Minnesota's Ground Water Programs Redux

By Linda Bruemmer, Minnesota Department of Health with input from Tom Clark, Minnesota Pollution Control Agency

Twenty-five years ago I wrote "A Consumer's Guide to Minnesota's Ground Water Programs" for one of the first newsletters for the MGWA. This summary of programs and contact phone numbers took one page and the area code was 612 for everyone. I probably could have listed all program managers by their first names. From that initial effort, Tom Clark and I co-authored a "User's Guide to Understanding Minnesota's Ground Water Resource," a 64-page report that was published in 1984 and updated in 1986 jointly by the Minnesota Pollution Control Agency (MPCA) and the former State Planning Agency. One central issue remains unanswered over the 25-year span of writing these reports. Is it ground water, ground-water, or groundwater?

Two key water-related strategies were completed in 1988: the Ground Water Protection Strategy by the MPCA and the Strategy for the Wise Use of Pesticides and Nutrients by the Minnesota Department of Agriculture (MDA). These strategies led to the drafting of the Ground Water Protection Act (GWPA) to address ground water related programs in a comprehensive bill. The bill was organized into ten articles to address a large array of ground water related subjects at one time, generated by cooperation of the Minnesota Department of Health (MDH), the Department of Natural Resources (DNR), MDA, MPCA, the Board of Water and Soil Resources (BWSR), the Minnesota Geological Survey (MGS), and the Environmental Quality Board (EQB).

In 1989, the GWPA was passed by the Minnesota Legislature and signed into law by Governor Rudy Perpich. The Legislative Commission on Water was created by the GWPA, but it was abolished in 1995 along with a number of other legislative commissions. However, many of the reporting requirements of the various water agencies required by the GWPA and later amendments remain in place. Reporting is now done primarily to the EQB and the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

How far have we come since then? Check out Tim Thurnblad's Minnesota Ground-Water Information Guide at http://www.mgwa.org/gwig/. We now all have websites and instant access to tremendous amounts of information. What hasn't changed is that we still need to collect data from each well that's constructed and sampled. We might get fewer calls from students asking for everything we know about ground water because it's now all on the internet. The words "sensitivity" and "sustainability" have been added to our water vocabulary. The focus on nonpoint source pollution and protection of ground water have become institutionalized in state government programs.

The focus of ground water monitoring programs has changed over the years as well, as have the sources and amount of funding dedicated to them. From one or two staff conducting ambient ground water monitoring in most of the 1980's, MPCA redesigned the program, with the support of funding from the LCCMR and the solid waste fee in the early 1990's, and by the close of the decade, Minnesota had a unique Statewide Baseline Network of chemistry data from 954 wells from the state's 14 principal aquifers. By 2000, the program had moved more toward studies of the effects of changes in land use on ground water resources, when funding issues again curtailed much of the ambient monitoring being conducted by MPCA. Now, the passage of the Clean Water Legacy Act and a new infusion of staff have raised hopes that ambient monitoring can once again serve its rightful place as an important tool for the assessment and protection of Minnesota's ground water resources.

The Continuing Evolution of Minnesota's Groundwater Legislation

Update by John Helland

I've had the pleasure of working for the state House of Representatives for parts of four decades, with a specialization in all kind of environmental issues and legislation. One important law was the 1989 Groundwater Management Act (referred to as "Act" in the text). It set in motion a number of new programs and requirements that are still in place and evolving today.

All of the state's primary environmental agencies played a role in the initiation and implementation of the Act, as well as a variety of other entities, including the University of Minnesota, Minnesota Geological Survey, League of Cities, Association of Counties, Association of Townships, watershed districts, soil and water conservation districts, and assorted farm, environmental, and business groups. The main goal of the Act was to ensure that groundwater was to be maintained in its natural condition, free from any degradation caused by human activities. The legislature acknowledged that this may not be always practicable, but encouraged the development of methods and technology that would make degradation prevention practicable.

Several actions since 1989 to achieve the legislative goal have been successfully completed, including the following:

- Stronger water conservation efforts were implemented and promoted by state and local agencies.
- New or increased water fees were added to reflect the cost of the resource use, and local water planning grants were funded.
- Greater monitoring and testing of pollutants were required as they move through groundwater.

In 1999, a new House Environment and Natural Resources Policy Subcommittee on Groundwater was formed to look into evolving issues. Because of the major elements and requirements of the Act, I thought it could be useful to review what the Act's accomplishments and unfulfilled goals might be.[1] Some ten-year-old issues got resolved, some only partially, and some not at all for a variety of reasons. New lawmakers and agency implementers come and go, and new variations of similar issues evolve that continue to highlight groundwater as a concern.

When summarizing my review and survey of the Act, I thought the Act accomplished some broader results than anything tangible mentioned in the research:

- The Act was a common civic good that brought diverse interests together in a bipartisan manner.

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Minnesota Ground Water Association

Volume 8, Number 3: September, 1989

A Summary of The Groundwater Act of 1989 (S.F. 262)

by John Helland, Legislative Analyst specializing in Environment and Natural Resources.

Article 1

Groundwater Protection

- States a goal that groundwater be maintained in its natural condition, free from degradation whenever practicable. (Sec. 1)
- Definitions are provided for the purpose of the chapter created by article 1 (103H). Terms defined are: agricultural chemical, health risk limits, best management practices, common detection, degradation, fertilizer, groundwater, pesticide, plant amendment, pollutant, pollution, registered use, registrant, sensitive area, soil amendment, water resources protection requirements. (Sec. 2)
- A process is established for the commissioner of natural resources and the Minnesota Geological Survey to designate sensitive areas. Sensitive areas are those areas where because of natural features there is significant risk of contamination of ground water from activities near or at the surface. (Sec. 3)
- Conservation easements are allowed for areas designated as sensitive areas and land in or immediately surrounding a sinkhole. (Sec. 4)
- A provision for a defense to liability is provided for a person who implements and maintains projects and practices from an adopted soil and water conservation plan that applies to the person's property and protection of groundwater. (Sec. 5)
- The commissioner of agriculture for agricultural chemicals and

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Continuing Evolution of Minnesota's Groundwater Legislation, cont.

- It led to a collective vested interest that left a legacy for future generations by setting goals to protect the public's drinking water.
- Groundwater, as an important natural resource, became better understood for future needs and management.
- By the Act's investment and new knowledge of the groundwater resource, the potential was created to save future public dollars in identifying resource quantity and preventing its contamination.

This century, the legislation passed mainly has dealt with fee raising, due to the budget and economic crises. Water appropriation permit and processing fees, water quality permit and water supply well fees, once-through heating and cooling systems, and a summer surcharge for municipal well use were all raised to help balance budgets and retain programs.

Additionally, twice – in 2004 and 2006 – the legislature approved consumptive use of groundwater under a permit of more than 2,000,000 gallons per day average in a 30-day period. The first permit resulted from a joint-powers agreement in Golden Valley, Crystal, and New Hope for their municipal water supply system. The second permit was an allowance for the proposed Excelsior energy project facility in Itasca County.

Since 2000, the legislature and state agencies have paid a lot of attention to failing individual septic treatment systems (ISTS), resulting in some significant law changes. A major law was enacted in 2003 that requires a fee of $25 for installation of new septic tanks, with the money directed to the Pollution Control Agency's (MPCA's) ISTS program. A pilot project started with three counties who inventoried any "imminent threat" ISTS; the project requires upgrades of those systems by May 2008. Also, the MPCA was to develop a ten-year plan that described what was needed to locate and upgrade all imminent-threat and failing ISTS in the state. That work and effort is ongoing.

The Clean Water Legacy issue and resulting legislation have been major initiatives this decade, with resulting implications for cleaning up impaired waters and curbing pollution from the surface water-groundwater connection. A law to identify straight-line pipes that discharge sewage to surface and groundwater was enacted. It requires the MPCA and local units of government to act together to bring these pipes into compliance with discharge standards. Individual parties can be fined for noncompliance with the requirement.

Since 2004, the MPCA, the Minnesota Department of Agriculture (MDA), and the Department of Natural Resources (DNR) have been cooperating on an integrated groundwater monitoring system to assess resource conditions, problem investigations, and remediation effectiveness. Trend groundwater monitoring on vulnerable aquifers and on up to 200 wells is part of this continuing effort.

This past session found the legislature strengthening the prohibition on diverting our water out of the Great Lakes watershed by becoming the first eligible state to adopt the Great Lakes Compact. Because of Minnesota law on water conservation and management, including the Act of 1989, our state permit system was at least the equal, if not significantly stronger, than the other Great Lakes states' permit systems.

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the pollution control agency for other pollutants must develop best management practices (BMP's) for the prevention of groundwater degradation. BMP's are by definition voluntary practices. (Sec. 6)

- All monitoring of groundwater quality by state agencies and political subdivisions must be submitted to the environmental quality board. The board will assess the quality of the data and maintain a computerized database of groundwater data submitted. (Sec. 7)
- The commissioner of health is required to promulgate health risk limits for substances degrading groundwater. The commissioner must review and revise, if necessary, the limits every four years. Existing recommended allowable limits for drinking water may be adopted by the commissioner as health risk limits. (Sec. 8)
- The commissioner of agriculture for agricultural chemicals and the pollution control agency for other pollutants are required to evaluate the detection of pollutants in groundwater. The commissioner or the agency must evaluate whether the pollution results from common detection and continue monitoring and evaluation to determine the pollution frequency and concentration trend. (Sec. 9)
- The commissioner of agriculture for agricultural chemicals and the pollution control agency for other pollutants are required to manage pollutants where groundwater degradation is detected. Where degradation is detected, the commissioner of agriculture or the pollution control agency must promote the implementation of BMP's.
- If BMP's are not effective, the commissioner of agriculture or the pollution control agency must adopt water-resource-protection requirements (WRPRs) that prevent and minimize pollution. The WRPRs can be for the whole state or for a portion designated by order of the commissioner of agriculture or the pollution control agency. (Sec. 10)
- The pollution control agency and the department of agriculture, in consultation with the board of water and soil resources, are required to conduct a study on nitrogen compounds in groundwater. The study will be submitted to the legislative water commission by July 12, 1991. The commission must provide recommendations to the legislature by November 15, 1991.

Article 2

Water Research Information and Education

- A legislative water committee is created to review state water policy and make recommendations to the legislature. The committee will consist of five members each from the house and the senate. The committee will sunset June 30, 1995. (Sec. 1)
- The commissioner of agriculture must establish a clearinghouse and other assistance to agricultural producers on sustainable agriculture and promote the use of integrated pest management.
- An environmental agriculture program is established. The board of water and soil resources, after review by the legislative committee on water and the Minnesota future resources commission, must award contracts for the program. (Sec. 3)
- Conservation easements under the reinvest in Minnesota resources program are allowed for sensitive areas and hillsides used for pasture. (Sections 4 to 6)
- The environmental quality board must prepare and submit a report on water research needs to the joint legislative committee on water and the Minnesota future resources commission by September 15 of each odd-numbered year. (Sec. 7)
- The local water resources protection and management program is established under the board of water and soil resources to provide assistance to counties to develop comprehensive local water plans or to carry out water resource protection programs identified in the water plans. (Sections 8 to 10)
- Sensitive areas and wellhead protection areas are added as components for which the comprehensive local water plans under statute must address. (Sec. 11)
- The University of Minnesota is added as an ex officio, nonvoting member of the board of water and soil resources. (Sec. 12)
- Additional water planning duties are added to the duties of the environmental quality board and the board must have a new plan and strategy by November 15, 1990, and every five years thereafter. (Sec. 13)

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MGWA Fall Conference

1989 Ground Water Legislation in Minnesota

The Minnesota Ground Water Association's fall quarterly meeting will be held November 1, 1989, on the St. Paul Campus of the University of Minnesota at the Student Activity Center.

The conference will provide an opportunity for Association members to learn more about the Minnesota Ground Water Protection Act which was passed this legislative session.

Speakers from various state agencies and departments will present some perspectives on how and why the legislation was passed and how the organizations propose to implement the different portions of the Act for which they are responsible.

The current list of speakers includes: **Judith Ball**, Minnesota Department of Health, **Pat Bloomgren**, Board of Water and Soil Resources, **Greg Buzicky**, Minnesota Department of Agriculture, and **Ron Nargang**, Minnesota Department of Natural Resources, Division of Waters.

Watch for an announcement with more details in early October.

Article 3

Wells, Borings, and Underground Uses

- The current wells, borings, and underground uses provisions in Minnesota Statutes, chapters 156A, 145A, 105, 84, 469 and 471 are recodified in chapter 103I.
- A **permit is required** for all non-drive-point wells constructed. Emergency permit exemptions are provided to protect public health or welfare, or to allow a well contractor to begin construction prior to obtaining a permit. Drive point wells are exempt from the permit requirement but after December 31, 1989, the owner of the well must notify the commissioner of health of the installation and location. A maintenance permit is required for a well that is not in use, inoperable, and unsealed. (Sec. 9, subdivisions 1 to 3)
- A well contractor license is required to drill, construct or repair a well except:

(1) a registered professional engineer, or certified hydrologist or hydrogeologist may construct a monitoring well;

(2) a limited well contractor may modify well casings or screens, construct drive-point wells, or install pumps or pumping equipment.

(3) an individual constructing a well on land they own or lease for farming or a place of abode; or

(4) an individual performing labor or service for a contractor under the direction of the contractor. (Sec. 9 subdivision 4)

- At grade monitoring wells are allowed for leak detection devices. (Sec. 9, subdivision 7)
- Potential sources of contamination may not be placed closer to a well than isolation distances prescribed by the commissioner of health. (Sec. 9, subdivision 6)
- A well identification label is required for all new wells. (Sec. 9, subdivision 7)
- A report of well completion or sealing must be submitted to the commisioner of health within 30 days of completion. The commissioner of health must send a copy of the report to the commissioner of natural resources, the local soil and water conservation district, and the Minnesota Geological Survey. (Sec. 9, subdivision 8)
- Permit fees are established as follows:

For a new well that produces less than 50 gpm, $50;

For a new well that produces 50 gpm or more, $100;

For an inoperable well, construction of a monitoring well or dewatering well, a groundwater thermal exchange device, or vertical heat exchanger, $50;

Annually for an unsealed monitoring well, $50; Annually for a dewatering well $25. (Sec. 10)

- After July 1, 1990, a seller must disclose the location of known wells before signing an agreement to transfer real property.
- A seller who fails to disclose the existence of a well at the time of sale is liable to the buyer for costs and reasonable attorney fees relating to the sealing of a well. (Sec. 14)
- The statute of limitations for a landowner's cause of action against a person whose action or inaction cause contamination of a well is established at six years after the owner discovers the contamination. (Sec. 15)
- Well sealing requirements are established for a well that:

-is contaminated

-was not sealed according to the provisions of this chapter; or

-endangers groundwater or is a safety or health hazard.

- Monitoring wells and dewatering wells must be sealed when no longer in use. (Sec. 16)
- The commissioner of natural resources must identify the location of abandoned wells located on state property.
- The state is prohibited from purchasing or selling land without identifying the location of all wells. (Sec. 17)
- The commissioner of health may order a well sealed that is:

-an imminent threat to public health or safety;

-required to be sealed under section 16; or

-a monitoring or dewatering well for which a maintenance permit is not renewed or obtained within 14 months after construction. (Sec. 18)

- Counties must issue sealed well certificates for wells properly sealed. (Sec. 19)
- The landowner liability for a sealed well is removed for contamination of groundwater from the well that occurs after the well is sealed, on wells that have properly recorded sealed-well certificates. (Sec. 20)
- A well-sealing cost-share program is established in the board of water and soil resources to provide grants to counties. The program sunsets June 30, 1995. Grants will be targeted to counties based on: the diversity of well construction, geologic conditions and land use; current use of affected aquifers; and aquifer susceptibility to contamination by unsealed wells. The state cost share is up to 75 percent or $2,000. After July 1, 1991, only a well sealing that is a priority action identified in approved local water plans willl be eligible for assistance. (Sec. 21)
- A property owner may apply to the board of water and soil resources for funding to seal wells. (Sec. 22)
- The commissioner of health and the board of water and soil resources have a governmental services lien for the cost of wells sealed under contract. (Sec. 23)
- Elevator shaft borings may not be made without a permit from the commissioner of health. (Sec. 24)
- Environmental bore holes must be constructed by a well contractor or monitoring well contractor. (Sec. 25)
- The license fee for a well contractor's license is $250, and an elevator shaft contractor's license is $50. An application fee for each of $50 is also required. A statewide surety bond of $10,000 in lieu of license bonds required by political subdivisions is required. (Sections 30 and 33)
- A limited well contractor's license and a limited well sealing

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contractor's license, with a license fee of $50 each, are provided for. (Sections 32 - 32)

- After December 31, 1990, monitoring well contractors who seek initial registration must meet examination and experience requirements of the commissioner of health. A statewide surety bond of $10,000 in lieu of license bonds required by political subdivisions is required. Application fees will be set by the commissioner of health. (Sec. 35)
- Administrative remedies including denial, suspension, or revocation of licensure and administrative penalties are provided. (Sections 44 and 45)

Article 4

Water Conservation

- Provisions on agricultural irrigation permits and consistency of permits with state, regional , and local water plans, deleted in section 2, are recodified. (Sec. 1)
- The water allocation priorities are amended to place power production that meets contingency planning provisions within the first priority. Power production in excess of a contingency plan remains at fourth priority. (Sec. 2)
- No new appropriation permits may be issued for once-through cooling systems using in excess of five million gallons annually. (Sec. 4)
- A water-use processing fee is established for each water-use permit, replacing the current statutory system. Except for once-through cooling systems, the water-use permit fee is 0.05 cents per 1,000 gallons for the first 50 million gallons and 0.1 cents per 1,000 gallons for amounts above 50 million gallons. The maximum is $2,000. The fee for once-through cooling systems is set at 5 cents per 1,000 gallons until December 31, 1991, 10 cents per 1,000 gallons during calendar years 1992 - 1996, and 15 cents per 1,000 gallons thereafter. The fees are based on permitted capacity and a fee must be $25 or more. (Sec. 5)
- Rules are authorized for conservation of public water supplies. (Sec. 6)
- Joint powers water management organizations are given authority to require water appropriation permits for nonessential uses below 10,000 gallons per day and one million gallons per year on protected watercourses in the metropolitan area with a drainage area less then 25 square miles. (Sec. 7)
- The commissioner of natural resources must study and report by February 15, 1990, to the legislative water commission, on the impact of consumptive water use on existing aquifers. (Sec. 8)

Article 5

Pesticide Amendments

- New definitions are provided for collection site, container, corrective action, local unit of government, owner of real property, pesticide end user, returnable container, and waste pesticides. (Sections 1 to 15)
- The commissioner of agriculture must develop a pesticide management plan for the prevention, evaluation, and mitigation of the occurrence of pesticides and pesticide breakdown products. (Sec. 17)
- The state must use integrated pest management techniques on public lands. (Sec. 18)
- Monitoring of urban and rural pesticide use must be done by the commissioner. (Sec. 19)
- The commisioner of agriculture is required to establish a waste pesticide collection program to collect waste pesticides from pesticide end users. The commissioner may assess costs for disposal on the end users and use the money in the waste pesticide collection account to pay for expenses of the program. (Sec. 20)
- a chemigation permit and antisiphon device are required for applying pesticides through an irrigation system from any source of irrigation water. (Sections 25 - 26)
- A fertilizer chemigation permit holder is exempt from the pesticide chemigation permit fee. (Sec. 27)
- After June 30, 1994, pesticide dealers and distributors must accept waste pesticides that remain in the original container unless there is a designated place in the county to return the unused portion. (Sec. 29)
- The annual application fee for pesticide registration is increased from $125 to one-tenth of one percent of gross sales of the pesticide within the state, with a minimum fee of $150. (Sec. 31)
- A person intending to discontinue registration of a pesticide in Minnesota must complete a total recall of the pesticide in the state within 60 days. (Sec. 33)
- The commissioner of agriculture, in connection with the extension service, must develop innovative educational and training programs addressing pesticide concerns. (Sec. 34)
- The certification period for a private applicator is reduced from five years to three years. (Sec. 46)
- The department of agriculture, in consultation with the pollution control agency and the Minnesota extension service, is required to develop a pesticide container collection and recycling pilot project. The department is required to report to the legislature by November 30, 1991, on recommendations for managing pesticide containers. (Sec. 52)

Article 6

Fertilizers, Soil Amendments, and Plant Amendments

- The curent provisions on fertilizers, soil amendments, and plant amendments from Minnesota Statutes, chapter 17, are recodified in chapter 18C.

Evolution of Groundwater Legislation, cont.

The growing concern over private well contamination in Washington County resulted in a new law, which includes sgnificant funding to reduce the perfluorochemicals PFOS and PFOA from drinking water supplies in the east metro area. The Minnesota Department of Health (MDH) recently adopted new Health Risk Limits for the above chemicals in conjunction with the concern. A new environmental health tracking and biomonitoring system is required for the MPCA, MDH, and MDA, in cooperation with the University of Minnesota, to develop data and plans for assessing environmental hazards and toxic chemicals on public health.

Continuing concerns that pose problems to our groundwater quality and quantity will be with us in the future, including the following:

- Volatile organic compounds, pharmaceutical compounds with potential endocrine disruptors, pesticide and fertilizer loads, and hazardous pathogens need to be continually monitored and dealt with.
- Although groundwater lies everywhere beneath our land surface, it isn't necessarily available for use everywhere because of the uneven distribution of aquifers. The potential for more corn ethanol and other biofuel plants in Minnesota may limit some aquifers for other uses.
- In the metropolitan area, the Metropolitan Council and communities are working on a master water supply plan, which is subject to DNR approval, so that community growth is evaluated for sustainability purposes and water-well permitting becomes more streamlined.

As a recent report from the Environmental Quality Board on water resources sustainability indicates, Minnesota's reputation as "water rich" isn't as prominent as it once was. The growing and significant demands on its renewable water resources make water supply and water quality management special concerns, especially with the projected one-million population growth anticipated in the next 25 years. The regulation, funding, research and data collection, and education efforts stemming from the 1989 Groundwater Act continue to greatly help the state in addressing these concerns and demands.

A somewhat obscure Senegalese poet, Baba Dioum, wrote a prescient poem that offers an analogy to the value of groundwater.

"In the end, we conserve only what we love.

We will love only what we understand.

We will understand only what we are taught."

[1] *For more on the Groundwater Act, see the House Research information brief, A Survey of the Groundwater Act of 1989, at www.house.leg.state.mn.us/hrd/pubs/gdwtract.pdf.*

Program Evolution at the Minnesota Geological Survey

by Dr. David L. Southwick, Director

Introduction

Most MGWA members presumably have used the products and services of the Minnesota Geological Survey (MGS) at one time or another, or at least know that MGS exists. Earlier in your careers, some of you may have confused the MGS with the U.S. Geological Survey (USGS), and perhaps some of you still do. If you didn't once confuse us with the Feds, maybe you thought we were an agency of state government, possibly a unit of the Department of Natural Resources. Wrong! The MGS actually is an applied research and public service unit of the University of Minnesota. Even though we live apart, our administrative home is in the Department of Geology and Geophysics, in the Institute of Technology.

