Minnesota Ground Water Association
www.mgwa.org

Newsletter

December 2011
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MGWA President Mindy Erickson

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President's Letter

On the heels of GSA 2011, I find myself in a contemplative mood.

On Monday, October 10, I hosted an award luncheon at which MGWA presented Professor Otto Strack, University of Minnesota, with our Lifetime Service Award. MGWA has only presented this award to three recipients during our 29 years in existence. The award luncheon was attended by approximately 65 current and former colleagues and students, family and friends, literally from around the world. The luncheon was preceded by an analytic groundwater modeling technical session, which included talks that looked back at Otto's career and contributions, presented current developments and looked forward to the future. Otto was actively involved in all of the conversations and openly touched by the outpouring of respect, appreciation and friendship expressed by the people who were present and several people not present but sent notes. The day was intellectually stimulating, personally rewarding and emotionally joyful: everything that the host of such an event hopes to achieve.

The following Tuesday morning, again on behalf of MGWA, I was a co-convener in a technical session devoted to remembering and honoring the legacy of Dr. Tom Winter and his seminal work in understanding groundwater/surface water interactions. Tom passed away in the autumn of 2010, so he was unable to personally enjoy this event, which also drew an international group of presenters and attendees, including friends, colleagues and family.

Actively participating in these two events, back-to-back, was a poignant reminder to me

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Taking the Pulse of the Membership:
Results of the First MGWA Salary Survey – Part Two

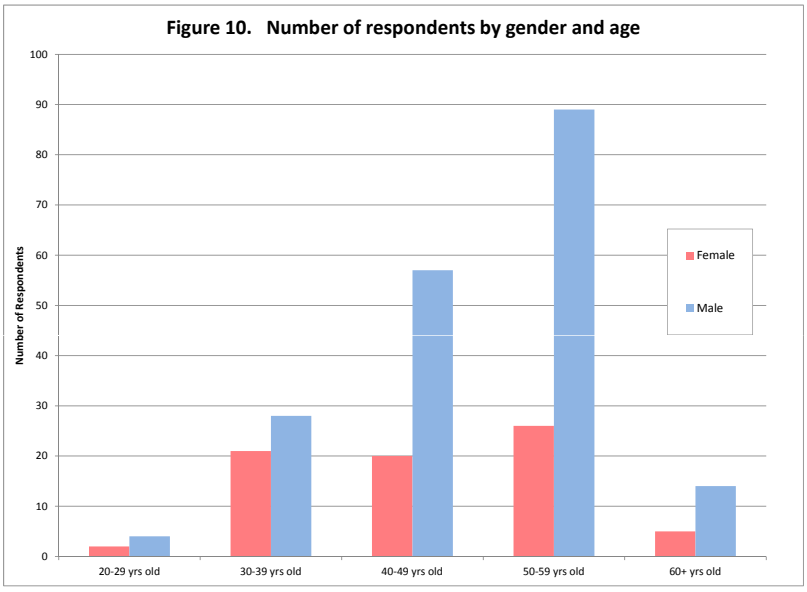
by Kelton Barr, President-Elect

This spring the MGWA initiated its first-ever salary survey of its members. In all, 299 of the 570 members participated, or 52.5 percent. This is a much higher percentage than other previous salary surveys carried out in our industry. Such a healthy participation should make the results both representative and meaningful. Thank you, all, for participating!

The results have been tabulated, and several of the findings will be reported in two installments in the *MGWA Newsletter.* This article will describe the educational levels and types of employment of our membership and the effects of these on levels of compensation as determined from the survey results. Please note that the tables referenced in this article and higher resolution versions of the figures can be found on the MGWA website for members (mgwa.org/newsletter_extras).

— continued on page 6

Figure 10. Number of respondents by gender and age



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Newsletter Deadlines

Issue	Due to Editor
March '12	02/03/12
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September '12	08/03/12
December '12	11/04/12

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MEMBER NEWS

John Barry Joins DNR's County Geologic Atlas Mapping Program

John Barry has joined the Minnesota Department of Natural Resources in the Ecological and Water Resources Division as a Mapping Project Hydrogeologist. Working out of the DNR St. Paul office, John will continue mapping work on the Chisago County Geologic Atlas, Part B that is currently underway. He will also assist the Groundwater Unit with data collection and analysis for future atlases and special projects. He previously worked as an environmental consultant for Emmons & Olivier Resources in Oakdale, MN.