History and Philosophy

The MGS was established March 1, 1872 by a legislative act which

MGS Program Evolution, cont.

instructed the Board of Regents of the University to organize a geological and natural history survey of the state and appropriated funds for the purpose (General Laws of Minnesota, 1872, Chapter 30). Section 2 of the act stated that the geological survey should be undertaken with a ". . . view to a complete account of the mineral kingdom as represented in the State. . ." Sections 7 and 8 required that maps and reports be prepared to convey the results of the geologic studies, and that these be distributed widely to the general public and the Legislature.

Since 1872 the MGS has been striving to deliver a full and credible account of the "mineral kingdom" in Minnesota. Because water is a naturally occurring, inorganic, crystalline solid in Minnesota during much of the year, and is, therefore, a mineral by generally accepted definition, the MGS for decades has interpreted its charge to include investigations of Minnesota's water resources. We are quite confident that the 1872 legislators understood the phase diagram for H_2O and therefore thought it superfluous to mention liquid water specifically in their instructions to the university regents.

In Minnesota, as in most other states, the state geological survey was among the first public entities to be organized explicitly for scientific purposes. Spurred by 19th-century socio-political fervor to conquer the wilderness, develop natural resources, and create wealth, governors and legislators were eager to assess their domains. Geologists were hired and field studies were initiated with the expectation that mineral deposits would be found to assure everlasting riches and water supplies would be identified to assure bountiful crops year after year. Of historical importance, however, was the fact that most states selected academic directors for their geological surveys and gave them broad latitude to conduct their studies in accordance with sound scientific principles. The

— continued on page 4

MGWA Newsletter, March 2000

MGS Program Evolution, cont.

objective of creating collective wealth from the natural resources of the land dovetailed perfectly with the missions of the land-grant universities that were springing up in states west of the Allegheny Front. Thus, many state geological surveys were organized within their state universities, and several, including Minnesota's, have remained there.

Meaningful basic research was a significant outcome of the integration of surveys with academic institutions. The early surveys made fundamental contributions to geomorphology, stratigraphy, paleontology, regional structural geology, economic geology, and other subdisciplines. However this basic work was not conducted independent of geography and practical considerations. It sprang from and contributed to the fundamental charge to decipher the geology of a place so that economic "good" might be enjoyed. The MGS tries to perpetuate that heritage. We consider our role to go beyond the mere delivery of geological information. New ideas and insights that expand the general comprehension of Minnesota's varied geology remain our most important products. Those new ideas and insights should enhance the state's economy in the long run by contributing to wealth in the material sense, and also to the quality of the environment in which we live.

Until about 30 years ago, geological accomplishments in the Lake Superior region (Minnesota, Wisconsin, Michigan, and northwestern Ontario) were measured mainly in terms of knowledge gained about the Precambrian rock record and the economic productivity generated — new mineral deposits discovered, new mines opened, and the tonnage of mineral commodities produced. This political and economic environment dictated the thrust of MGS activities and strongly influenced the research agenda of the Department of Geology at the University of Minnesota.

In recent years, globally mushrooming human populations have increased the competition for land, water, and mineral resources, and planning for the conservation and wise use of these has become a major expectation of today's public officials. The concerns of society in the Lake Superior region for sources of safe drinking water and the availability of recreationally suitable lands and surface waters have eclipsed concerns about the availability of gold, copper, or gravel. As a direct result, environmental issues now drive geological survey programs. At MGS, we now devote fully three fourths of our professional effort to topics that in one way or another relate to hydrogeology and environmental land-use issues.

Despite current public indifference toward mineral commodities, good resource-management policy must acknowledge the legitimate place of the mining industry in today's world. The mining industry provides materials that are vital to modern society, and is capable of producing them in an environmentally responsible manner. Mineral resources are where they are, regardless of inconvenience or human desires to have them in someone else's back yard. Mining operations should be factored into long-range environmental planning, and should be permitted if mining plans pass appropriate scientific and public review.

Current MGS Activities : General Comments

Many MGS products are intended to aid the public and its decision-making officials in allocating land, water, and mineral resources. Two of these — County Geologic Atlases (CGAs) and Regional Hydrogeologic Assessments (RHAs) — are familiar to most practicing Minnesota hydrogeologists and will not be discussed at length (Fig. 1). It is worthwhile emphasizing that (1) CGAs and RHAs

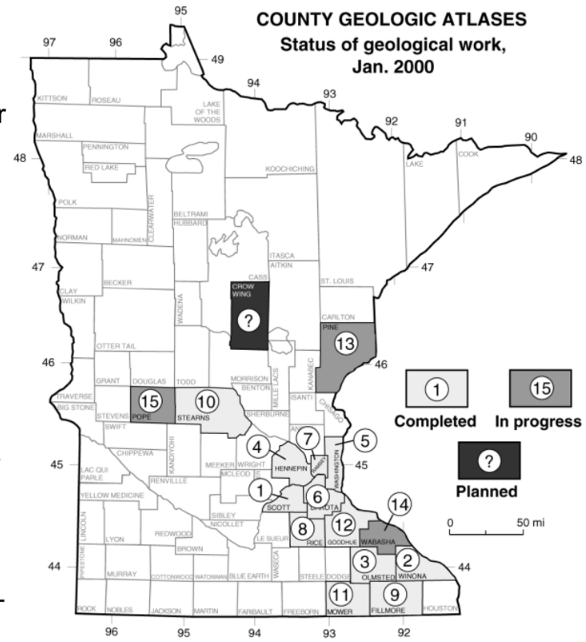

Figure 1a

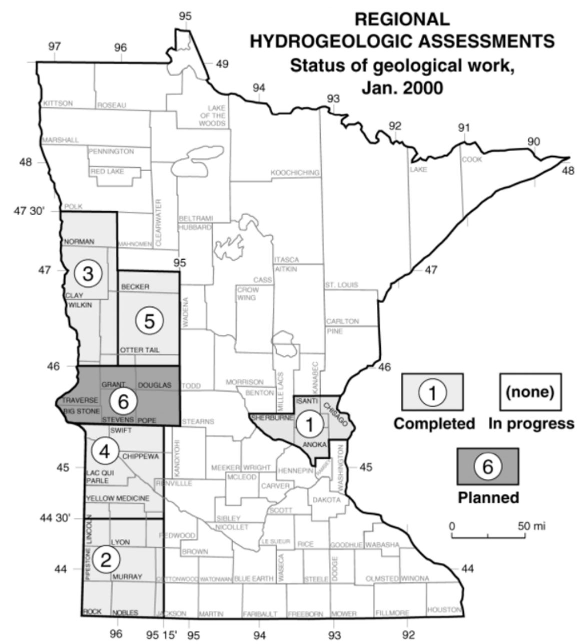

Figure 1b

Figure 1 — Status of CGA and RHA production (1a and 1b, respectively). Status shown only for MGS components of projects; DNR components (hydrogeology) necessarily lag behind MGS components (geology).

Numbers indicate sequence of completion.

are produced jointly by MGS and DNR Waters; (2) those produced since 1993 are available in GIS formats; and (3) the published and soon-to-be published CGAs and RHAs cover approximately 49% of the land area of Minnesota where approximately 73% of the state's population resides. The long-term goal of the program is to cover the main population growth corridors, the sand plains, and the agricultural lands of the state with either CGA or RHA mapping in a reasonable period of time.

Other MGS geologic mapping activities may be less well known to the MGWA community. These include (1) the STATEMAP program, funded by the USGS as a 50:50 federal-state co-op; (2) mapping projects recommended by the Minnesota Minerals Coordinating Committee (MCC) and funded from the Minerals Diversification Account administered by the DNR; and (3) mapping projects funded individually by various state and county agencies or by the MGS itself, from its base operating budget. In addition to these mapping endeavors, the MGS conducts a variety of derivative research projects on many specialized topics. Many of these bear directly on environmental or hydrogeological issues.

STATEMAP

The STATEMAP program started in 1992 with passage of the National Cooperative Geologic Mapping Act by Congress. The act was reauthorized in 1997 and again in 1999; it currently operates through the 2005 federal fiscal year. Its fundamental premise is that geologic maps are critical to sound resource management, and that the production of geologic maps is therefore in the interest of the nation.

Operationally, the national task of geologic mapping consists of two parallel efforts: to produce new detailed maps at scale 1:24,000 in GIS-ready format, and to capture older geologic maps by recompiling them digitally at scale 1:100,000. The first effort addresses the need for detailed geologic mapping in critical areas, whereas the second will lead eventually to a nationwide database of geologic mapping that is organized on the basis of standard 30' x 60' topographic quadrangles. The mapping task is further divided into three program elements: FEDMAP, the production of maps on federal lands or in areas deemed to have federal significance (USGS responsibility); STATEMAP, the production of maps for areas that the individual states accord mapping priority (state responsibility), and EDMAP, a program to support the university training of new geologic mappers (university responsibility). All three elements are coordinated administratively.

Mapping priorities under STATEMAP are set by mapping advisory committees in each state. The Minnesota committee consists of five members; one each from the DNR, the state agencies other than DNR, MGWA, the local section of AIPG, and the Minnesota Exploration Association (MExA). These people meet annually and pass their recommendations for mapping to MGS. MGS then applies for funding support through a competitive process that is open to all 50 states and the Commonwealth of Puerto Rico. The funding pie is sliced for a given fiscal year, and the application process is repeated the next year.

To date, the Minnesota STATEMAP projects have focused on mapping surficial materials in the urbanizing corridor between Rochester and St. Cloud (Fig. 2). Starting in July, 2000 we will break from that mold by mapping the surficial geology of three 7.5 minute quads in the Brainerd area.

MCC projects

The Minerals Coordinating Committee consists of 10 members, one each from DNR Division of Lands and Minerals, MGS, NRRI, MPCA, IRRRB, U of M Institute of Technology, United Steelworkers of America, the iron-ore/ taconite industry, the nonferrous metallic minerals industry, and the industrial minerals industry. These people meet several times a year to receive, screen, and fund research proposals from groups at DNR, MGS, and NRRI, to receive reports from agencies and the minerals industries, and to develop coordinated strategies for legislative action pertinent to the minerals sector. Projects funded through the MCC process obviously are relevant to minerals issues, but they address many hydrogeological factors involved in mine design, environmental monitoring, and mine closure in addition to the geological and metallurgical factors associated with mineral exploration and processing. The overarching goal is to promote an environmentally responsible mining industry in Minnesota.

Most of the MCC work undertaken by the MGS has been geological and geophysical mapping in areas thought to be prospective for mineral deposits. It has emphasized "hard-rock" studies in northern and east-central Minnesota (Fig. 3), but has included the mapping of Quaternary materials near the Rainy River and the delineation of construction aggregate

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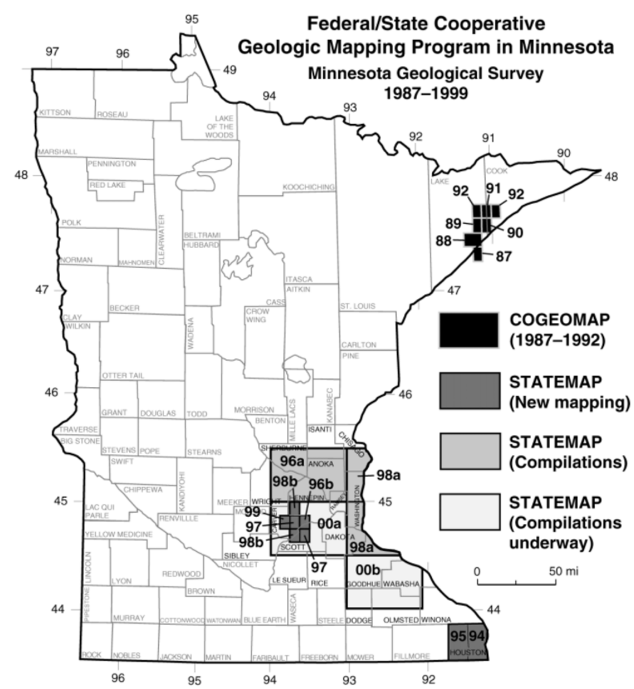

Figure 2 — Minnesota STATEMAP products by year.

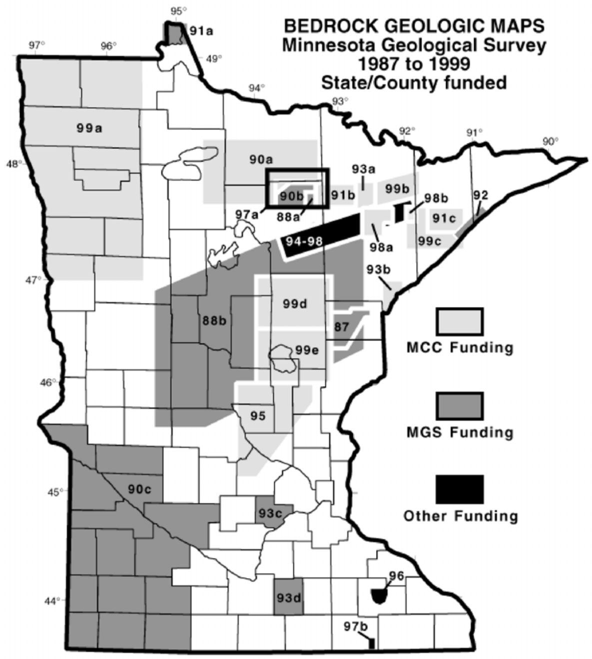

Figure 3a

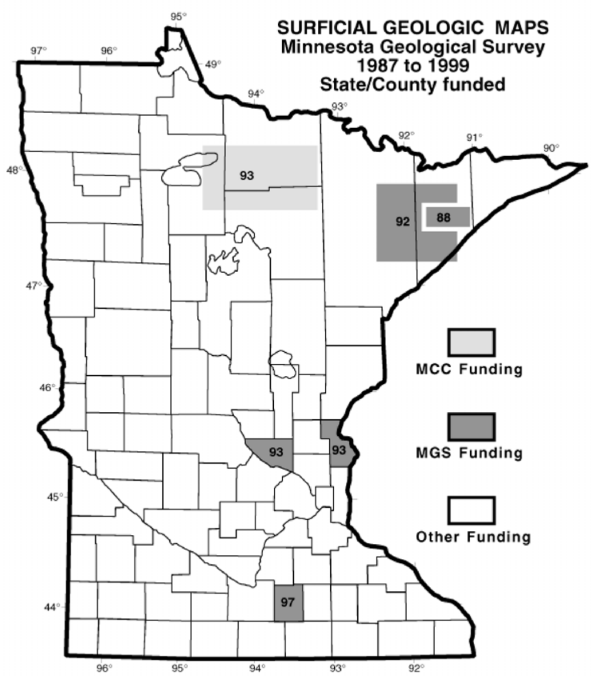

Figure 3b

Figure 3 — Mapping projects undertaken with state, county, and local funding since 1987. Excludes CGA/RHA and STATEMAP output. Bedrock projects (3a) are distinguished from Quaternary projects (3b). Numbers indicate year of publication.

resources in the Seven County Metropolitan Area. Our current MCC projects are (1) a geological and geophysical compilation and summary of the entire Duluth Complex; (2) an aggregate inventory of Chisago County; (3) a bedrock geologic map of the Eagles Nest quadrangle in the Vermilion district; and (4) development of a database of MGS publications and unpublished holdings.

Other MGS Projects

The MGS is constantly on the lookout for funded projects with state and federal agencies, county and local agencies, and the private sector. At any given time we have five or more of these underway, and the majority of them are primarily hydrogeologic. In addition, we fund a limited number of projects internally through our university base budget.

At the present time we are cooperating partners with the DNR on a major LCMR-supported project to understand the interactions of surface hydrology and near-surface hydrogeology of mined lands on the western Mesabi range. We are continuing with several inter-related projects on the hydrogeology of the Mississippi River corridor between St. Cloud and Little Falls that are funded through the Minnesota Department of Health by the U.S. Environmental Protection Agency. We are doing a regional recharge study of the Seven County Metropolitan Area in cooperation with the USGS and the involved county governments. We are obtaining new understanding of ground-water flow in the Prairie du Chien Group through down-hole hydrogeologic testing (LCMR support). We are cooperating with various entities to develop a modified hydrostratigraphic framework for southeastern Minnesota. We are even thinking about delving into the infamous University Library Access Center site on the West Bank and doing a hydrogeologic post mortem. Time will tell.

Postscript

The MGS greatly appreciates the professional cooperation it has received from the MGWA membership over the years. We welcome your continuing suggestions and support, and invite you to visit our website (http://www.geo.umn.edu/mgs) or offices if you have questions or comments on the information presented above.

COMMENTARY

Program Evolution at the Minnesota Geological Survey

Commentary by Dale Setterholm, Minnesota Geological Survey

Programs are a means of carrying out the mission of the Minnesota Geological Survey (MGS). Our mission remains unchanged, but the activities and products that fulfill it never stop changing. The major focus of our work is completion of comprehensive geologic mapping and associated databases at 1:100,000 scale (or more detailed) statewide. By comprehensive we mean bedrock geology, surficial geology, characterization of the vertical sequences in the glacial and bedrock geology, bedrock topography, drift thickness, derivative maps (ex: mineral endowment), and the associated databases such as County Well Index, geophysical data, geochemistry, and others. Creating all these elements at the same time is efficient; it improves the quality of each element and, most importantly, it increases the applicability of the work to a variety of purposes. MGS tries to deliver this information in formats appropriate for as many users as possible. The ability of geographic information systems to pro-

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Program Evolution at MGS, cont.

duce customized maps or other presentations of the data and to interact with other types of data make them an integral part of our work.

MGS utilizes the same major programs as we did in 2000, but with some variations in each program, and in how they interact. While there is an emphasis on geology that supports water management, this is more apparent in funding strategies than in the products themselves. We find that comprehensive geologic mapping and databases are the most efficient and effective means of addressing a variety of needs that change over time.

The County Geologic Atlas and Regional Hydrogeologic Assessment Program (with contributions from Jan Falteisek, DNR Waters, program cooperator)

The news here is both good and not so good. In the not so good category is the bare fact that DNR funding for this program since the 2000-2001 biennium has been severely cut (almost exactly in half), with consequent loss of staff and thus limits to how many projects can be moved forward at a time, even with the support of county partners. With that level of agency funding, only a few atlas reports (either Part A, geology, or Part B, ground water) can be published in any year.

Notwithstanding the discouraging agency funding news, there's still a fair amount of good news. First, a number of reports have been published and new projects started. MGS has published Part A of the Pine, Wabasha, Pope, Crow Wing, and Todd County Geologic Atlases (CGA). With separate funding from Scott County, their original 1982 atlas was updated by the MGS and republished in 2006. This may be the start of a continuing cycle of updates to older atlases. The update includes, among other improvements, maps of buried sand bodies in the glacial drift, which was not included in the original 1982 atlas. In addition, the MGS published in 2006 Part A of the Traverse-Grant Regional Hydrogeologic Assessment (RHA). DNR Waters has published Part B of the Mower, Goodhue, Pine, Wabasha, and Pope CGAs. DNR Waters published in 2002 Part B of the Otter Tail RHA. Projects underway include Crow Wing, Todd, Carlton, McLeod, and Carver CGAs and the Traverse-Grant RHA. Part A reports for Crow Wing and Todd CGAs and the Traverse-Grant RHA are already available. A map summarizing the status of County Geologic Atlas and Regional Hydrogeologic Assessment projects is presented in Figure 1.

Also encouraging is the additional funding the MGS obtained this last legislative session through the Legislative and Citizen's Commission on Minnesota Resources (LCCMR) that enabled two additional CGAs, Benton and Chisago, to start.

What may be of particular interest to many MGWA members is the continued development of GIS tools and techniques to improve mapping and analysis in the third dimension. Much of the recent improvement is based on the construction, using GIS technology, of many closely-spaced cross-sections, which has become easier with batch processing. Additional tools have been developed to capture the cross-section data and construct grid (map view) files of geologic contact surfaces. These products are especially important in areas of the state that depend on buried

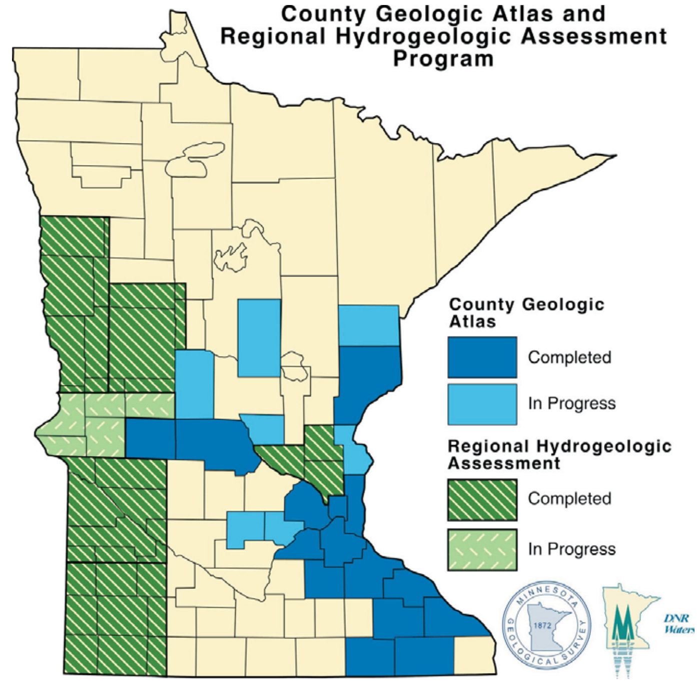

Figure 1: Status of the County Geologic Atlas and Regional Hydrogeologic Assessment Program (2007).

sand and gravel aquifers, most of which have not been adequately mapped. This geologic framework is essential to efforts to protect and wisely use our aquifers.

The long-term goal for CGAs has not changed. Priority areas continue to be population centers, growth corridors, and sensitive landscapes. Work on RHAs will be deemphasized with efforts directed instead toward CGAs.

The best news may be that county geologic atlases continue to be a high quality information resource for counties and ground water professionals. With the incorporation of new technology and improved understanding of the geologic environment, the county atlas series should continue to meet the needs of counties and professionals well into the future.

The STATEMAP Program

MGS utilizes the STATEMAP Program of the National Cooperative Geologic Mapping Act to match MGS funds with USGS dollars and double the amount of mapping those funds can produce. In the period 2001-2007 MGS has mapped approximately thirty-five quadrangles at 1:24,000 scale, and nine 30 x 60 minute quadrangles at 1:100,000 scale. In many cases the geologic maps are accompanied by associated databases, and all are produced in digital form. This work has been funded by $1,015,161 in federal funds and an equal amount of MGS base funds. This program is challenging in that it requires map production within a one year cycle. It interacts with other mapping programs at MGS in several ways. For example, STATEMAP work may initiate mapping in new areas, provide additional detail in areas previously mapped, or rectify and compile several maps into a new and digital format. MGS is currently mapping three quadrangles in the Duluth area under this program to enable geologic coverage for a large population center in an area unlikely to host a county geologic atlas.

Program Evolution at MGS, cont.

Minerals Coordinating Committee (MCC) Program

The MCC continues to support geologic and geophysical mapping by MGS. The mapping supports mineral resource management, but can also benefit mineland reclamation and other uses. In recent years, MCC projects at MGS have upgraded the aeromagnetic database and related processing system at MGS, produced bedrock and Quaternary mapping of the Mesabi Range, evaluated the potential for platinum group elements in mafic intrusions other than the Duluth Complex, and produced maps of the aggregate resources of Itasca County. MGS has just initiated an effort to compile new statewide bedrock geology and bedrock topography maps, and geochemical data with MCC support.

Other MGS Projects

MGS continues to partner with a variety of federal, state, tribal, and local government entities to accomplish geologic mapping. Examples from recent years include:

- Mapping to support water supply management in the Twin Cities area funded by the Metropolitan Council
- Geophysical logging and geologic analysis in the Lake Elmo area and mapping of bedrock geology and karst features in southeastern Minnesota funded by MPCA
- Mapping of geology and related aggregate resources in the Chippewa National Forest funded by the U.S. Forest Service
- Geologic and hydrogeologic mapping of the Mesabi Iron Range and acceleration of the County Geologic Atlas Program funded by the Legislative and Citizen's Commission on Minnesota Resources
- Improvements to the County Well Index Database, mapping of the St. Lawrence Formation, and an investigation of the Jordan Sandstone Structure in southern Washington County funded by the Minnesota Department of Health
- 3D modeling of the geology, and a regional inventory of ground water resources in the Fargo-Moorhead area funded by the U.S. Bureau of Reclamation
- Geologic mapping in support of ground water management funded by the Shakopee Mdewakanton Sioux Community
- Stream sediment and soil sampling funded by the USGS
- Till geochemistry and indicator mineral surveys funded by the Western Mining Company
- Partnerships with the MPCA, the St. Croix Watershed Research Station, the Geology Department at the University of Minnesota, and local watershed organizations to investigate sediment sources in the Minnesota River, Lake Pepin, and tributaries.

Challenges

Base funding to the Minnesota Geological Survey is provided by the legislature and is controlled by the willingness of the University of Minnesota to request adequate funding. Since 2000, that base funding has increased by 0.6%. To facilitate as much mapping as possible, MGS relies heavily on temporary funding from grants and contracts. This makes the organization vulnerable to dramatic fluctuations in funding levels and correlative reductions in staffing. This is an organization where personnel costs can exceed 90% of income. Consequently, full time staffing has been reduced from 31 to 25, and went as low as 22 in 2004.

We are fortunate to have a highly experienced and capable staff that has combined great effort with new technology to maintain or even increase map production in spite of these developments. The MGS staff averages 52 years in age with 23 years of experience. Our challenge is to find the necessary resources to bring in a new generation of geologic mappers and pass along the skills, experience, and attitude of current staff before they leave.

— Jim Stark and Dave Wall describe results of CAFOs on the Fall 2000 Field Trip, photo by Kelton Barr

— Minnesota Department of Natural Resources Hydrologist Jeff Green met with Kamba village officials during missionary work in Kenya. Green used his skills as a hydrologist to suggest ways the village coud provide cleaner water to residents. June 2000.

— Dr. Harvey Thorleifson's enthralled audience, Fall Conference 2004.

Remediation

The Effects of Air Sparging on Aquifer Hydraulic Conductivity

— Hans Neve, Hydrologist, Ground Water Unit, Minnesota Pollution Control Agency

Introduction

Air sparging is a remediation technique used to remove organic contaminants from aquifers. Under favorable geologic conditions it can be a very effective remediation technique for some types of contaminants. This technology involves injecting air into contaminated aquifers. Injected air can remove contaminants through volatilization and enhanced aerobic biodegradation. Volatile contaminants can partition from ground water into injected air and be transferred to the vadose zone where they can then be extracted more efficiently. Air sparging can also provide a source of oxygen to ground water enhancing aerobic biodegradation. Air sparging produces both physical and chemical changes in aquifers, many of which are poorly understood.

Air injected into an aquifer must occupy a portion of the available pore space. These air filled pore spaces cannot transmit significant amounts of water, hence the flow of water is restricted to the remaining water filled pores. Injected air that occupies a significant portion of the available pore space may cause a local zone of low hydraulic conductivity which may in turn change the direction and rate of ground water and contaminant movement. This study measures changes in hydraulic conductivity produced by air sparging.

Laboratory Test Experimental Design

This study assessed changes in hydraulic conductivity produced by air sparging in laboratory and field experiments. A variety of sediment samples with different grain size distributions were tested during laboratory experiments. A constant head permeameter, modified to facilitate air injection was used to determine the hydraulic conductivity of sediment samples during laboratory tests. A schematic diagram of the permeameter is shown in Figure 1 (Page 8). A permeable plate was clamped to the top of the permeameter. This held the sediment sample in place, while allowing both water and air to be discharged from the apparatus. Using Darcy's Law, the hydraulic conductivity of a sediment sample can be determined at any point in time by measuring: the drop in hydraulic head across the sediment column, the length of the sediment column, the cross sectional area perpendicular to the flow of water, and the discharge of water through the sediment sample.

Laboratory tests consisted of determining the hydraulic conductivity of sediment samples before air was injected, during air injection, and for a period following air injection. The hydraulic conductivity of each sediment sample was determined before air injection. Air was then injected into each sediment sample at the following rates: 0.05, 0.1, 0.15, 0.2, 0.25, 0.33, 0.5, 1, 1.5, 2 and 3 cubic feet per minute (CFM). Air was injected at each flow rate for a period of approximately 10 minutes. At the end of the 10 minute period hydraulic conductivity was measured, following this the air flow rate was increased. Following air injection at 3 CFM the air flow was discontinued and hydraulic conductivity was measured. Values of hydraulic conductivity obtained before air injection were compared with hydraulic conductivities measured during and after air injection to assess the influence of air sparging.

Nine sediment samples were tested in during laboratory experiments. Sediments used are commercially available sands and gravels. Grain size distribution curves of these sediments are presented in Figure 2 (page 8). Sediments used in tests 2 through 6 are poorly-graded sediments ranging from fine-grained sand used in test 1 to fine-grained gravel used in test 6. Sediments used in tests 7,8, and 9 are well-graded.

Meaningful results were not obtained from laboratory test 1, hence the data are not presented. A deficiency of the laboratory apparatus is that it is not able to test fine-grained sand and finer sediments. The resistance to air flow in fine-grained sediments was sufficient to induce injected air to flow downward through the water filled chamber at the bottom of the permeameter and out of the permeameter through the filled reservoir, rather than upward through the sediment sample. This short circuiting phenomenon prevents fine-grained sands and all finer sediments from being tested with this laboratory apparatus.

Laboratory Test Data

Data from selected laboratory tests are presented in Figure 3:

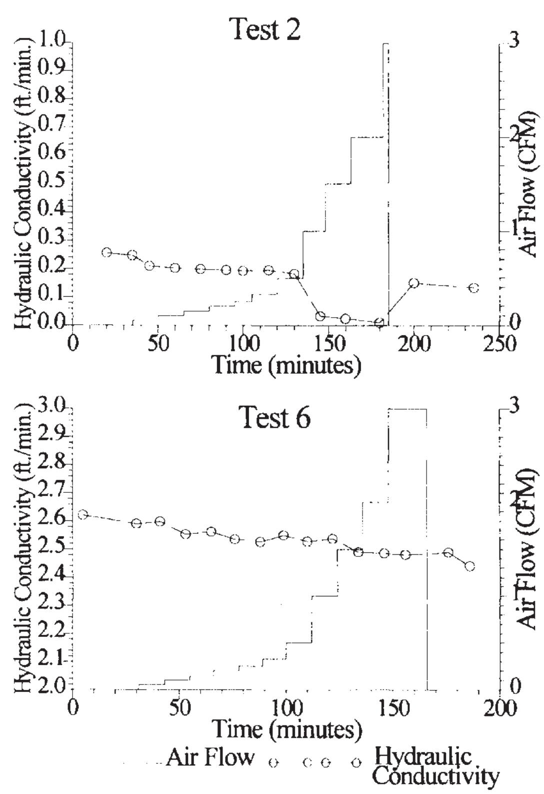

Figure 3. Data from laboratory tests 2 and 6.

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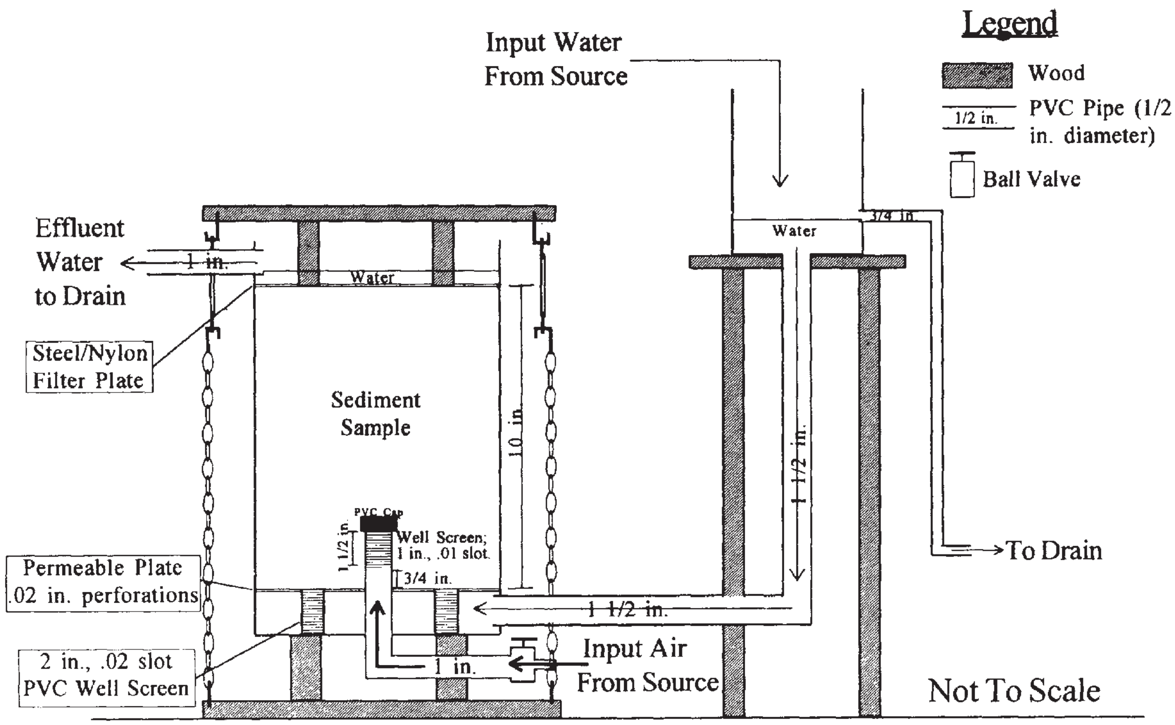

Figure 1. Modified constant head permeameter used in laboratory experiments.

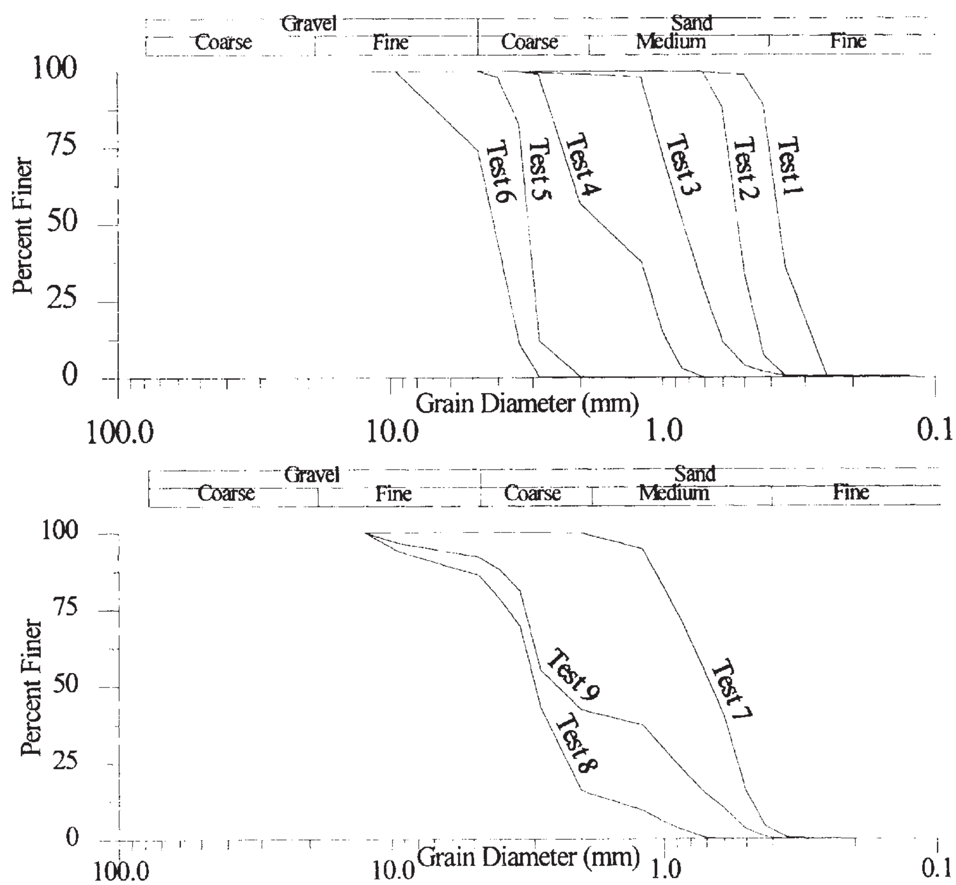

Figure 2. Grain size distribution of sediments used during laboratory tests.

Air Sparging and Hydraulic Conductivity, cont.

The sediments used in tests 2 and 6 are medium-grained sand and coarse-grained sand to fine grained gravel, respectively. During test 2 hydraulic conductivity was not affected at low air injection rates, while at high air injection rates (0.5 CFM and larger) it was reduced.

Data for all laboratory tests are summarized in table 1 (page 10). The maximum reduction in hydraulic conductivity is presented as a factor to which hydraulic conductivity was lowered during laboratory tests. This was calculated from the lowest measured hydraulic conductivity and a baseline hydraulic conductivity. The baseline hydraulic conductivity was calculated by averaging several data points before hydraulic conductivity was lowered at high air flow rates.

The largest reduction in hydraulic conductivity was measured during laboratory test 2 (medium grained sand). This was greater than an order of magnitude reduction, and was produced by injecting 2.5 CFM of air into the medium-grained sand tested. All other sediments tested showed a maximum reduction ranging from a factor of 4.4 to essentially no reduction for fine-grained gravel.

Laboratory Test Interpretations

The reduction in hydraulic conductivity is related to sediment grain size. Fine-grained sediments showed a larger maximum reduction in hydraulic conductivity than did coarse-grained sediments. This is likely the result of coarse-grained sediments having larger interconnected pore spaces. Hence a given amount of injected air will occupy a smaller portion of the total available interconnected pore space in coarse-grained sediments as compared to fine-grained sediments. This produces a smaller overall reduction in hydraulic conductivity for coarse-grained sediments.

The influence of heterogeneity was assessed during laboratory test 10. With the exception of this test, all sediment samples were relatively uniform. A non-uniform sediment was created by sieving sediment sample 4, separating grains greater than 2 mm in diameter and grains smaller than 1 mm in diameter from the rest of the sediment. This produced three sediments from the original sample. These subsamples were packed into the permeameter in randomly alternating thin layers. This produced a subtle layering which is believed by the author to more accurately represent the stratigraphy of most natural sediments.

Although tests 4 and 10 utilize the same sediment sample, the subtle layering present in test 10 more than doubled the reduction in hydraulic conductivity. This suggests that subtle lithologic variations may have a significant influence on the migration of injected air in aquifers. Both water and air preferentially flow through the largest available pores. When large amounts of air are present in a water saturated media, air will preferentially dewater and flow through larger pores forcing water to flow through smaller water filled pore spaces. When a limited numbers of large interconnected pores are available, as is the case for the stratified sediment in test 10, a larger reduction in hydraulic conductivity results.

Field Site Characteristics

The field site for this research is located within the Western Michigan University Asylum Lake Research Park, Kalamazoo, Michigan. The water table at the study site is approximately 17 feet below grade with ground-water flow toward the east, north-east. The vadose zone geology at the research site consists of clay to a depth of approximately 10 feet. Underlying the surface clay layer are glacial outwash deposits of sand and gravel. The unconfined aquifer consists of medium- to fine-grained sand.

The well field constructed for this research consists of ground-water monitoring wells and an air injection well (Figure 4). The air injection well (well 34) is constructed of an 1-inch diameter PVC screened from 28 to 33 feet below the water table. A network of monitoring wells was installed surrounding the air injection well. Monitoring wells are constructed of 2-inch inside diameter, flush threaded PVC with .01-inch slot screens of variable length. Artificial filter packs were not used in the construction of ground-water monitoring wells. Instead the aquifer material was allowed to collapse around the installed well screen. This may produce more representative values of hydraulic conductivity from slug tests, and minimize the creation of preferential air flow pathways adjacent to wells.

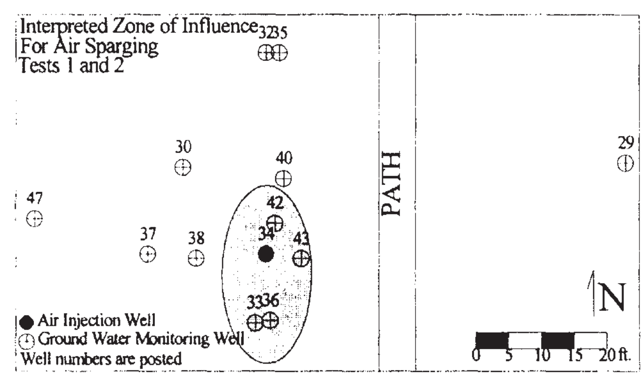

Figure 4. Zone of influence produced by air sparging.

Field Test Experimental Design

Field tests included several sets of slug tests and two air sparging tests. Aquifer hydraulic conductivity was determined using pneumatic slug test procedures. Slug tests were conducted before air sparging to determine a baseline aquifer hydraulic conductivity. The influence of air sparging was interpreted from comparing these initial values with slug test data obtained during and after air sparging tests. Time-displacement data from each slug test were recorded using a pressure transducer and data logger. The Bouwer and Rice method was used to analyze these data to obtain a value of hydraulic conductivity for each test.

For slug tests during and after air sparging, each well of interest was slug tested two or three times in sequence to

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Table 1
Maximum Reduction in Hydraulic Conductivity Determined From Laboratory Experiments

Test Number	D_{25} 75% Coarser (mm)	D_{50} Median Grain Size (mm)	Baseline Hydraulic Conductivity (ft./min.)	Lowest Measured Hydraulic Conductivity (ft./min.)	Factor of Hydraulic Conductivity Reduction
2	0.5	0.6	0.190	0.009	21
3	0.7	0.8	0.245	0.118	2
4	1	1.6	0.440	0.337	1.3
5	2.9	3.1	2.14	1.90	1.1
6	3.6	4.1	2.52	2.48	1.01
7	0.5	0.7	0.181	0.058	3.1
8	2.2	2.9	0.660	0.425	1.6
9	0.9	2.4	0.194	0.044	4.4
10	1	1.6	0.394	0.124	3.2

Table 2
Average Hydraulic Conductivities Determined From Slug Tests

Well No.	Pre- Air Sparging	Air Sparging Test 1	3 Hours After Air Sparging Test 1	1 Week After Air Sparging Test 1	Air Sparging Test 2 Step 3	Air Sparging Test 2 Step 5	17 Hours After Air Sparging Test 2	1 Week After Air Sparging Test 2
Wells Outside the Air Sparging Zone of Influence								
AL-30	.015		.018	.017				
AL-38	.010	.012	.013	.010				
Wells Within the Air Sparging Zone of Influence								
AL-33	.007	Turb*	.003	.015	Turb*	Turb*		
AL-42	.019	.005	.012	.021	.004	.007	.015	.023
AL-43	.014	.013	.011	.014	.013	.013	.015	.010

*Turb indicates slug tests were unable to be conducted due to excessive turbulence in the well.

Air Sparging and Hydraulic Conductivity, cont.

obtain an average hydraulic conductivity for each testing event. Five of the 12 wells in the well field were slug tested. Wells 30, 38, 33, 42, and 43 were slug tested. These wells were selected based on their proximity to the air injection well and well construction. The well construction of some wells does not allow effective slug tests to be conducted. Water table observation wells (wells 35, 36 and 37) have less than 1 foot of the five foot screened interval within the saturated zone and were therefore not tested. Water table observation wells were installed to measure the water table mound produced by air sparging and were not designed to facilitate slug tests. Wells 40, 29, 37 and, 32 were not within or adjacent to the air sparging zone of influence and were therefore not slug tested.

Prior to air sparging each well of interest was slug tested 10 times. This was done to determine: (1) the consistency and reproducibility of the slug test hydraulic conductivity data and (2) if the process of slug testing a well alters the value of hydraulic conductivity obtained from future slug tests. Slug testing could alter hydraulic conductivity if wells were initially inadequately developed allowing successive slug tests to further develop wells increasing the measured hydraulic conductivity. These pre-air sparging tests revealed that the measured hydraulic conductivity is relatively consistent between successive tests of the same well. No trend of increasing hydraulic conductivity is observed. This indicates that slug tests did not further develop the wells being tested, and that significant variations in hydraulic conductivity cannot be attributed to the variability of slug test measurements.

Two field air sparging tests were conducted. For each test air was injected using well 34. Air was initially injected at a low flow rate, 0.4 and 0.5 CFM for air sparging tests 1 and 2, respectively. Air flow rates were increased in steps, maximum air injection rates for air sparging tests 1 and 2 were 1.5 and 1 CFM, respectively.

Increases in well head space air pressures were used to interpret a zone of influence produced by air sparging. A large increase in head space air pressure results from air entering monitoring wells through the screen, bubbling through the water column, and accumulating in the head space. A significant increase in head space air pressure indicates that the well is screened within the zone of influence. During air sparging, test, wells were slug tested when the air sparging zone of influence was able to be identified and was stable. Slug tests were conducted at two intervals during air sparging test 2 and at a single interval during air sparging test 1.

Field Test Data and Interpretations

The interpreted zone of influence for field air sparging tests is shown in Figure 4, this zone of influence was interpreted for the time period during which slug tests were conducted. Four monitoring wells are within the zone of influence, wells 33, 36, 42, and 43. However, not all of these wells could be slug tested during air sparging tests. Well 36 is a water table observation well with a 6 inch water column, hence it could not be effectively slug tested. Well 33 was leaking a significant amount of air during both air sparging tests. This produced a crude air lift pump in the well which periodically raised the water level in the well 17 feet causing the well to be artesian. This prevented the well from being slug tested during air sparging , hence only hydraulic conductivity data before and after air sparging tests are available for well 33. During air sparging tests hydraulic conductivity data was only able to be obtained from wells 42 and 43.