Paul Putzier and Glen Champion Join DNR's Division of Ecological and Water Resources

Paul Putzier is a new Hydrogeologist in the Hydrogeology and Groundwater Unit of the DNR's Division of Ecological and Water Resources, supporting the agency's Clean Water Legacy - Drinking Water Protection work. Paul's primary work is helping to develop the concept of Groundwater Management Areas. Most recently Paul was a section leader at HDR Engineering, completing Environmental Impact Statement (EIS) work on projects for wind farms, pipelines and transportation. Prior to his EIS activity, Paul was a Project Manager at AECOM for approximately 15 years leading investigation and remediation of state and federal Superfund, brownfield and other sites.

Glen Champion recently joined the DNR's Division of Ecological and Water Resources as a Hydrogeologist in the Hydrogeology and Groundwater Unit. He works as a groundwater modeller with a team of DNR staff and local stakeholders on the development of Water Appropriation and Use Management Plans for Groundwater Management Areas being developed in several areas of Minnesota.

Glen was previously employed at the Minnesota Department of Agriculture.

Other Changes

Clinton Jordahl, **Mark Janovec** and **Richard Foster** are now employed at Stantec due a change in ownership of their former company, Bonestroo. On September 2, 2011, Stantec acquired Bonestroo, Inc. and Bonestroo Services, LLC (Bonestroo), which added approximately 275 staff. An engineering, planning, and environmental science firm with offices in Minnesota, Wisconsin, Illinois, Michigan, and North Dakota, Bonestroo extends Stantec's expertise in several disciplines in which they specialize.

Daniel Hunter is now with Nova Consulting Group. He can be reached at (952)448-9393 or dan.hunter@novaconsuling.com.

Andrew Fiskness is now a Project Geologist at AMEC Environment & Infrastructure. He can be reached at andrew.fiskness@amec.com.

Carolyn Boben is now with the Minnesota Department of Transportation. She can be reached at carolyn.boben@state.mn.us.

Richard Manser is now with Barr Engineering Company. He can be reached at (952)842-3575.

2012 MGWA OFFICER CANDIDATES

Robert Tipping – MGS

Bob, candidate for President-Elect, is a senior scientist at the Minnesota Geological Survey. His job is a combination of applied research and outreach. Bob's research interests include geology/hydrogeology of fractured and karst terrain, groundwater-surface water interaction, aquifer characterization, groundwater chemistry, and GIS applications to geologic/hydrogeologic research. His outreach tasks include teaching, serving on technical advisory boards, and responding to public inquires about anything Minnesota groundwater related. Bob has a BA in History from Carleton College, an MS in Geology from the University of Minnesota, and is a PhD candidate in Water Resources Science at the University of Minnesota.

"MGWA works because it successfully brings people together from the consulting community, academic institutions, and resource management – both at local and state levels. I enjoy the conferences and benefit from the formal talks and, more so, from informal meetings with other attendees. The MGWA newsletter is full of useful information, and the MGWA and associated Foundation work in outreach and education is excellent. I would like to contribute in any way that continues to make MGWA relevant to a broad range of people interested in groundwater."

Julie Ekman - MN DNR

Julie, candidate for Secretary, supervises the Water Permits Programs unit in the DNR Division of Ecological and Water Resources. She is responsible for developing, implementing, and administering the DNR's statewide regulatory programs for the alteration of public waters and the use of surface and ground waters. She has worked for the Department of Natural Resources since 1995. Starting as an intern in what was then the Division of Waters she assisted with surface water and groundwater studies. Next, as a hydrogeologist, she worked in the County Geologic Atlas program developing the Otter Tail Regional Hydrogeologic Assessment. She began work on the Pine County Geologic Atlas before taking a position as an Area Hydrologist serving counties in the Twin Cities metropolitan area. Julie has a Bachelor of Science Degree in Geological Engineering from the University of Minnesota Civil Engineering Department. She has been a member of Minnesota Ground Water Association for 13 years.

President's Letter, cont.

to 'seize the day.' Our personal and professional lives can be filled with uncertainty, change and regret – but also opportunity, joy and fulfillment. But we need to take advantage of our opportunities to realize joy and fulfillment. So thank that mentor who helped you along your career path. Volunteer at that event or for that organization that matters to you. Tell a child that you are proud of her/him. Take that risk in order to realize a dream. Seize the day.