Hydraulic conductivity data from field tests are summarized in table 2 (page 10). Each data point in table 2 is an average hydraulic conductivity from at least 3 slug tests of the same well for each time period. As would be expected, wells outside the air sparging zone of influence are not affected. Wells 33, 42 and 43 were within the zone of influence and were slug tested. Hydraulic conductivity data from well 43 are relatively consistent before, during and after air sparging. However, well 42 shows a factor of 3 to a factor of 5 reduction in hydraulic conductivity during air sparging. Although wells 42 and 43 are the same radial distance from the air injection well, the anisotropy of the aquifer favors air flow toward well 42, rather than well 43, hence well 43 is on the edge of the zone of influence, while well 42 is well within the zone of influence. Given their relative positions within the zone of influence, the density of air flow channels should be larger adjacent to well 42, relative to well 43. This larger density of air channels will consume a larger percentage of the available interconnected pore space, resulting in the observed reduction in hydraulic conductivity. Adjacent to well 43 the percentage of interconnected pore space consumed by injected air was much smaller and produced essentially no decrease in hydraulic conductivity.

Observations made using a down-hole video camera revealed that air entering monitoring wells produced turbulence in the water columns of wells screened within the air sparging zone of influence. This turbulence must be considered when interpreting slug test data. The effects of air sparging were interpreted by comparing slug test data obtained from static water columns (pre-air sparging slug tests) with slug test data from turbulent water columns (slug tests during air sparging). Wells 42 and 43 were leaking air to the surface during air sparging, hence both had turbulent water columns during air sparging. Before and after air sparging, water columns were static. Bouwer and Rice time-displacement plots reveal that for static and turbulent water columns there is a contrast in the sharpness of time-displacement data measured by transducers. Hence the quality of the straight line fit using the Bouwer and Rice method varies slightly. Water column turbulence has a small influence on the quality of transducer data. However, for both turbulent and static water columns, time-displacement data could be fit to a straight line. Water column turbulence does not have a significant effect on the calculated value of hydraulic conductivity. If water column turbulence were the cause of the observed reduction in hydraulic conductivity, the effect would have been observed in both of these wells. The reduction in hydraulic conductiv-

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Air Sparging and Hydraulic Conductivity, cont.

ity observed during field tests cannot be attributed to water column turbulence.

Discussion and Conclusions

Both laboratory and field tests show that air sparging reduces aquifer hydraulic conductivity. Laboratory tests indicate that for a given air injection rate, the reduction in hydraulic conductivity is related to sediment grain size. Fine- to medium-grained sands showed a larger reduction in hydraulic conductivity relative to coarse-grained sediments. The reduction in hydraulic conductivity during laboratory experiments occurred only at relatively high air injection rates (1 CFM and greater). Injecting air at lower flow rates produced no observable effect. At the highest air injection rate (3 CFM) the hydraulic conductivity of the finest sediment tested (test 2) was reduced by a factor of 21. The hydraulic conductivity reduction of all other sediments tested during laboratory experiments ranged from no measurable reduction to a factor of 4 reduction, at the highest air flow rates (2.5 and 3 CFM).

Field hydraulic conductivity data also show a reduction in hydraulic conductivity related to air sparging. This effect appears to be limited to a small portion of the aquifer directly adjacent to the point of air injection. Portions of the aquifer outside this immediate zone of influence which were known to contain some injected air showed no significant reduction in hydraulic conductivity. In field tests, hydraulic conductivity was reduced by a factor of 3 to a factor of 5. Considering that values of hydraulic conductivity can span 12 orders of magnitude, data from field and laboratory tests suggest that air sparging in a relatively homogeneous media is unlikely to produce a widespread barrier to the flow of water in space or time.

The effectiveness of air sparging as a remediation technique is largely dictated by the density of air flow channels in an aquifer. The results of this study suggest that the density of air flow channels directly adjacent to an air injection well will likely be large. In other portions of the zone of influence air channel density will be lower. Hence the remediation rate may vary for different portions of the zone of influence.

Both laboratory sediment samples and the sandy aquifer tested in the field lacked large lithologic variations. The influence of air sparging on hydraulic conductivity may be somewhat different for extremely heterogeneous aquifers. The presence of heterogeneities may produce zones of lower hydraulic conductivity extending some distance from an air injection point.

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COMMENTARY

Blowing Bubbles Through a Straw?

Commentary by Hans Neve, Minnesota Pollution Control Agency

When asked to write a commentary on research work that I conducted over a decade ago I was forced to admit to myself that I have been away from the subject for quite some time. Searching Google to see what interesting developments I have missed in the world of air sparging, I encountered the following definition.

"Air sparging - A process to remove contaminants from ground water. Air is injected into groundwater, causing bubbles that trap contaminants. It's like blowing bubbles from a straw into a bowl of water. As the bubbles rise, the contaminants are removed from the groundwater"

Yes, air sparging is a process for removing contaminants from ground water. Air sparging can be a very successful remediation technology when the system is properly designed and the site has the right geology. The remainder of the definition, however, gives me pause.

Trying to introduce a material into an aquifer in a relatively even distribution, over a relatively larger area, in a short period of time, to achieve a ground water contaminant remediation goal is far more difficult and complicated than blowing through a straw, or well. At the time I conducted this research the conceptual model of air migrating as discrete bubbles in a porous media was being abandoned. Today we know that injected air migrates through interconnected pore spaces in aquifers not as discrete air bubbles, but in interconnected air channels. These air channels are created when injected air preferentially dewaters the largest interconnected pore spaces.

Preventing the flow of water through some number of the largest interconnected pore spaces in an aquifer by filling them with air or some other gas should impact the hydraulic conductivity. The question is, "Will the impact be large enough in extent and magnitude to impact the remediation goal?" In trying to answer this question you also stumble upon clues to the question of what is the effective zone of influence. The exact zone of influence, of course, depends on many factors but "relatively small" seems to describe it for many cases. For those willing to take on the challenge of injecting "things" into aquifers to make other "things" go away, it seems to be a common reality that the radius of influence for a vertical injection point will usually be small. Success in such an endeavor will come from knowing the aquifer system that you are attempting to influence and constructing an injection system that addresses the reality of a small radius of influence.

Minnesota Ground Water Association

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COMMENTARY

Commentary on Natural Attenuation of Ground Water Contaminants

By Mark Ferrey, Minnesota Pollution Control Agency

When Natural Attenuation of Ground Water Contaminants appeared in 1998, there was still vigorous debate over the very idea of relying on natural attenuation to remediate sites that were contaminated with chlorinated solvents. It was only twelve years earlier that research (Wilson et al., 1986) showed that trichloroethylene (TCE) was biologically degradable under anaerobic conditions in the ground water environment; the concept that this "intrinsic" degradation could be viewed as a sufficient remedy for contaminated ground water seemed, to many, to abandon a preference for an "active" cleanup at Superfund sites.

Much of the debate surrounding the application of natural attenuation as a remedy has subsided, due in large part to detailed studies that clearly demonstrate that, given the right conditions, it is quite effective at mitigating the transport of contaminants in the ground water and limiting the overall extent of contamination (Suarez and Rifai, 2000). Attention is now focused on ways to enhance the existing intrinsic degradation processes in the ground water, combining the principles of active bioremediation with an understanding of natural attenuation. For example, understanding the role of organic carbon in the degradation of chlorinated solvents led to the concept of injecting vegetable oil or lactate to ground water, an approach that has, at several

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Natural Attenuation of Ground Water Contaminants

Mark L. Ferry, Soil Scientist, MPCA

Shortly after Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act ("Superfund") in 1980, the Council on Environmental Quality released the landmark "Contamination of Groundwater by Organic Chemicals". This document, which compiled numerous individual reports of ground water contamination, confirmed that chlorinated solvents were the most common type of ground water contaminant, noting that there was "serious contamination of drinking water wells in 34 states". Since then, agressive remediation efforts have focused on restoring contaminated ground water to the national critieria established in 1987, the federal maximum contaminant levels (MCLs).

It's probably fair to say that early attempts at ground water remediation rested on two assumptions: first, that the contaminants benzene, toluene, ethylbenzene, xylene, trichloroethylene, and perchloroethylene were virtually non-biodegradable in ground water systems (it was only relatively recently recognized that bacteria were even present in ground water) and that, once present, these contaminants would persist in the ground water until diluted or removed. Second, there was a general expectation that ground water could be remediated to potability within reasonable timeframes by pumping contaminated ground water from the aquifer.

Results of these efforts has shown that pumping systems are not cost-effective in *restoring* ground water to potability. In addition, research has demonstrated that these contaminants are very biodegradable in ground water under certain conditions. A detailed discussion of the mechanisms behind the biodegradation of these substances is beyond the scope of this article. However, it is now known that chlorinated aliphatic compounds (chlorinated ethenes and ethanes) decompose *in situ* under sulfidogenic or methanogenic conditions. Perchloroethylene, for example, loses chlorine atoms under these conditions to yield trichloroethylene, the *cis*- isomer of dichloroethylene, vinyl chloride, and ethene. This *reductive dehalogenation* may occur at rates that exceed rates of remediation that are possible through engineered systems; the potential for the *in situ* destruction of ground water contaminants has heightened interest in demonstrating that monitored natural attenuation, or intrinsic remediation, is itself a viable remedy for contaminated ground water.

The Minnesota Pollution Control Agency's guidance on the *Monitored Natural Attenuation of Chlorinated Solvents in Ground Water* defines standards for demonstrating that natural attenuation is a remedy for ground water that is contaminated with chlorinated solvents. It specifies that, to be a remedy,

> *natural attenuation is the demonstration that biodegradation, when combined with dispersion, volatilization, abiotic degradation, and*

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— Lanya Ross demonstrates the physcial ground water model at the Fox 9 Girls and Science event.

Natural Attenuation, cont.

sorption will reduce the concentrations of contaminants and their toxic daughter products before posing unacceptable levels of risk to human health or the environment or exceed ground water criteria at established points of compliance.

This article highlights some of the technical points covered in that document.

Demonstrating that natural attenuation is a remedy must include evidence that the degradation of a contaminant is possible under the existing ground water conditions. Whereas contaminants such as benzene, toluene, ethylbenzene, and xylene readily degrade aerobically, perchloroethylene or carbon tetrachloride (as discussed above) require strongly reducing conditions for biodegradation. Analysis of the ground water geochemistry will reveal the oxidation/reduction (redox) status of the system, and therefore the potential for degradation of particular compounds. Redox conditions may differ depending on the sampling location in the plume, both spatially and vertically.

Figure 1 shows the range of Eh and the corresponding electron acceptor reactions that favor the degradation of trichloroethylene, perchloroethylene, and trichloroethane. Thus, measurements of oxygen, Eh, iron II, manganese II, sulfate, sulfide, nitrate, and methane in the ground water reveal the redox status of the ground water. Many of these analytes can be measured in the field: oxygen and Eh readings are taken via calibrated probes through a "low flow" cell, together with readings of pH and conductivity. Manganese II, iron II, sulfate, and nitrate can be measured inexpensively using field test kits.

Contaminant breakdown products provide evidence that a compound is degrading *in situ*. For example, the presence of vinyl chloride, *cis*-dichloroethylene (at five times the concentration of the *trans* isomer), and elevated concentrations of chloride above background indicate that reductive dechlorination processes are occurring.

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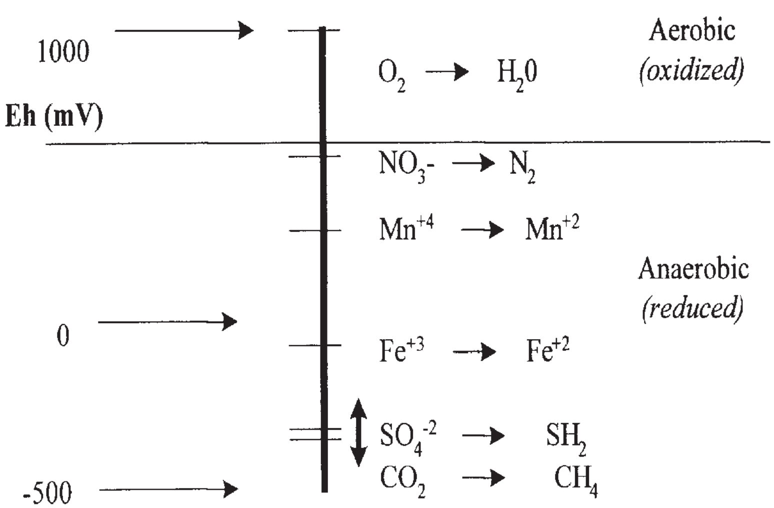

(Modified from Bouwer, 1993.)

Figure 1. The presence of particular electron acceptors indicates the oxidation/reduction status of the ground water. This figure correlates geochemical half-reactions to the corresponding oxidation/reduction potential in millivolts. The bold arrow indicates the range of conditions most favorable to the dechlorination of chlorinated solvents such as tetrachloroethylene or trichloroethylene.

Natural Attenuation, cont.

sites, increased the rates of contaminant degradation. Microbiological studies have yielded molecular genetic tools that can show the presence of specific bacteria that break down particular contaminants in the ground water. Bioaugmentation – the addition of microbes to the ground water for remediation – is a more feasible option because of this research on natural attenuation reactions.

Other work over the last ten years has shown that non-biological reactions involving iron oxides might play a more important role than biological degradation in restoring ground water at some sites. A detailed natural attenuation study of the deep ground water at the Twin Cities Army Ammunition Plant (TCAAP) (Wilson et al., 2001) showed that the ground water environment, which is manganese and iron reducing, is unfavorable to the anaerobic biological degradation of dichloroethylene (DCE) and TCE. The absence of vinyl chloride and ethene – the biodegradation products of TCE – and the development of a large contaminant plume were consistent with the results of that analysis. However, ground water modeling indicated that the plume should have been very much larger if the contaminants were not being destroyed by some unknown process in the aquifer.

To find out what was responsible for this apparent attenuation, we constructed microcosms made of soil collected from beneath the water table at the site. DCE was added to the microcosms, which were then sealed and incubated under anaerobic conditions in the laboratory. In the microcosms that were heat-killed prior to the incubation (eliminating the potential for biological degradation of the contaminant,) both 1,2-DCE and 1,1-DCE disappeared at a first-order rate of at least 0.3 per year (Figure 1) (Ferrey et al, 2004). This rate of decay could account for the current configuration of the contaminant plume in the deep ground water at TCAAP. It also matched the rate of DCE disappearance observed in a monitoring well near the location of sediment collection for the microcosm study (Figure 2). This non-biological process is also responsible for contaminant attenuation at

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Natural Attenuation, cont.

However, a qualitative assessment that demonstrates the degradation of a contaminant *in situ* does not automatically prove that natural attenuation is a remedy for a site. The degradation of trichloroethylene in ground water is not desirable if it results in exposure to vinyl chloride, which is more toxic than the trichloroethylene. Therefore, it is also important to demonstrate that the products of degradation are not a cause for concern.

Also, if ground water conditions are favorable for chlorinated solvent degradation, an estimate of the degradation rate is needed. Methods to estimate degradation rates include microcosm studies, rates derived from site-specific field data, and values found in the literature.

If aquifer sediment samples can be obtained, microcosms can be set up under controlled conditions in the laboratory. Microcosm studies are most useful in discovering whether a contaminant or set of contaminants is biodegradable. Since conditions are tightly controlled, it is possible to determine how a change in one parameter (for example, pH) will effect the biodegradability of a contaminant. However, microcosm studies almost always overestimate rates that actually occur in the field by 100-11,000%. (See the review article by Blackburn, 1998)

Field measurements of natural attenuation rates can be made using historical contaminant concentration data. Plotting the natural logarithm of trichloroethylene concentrations versus the distance of the well from the source (Figure 2) can be helpful as per the method of Buschek and Alcantar (1995). Assuming that the relationship is linear, then

$$\ln(C_x) = -\left(k\frac{x}{v_x}\right) + \ln(C_0)$$

Equation 1.

Where

x = the distance from the source area in feet;

v_x= the velocity of ground water in the x direction;

C_x = the concentration of contaminant at x;

k= the overall attenuation rate constant; and

C_0 = the concentration of contaminant at the source area.

The slope of this linear relationship is $\left(\frac{k}{v_x}\right)$; multiplying this term by the ground water velocity v_x gives the natural attenuation rate including biodegradation, sorption, and dilution for a given contaminant. Once this attenuation rate is calculated, Buschek and Alcantar go on to describe a method to estimate attenuation due solely to biodegradation, which is useful in modeling the fate of contaminants in ground water with time.

A similar approach involves an *in situ* tracer analysis. The concentrations of a contaminant in a given well is compared to the concentration in a downgradient well (Wiedemeier *et al.*, 1996b). It assumes the same basic logarithmic relationship as discussed above; solving Equation 1 for *k*:

$$\frac{\ln\left[\frac{Cx}{Co}\right]}{t} = k \quad \text{Equation 2.}$$

where *t* is estimated by dividing the distance between the wells by the ground water velocity ($\frac{x}{v_x}$).

The *in situ* biodegradation rate is estimated by correcting for dilution with a conservative tracer in the ground water, such as chloride:

$$Cx(corrected) = Cx\left[\frac{Cl^-{}_o}{Cl^-{}_x}\right].$$

Equation 3.

Replacing the C_x term in Equation 2 with $C_{x(corrected)}$ from Equation 3 yields an estimate of the biodegradation rate in the ground water between the two wells. This approach can be repeated for other well pairs and can be compared to *k* for the overall plume. It is important to note that one needs to assume a static plume for these calculations to be valid.

Finally, contaminant degradation rates found in the literature are useful in some circumstances and often appear in natural attenuation studies and reports. They are valuable for rough comparisons between the site-specific attenuation rates discussed above with what others have found at other sites. Published rates can also be used in initial modeling efforts to determine the bounds of what is feasible in terms of natural attenuation.

However, there are three major concerns in adopting literature degradation rates: first, because every site is different, degradation rates are unique to the conditions under which they were measured. Applying them universally to a variety of sites will very likely over- or underestimate by large margins the actual degradation rates occurring at the site. Second, the conditions under which many published degradation rates were found are not always stated.

The degradation rates derived from microcosms of sewage sludge clearly are not representative of the rates that predominate in ground water! Third, (as mentioned above) published degradation rates are often derived from microcosm studies that

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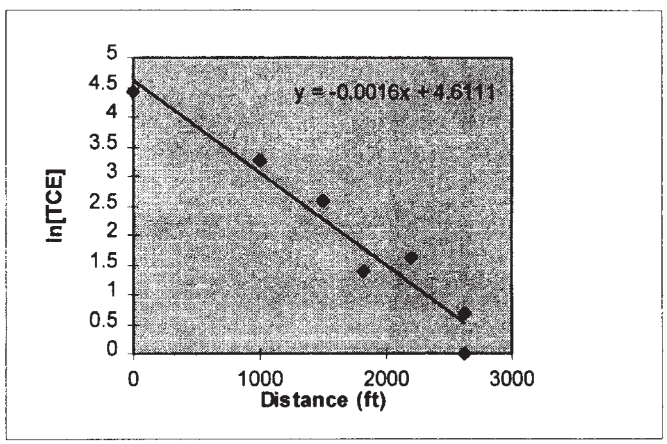

Figure 2. Regression of the natural log of TCE concentration by distance from the source area. The overall attenuation rate equals the slope multiplied by the ground water velocity. For this site, ($-0.0016 ft^{-1}$) (124 ft/yr), or $k = -0.198\ yr^{-1}$.

Natural Attenuation, cont.

usually overestimate *in situ* attenuation rates for a site.

In addition to the contaminant degradation rate, the rate at which the contaminants are migrating with ground water is needed. The rate of contaminant transport can be estimated by calculating a retardation factor for individual chemicals:

$$R_f = 1+[(K_{oc})(f_{oc})(\rho)/n] \quad \text{Equation 4.}$$

and

$$v_c = v_x / R_f \quad \text{Equation 5.}$$

where

K_{oc} = published organic carbon partitioning coefficient for the contaminant;

n = porosity (assumed to be 0.25 to 0.3);

ρ = soil density (assumed to be 1.7);

f_{oc} = fraction of organic carbon in ground water sediments (sampled);

v = the transport velocity of the contaminant in ground water;

R_f = the retardation factor.

These biodegradation and contaminant transport rates can be incorporated in fate and transport models that simulate the effect of natural attenuation at the site. The goal of modeling is to determine whether the rate of degradation, when compared to the rate of contaminant transport, is sufficient to prevent further spreading of the contamination. BIOSCREEN (Newell et al., 1996) is one fate and transport screening model that is based on the Domenico analytical solute transport model. It can simulate solute transport a) without a decay rate, or b) with the decay rate as measured in the above equations. Modeling without a degradation term predicts how far the contaminant will migrate if no biodegradation is possible. This is contrasted to the projected extent of the plume if the estimate of biodegradation from field measurements is included in the modeling. Actual field data can be compared with modeled projections.

If biodegradation is occurring, the ground water plume will, at some point, achieve a dynamic equilibrium; though forces of attenuation prevent the spread of contamination further downgradient, it is maintained by the upgradient source of contamination. Modeling should assist in estimating the length of the plume at equilibrium and how long it will take before this equilibrium is established. Modeling "best" and "worst" case scenarios by modifying the degradation rates and contaminant transport rates can help set realistic bounds on the possibilities for plume expansion.

A sound case for a natural attenuation remedy should include the measurements of the redox conditions, the assessments of the biodegradability of a given contaminant, the estimates of biodegradation rate and contaminant transport, and the modeling. The overall picture of the effect of natural attenuation on the ground water contamination should be a convincing one.

Verification that the measurements and simulations of natural attenuation are accurate requires additional sampling to demonstrate that the plume is not expanding, and that the geochemical environment and redox conditions are stable. A proposal for natural attenuation as a partial or a full remedy should include recommendations for additional monitoring points (if needed), a sampling schedule that can demonstrate the effectiveness of natural attenuation over time, and provisions for alternate responses if natural attenuation proves inadequate as a remedy.

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— Jay Frischman and Mike Liljegren demonstrate aquifer test techniques at the Spring 2002 'Outdoor Action' Drilling and Well Techniques Conference.

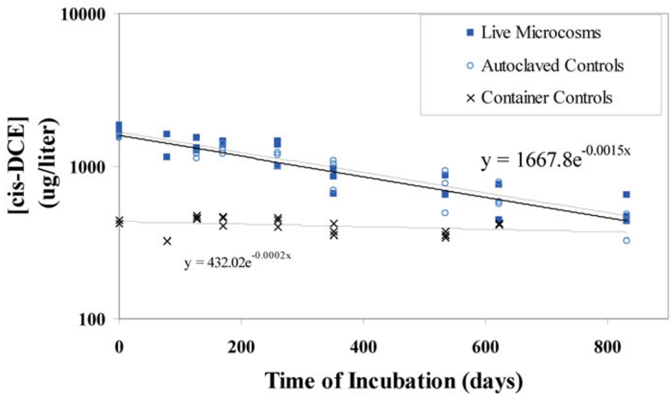

Figure 1. Degradation of cis-dichloroethylene as a function of time in microcosms made from soil collected beneath the water table at the TCAAP site. The first order rate of decay, -0.0015 per day, translates into about -0.5 per year, or a half-life of 1.4 years.

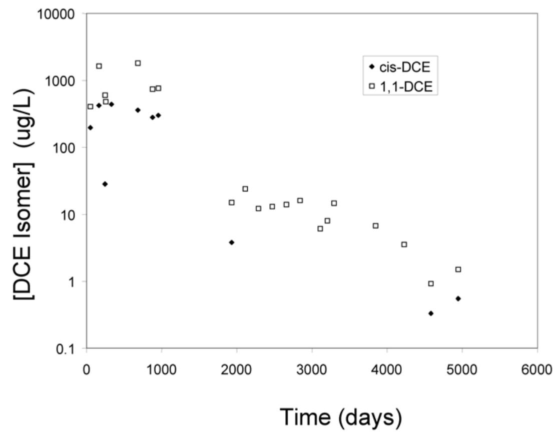

Figure 2. 1,1-DCE and 1,2-DCE concentration data from a monitoring well at TCAAP over a thirteen year period. The first-order rate of decay for DCE in the ground water at this location is -0.0015 per day, consistent with the rate of decay observed in the microcosms that contained ground water sediment collected nearby. Other monitoring wells show similar results.

two other shallow ground water sites at TCAAP, where very high rates of contaminant degradation have been observed.

The mechanisms underlying this degradation are not clear. We suspect that magnetite (Fe_3O_4) is somehow involved in the destruction of the chlorinated solvents (Lee and Batchelor, 2002). But the typical daughter products of reductive biological degradation – vinyl chloride and ethene – are not generated by the abiotic degradation observed at this site. Other studies have demonstrated similar abiotic degradation due to iron sulfide.

The work on abiotic degradation has implications for how sites are evaluated for natural attenuation remedies. Currently, the major factor in reducing concentrations of contaminant mass is assumed to be biological degradation. The existing technical guidance and "protocols" on natural attenuation (MPCA, 2006) focus mainly on showing that biodegradation of a contaminant is occurring, either through a) identifying breakdown products unique to its biological degradation or by b) determining that the ground water environment is conducive to anaerobic biodegradation reactions. That approach will not predict the abiotic degradation that we have studied. Abiotic degradation of chlorinated solvents does not generate similar daughter products, nor is it restricted to highly reducing conditions in ground water.

The lack of a simple screening method for abiotic degradation highlights the need for accurate contaminant fate and transport modeling. At the TCAAP sites described here, analytic and numerical modeling showed that the ground water contaminant plumes should have been much more extensive than ground water monitoring indicated, suggesting that the contaminants were breaking down due to some unknown process. Future study may provide tools with which to screen sites for abiotic degradation. In the meantime, ground water modeling followed by microcosm studies that can demonstrate abiotic degradation of chlorinated solvents appears to be the only way to clearly demonstrate that abiotic natural attenuation is effective at a particular site.

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Natural Attenuation of Petroleum Hydrocarbons

Commentary by Geoffrey Delin and Barbara Bekins, U.S. Geological Survey

Ground-water contamination by crude oil, and other petroleum-based liquids, is a widespread problem. An average of 83 crude-oil spills occurred per year during 1994-96 in the United States, each spilling about 50,000 barrels of crude oil (U.S. Office of Pipeline Safety, electronic commun., 1997). Natural attenuation, or passive bioremediation, has become a primary remedial option for regulatory agencies across the country in relatively low risk ground-water contamination cases.

The processes involved during natural attenuation of petroleum hydrocarbons include: aerobic and anaerobic biodegradation; dispersion; dissolution; volatilization; and adsorption. Of these, biodegradation is the primary process that results in significant mass reduction of the petroleum product. Petroleum hydrocarbons and their constituents generally are biodegradable as long as indigenous microorganisms have an adequate supply of nutri-

— *continued on page 101.*

Natural Attenuation of Petroleum Hydrocarbons, cont.

ents and electron acceptors, and biological activity is not inhibited by substances toxic to the organisms. Aerobic biodegradation tends to occur at the fringe of the dissolved plume and consumes oxygen. Anaerobic biodegradation is predominant at the core of the plume and may occur much slower than aerobic biodegradation. Site and soil conditions play a significant role in biodegradation efficiencies due to transport of both the impacted water and needed oxidants and nutrients.

Under the appropriate conditions, natural attenuation can reduce the potential impact of a petroleum release from being transported to sensitive receptors. However, natural attenuation is not appropriate at all sites. The rates of biodegradation are typically slow and levels may not reach maximum contaminant levels for decades. Additionally, long term monitoring is needed to demonstrate concentrations are continually decreasing at a rate appropriate to protect potential receptors.

Interdisciplinary investigations are critical to build a foundation of knowledge on fundamental processes controlling natural attenuation of petroleum hydrocarbons in the subsurface. One such study is the ongoing investigation at the Bemidji, Minnesota crude-oil spill site, which is one of the better characterized sites of its kind in the world. The goal of research sites such as these is to provide information and methods to help evaluate the potential for, and long-term performance of, natural and enhanced bioremediation of hydrocarbon contamination across the nation. The Bemidji site offered the first research that documented limitation of crude-oil contamination largely by natural attenuation. Ongoing research results have been directly applicable to decisions to use natural attenuation to remediate similar sites, to design performance monitoring, and to prioritize sites for remedial action which may result in less expensive remedial actions (Wiedemeier and others, 1995).

The oil phase that occurs as floating product on the water table and as residuum on sediment grains provided a continued source of hydrocarbon to the ground-water and vapor plumes. Knowledge of the geochemistry of a contaminated aquifer is important to understanding the chemical and biological processes controlling the migration of hydrocarbon contaminants in the subsurface. Different geochemical zones have been identified at the Bemidji site within the saturated zone (Baedecker and others, 1993; Bennett and others, 1993) (Figure 1). Zone 1 consists of oxygenated uncontaminated native ground water. Zone 2, which is below an area where crude oil sprayed on the ground, is characterized by low oxygen concentrations and high concentrations of total dissolved inorganic and organic carbon. Zone 3, beneath and immediately downgradient of the floating oil, consists of an anoxic plume of ground water containing high concentrations of hydrocarbons, dissolved manganese (Mn^{2+}), iron (Fe^{2+}), and methane (CH_4). Zone 4, a transition zone from anoxic to oxygenated conditions, contains low concentrations of hydrocarbons as a result of aerobic degradation processes. Zone 5 consists of oxygenated water downgradient from the contamination plume that contains slightly higher concentrations of dissolved constituents, such as benzene, toluene, ethylbenzene, and xylene (BTEX).

In the unsaturated zone, volatile oil components undergo volatilization, diffusion, and biodegradation. Monitoring results of the distributions of gases, including hydrocarbon, oxygen (O_2), carbon dioxide (CO_2), and methane (CH_4), in the unsaturated zone were used to identify three geochemical zones at the Bemidji site (Figure 1) (Delin and others, 1998). Zone 6 exhibits near atmospheric concentrations of O_2. Zone 7, a transition zone, is defined by lower concentrations of O_2 (10-20 percent), hydrocarbon concentrations less than 1 part per million (ppm), and higher concentrations of CO_2 (0-10 percent) and CH_4 (0-10 percent). Zone 8, immediately above the oil body, is relatively anoxic and contains maximum concentrations of CO_2 (>10 percent), CH_4 (>10 percent), and hydrocarbon (>1 ppm). The distribution of gases at oil pool sites can change considerably in time. For example, as of 1985 the leading edge of the plume of hydrocarbon vapors at the Bemidji site (concentrations > 1 ppm, zone 7) in the unsaturated zone was about 150 m downgradient (Hult and Grabbe, 1988). As of 1997 the plume of vapors had receded to about 75 m downgradient (Figure 1) and the receding likely was due to aerobic biodegradation.

Measurements of microbial populations can be informative in evaluating the natural attenuation capacity of an aquifer. In a background area at the Bemidji site, for example, aerobes and fermenters were the only significant microbes detected using a culture-based method (Essaid and others, 1995). Within the dissolved plume the microorganism counts were consistent with a degradation sequence conceptual model of aerobic degradation, followed by Mn/Fe reduction, and finally methanogenesis. There were 10^4-10^5 iron-reducers per gram in the contaminated aquifer compared to none detected in the uncontaminated background area. Similarly there are 10^2 methanogens per gram in the plume and none detected in the background area. This result is similar to that of Godsy and others (1992) who reported a 100-fold increase in methanogens within a creosote plume. In general, greater numbers of microorganisms were found closer to the oil body and in the upper half of the plume. Denitrifiers and sulfate reducers are present in lower numbers than all other types of microbes, in accordance with the low availability of nitrate and

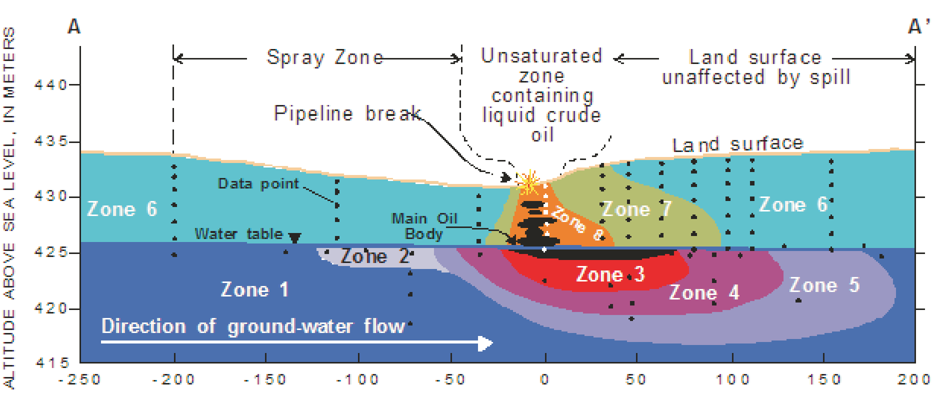

Figure 1. Geochemical zones in the unsaturated and saturated zones at the Bemidji, Minnesota crude-oil spill site, 1997 (from Delin and others, 1998).

— continued on page 102.

Natural Attenuation of Petroleum Hydrocarbons, cont.

sulfate in the ground water. The data were used to formulate a model of biodegradation of the contaminants coupled to growth of the microbial population.

Results of research at the Bemidji site have indicated that anaerobic degradation is a significant process active at sites of petroleum hydrocarbon contamination. Modeling results (Essaid and others, 1995) indicated that aerobic degradation accounted for 40 percent of the total dissolved organic carbon (DOC) degraded and anaerobic processes accounted for 60 percent: 5 percent by Mn reduction, 19 percent by Fe reduction, and 36 percent by methanogenesis. The model results indicate that anaerobic processes account for more than one-half of the removal of DOC at this site, consistent with the geochemical evidence. In addition, model simulations indicate that anaerobic degradation removed 77 percent of the BTEX that dissolved in the water phase and aerobic degradation removed 17 percent (Essaid and others, 2003).

Ongoing and future research on natural attenuation of petroleum hydrocarbons likely will emphasize biogeochemical processes in the unsaturated zone. Field and laboratory results could be linked with results from computer modeling in order to develop a comprehensive understanding of the fate and transport of hydrocarbons in the unsaturated zone.

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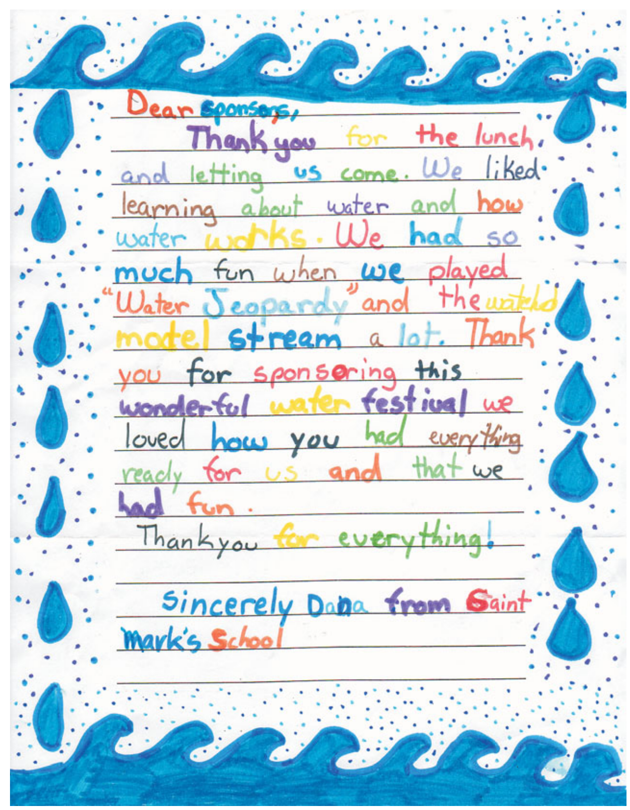
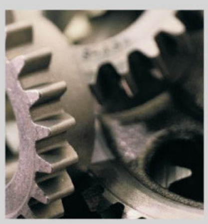
— Student Recruitment Poster (December 2000)



— MGWAF received this note from one of the children in attendance at the 2007 Metro Children's Water Festival

Ground Water History


Minnesota Ground Water Association

Volume 16, Number 1: March, 1997

— *Tom Clark descends into the maw of the world's largest dug well in Greensburg Kansas (above) and poses near the billboard that explains the well's history (below). At 32 feet in diameter and 109 feet deep, this well is still impressive.*

Along the Great Wall: Mapping the Springs of the Twin Cities

by Greg Brick

"It is to this ignorance or oblivion that the city spring-hunter owes much of the charm and enjoyment of a quest which yields in a measure the excitement of a voyage of discovery. Greatly satisfying indeed is the draught from a spring where none is said to exist, and which has been come upon after patiently and inductively following a trail marked only by a moistened stone here, a willow farther on; and then a piece of watercress." James Reuel Smith (1852-1935)

The modern groundwater professional can become so accustomed to associating groundwater with wells as to forget that there is another whole side of the subject, the study of springs. While no longer an important source of drinking water in this country, springs are still useful for monitoring groundwater pollution, or in defining aquifer characteristics, as shown in a recent article by Werner (1996).

Water wells drilled in Minnesota since the mid 1970s have been assigned unique numbers by the Minnesota Department of Health. Older wells also are being located and assigned unique numbers. No such database exists for springs. USGS quadrangles usually omit them. The nearest thing to a description of the springs of the Twin Cities was George M. Schwartz's *Geology of the Minneapolis-St. Paul Metropolitan Area* (1936), which included a classification scheme and chemical analyses. There were major omissions, however. Neither the largest nor the most famous springs in Minneapolis, for example, were mentioned. It was toward filling this void that Professor Calvin Alexander, at the University of Minnesota, suggested, as a research project, that I should (re)locate and map the springs of the Twin Cities.

I found inspiration in one of the greatest spring-hunters of all time, James Reuel Smith, whose *Springs and Wells of Manhattan and The Bronx* was published in 1938. Smith bicycled around Manhattan at the end of the nineteenth century describing and photographing springs just before they were obliterated by the tide of urbanization that swept northwards up that island. After an area becomes covered with paving and buildings most rainwater is carried off by sewers, and there is little recharge.

Smith's account was full of picturesque detail. How surprising it is, for example, to look at a photograph of what appears to be a doghouse or an outhouse on a street corner, only to read that it was in fact a springhouse—one of the ancestors of the modern refrigerator! According to Smith, the New York City Health Department put Paris Green, a deadly poison, in springs and wells, to discourage the use of these fever-inducing waters. They preferred that everyone drink water from the Croton Aqueduct. Not surprisingly, Smith found that local residents often were reluctant to tell him where their springs were.

Smith had described some very minor springs (including dry ones), referencing their locations according to the Manhattan street grid. My own mapping project, using topographic quadrangles, could not aim at such completeness. Surficial springs at low points in glacial drift, a consequence of poorly integrated post-glacial drainage, were far too common, and required extensive access to private property. I chose to limit'systematic prospecting to springs visible in the gorge of the Mississippi River. This wall of bedrock exposure, 80 feet high, stretching from St Anthony Falls to Hastings, became an enduring motif.

Springs, cont.

My first attempt at mapping, in January, 1993, lasted all of a day. I had framed the plan of locating the springs in wintertime. Springwater freezes to form icicles on the bluffs, and in the absence of leaf cover, mapping should be as easy as strolling along the opposite bank with a clipboard. But I found that at a distance of a quarter mile (the width of the gorge) it was difficult to distinguish, even with binoculars, ice formations created by springs, from those by culverts, etc. It also appeared that the size of an ice formation was inversely proportional to the discharge. Small seeps, which I didn't care to map, create large formations because their output freezes on the formations themselves, while large springs melt everything nearby. For these reasons, I had to be right up at the outcrop.

The close-up approach proved fatiguing—and dangerous. I spent more time mountaineering than mapping. I had to walk along the top of a wedge of loose stones that mantled the foot of the bluffs. This material, at the angle of repose, was concealed by snow.

I had some nasty falls (I was wearing old dress shoes at the time), and nearly ended up with frostbite. At the end of the day, as the sun was setting, I remember going down on my belly and slithering behind an icicle as stout as an oak tree, to get to the next foothold. Needless to say, I hadn't covered much ground. The mapping project disintegrated into the bleak prospect of inching across miles of treacherous scree in sub-zero weather. I decided to postpone operations until summer, and the delay proved fortunate. The year 1993 was to be notorious for heavy rainfall (and extensive flooding) in the Upper Mississippi Valley, enough water to revive even the most dormant springs, some of which I was never to see again.
When I resumed mapping, I found that the springs were not randomly distributed. After plotting just a few of them among the contour lines a striking pattern emerged. Most springs fell into one of about seven different spring-lines, each of which represented a perched water-table at a contact between rock formations, porous rocks underlain by impervious beds. I will describe the springs in terms of the spring-lines to which they belong, in descending order of elevation (see Figures 1 and 2).

The highest (and shortest) spring-line followed the **Galena Limestone-Decorah Shale contact**. The springs emerge high up on the walls of the "amphitheaters" formed by the abandoned claypits of the former Twin City Brick Company, in Lilydale Park (West St. Paul). They are most conspicuous in winter, when their frozen cascades become the most popular ice-climbing spot in the cities. In summer, a sea of cattails covers the floors of the claypits. This type of spring is common throughout Minnesota's karst regions.

The second highest spring-line followed the **glacial drift-Decorah Shale contact**. This type had been recorded by Winchell (1888) and diagrammed by Schwartz & Thiel (1954). When plotted, they formed a pattern on the map that I nicknamed, for my own amusement, "St. Paul's diamond necklace:" a great loop of two dozen springs, about eight miles long, beginning near the Cathedral in downtown St Paul, looping south round Highland Park at the 850-900 ft level, then north again to the Town & Country Club, at the Lake Street bridge, where it ends. Since the contact was not visible, its presence was inferred based on the elevation of the top of the Decorah Shale, as determined from the bedrock topography map of Mossler (1992).

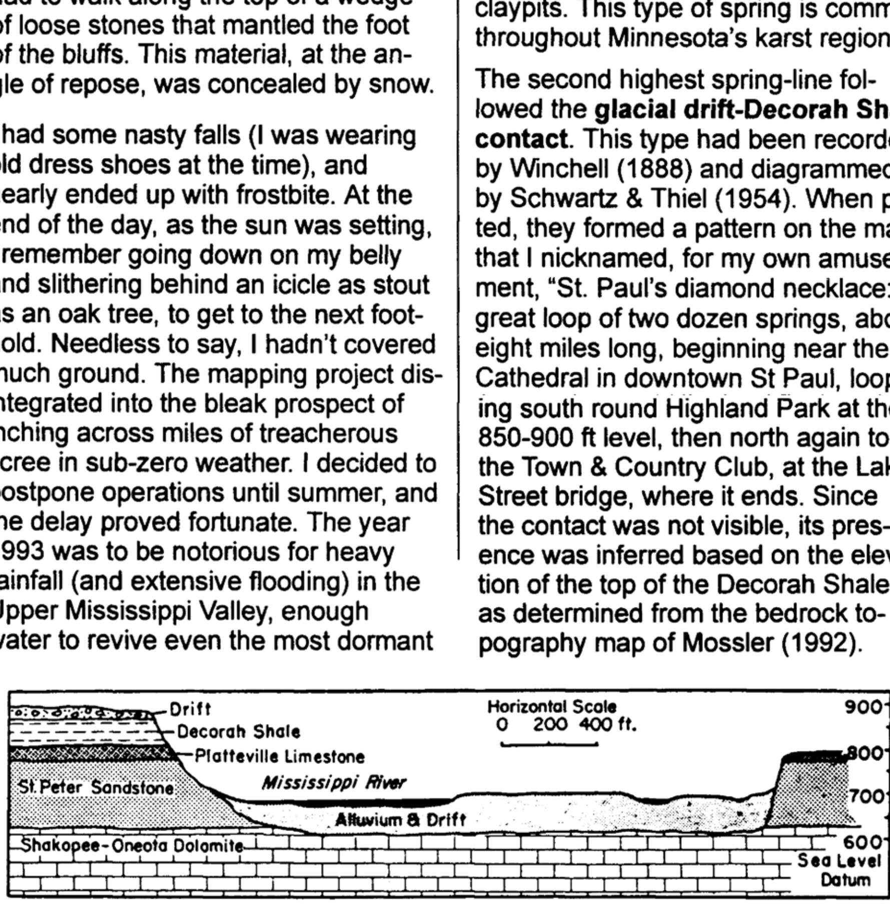


Figure 1: Cross Section of Mississippi River at Robert Street, St. Paul, Looking upstream. From: Schwartz and Thiel (1954).

Mapping the Decorah spring-line through the Irvine Street area of St. Paul, below Summit Avenue, was the most scenic part of the project. Historic houses cling to the steep slopes, and I was spring-hunting among the gables. At a place called "Rue Eugene-Dupont," water poured from a crack in the driveway, streaming downhill along the switchbacks, before vanishing into a sewer. Where the spring-line crossed Grand Avenue, I found ornate lampposts with water gushing from their bases, which were swathed with filamentous algae. Along Pleasant Avenue (as at its intersections with St Albans and with St Clair), there were retaining walls built of limestone rubble masonry, at the foot of which there were springs. A local resident recalled that his parents used to drink water from the Pleasant Street springs.

Highland Spring is the most famous Decorah spring. Located near what is today the intersection of Randolph and Lexington, this spring supplied the Nettleton dairy farm (1871-1885) and was bottled and sold by the Wardell family (1900-1965), the only commercial springwater produced in St Paul. Empson (1975), who researched the history of this spring, wrote that "Today the spring is routed into the sewer system, but the curious can walk behind [Montcalm Estates], and by peering down the manhole grating, see the flow of the spring from the hillside above, running at its constant 27 gallons a minute." Being morbidly curious, I had to remove the grating and descend into the manhole itself, where I found springwater pouring from the mouth of a pipe.

Further along, at Sunny Slope Lane, behind Sibley Plaza, I encountered a rivulet flowing in the street, and traced it to a private residence (#1760). Had I not been walking a spring-line, I would have missed this spring, because it was easy to assume that someone had left a garden hose running in the front yard. Contacting the owner, I learned that there was a trapdoor in the basement that could be lifted to view the spring. It is likely that there are many more stories of this character, that go unrecorded.