Another theme that touched me at GSA was the decrease in funding for environmental work across the country. We in Minnesota are in the exceptional situation of reasonable funding because we voted overwhelmingly to increase our sales tax to fund the Clean Water, Land and Legacy Amendment. Millions of dollars are generated each year for water-related projects. We have a unique opportunity to think big and set our sights high, and we have the funding to realize our collective goals if we can generate the support of the financial decision-makers. MGWA and its members can play an important role to help move the clean water vision forward.

It has been my pleasure to serve as MGWA's president in 2011, and I am delighted that I will be succeeded by such a well-respected member of our groundwater community, Kelton Barr. I thank Steve Robertson, out-going Past President, and Jill Trescott, out-going secretary, for their volunteer service to MGWA as Board members the past few years. In January, the Board will welcome two new members into the positions of President-elect and Secretary. Look for information on these officer candidates in this issue. Have a wonderful winter!

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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.

MGWA's Corporate Members for 2011

Barr Engineering

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AMEC Geomatrix

Leggette, Brashears & Graham, Inc.

Northeast Technical Services

Links at www.mgwa.org

Abbreviations and Acronyms

- ASTM – American Society for Testing and Materials
- DNR – Minnesota Department of Natural Resources
- MDA – Minnesota Department of Agriculture
- MDH – Minnesota Department of Health
- MGS – Minnesota Geological Survey
- MPCA – Minnesota Pollution Control Agency
- USEPA or EPA – United States Environmental Protection Agency
- USGS – United States Geological Survey

GSA WRAP-UP

GSA 2011 Annual Meeting

by Mindy Erickson, MGWA President

The GSA 2011 annual meeting was a rousing success by any measure – even by the numbers. There were 711 Minnesota participants out of approximately 6,500 meeting registrants. Our local community made up more than 10% of the total attendee count! It is fantastic that so many of our geosciences professionals and students were able to take advantage of attending the GSA annual meeting in Minneapolis. What fun to attend technical sessions ranging from volcanology to solar system geology, in addition to our more familiar environmental and water-related sessions. Disneyland for geo-geeks, indeed. MGWA extends a heartfelt thanks to Harvey Thorleifson, local planning committee chairperson, as well as the rest of the local planning committee and the GSA staff, for their significant roles in making GSA 2011 the event that it was.

The MGWA Board and members also played an active role in GSA. More than 150 MGWA members attended the conference, and MGWA members convened several technical sessions and led a number of field trips. Technical session topics ranged from groundwater/surface water interactions and groundwater modeling to trace elements, petroleum contamination/remediation and karst. Field trips included SE Minnesota karst, Twin Cities caves, cycling the Mississippi River Gorge, and northern Minnesota lakes, wetlands, streams, and groundwater exchange. These sessions and field trips were well attended and received great reviews from attendees. See Julia Steenberg's article on Platteville Formation hydrostratigraphy later in this issue for an analysis pertaining to one of the field trips in the Twin Cities.

Additionally, about two dozen volunteers staffed the MGWA booth over the four days of GSA. The MGWA booth served as a venue for educating passers-by about groundwater and recruiting potential new members – and as a gathering place for current MGWA members. Audrey Van Cleve, Jeanette Leete, and Sean Hunt made the MGWA booth a reality by handling all of the logistics.

MGWA Booth and Display in the Exhibit Hall

A key event for MGWA was presenting Professor Otto Strack, University of Minnesota, our Lifetime Service Award at an award luncheon held in conjunction with GSA. MGWA has only presented this award to three recipients during our almost 30 years in existence. The award luncheon was hosted by MGWA President Mindy Erickson, and it was and attended by approximately 65 current and former colleagues and students, family and friends, literally from around the world. Preceding the luncheon was an analytic groundwater modeling technical session convened by Otto's former student, Professor Henk Haitjema, and his University of Minnesota colleague, Professor Randal Barnes. The technical session included talks that looked back at Otto's career and contributions, presented current developments, and looked forward to the future. See Otto's

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GSA Report, cont.

letter to MGWA for his perspective on his career and receiving the award.

What's next? MGWA will host its spring conference, as usual. But in the fall, we will host the Midwest Groundwater Conference (MWGWC) October 1 – 3, 2012. In conjunction with the MWGWC, we will celebrate our 30th anniversary! Stay tuned for more information about both 2012 conferences.