Walking the spring-line shed light on

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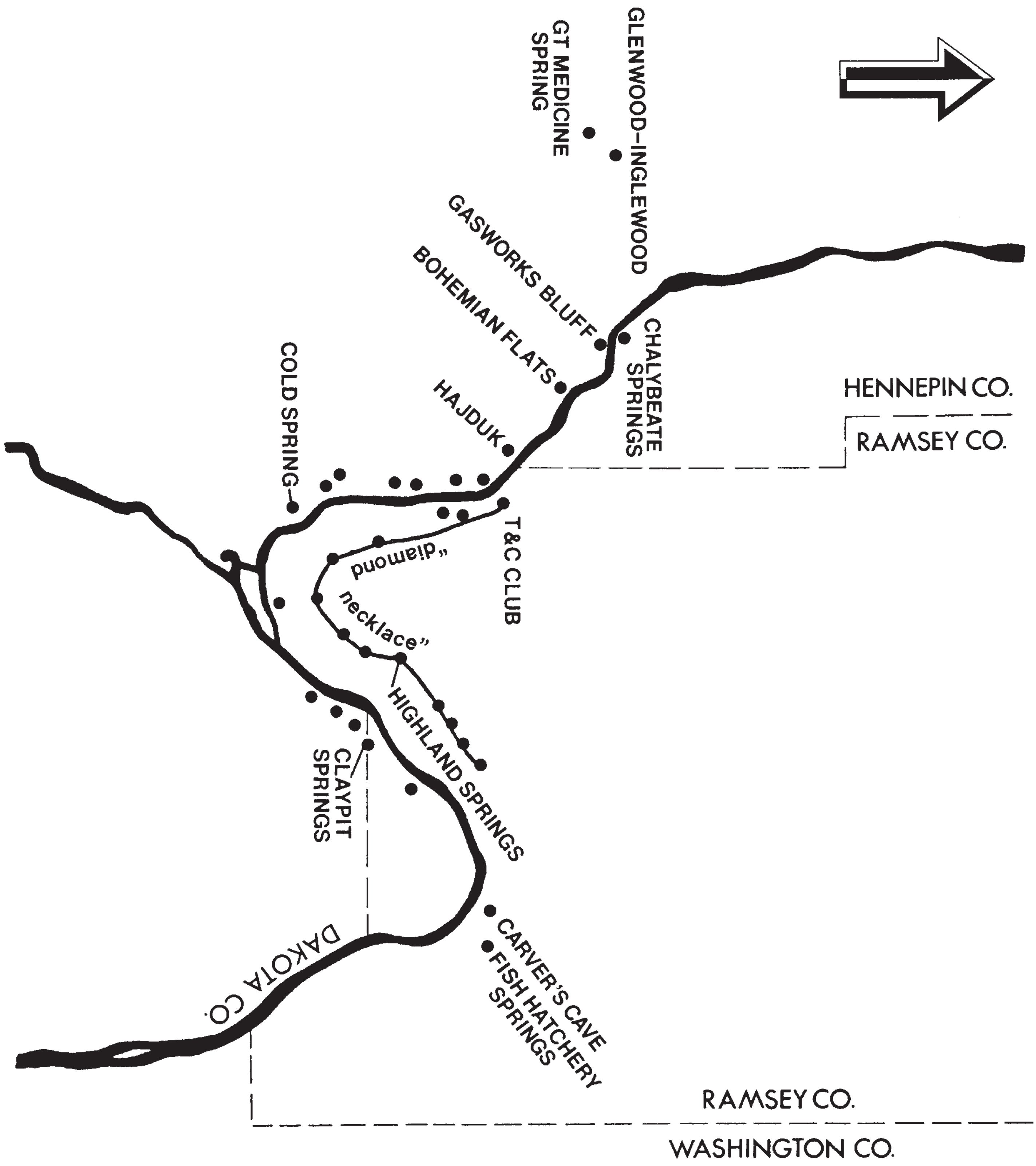

Figure 2: Spring locations in the Twin Cities area. Many small springs omitted for clarity.

Springs, cont.

other features. At St Catherine's College there is Dew Drop Pond, about an acre in size, which I had known about for years. Its 890-ft elevation now suggested to me that it was fed by Decorah springs. It has the melancholy distinction of being the only local spring in which people have drowned.

Finally, the "necklace" ended at the Town & Country Club, where there was a spring in the golf course rough. Surrounded by giant willow trees, the scenery here probably best recreates the appearance of the Decorah springs back in the early days of St Paul. A sign on the gatepost dated the club to 1888.

The third highest spring-line followed the **glacial drift-Platteville Limestone contact**. It was most noticeable along Mississippi River Boulevard in St Paul where the springs, eroding headward, have carved ravines, necessitating a series of bridges and bends in the road. By far the most spectacular of these was Shadow Falls, at the west end of Summit Avenue.

Initially, I was skeptical of the claim by Nason (1932) and others that Shadow Falls was a spring, because I had traced the water upstream from the falls to a point near the head of the ravine, where it gushed from the earth, and when I applied a shovel to this so-called spring, the blade struck a buried object. Clearing the soil away, I saw water gushing from the joint between two segments of vitrified pipe. Sewer maps at the St Paul Public Works Department did not depict a pipe in this location, but I surmised that one had been laid down the axis of the ravine to drain local runoff, its outfall had become plugged, and the water erupted at a loose joint. Hardly a spring! But when I came across Plympton's 1839 map of the Fort Snelling Military Reserve, which identified Shadow Falls as "Spring Leap," I changed my mind. Even before human modifications there was a spring here.

The St Paul Seminary spring belongs to the same type. At the head of the ravine associated with this spring there is a grotto and basin, constructed of cobbles mortared together.

The fourth highest spring-line followed seams of bentonite in the **Platteville Limestone**. This bentonite, a clay, resulted from volcanic ash-falls in Ordovician times (Sloan, 1987). While all the springs hitherto discussed were found in St Paul, this type was confined to Minneapolis. Thus, generally, while St Paul is a city of Decorah springs, Minneapolis is a city of Platteville springs.

The spring with the longest recorded history in Minnesota is Cold Spring (a.k.a. Baker's Spring), a Platteville spring near Fort Snelling. Its name arose because soldiers at the fort, from 1820 onwards, preferred drinking cold spring water rather than warm river water. The spring gave its name to Camp Coldwater, which they inhabited while the fort was under construction. In 1853, a hotel was erected. Prior to the 1890s, a wall of limestone rubble masonry was built around the spring, creating a reservoir. After World War II the Bureau of Mines took over the site and stocked the pool with trout (U.S. Department of the Interior, 1991). Using a 5-gallon bucket and a stopwatch, I determined the discharge to be 60 gallons per minute, at a point where the pool spilled over a weir. Cold Spring is presently in danger of being obliterated by a realignment of Highway 55. The 1839 Plympton map depicted other springs in the vicinity, such as Big Spring and "Four Springs," near where the Mall of America now stands.

But of all the springs in the Twin Cities, the only one to achieve *national* fame was Chalybeate Springs, a Platteville spring just below St Anthony Falls. Previous to the Civil War a hotel called the Winslow House was crowded by the wealthy and fashionable of the South who came hither to escape the heat and drink from the chalybeate (iron-bearing) springs (O'Brien, 1904). After the war, a special purpose structure, the Chalybeate Springs Resort, was built. The state geologist, himself, pronounced the waters "medicinal" (Winchell, 1877). Located in Pillsbury Park, the springs flow today as copiously as ever.

Platteville springs also supplied drinking water to the Bohemian Flats community that once existed on the floodplain below the west end of the Washington Avenue bridge. However, springwater is too hard for doing laundry, so barrels were set out to catch the soft rain water for washday (Work Projects Administration, 1986). These springs are the reason why Riverside

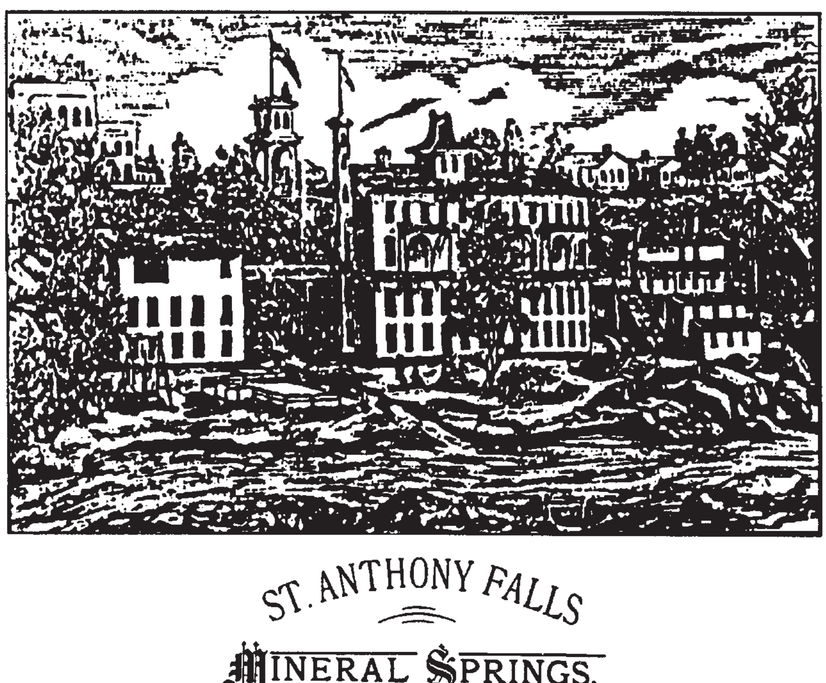

Figure 3: Chalybeate Springs Resort in Minneapolis

Springs, cont.

Park is often closed in winter: water spills out over the road and freezes, causing automobile accidents.

Hajduk Spring, located near the old Milwaukee Road trestle, north of the Lake Street bridge, is probably the only Platteville spring from which people still drink. First described by Schwartz (1936), it was officially named after its chief promoter, Harry Hajduk (pronounced Hi-duck), by the Minneapolis Park Board, in 1977. At the same time, a platform was erected at the foot of the cliff to make it easier to fill jugs (Meier, 1977). This is our best example of a falling spring, i.e., a spring that creates a waterfall. (Shadow Falls flows as a stream before taking the plunge, rather than falling straight from the cliff face.) So colorfully had this spring stained the cliff face red, that it inspired me to a naive color classification scheme for springs!

Other Platteville waters are not so potable. At Gasworks Bluff, near the west end of the I-35 bridge, I found springs which, because of their sulfide aroma and the appearance of the material they had deposited, I recorded in my fieldbook as "bird-dropping springs." You get the picture. Cheers!

In winter the big Platteville springs become thermal oases for wildlife. Springwater, above the freezing point as it resurges, melts snow at the foot of the bluffs, creating areas where the ground remains unfrozen. I frequently observed robins in these places.

The fifth highest spring-line, along the **Platteville Limestone-Glenwood Shale contact**, was a disappointment. You would expect to find springs at the top of an impervious shale (as at the top of the Decorah Shale), but there were only a few miserable seeps at this contact, probably because the bentonite seams in the Platteville have already pirated most of the water.

The sixth highest spring-line occurs where the water table in the **St Peter Sandstone** intersects the river gorge. Most famous in this category were the two cave springs, Carver's Cave and Fountain Cave. There are St Peter springs along Minnehaha Creek, below the falls, where a bronze plaque affixed to a glacial erratic boulder, draws attention to them. Schwartz (1936) described St Peter springs between St Paul and Mendota. While walking the Chicago & Northwestern tracks near Lake Pickerel, dodging the occasional train, I saw several of these. I came to expect one wherever I saw a culvert crossing under the tracks.

The largest springs in the Metro area occur where the Mississippi crosscuts its own, **preglacial channels**. The St Paul Fish Hatchery springs, below Dayton's Bluff, with a discharge of 400 gallons per minute, were the most famous of these (Castle, 1912). Between 1974 and 1976 (when records were kept) the chloride concentrations of this springwater increased, peaking in winter, presumably a result of salt applied to nearby Warner Road. These springs serve as a clandestine water supply for the homeless, who live in the woods along the Point Douglas Trail.

The Pine Bend springs, which gave Spring Lake its name, belong to the same type. Driving down to a landing on the lake (in fact, an expanded reach of the Mississippi), I found a boat-rental shop called "Bud's Place," bearing a sign depicting a fountain spouting into the air. Perhaps an allusion to the springs? When I asked "Bud" where I might see the springs so romantically depicted, however, he replied that they were actually in the bed of the river, and that I would have to come back in winter, when ascending columns of springwater melted holes in the ice. I had recently acquired a SCUBA certification, and Calvin suggested that I dive down and fetch a sample with an upside-down jar. In fact, the situation is more complicated than Bud knew, as there are probably three types of springs at Pine Bend (Schwartz, 1936).

Our most famous **surficial spring** is Glenwood-Inglewood Springs, known at office coolers throughout the Metro area. Winchell (1905) drafted a cross-section of the geology of this spring, showing how the water emerged from a gravel-clay contact on the banks of Bassett Creek, in Minneapolis. The water utilized at present is not derived from the original spring but from pipes driven through the clay into a water-bearing sand bed. Other surficial springs feed the Minneapolis chain of lakes.

Nearby, in Glenwood Park, was the Great Medicine Spring. In 1874, Col. John H. Stevens, the first settler in Minneapolis, said that this spring was frequented by Native Americans, "who came hundreds of miles to get the benefit of its medicinal qualities" (Gallagher *et al*, 1992). By the time I arrived on the scene, the spring seemed to be in need of some medicine itself. It dripped from the mouth of a pipe with all the gusto of a leaking faucet.

The so-called "boiling springs" on the Hattenberger farm, southeast of Shakopee, "boil" vigorously at intervals of a few minutes. The "boiling" is merely an upwelling of water, probably due to suspended sediments in the pool, which settle down and confine the water until the pressure builds up sufficiently to burst through.

The **lost springs** of the Twin Cities are a subject in their own right. By "lost" I mean dried up or unlocatable. They are a mixed bag, geologically speaking, and it is not always clear from the literature what types of springs they were. What was the Rum Town spring across from Fort Snelling, for example, or the Ninth Street springs in downtown St Paul, or the Swede Hollow spring? But of all places, the University of Minnesota area was most densely populated by these ghosts. The University Spring, for example, was located on the banks of Tuttle's Creek, whose dry gulch still separates Eastbank Campus from Dinkytown. This spring was used to supply water to the early University, a hydraulic ram raising the water to the buildings. The class of 1885 built a wall about the spring and fixed it up as a memorial (Johnson, 1908). The spring became contaminated with sewage, the student newspaper lampooned the contents of the water, and when the Northern Pacific tracks were laid along the creek bed in 1924, it vanished altogether. Again, there used to be springs flowing in a former botany greenhouse at the university. After much detective work, involving examination of old maps in the university archives, interviewing retired botanists, etc., I finally identified this former spring with a dried cal-

Springs, cont.

careous tufa deposit behind Boynton Health Center, in what had been the old University limestone quarry. Other springs recorded by Winchell (1877), such as the Russell Mineral Spring, which bubbled up into a cellar in Dinkytown, and a "Petrified Moss" spring, somewhere on the bluffs near Campus, were unlocatable.

I maintain files (with photographs) of the springs of the Twin Cities as an on-going project, so if anyone has something they would like to share, I would like to hear from them. Address: P.O. Box 152, Willington, CT, 06279. Email: gab94002@uconnvm.uconn.edu.

Greg Brick holds degrees in biology and geology from the University of Minnesota, and a master's degree in geology from the University of Connecticut. He has worked for environmental consulting firms in Massachusetts, and presently seeks employment in Minnesota. Have any leads?

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COMMENTARY

Twin Cites Springs Postscript

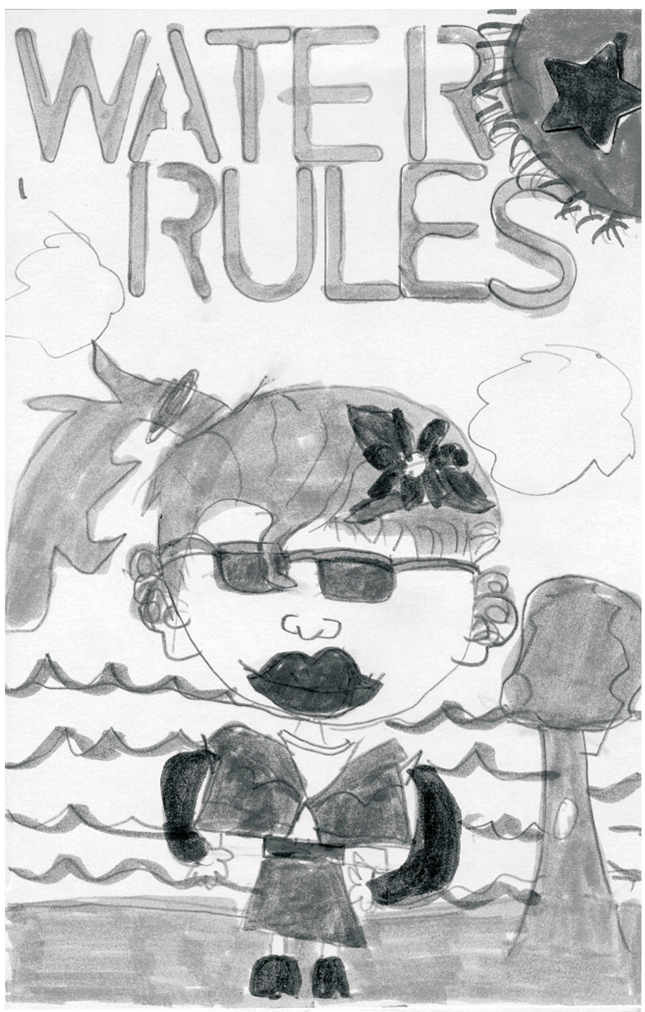
By Greg Brick

While taking a ground water course at the University of Minnesota in 1992, I once nearly passed out in the classroom during an exam from having overdosed on "Jet-Alert" ™ caffeine tablets. I had studied all night for one of the "domino" exams, as I called them, where the first question's answer is needed to continue on to the next question. Miss it and you are pretty much dead in the water. That was back in the days when the ground water industry was actually booming and there was a lot of competition. Spring-hunting was a romantic, much-neglected aspect of ground water and a welcome diversion from all those well-pump equations!

I became interested in springs after reading James Reuel Smith's Springs and Wells of Manhattan and the Bronx. Smith bicycled around Manhattan circa 1900, recording many quaint stories about its vanishing springs. The idea of tracking down historical springs, especially in an urban setting, and seeing what had happened to them, as well as finding new springs, thereafter held a fascination for me, becoming the inspiration for my 1993 Twin Cities springs survey. The 1997 summary article, as reprinted here, contains a few minor errors, largely because it was written while I was at the University of Connecticut, and could not double-check some findings.

With regard to the "Ground Water History" column, I began collecting miscellaneous information about local springs starting with the 1993 survey. The Minnesota Pollution Control Agency took an interest in the data for the Metro Model, and the column became another way to get the information out there. Someday, I hope the Minnesota Geological Survey will issue a comprehensive publication on this topic!

Fun Stories



— This is the cover of a thank you card sent to the Minnsota Ground Water Association Foundation after the Metro Children's Water Festival. This attendee seems to have the right idea!

STATE OF MINNESOTA
OFFICE OF THE GOVERNOR
SAINT PAUL

November 17, 1982

ALBERT H. QUIE
GOVERNOR

Dear Friends:

On the occasion of your first meeting, it is a pleasure to send greetings to the newly-formed Minnesota Ground Water Association. I urge this congress of professionals to take advantage of the national interest in water issues and to transform it into a productive time for developing public awareness of ground water resources. Future wise management of our water in Minnesota is dependent upon a strong, basic understanding of the nature of ground water.

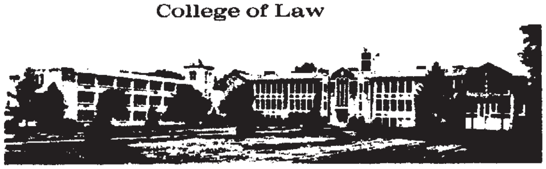
Good luck to you and the members of the Association. It is my hope that all Minnesotans will benefit from the comprehensive approach to the science of ground water hydrology which is afforded by the variety of professions represented in your membership.

Sincerely,

Albert H. Quie

ALBERT H. QUIE
GOVERNOR

WILLIAM MITCHELL
College of Law



875 SUMMIT AVENUE ☐ ST. PAUL, MINNESOTA 55105 ☐ (612) 227-9171

November 24, 1982

Pat Leonard-Mayer
Minnesota Ground Water Association
P.O. Box 3362
St. Paul, MN 55165

Dear Pat:

Congratulations on tackling a difficult but significant public service. The resource of groundwater is invaluable. As you build awareness of the threats to that asset, you will be serving in an important way the long range interests of our state.

I hope you can successfully deal with the reality of "Out of sight, out of mind," and win appropriate attention so that our state will face up to the challenge of protecting our groundwater. It looks to me like your organization is going about its work in a sensible way.

Sincerely,

Jack Davies

Jack Davies
Professor of Law
State Senator

JD/cl

STATE OF MINNESOTA

THE GREAT SEAL OF THE STATE OF MINNESOTA 1858

Proclamation

WHEREAS: Ground water in Minnesota is recognized to be an important and valuable natural resource; and

WHEREAS: The Minnesota Ground Water Association was formed in 1982 to serve the citizens of Minnesota; and

WHEREAS: The Minnesota Ground Water Association has pledged to advocate for the wise use and protection of ground water to provide education to users of Minnesota ground water; and

WHEREAS: There are over 600 members in the Minnesota Ground Water Association, including technical professionals, legislators and other concerned citizens; and

WHEREAS: The Minnesota Ground Water Association is celebrating 10 years of service to the State of Minnesota;

NOW THEREFORE, I, ARNE H. CARLSON, Governor of the State of Minnesota, do hereby proclaim November 10, 1992 to be

M I N N E S O T A   G R O U N D   W A T E R   A S S O C I A T I O N   D A Y

IN WITNESS WHEREOF, I have hereunto set my hand and caused the Great Seal of the State of Minnesota to be affixed at the State Capitol this tenth day of November in the year of our Lord one thousand nine hundred and ninety-two, and of the State the one hundred thirty-fourth.

Arne H. Carlson
GOVERNOR

Joan A. Growe
SECRETARY OF STATE

The 'Rotini Screen'

The Capillary Fringe

Bergerson-Caswell drillers display special equipment from recent field work done in Faribault for the Minnesota Pollution Control Agency (MPCA)—the cork-screw or "rotini" screen. It augers through the tightest formations, allowing for easy well completions, and, at the end of the day, it cooks up "al dente" in just 12 minutes. However, sample bailing is still problematic.

Actually, at the beginning of the project the screen was straight. The driller advanced hollow stem augers with a plastic centerplug to the intended screened interval, then attempted to set the screen/casing assembly. This usually involves knocking the centerplug out of the augers by driving the screen/casing assembly downwards and simultaneously withdrawing the augers 1 to 3 feet. The formation collapses around the screen and the temporary well is complete. However, in this case, even after hammering the screen/casing assembly, the plug did not budge. After several attempts, the driller withdrew the screen only to find it had buckled to a spiral shape, confined by the inside diameter of the hollow stem augers.

Bon appetit!

— Contributed by Jim Lundy, MPCA

— From Volume 17 , Number 4

—Steve Schoff with the 'rotini screen'. It held a place of honor in the MPCA equipment warehouse for a year or two. Then it disappeared (probably to Kaplan's metal recycling along with a missing set of auger flights).

Federal Agencies to "Go Metric" by 1992

The Omnibus Trade and Competitiveness Act of 1988 contains a section that amends the U.S. National Metric Act of 1975 to state that Congress directs each Federal Agency to convert to the metric system by 1992.

Metric conversion was included in the OTCA Bill because Congress realized that a metric changeover can make the U.S. economy stronger by helping industry compete in the international trade markets. The Common Market countries have agreed to prohibit the sale of non-metric dimensioned products in their countries after 1992.

Members wanting more information on the metric section of the 1988 Omnibus Act can contact A. Ivan Johnson, Chairman, ASCE/COM, 7474 Upham Court, Arvada, CO 80003.

— From Volume 8, Number 1

NASA goes metric for Moon missions

By William Atkins — Wednesday, 17 January 2007

Every country in the world has adopted the metric system for its units of measurements except for Liberia, Myanmar (formerly Burma), and the United States. The people of the United States tried to convert to metric — mostly in the 1960s and 1970s (remember metrification?) — but it failed miserably. However, to avoid confusion, minimize safety concerns, and support international cooperation, NASA has decided to use the metric units for all operations with respect to its new lunar initiatives.

— ItWire.com

U.S. Government Goes Metric

A statute that went on the books on July 28, 1866 will soon be implemented by the federal government. Last summer, President Bush signed Executive Order 12770, which requires federal agencies to begin using the metric system on September 30. That means that Bush put his name to the bill 125 years after Congress legalized the measurement standard for use in the U.S. and 11 years after it passed the Metric Conversion Act of 1975.

Private sector use of grams, meters, liter, and so forth will still be voluntary, but those doing business with the federal government should stock up on those metric conversion kits. The law says Uncle Sam will use metric measures even in "procurements, grants, and other business-related activities."

—Water Well Journal, August '92

— From Volume 11, Number 2

Now where did I park that car?

Lost a VW Lately?

A lime-green Volkswagen was among items discovered in a Floyd County, Iowa sinkhole, one of several sinkholes to be cleaned in a new environmental program.

The one-acre sinkhole also contained automobile tires, toys, scrap iron, old jars and cans, sheets of corrugated metal, bottles of all kinds, and rusted-out pesticide containers. State officials said the hole had been used as a public dump.

The sinkhole is one of 33 on 29 farms spread across seven northern and northeast Iowa counties that were earmarked for the initial cleanup and clean-out operation in 1992.

A similar schedule is planned for subsequent years. State officials say nearly 13,000 sinkholes have been identified in the seven Iowa counties, but only about 200 are thought to have been used as public dumps.

The effort to repair the 33 sinkholes was expected to cost $350,000 in state money during 1992. The money comes from a tax on farm chemicals, including nitrogen fertilizer, established by the 1987 Iowa Ground Water Protection Act.

—Iowa Water Well News

— From Volume 12, Number 1

Which is it? ....

Editorial Note: Ground Water or Groundwater

Many readers may have noticed inconsistencies in past issues of the newsletter in the spelling of the resource we are trying to protect. This is especially apparent in this issue where the authors of the two lead technical articles (both Hydrogeologists with the Minnesota Pollution Control Agency I might add) have chosen a different spelling. Andrew Streitz prefers “groundwater” while Jim Lundy likes “ground water”. And these guys work on the same floor!

Since this is a debate that has raged for decades and will probably continue into the next century, I’ve chosen to take a “soft” editorial approach to the issue and follow the author’s wishes. It makes the job of your volunteer editor and overworked publisher a little easier and hopefully keeps our authors happy, too. Speaking of authors, we are always looking for new ideas and discussion of emerging issues to feature in the newsletter. If you have something you’d like to see in print or an article or announcement you think would be of interest to our readers, please submit them to me at the MGWA address or to MPCA, 520 Lafayette Rd, St. Paul, MN 55155 (phone: 612-296-8580; fax: 612-296-9707; email: tom.clark@pca.state.mn.us)

— From Volume 14, Number 4

*— Image from the USGS **Ground Water** page: capp.water.usgs.gov/GIP/gw_gip/*

MGWA Data

—1997 Fall Field Trip to Southeast Minnesota

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1982		Gil Gabanski	Dennis Woodward	Kent Peterson	Kelton Barr	Pat Leonard-Meyer/ Pamela Watson
1983	Gil Gabanski	Gil Gabanski	Dennis Woodward	Kent Peterson	Kelton Barr	Pat Leonard-Meyer/ Pamela Watson
1984	Gil Gabanski	Gil Gabanski	Dennis Woodward	Gretchen Sabel	Kelton Barr	Pat Leonard-Meyer
1985	Gil Gabanski	Gil Gabanski	Jerry Rick	Gretchen Sabel	Jim Stark	Kevin Powers
1986	Gil Gabanski	Jerry Rick	Rick Johnston	Gretchen Sabel	Jim Stark	Kevin Powers
1987	Jerry Rick	Rick Johnston	Linda Lehman	Pat Bloomgren	Jim Stark	Kevin Powers
1988	Rick Johnston	Linda Lehman	Bob Karls	Pat Bloomgren	Gordy Hess	Lee Trotta
1989	Linda Lehman	Linda Lehman	Bob Karls	Don Jakes	Gordy Hess	Lee Trotta
1990	Linda Lehman	Bob Karls	Gordy Hess	Don Jakes	Bob Beltrame	Lee Trotta
1991	Bob Karls	Gordy Hess	Sheila Grow	Susan Price	Bob Beltrame	Jan Falteisek
1992	Gordy Hess	Sheila Grow	Larry Johnson	Susan Price	Bruce Olsen	Jan Falteisek
1993	Sheila Grow	Larry Johnson	Doug Connell	Rita O'Connell	Bruce Olsen	Jan Falteisek
1994	Larry Johnson	Doug Connell	Cathy O'Dell	Rita O'Connell	Rich Soule	Jan Falteisek
1995	Doug Connell	Cathy O'Dell	Gretchen Sabel	Paul Putzier	Rich Soule	Tom Clark
1996	Cathy O'Dell	Gretchen Sabel	Ray Wuolo	Paul Putzier	Jan Falteisek	Tom Clark/ Jim Almendinger ads
1997	Gretchen Sabel	Ray Wuolo	Paula Berger	Paul Bulger	Jan Falteisek	Tom Clark/ Jim Almendinger ads
1998	Ray Wuolo	Paula Berger	Jim Piegat	Paul Bulger	Jan Falteisek	Tom Clark/ Leigh Harrod ads
1999	Paula Berger	Jim Piegat	Jim Lundy	Lee Trotta	Jan Falteisek	Tom Clark/ Leigh Harrod ads
2000	Jim Piegat	Jim Lundy	Jim Stark	Lee Trotta	Jan Falteisek	Tom Clark/ Jim Aiken ads
2001	Jim Lundy	Jim Stark	Robert Caho	Eric Hansen	Jan Falteisek	Tom Clark/ Jim Aiken ads
2002	Jim Stark	Robert Caho	Marty Bonnell	Eric Hansen	Jon Pollock	Norman Mojfeld / Jim Aiken ads
2003	Robert Caho	Marty Bonnell	Chris Elvrum	Eric Hansen	Jon Pollock	Norman Mojfeld / Jim Aiken ads
2004	Marty Bonnell	Chris Elvrum	Laurel Reeves	Eric Hansen	Jon Pollock	Norman Mojfeld / Jim Aiken ads
2005	Chris Elvrum	Laurel Reeves	Dale Setterholm	Craig Kurtz	Jon Pollock	Norman Mojfeld / Jim Aiken ads
2006	Laurel Reeves	Dale Setterholm	Jeff Stoner	Craig Kurtz	Jon Pollock	Norman Mojfeld / Jim Aiken ads
2007	Dale Setterholm	Jeff Stoner	Stu Grubb	Craig Kurtz	Jon Pollock	Norman Mojfeld / Jim Aiken ads

*The office of Secretary was combined with Membership Chair after 1985. Tom Clark was Membership Chair from 1982 to 1985.

CONFERENCES

Date	Conference Title
Fall 1982	Hazardous Waste Disposal and Ground Water Contamination
Spring 1983	Legal and Regulatory Aspects of Ground Water Contamination in Minnesota
Summer 1983	Drilling, Sampling and Monitoring Well Installation
Fall 1983	The Whys Wherefores, Hows, and I-Told-You-Sos of Piezometer Installation
Spring, 1984	The Professional as an Expert Witness
Summer, 1984	Ground Water Quality Sampling and Analysis
Spring, 1985	Implementation of Wisconsin's Ground Water Law
Fall, 1985	Geophysical Techniques in Ground Water Studies
Spring, 1986	Geophysical Exploration
Fall, 1986	Ground Water Contamination with Dr. John A. Cherry
Spring, 1987	Hydrocarbon Contamination
Spring, 1988	Radium in Ground Water: Origin, Occurrence, Treatment and Health Effects
Fall, 1988	Water Treatment Options: Coping with Contaminated Ground Water
April, 1989	Geological Sensitivity of Ground Water to Contamination
February, 1989	Property Transfer: Environmental Liability and Site Assessment
June 1989	New Methods for Ground Water Protection in the German Democratic Republic
November 1, 1989	1989 Ground Water Legislation in Minnesota
Spring, 1990	Project Management
May, 1990	Field Techniques and Data Interpretation
November 14, 1990	Risk Assessment (Environmental Risks – Contrasting Perceptions)
March 28, 1991	Remediation Technologies for the Unsaturated Zone
November 26, 1991	Innovations in Field Screening Methods and Geotechnical Applications
April 14, 1992	Updates and Innovations in Drilling and Well Construction
November 10, 1992	Characterizing Aquifer Conditions
April 20, 1993	Applications of Geographic Information Systems for Investigating Ground Water Resources
November 30, 1993	Land Use and Ground Water Protection: Making the Connection
April 5, 1994	Landfill Gases, Genesis, Detection, and Control
November 7, 1994	Directions in Ground Water Remediation
May 8, 1995	Technical Communication with the Public: Ground Rules for Scientists

October 27, 1995	Use of Isotopes in Hydrology
April 25, 1996	Applied Ground Water Management: Wellhead Protection and Beyond
November 12, 1996	Datalogger Concepts and Applications in Hydrogeology
April 28, 1997	Licensing of Geoscientists in Minnesota
November 14, 1997	Surface Water / Ground Water Interaction
April 17, 1998	Brownfield Redevelopment and Ground Water Protection
November 13, 1998	New and Emerging Technologies in the Study and Remediation of Ground Water
April 30, 1999	New Leadership in Evolving Ground Water Policy
November 19, 1999	Surface Geophysics: Applications for Ground Water Professionals
May 5, 2000	Minnesota Water Law
November 3, 2000	Minnesota's Emerging Ground Water Quality Issues – Tuning up the 1989 Ground Water Protection Act
April 10, 2001	Emerging Issues in Ground Water Technology and Science
November 6, 2001	The Value of Minnesota's Ground Water
April 23, 2002	Effective Drilling and Well Techniques in Minnesota
November 12, 2002	Municipalities and Ground Water Supply Issues
April 17, 2003	Interaction of Ground Water and Surface Water
May 4, 2003	Ground Water Contamination: State of the State
November 10, 2003	Water Conservation in Minnesota: Is it time to get serious?
June 18, 2004	Calcareous Fens of Southeastern Minnesota Technical Workshop and Field Trip (special seminar presented in cooperation with the City of Rochester, Rochester Public Utilities, DNR)
November 16, 2004	Management and Analysis of Ground Water Data
May 19, 2005	Ground Water Sustainability Symposium (in conjunction with GSA)
November 17, 2005	Geochemistry for Scientific Investigations
November 18, 2005	Isotope Hydrology Workshop
April 12, 2006	Better Ground Water by Design – A Review of Practices and Systems that Impact Ground Water
November 14, 2006	Ground Water Management – The Minnesota Model: Data, Tools, Techniques, and Organization
April 19, 2007	Methods for Solving Complex Ground Water Problems
November 13, 2007	Addressing Ground-Water Issues for the Next Generation

Year	Date	Location	Cooperators[1]
1991	September 20-21	Southeast Minnesota, Southwest Wisconsin (LaCrosse, Winona)	AIPG (MN, WI), Wisc. GW Assoc., Iowa GW Assoc.
1992	September 11-12	Northern Minnesota, Duluth Area	
1993	September 10	Upper Minnesota River Valley (New Ulm, Redwood Falls)	AIPG
1994		Central Minnesota (St. Cloud)	AIPG
1995	September 8-9	Mesabi Iron Range	AIPG, Mesabi Range Geological Society
1996	September 13-14	Twin Cities Metro Area	AIPG
1997	September 26-27	Southeast Minnesota	AIPG, AWG
1998	September 19-20	Western Wisconsin, North-central Minnesota Glacial Stratigraphy	
1999	September 10-11	North Shore, Gunflint Trail	AIPG, AWG
2000	September 23-24	Lower Minnesota River Valley	AIPG, AWG
2001	October 12-13	Brainerd Lakes Area	AIPG, AIH
2003	September 26-27	St. Croix River Valley	AIPG, MGWA

[1]Cooperators are if known. AIPG: American Institute of Professional Geologists, AWG: Association for Women Geoscientists, AIH: American Institute of Hydrology.

Selected Bibliography by Topic: 25 Years of MGWA Newsletter Issues

The full bibliography appears at:
www.mgwa.org/newsletter/bibliography.pdf

Ground Water Conceptual Frameworks

v2 n2:

Hydrogeology 1885 - Review of a paper written by Thomas C. Chamberlin, Pat Leonard-Meyer

v10 n3:

Minnesota ground water contamination susceptibility map, Eric Porcher

Hydrogeology: it is, David Stephenson, Bruce L. Cutright, William W. Woessner

v11 n4:

Hydrogeology and pollution sensitivity of Quaternary and Prairie du Chien-Jordan Aquifers in Ramsey County, Roman Kanivetsky, Patrick Twiss, Jan Falteisek

v13 n4:

Ground water is key to protecting Savage Fen, Ray Wuolo

v14 n4:

St. Lawrence Formation investigation, Mike Convery, Jim Walsh

v16 n1:

Along the great wall: mapping the springs of the Twin Cities, Greg Brick

v16 n3:

Winona County sinkholes, Janet Dalgleish, Suzanne Magdalene

Life on "the edge" - Rochester plans ahead to protect recharge areas, Tom Clark

Karst hydrogeology report available for Le Roy Township, Mower County

Regional Hydrogeologic Assessment - Southwestern Minnesota - Part B available

v17 n1:

Hydrogeology and pollution sensitivity of the St. Peter-Prairie du Chien-Jordan Aquifer in Rice County, Minnesota, Moira Campion

v17 n2:

Hydrostratigraphy of Paleozoic bedrock, Southeastern Minnesota, Anthony C. Runkel

v20 n4:

Fall field trip: Brainerd Area geology, Roman Kanivetsky

v21 n2:

Shallow buried aquifers of Murray County, Minnesota, James A. Berg

v21 n3:

From small springs, great rivers flow, Marcey L. Westick

v22 n1:

Hydrogeology in Southeastern Minnesota, Tony Runkel

v22 n2:

Lithostratigraphy and hydrostratigraphy of Pope County, West Central Minnesota, Kenneth L. Harris, James A. Berg

v23 n1:

Why is ground water biodiversity important?, Tim Thurnblad

v23 n2:

Pine County Geologic Atlas, Part B —- hydrogeology and pollution sensitivity, Jim Berg

How geology contributes to water quality impairments — an example from Walker Brook, Red River of the North Watershed, Minnesota, Molly MacGregor, Joseph Magner and Robert Melchior

v23 n3:

Crow Wing County Geologic Atlas, Part A, completed, Dale Setterholm

v23 n4:

Unique hydrogeology poses environmental challenge for Askov, Kurt Schroeder

Learning to make better decisions with the Pine County Geologic Atlas, Jan Falteisek

v24 n3:

Wabasha County Geologic Atlas, Part B – hydrogeology and pollution sensitivity, Todd Petersen

Bedrock faults in Southern Washington County, Robert Tipping and John Mossler

v25 n2:

Dancing Waters sinkhole: summary of events, Steve Kernik

v25 n3:

Mapping multiple buried aquifers for the Pope County Geologic Atlas, Part B, Jim Berg

v26 n2:

Five buried Quaternary aquifer systems mapped for Stearns and Western Benton, Sherburne Counties, Jim Berg

Tools and Datasets

v1 n4:

Conjunctive surface-groundwater simulation

v2 n2:

Analytical functions for a microcomputer

v9 n2:

Model validation: bringing three views together, Paul van der Heijde

v9 n3:

Groundwater mechanics (book review)

v10 n1:

Transferring models to users

v10 n2:

Near-surface geophysics: a tool for the hydrogeologist, Todd Petersen

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Selected Bibliography, cont.

v12 n2:

EPA publication defines minimum elements for groundwater quality datasets

GIS – groundwater applications focus of MGWA spring seminar

v12 n4:

Publications explain geographic information systems

v13 n4:

Ground water is key to protecting Savage fen

Analytic element modeling of Hennepin County aquifers with a geographic information system, Leigh Harrod and James Piegat

v14 n3:

Groundwater clearinghouse coordinates crucial information, Suzanne Maeder, LMIC

v14 n4:

Twin Cities Metropolitan Area ground water model

v15 n3:

Operation of Minnesota statewide baseline ground water monitoring program using a GIS/GPS database

v16 n3:

Use of chemical and isotopic data for wellhead protection area delineation in fractured aquifers, James Walsh

v16 n4:

Managing subsurface geologic information in Minnesota – a 25 year status report, G. Morey, D. Setterholm, R. Tipping, MGS

Southwest metro groundwater workgroup: a subregional approach to water supply planning, Gary Oberts

v18 n2:

Use of ground water models, John Bredehoeft

v18 n3:

High-resolution flow logging in Minnesota, Frederick L Paillet

Metro groundwater model – site applications, Andrew Streitz, John Seaberg, Doug Hansen

v19 n4:

Metro model e-zine: lower aquifers report – a new look at old aquifers

v20 n1:

The use of multispectral images for locating wetland and high water table conditions, City of Rochester, Minnesota, Dan Barrett, Tim Modjeski, Terry Lee

New ArcView extension from DNR waters helps make geologic cross sections, Jim Berg, Randy McGregor

MDH county well index improvements for GIS applications

v20 n4:

Governor commends metro model — posthumously

v23 n1:

What is the oldest measured groundwater age in Minnesota? Scott C. Alexander, Karen Sherper Rohs, and E. Calvin Alexander, Jr.

USGS realtime ground-water level monitoring network, Geoff Delin, USGS

v23 n3:

Putting the Twin Cities Metropolitan ground water model to work, Doug Hansen, Chris Elvrum

v23 n4:

MDH launches CWI on-line

v24 n2:

Web availability of Metropolitan Council environmental monitoring data

Natural Contaminants and Monitoring

v1 n2:

Ambient ground water monitoring program, Tom Clark

v2 n3:

MDH VOC study

Procedures for ground water monitoring, MPCA Draft Guidance

v2 n4:

Groundwater quality sampling and analysis

v5 n2:

MPCA Groundwater Monitoring forum

v5 n3:

Safety risks of open boreholes, Mike Convery

v5 n4:

Minnesota Department of Agriculture launches pesticide study, Greg Buzicky

v6 n3:

Aquifer management (Mt. Simon), Ron Nargang

v7 n1:

Radium in drinking water, L.Lehman and Assoc

v7 n2:

That tricky radon gas can be beat, Frank J. Donia of Applied Radon

v7 n3:

USGS report describes Minnesota groundwater quality

v7 n4:

Trends in Minnesota resource conditions

v8 n3:

Arsenic in Minnesota, From MPCA brochures

v9 n1:

Midwest herbicides, USGS

v9 n4:

Risk assessment and control: management of radon in drinking water, William A. Mills.

v11 n2:

MDH tritium study, James Walsh, MDH

v11 n3:

Groundwater monitoring sections started by ASTM

Tritium in groundwater as a tool to estimate well vulnerability, James Walsh, MDH

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Selected Bibliography, cont.

v13 n2:

Publication covers groundwater monitoring, investigation, and modeling

v14 n1:

MPCA ground water sampling guidance: development of sampling plans, protocols, reports

v14 n2:

Little evidence of pesticides, industrial contaminants found in State's community drinking water systems

v14 n3:

CDC/MDH midwest water quality study

v15 n2:

DNR grid drilling program

v15 n3:

Operation on Minnesota statewide baseline groundwater monitoring program using a GIS/GPS database

MPCA example sampling protocol

v16 n2:

DNR southwest Minnesota ground water exploration project

Tracers in groundwater, James Walsh, MDH

v16 n3:

Use of chemical and isotopic data for WHPA delineation in fractured aquifers, James Walsh, MDH

v17 n2:

Drinking water report produces little evidence of contamination

The Minnesota Arsenic Study (MARS), Mindy Salisbury and Rich Soule, MDH

v17 n3:

Report on groundwater quality in southwest Minnesota

v17 n4:

DNR water level observation well program update

v18 n2:

Arsenic and drinking water: human health effects, conference summary

v19 n1:

MDH activities concerning radon in water and air, MDH

MDH develops hbv for total petroleum hydrocarbons, MDH

Modification of special well construction area-Twin Cities army ammunition plant, MDH

v19 n2:

Emerging issues: are you drinking drugs along with your coffee?

Water level data on-line

v19 n3:

MPCA releases results of ground water quality study in Cottage Grove

v19 n4:

The Minnesota Arsenic Study (MARS): mechanism and occurrence of arsenic in Western Minnesota drinking water, Michael E. Berndt, Richard G. Soule, and Melinda L. Erickson

v20 n1:

EPA publishes final arsenic rule – but is it the last word?

v20 n4:

EPA to adopt Clinton arsenic standard, Katharine Q. Seelye, reprint from New York Times

Mapping arsenic in ground water – Minnesota data, Tom Clark

Minnesota impact of new As[Arsenic] standard

Dye tracing study to Camp Coldwater Spring, Minneapolis, Minnesota

v21 n1:

Hastings area nitrate study, Jill Trescott, Dakota County

v22 n2:

Groundwater and urban growth – running on empty

v23 n1:

Arsenic in drinking water and health, Jean Johnson, MDH.

The new arsenic mcl and community water systems in Minnesota, Karla Peterson, MDH.