From top: Head table at the Award Luncheon for Professor Strack; Full house at the luncheon; MGWA President Mindy Erickson presents the MGWA Outstanding Service Award to Professor Otto Strack.

Letter from Dr. Strack to MGWA

Minneapolis, October 14, 2011

Dear Jeanette, Mindy, Henk, and Randal:

Rumor has it that all of you have been instrumental in the award that was given to me last Monday by the Minnesota Groundwater Association. As I mentioned in my acceptance speech, I am deeply honored and touched by the award. Perhaps it is appropriate to explain in a little more detail why this particular honor is so special for me.

I began to feel very much at home, both as a Minnesota resident, and as a faculty member of the University of Minnesota, quite soon after our arrival in Minnesota in 1974. At some point in my career, quite early in fact, it became clear to me what the meaning is of a Land-Grant institution. This happened when I read about the civil war, and, in particular about Abraham Lincoln; I understood that these Land-Grant Universities were established during the Lincoln administration as centers of higher learning with the express charge to serve the state they were established in. The funding of these institutions was obtained from the sales, or granting, of federal lands. I found this an intriguing and appealing idea, and have tried since then to act in accordance with the basic idea of a Land-Grant institution.

I decided that it would be most appropriate for a faculty member at the University to focus on education, rather than direct involvement in state business, of students, state employees, and members of the business community in Minnesota, attempting to create a desire for understanding basic principles of groundwater flow. Over time, I have given many short courses and presentations at agencies and consulting firms in addition to 37 years of teaching formal courses in groundwater flow, with that express purpose in mind. I always hoped that this approach would bear fruit, and sometimes flattered myself with the idea that I perhaps contributed a bit to the extraordinary high level of understanding of groundwater flow and management in the State of Minnesota. There is little doubt about the high level of groundwater management in the State as compared to other places, both inside and outside the country. This is to a large extent due to the professionalism of numerous individuals working for state agencies, demanding an equally high level of performance by consultants.

I view the award granted to me by the Association as confirmation that I might have indeed succeeded to some extent in what I set out to do. I hope that you will understand how much satisfaction and happiness this confirmation has given me.

I will never forget Monday, October 10, 2011, and I am equally unlikely to forget what your efforts mean to me.

With best wishes,

Otto D.L. Strack
Professor of Civl and Geological Engineering
University of Minnesota

Gender Demographics of the Membership

Only 33, or 11.0 percent of the respondents declined to state their gender. The remaining respondents were separated by gender and were further subdivided by their decadal age group – i.e. whether they were in their 20s, their 30, etc. Age was used as the most precise indicator of general experience; while experience was queried in the survey, it was more descriptive with the amount of experience at different types of employers reported by groups of years (e.g. 1-5 years, 6-10 years, etc.). The resulting distribution of member respondents by age and gender is shown in Figure 10 (continuing the numbering from the first article).

Starting with the oldest cohort, those 60-plus years old, this is the second-smallest group, likely reflecting the effects of retirement as well as the limited employment in the groundwater field that existed in the 1970s. This cohort has 19 members or 7.1% of the respondents, comprised of 26.3% females and 73.7% males. With the passage of CERCLA and other landmark legislation, employment in the groundwater field rapidly expanded; correspondingly, the cohort of those respondents in their 50s is the largest, with 115 members or 43.2% of the respondents. This cohort also had the smallest contingent of females – 22.6% compared to 77.4% males.

As the groundwater field matured, new employment opportunities, (or the number of colleagues joining MGWA), have apparently decreased with time with fewer members in the younger cohorts than in the older. The cohort of respondents in their 40s has 77 members or 28.9% of the respondents, with 26.0% females and 74.0% males. The cohort of respondents in their 30s has 49 members or 18.4% of the respondents, with 42.9% females and 57.1% males, the greatest proportion of females of all the cohorts. Finally, the cohort of respondents in their 20s has 6 members or 2.3% of the respondents, with 33.3% females and 66.7% males. This is the smallest cohort, and the female:male ratio may actually be similar to the 30s cohort, but is somewhat skewed by small sample size. Because of its small sample size, the remainder of the article generally excludes this age cohort from further discussion. The numerical results are compiled in Table 5 on the member website.

Compensation by Gender and Age

The annual salary, consisting of reported base salary, bonuses, and overtime, has been summarized by gender and age groups for the respondents in Table 5. Because some of the respondents did not give their salary information, the number of respondents in this summary of results is 266. This salary information is also shown in Figures 11 and 12 for female and male respondents, respectively. Annual benefits (employer contributions for insurance, retirement, and other perks) are similarly summarized in Table 6 and shown on Figures 13 and 14 for female and male respondents, respectively. Finally, paid time off (PTO) information (vacation, medical and other leaves) is summarized in Table 7.

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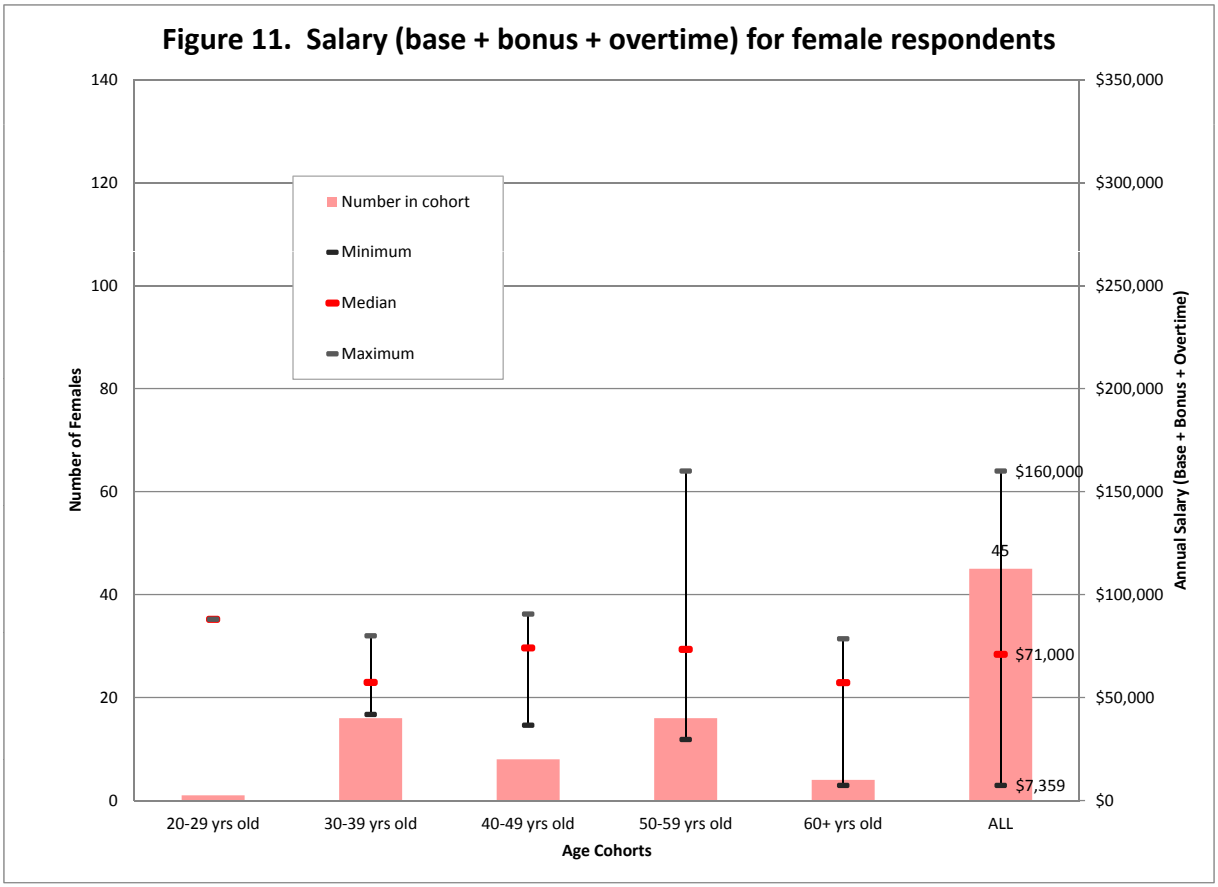
Figure 11. Salary (base + bonus + overtime) for female respondents
Number in cohort
Minimum
Median
Maximum
Number of Females
Annual Salary (Base + Bonus + Overtime)
140
120
100
80
60
40
20
0
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
$160,000
45
$71,000
$7,359
20-29 yrs old
30-39 yrs old
40-49 yrs old
50-59 yrs old
60+ yrs old
ALL
Age Cohorts