Arsenic in Minnesota ground water: recent research and implications for Minnesota, Melinda L. Erickson, Randal J. Barnes

Update on ground water level monitoring in Minnesota, Laurel Reeves, DNR

v23 n2:

MPCA ambient ground water quality monitoring in Minnesota

v23 n3:

"*Nailing" arsenic – tainted water,* Reprint from Science News.

v24 n1:

States' ten year water quality monitoring strategy

v24 n3:

Private water wells in Minnesota: recommended tests for contaminants, Michael P. Convery

v25 n2:

Dakota County ambient ground water quality study, Vanessa Demuth and Jill Trescott, Dakota County

v25 n3:

USGS, MDH issue water quality reports

USGS releases report on inorganic and organic contaminants in domestic wells

Policies and Programs

v1 n2:

A consumer's guide to Minnesota's ground water programs, Linda Bruemmer

v5 n2:

Environmental mediation, Pat Leonard-Mayer

v6 n2:

Clean Water Partnership Program

v6 n3:

National ground water legislation summary, Holly Stoerker

Avoiding environmental liability in real estate transactions, Greg Fontaine

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Selected Bibliography, cont.

Aquifer management, Ron Nargang

v7 n1:

Policy issues, Marilyn Lundberg

Minnesota ground water protection strategy, 1988, Gretchen Sabel

v7 n3:

Minnesota ground water protection strategy (president's page), Linda Lehman

Environmental laws – waste management act amendments, environmental trust fund

Drought of 1988, Lee Trotta

v7 n4:

Comprehensive local water planning, Denice DeFrates

Trends in Minnesota resource conditions from EQB report

Comprehensive Water Resources Protection Act of 1989, John Wells

v8 n1:

Property transfer issues from the PCA perspective, Robyn Livermore

Environmental liability and real estate, Jim Benson

Interpretation of data collected during a phase I environmental audit, Shawn Ruotsinoja

Ground water standards – two different perspectives, Michael Apgar

Ground water quality standards in South Dakota, Barbara Nielsen

v8 n2:

Abandoned well survey completed by MDH, Peter Zimmerman

v8 n3:

A summary of the Groundwater Act of 1989, John Helland

Ground water primer (Nebraska Extension), DeLynn Hay

v9 n1:

Abandoned well study, Hennepin Conservation District

Update on well sealing cost-share grant program, Water Bill Board

Toward national policy coordination: improving intergovernmental relations, Interstate Conference

v9 n3:

Well disclosure information, Minnesota Dept. of Health (MDH) Well Management News

Proposed rules: limited dewatering and sealing licenses, construction permits (MDH)

Carlson's environmental policy, Arne Carlson position paper

v9 n4:

MDH developing health-based ground water standards

v10 n1:

EPA proposes drinking water standards

v10 n2:

Investigations assess risks, Steven Christenson

Professional Registration, Certification and Definition

v10 n3:

Well plan review requirements, MDH Well Management News

State underground storage tanks rules become effective

v10 n4:

Update on MGS — in case you haven't heard (funding restored)

Liability issues and ASFE

Update on the ASTM subcommittee on groundwater and vadose zone investigations

Older americans useful at finding abandoned wells, Water Well Journal 11/91

v11 n4:

Legislative update

v12 n2:

Proposed licensing of geologists in Minnesota

v12 n4:

Health risk limit rules for groundwater contaminants adopted, Roberta Aitchison-Olson

v13 n1:

The Minnesota Water Information Line, Daniel Sola

v13 n3:

Groundwater and sustainable agriculture, Larry Johnson

Update on Minnesota geologist registration

v13 n4:

Health dept. health risk limits – rules for 119 ground water contaminants

v14 n2:

Health risk limits rules now include 120 ground water contaminants, Roberta Aitchison-Olson, Larry Gust

New on-line water information services

Professional geoscientist registration bill passes

v14 n3:

1995 legislative summary (includes amendments to groundwater protection act)

Minnesota Water Line expands

v14 n4:

Wellhead Protection Rule development

Reauthorization of the Safe Drinking Water Act: Senate Bill 1316 introduced

v15 n1:

MPCA adopts new rules for individual sewage treatment systems, Gretchen Sabel

Minnesota Water Line gets off the ground, Deanne Roquet

v15 n2:

Lost wells found, Jim Berg

v15 n3:

New special well construction area designated for wells at TCAAP, MDH Well Management News

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v15 n4:

Safe Drinking Water Act (SDWA) reauthorization signed

Geoscience rules status update

v16 n2:

Ionizing radiation rules to change

v16 n3:

Life on "The Edge"- Rochester plans ahead to protect recharge areas, Tom Clark

v16 n4:

SW metro groundwater workshop: subregional approach to water supply planning, Marcia Honald, Gary Oberts

v17 n1:

Geoscience licensure grandparenting period ends August 5, 1998

Well construction area designated for wells in St. Paul Park/Newport

v17 n2:

New Special Well Construction Area – City of East Bethel, Anoka Co., MDH Well Management News

v17 n3:

MPCA switches to new organizational structure

v19 n1:

Program evolution at the Minnesota Geological Survey, David L. Southwick

A look back (GW consulting over the past 15 years), Ray Wuolo

Continuing education: Minnesota Statute 326.107

v19 n4:

Minnesota's emerging issues – what science is telling us – ground water law in Minnesota

v20 n1:

Practical ideas to increase effectiveness of ground water management,

Future directions of ground water law

EPA Ground Water Rule

v21 n1:

Overview of EQB water resources management activities, Michael Tietz

v21 n2:

Revision of the Health Risk Limits for Ground Water Rule, Anne Kukowski

v21 n3:

Well and boring rules being revised, Ron Thompson

v22 n2:

Ground water and urban growth-running on empty, MPCA Indicator of the Month

v22 n4:

Pawlenty Administration's Clean Water Initiative, Tom Clark

v23 n3:

Role of MDH in protecting drinking water, Stew Thornley

v23 n4:

Notice of intent to amend rules (Chapter 4725, Wells and Borings), Ron Thompson

v24 n2:

Thoughts on the MGWA ground water sustainability symposium, John Wells

v24 n3:

Metro Council water supply planning legislation, Chris Elvrum

v25 n1:

Communicating about ground water contamination, Tannie Eshenaur

Minnesota's Environment 2005: how are we doing? focus on drinking water, Tom Clark

v25 n4:

Clean Water Legacy Act signed

Remediation

v3 n2:

Leaking underground storage tanks, Tom Clark

v9 n2:

Estimation of duration of groundwater contamination pumpouts, Donald F. Kidd and Randall R. Miller

v13 n1:

Water balance of abandoned mine pits, John L. Adams

v15 n2:

Effects of air sparging on aquifer hydraulic conductivity, Hans Neve

v17 n3:

Natural attenuation of ground water contaminants, Mark Ferrey

v21 n1:

In-situ oxidation of chlorinated organics, Mark Millsop

Ground-Water History

v2 n2:

Hydrogeology 1885 – review of a paper written by Thomas C. Chamberlin, Pat Leonard-Meyer

v16 n1:

Along the great wall: mapping the springs of the Twin Cities, Greg Brick

v22 n1:

The virtual hall of springs, Greg Brick

v23 n4:

The prehistory of Mystery Cave: "Well-known Subterranean Passages", Greg Brick

v24 n1:

"Nature's Laboratory": the virtues of antebellum groundwater, Greg Brick

v24 n2:

Groundwater gods: hydromythology at camp coldwater, Greg Brick

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Selected Bibliography, cont.

v24 n3:

A piping voice: theories of cave genesis in Minnesota prior to 1880, Greg Brick

v24 n4:

St. Paul's legendary subterranean lakes, Greg Brick

v25 n1:

Little Minnehaha Falls: the great subterranean spring of Minneapolis, Greg Brick

v25 n3:

Baldwin Latham, the engineer who supposedly brought you "Ground Water" in 1890, Greg Brick

v25 n4:

Viking water wells in the late ninth century, Greg Brick

v26 n1:

Apocalyptic waters: an early account of ground water pollution in Minnesota, Greg Brick

v26 n2:

The Highland Park Spring Water Company, Greg Brick

v26 n3:

St. Paul's "Diamond Necklace", Greg Brick

Important Historical Notes

v1 n2:

Letters from Governor and State Senate, Governor Al Quie and State Senator Jack Davies

v1 n3:

Current ground water research in Minnesota, MGWA

v2 n3:

Current ground water research in Minnesota, MGWA

v5 n4:

MPCA hydrologist job listings, MPCA

v6 n2:

Advertisement—"I (heart) Toxic Waste", Amazing Enterprises

v7 n3:

MGS publications, Dale Setterholm

v7 n4:

Just trying to make a buck, National Geodetic Survey

v8 n1:

Feds go metric by 1992

v8 n3:

Fiberglass casing

v9 n1:

Ground water concerns rank highly in Ford study, Points (reprint)

v9 n3:

Moosehead environmental campaign, Land Letter (reprint)

v10 n3:

Leeches as water samplers, Hydata (reprint)

MGS may close, EOS (reprint)

v11 n1:

Prehistoric wooden well In Germany, Nature (reprint)

Recycled paper donor report, MGWA

v11 n2:

Texas controls aquifer by crying a river, US Water News (reprint)

US Government goes metric, Water Well Journal (reprint)

v11 n4:

Earwigs can cause problems in wells, Water Well Journal (reprint)

MGWA Days (Governor's proclamation)

v12 n1:

Lost a VW lately?, Iowa Water News (reprint)

Pleistocene ice from well cuttings, Water Well Journal (reprint)

v12 n2:

Horwood's short laws of data processing

v13 n3:

Ground water flow models (ant farm), Rich Soule

v14 n4:

Ground water or groundwater, Tom Clark

Landfill gases conference, MDH

v16 n3:

Bonnie Holz named GW Hero, Groundwater Foundation News (reprint)

v17 n2:

MGWA eliminates post office box, MGWA

v19 n2:

Hydrologist uses job skills to help, Jeff Green

v20 n3:

Kenya 2001, Jeff Green

v22 n1:

Black holes, Tom Clark

MGWA FOUNDATION NEWS

Minnesota Ground Water Association Foundation Board Meeting Minutes

Meeting Date:	Tuesday, September 11, 2007
Location:	Fresh Grounds, St. Paul
From:	Cathy Villas-Horns (Secretary)
Members Present:	David Liverseed, Gilbert Gabanski, Amanda Goebel, Christopher Elvrum, Dale Setterholm and Cathy Villas-Horns. MGWA Management Present: Jeanette Leete and Sean Hunt
Agenda items:	Review of Minutes, Treasurers Report, Old Business, New Business, Next Meeting (Date and Place). Gil called the meeting to order.
Review of Minutes	The meeting minutes for the June 12, 2007 meeting were approved via e-mail on June 27, 2007. However, the minutes were amended by Sean Hunt at the meeting to include "MN" in the last sentence of New Business. The minutes from the June 12, 2007 meeting were amended and sent to members on September 17, 2007.
Treasurer's Report	Foundation balance to date is $77,050.69. The MGWAF Quarterly Financial Report was provided at the meeting by Dave. Interest in the amount of $896.27 was accrued since 6/11/07. This interest was swept into the endowment. The MGWAF also received $9500 from the MGWA for the endowment in the spring. Discussion was initiated at the June 2007 MGWAF meeting on the policy of MGWA donations to the MGWAF, and this discussion continued at this meeting. Jennie stated that the MGWA Board policy on designating donations to the endowment of the MGWAF is found in the MGWA Officers Manual. She will provide a copy of the document. Jennie provided information on the recent audit by the MN Dept. of Revenue of the MGWA. The MGWA is a 501(c)(4) organization, which provides an exemption from federal income tax but not state sales and use tax. MGWAF is a 501(c)(3), which is eligible for exemption from state sales and use tax. Jennie has applied for the state sales tax exemption for the MGWAF. The MGWA is being required to pay for sales taxes not collected by the University Conference Center and for use tax not collected by the vendor when the MGWA's printer was purchased. MGWA requires WRI Association Management Co. to carry business insurance and both MGWA and MGWAF have delegated many tasks to WRI that might generate liability. In addition WRI's insurance company provides a rider for the insurance that the University Conference Center requires MGWA to provide.
Old Business	SMM Ground Water Display – The Ground Water Display at the SMM is open!! Two sand tank type models and the acknowledgement panel will be added at a later date. An e-mail was sent to the MGWA membership notifying them that the Ground Water Display was open. A photo and article will be included in the next MGWA newsletter. The SMM may need additional money on an annual basis to pay for the fall shut down of the flowing well by a licensed well contractor. Highlights of MGWA Board meeting from Dale: The fall MGWA newsletter is underway. The fall field trip has been postponed. The 25th anniversary of the MGWA will be celebrated by a social hour and banquet immediately after the fall conference, which will be held on Tuesday, November 13. The title of the fall conference is "Addressing Ground Water Issues for the Next Generation". The keynote speaker is Jeff Bacon.
New Business	Grant Request – A request for $500 for ground water education at the FOX 9 Girls and Science Event on October 13, 2007 at RiverCenter was received from Lanya Ross of the Met Council. Motion was made by Amanda to approve, seconded by Dave. Motion passed. MGWA Foundation website – Chris revised the description of the MGWAF on the MGWA website, and a copy of the revised information was provided.
Next Meeting	The next meeting will be December 11, 2007 at 11:30 AM. Dave will determine if Opus can provide a room for the next meeting. Meeting adjourned.

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Giving Back

For 25 years MGWA has offered conferences and newsletters as part of its purpose to provide groundwater education. Membership in the MGWA has been and is today very inexpensive and the cost to attend conferences is more affordable than other water resource organizations.

We get a lot from MGWA for not a lot of money.

The need for an organization to provide an affordable forum for ground-water education was one of the reasons we founded the MGWA.

MGWA established the MGWA Foundation (a non-profit, tax-exempt 501(c)(3) organization) to raise and distribute funds for ground-water education and promotion of public awareness of ground water. Some of the Foundation's programs include:

- the education of the public
- the provision of scholarship funds for students studying the ground-water resource
- the provision of assistance to educational institutions in support of ground-water education programs, and
- the organization of or support of seminars, conferences, field trips, and other events that serve to educate, and are open to, the public.

The Foundation has sponsored university, college, and high school groundwater field trips; an annual water festival day for elementary students; student fees to attend the MGWA conferences; Make a Splash Girl Scout Camp; a groundwater booth at the Girls and Science event and at the Science Madness event at the Science Museum of Minnesota and a public ground-water display at the Science Museums's Big Back Yard, to name a few. Foundation funds currently total more than $77,000.

The Foundation's next goal is to establish a scholarship fund for students studying ground water. The Foundation Board determined that we need to increase the endowment to $100,000 in order to fund a significant scholarship. We need your help to achieve this goal.

The reason MGWA is successful and has kept the cost of membership and conferences so affordable is because of the dedication of those who give back by donating their time to managing the MGWA, assembling the newsletter, and organizing the conferences. You can give back to your profession by being a volunteer, serving as an officer, or working on the newsletter. You can also give back by making a financial contribution.

Volunteering your time

I have been asked, "Why should anyone donate their time?" and "What's in it for me?" I cannot tell you what you as an individual will get back, but let me share my story of addressing "what is in it for me" and "why you should give back." I see them as connected.

Over the last 30 years I have given back my time to a multitude of professional organizations. For me, I improved my skills immeasurably to organize, execute, lead, write, and speak. I learned more about working toward a common goal as a team and what that took (how to listen and hear what others had to offer, how to compromise), the fun of doing that, and from time to time some recognition that we shared as a team. Sharing knowledge, learning new concepts, and the satisfaction of accomplishing a goal are all major rewards from working with a volunteer group. Above all, I have made many professional contacts; met people who are reliable and knowledgeable and have made some life long friends. I am a better professional because of the time spent working with so many other volunteers. I have even been offered job opportunities that were a result of my volunteer activities. I know the time I gave has been of great value to me. Professional development, satisfaction…this can be "what's in it for you!"

Financial contributions:

Not everyone can give back time, many do not have any additional hours left in the day to give to an organization. We all cannot give time to every group we want to work with. The alternative is to give back by making a financial contribution. Think of a contribution as an investment in your own professional education and training, an investment in public education, and an investment in the education of our children. This is what the MGWA does so well with the support of volunteers. Think what else we can do for others if you help out.

Consider this when you renew your membership: If your profession has been good for you, give something back to it. Without those who give back to their profession, financially or with time, the profession does not grow, if people do not step up, the organization dies.

Please consider making a donation to the MGWA Foundation. Please ask your employer to make a contribution. We can achieve our goal if every member helps.

Members can access the current year's newsletters in the 'Members Only' area of the web page.

The user name is mgwa and the password is emailed to members with each announcement of newsletter availability.

***MGWA Foundation Grant Request Deadlines are quarterly:
March 1
June 1
September 1
December 1***

MGWA BOARD MINUTES

Minnesota Ground Water Association Board Meeting Minutes
Regular Monthly Meetings

Meeting Date	9/14/07
Place	Keys Café, Lexington and Larpenteur in Roseville, Minnesota
Attending	Jeff Stoner, President; Dale Setterholm, Past President; Stu Grubb, President Elect; Craig Kurtz, Treasurer; Jon Pollock, Secretary; Norm Mofjeld, Newsletter Editor; Sean Hunt, WRI; Jennie Leete, WRI.
Agenda	Meeting called to order at 1133. No additions to agenda.
Past Minutes	The August 29, 2007 minutes were approved with modifications.
Treasury	Treasurer faxed response to IRS on August 31, 2007, and called the IRS two times the following week to make sure they received the fax. Called again on 9/14/07. IRS said they had not received the fax. Treasurer will mail the letter. The response was due on September 10, 2007. Treasurer will include fax confirmation sheet with letter being mailed. Audit check was sent to the Minnesota Department of Revenue on September 4, 2007, with all signed paperwork.
Foundation	Met on September 11, 2007. Foundation Treasurer questioning the purpose of the Foundation since MGWA specifies to Foundation how much money should go into endowment and how much is available for distribution to applicants. Foundation does have the ability to raise money on its own. Foundation approved grant of up to $500.00 for Fox 9 Girls in Science program. Jennie handed out material showing the roles of MGWA and the MGWA Foundation.
Newsletter	September issue delivered to WRI.
WRI Report	Directory and newsletter advertising rates discussed. Motion to change advertising rates as follows:

	Directory (2 issues/year)	Newsletter (4 issues/year)
Business Card	$50 to $50	$66 to $100
Qtr Page	$99 to $100	$121 to $150
Half Page	$190 to $200	$225 to $250
Fill Page	$360 to $400	$425 to $500
Inside Cover	$395 to $500	not available

Motion carried. No change to corporate rates.
Discussion about purchasing black embossed portfolios for conference attendees. Motion to approve expenditure of up to $3000.00 to purchase portfolios to be handed out at 2007 25th Anniversary MGWA Fall Conference with the understanding that the money will be reimbursed through conference fees. Motion carried.

Old Business

MGWA 25th Anniversary Publication: Norm handed out list of articles and who will be providing commentary. Reviewing photographs to go on cover. Photographs will be sent to WRI at beginning of October to provide 6 weeks for layout and printing. Newsletter team wants to review final draft prior to printing.

Fall Conference: Draft of handout provided by President. Talks will be approximately 20 minutes. Two sessions in morning, lunch, MGWA business, keynote speaker, one afternoon session. If anybody is interested in contacting students and faculty to arrange for student posters for conference please contact the MGWA President.

MAWD: President Elect will man booth at Minnesota Association of Watershed Districts conference November 29 through December 1st. Display is currently at WRI. There will be no charge to set up the display at the conference. MPCA has a display we may want to try to get for MGWA fall conference.

Next Meeting: October 17, 2007, at 11:30 at Fresh Grounds at 1362 West 7th Street, St. Paul, Minnesota. Meeting adjourned at 12:54.

The MGWA Board of Directors meets once a month.

All members are welcome to attend and observe.

Send your comments to editor@mgwa.org

Minutes of the First Meeting of the Organizing Committee

MINNESOTA GROUND WATER ASSOCIATION
Minutes - First Organizational Meeting
1:00 P.M., Friday, June 4, 1982
Twin Cities Research Center

Attending: Patricia Leonard-Mayer, Pamela Watson, Kent Peterson, USBuMines; Desyl Peterson, Popham and Haik; Don Jakes, Tom Clark, MPCA; Linda Bruemmer, Water Planning Board; Kelton Barr, Barr Engineering; Sarah Tufford, MDNR.

Following introductions and a welcome to the Twin Cities Research Center, an informal discussion took place regarding the need for an organization to deal with ground water and the relationship of such a group to existing organizations in Minnesota. The following ideas were discussed:

-affiliation with an existing organization that has been active in the Twin Cities or throughout Minnesota; among the groups discussed were

- *Twin Cities Geologists - the original, non-lobbying, mainly scientific but somewhat social organization
- *Geotechnical Society - members originally with TCG, technical interests mainly in the areas of soil and rock mechanics
- *Minnesota Chapter, American Water Resources Association - purpose is to exchange ideas and information on the subject of water resources, members are from all walks of life, does not have many ground water programs but could benefit from it, is becoming somewhat political

- who are the potential members? we should contact biologists, legal professionals, park and recreation personnel, etc.

- will meeting programs be strictly technical? somewhat, we should have a variety, we could have an associate membership for those who are least interested in the technical aspects of the organization.

- Bylaws were discussed briefly; the bylaws of the Colorado Ground Water Association will be used as a guide with the following changes: the Vice President should be the Program Chairman; we will have regular members, student members, associate members - benefits and dues to be worked out later. Pam Watson will write a rough draft of the bylaws before the end of the month.

The group agreed that affiliation with the Technical Division of the National Water Well Association would be most beneficial overall. Pat Leonard-Mayer will contact the NWWA about obtaining a loan.

A membership Committee was established -Kent Peterson, Kelton Barr, Sarah Tufford - they will compose and send out a questionaire in order to determine the interests of potential members.

The Second Organizational Meeting will be called by the members of the Membership Committee after they have compiled the responses to the questionaire.

Pamela Watson

First Dues Notice

SAMPLE

Paid - Ck. 3538

TD

Dear MGWA Member,

Payment of annual dues is a requirement for continued membership in the Minnesota Ground Water Association. According to our records, your regular ~~student~~ fee of $10.00 ~~$5.00~~ is due by Oct 1. To continue to receive the benefits of membership in the Association, mail your check to MGWA, P.O. Box 3362, St. Paul, MN 55165.
Thank you.

11/82

Thomas P. Clark
3572 Golfview Drive
White Bear Lake, MN 55110

Back Cover:

clockwise from upper left:

Paula Berger and Kate Kleiter at Yucca Mountain

Quarry exposure of paleokarst

John Aho in the field

Greg Brick at Little Minnehaha Falls

Celine Lyman truly 'in the field'

Eric Mohring Fish Printing at Metro Children's Water Festival

Calvin Alexander at Sinkhole Kiosk on the Root River Trail

2005 LCMR/MGWA metro site visit/tour

flowing well @ Science Museum of Minn.

Kraemer quarry

looking at an aquifer from the inside—sort of

near the mighty Mississippi

not the best time of year to see a fen

basin hydrogeology

Savage Fen stop

occasionally Boiling Springs ~ "anytime now!"


Protecting groundwater


Fish
Printing