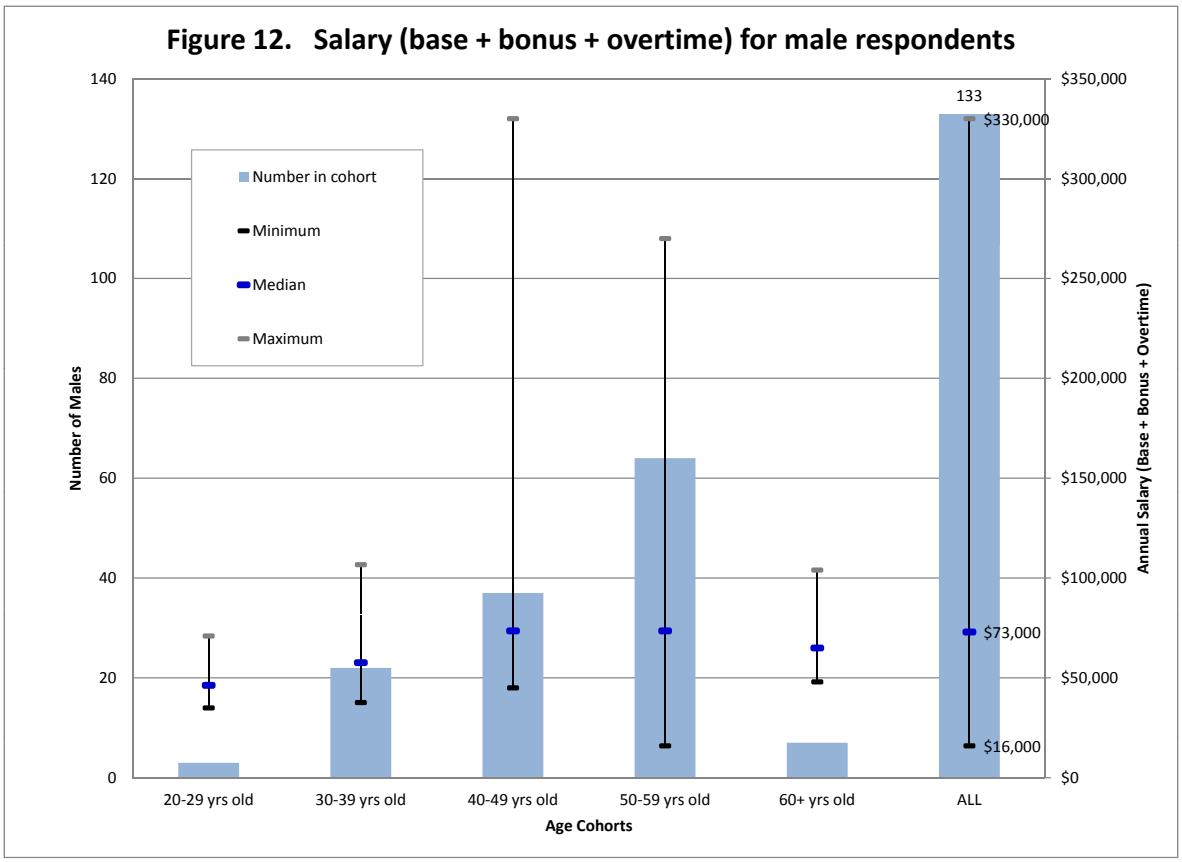
Figure 12. Salary (base + bonus + overtime) for male respondents
Number in cohort
Minimum
Median
Maximum
Number of Males
Annual Salary (Base + Bonus + Overtime)
140
120
100
80
60
40
20
0
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
133
$330,000
$73,000
$16,000
20-29 yrs old
30-39 yrs old
40-49 yrs old
50-59 yrs old
60+ yrs old
ALL
Age Cohorts

Salary Survey Results, part 2, cont.

The median salaries for the successive female age cohorts show a generally increasing trend. Rounding to the nearest thousand, the median salary for female respondents in their 30s is $57,000, increasing to $74,000 for female respondents in their 40s and 50s. Median salaries for female respondents 60 and over decrease to $57,000.

The median salaries for the successive male age cohorts also show a general increasing pattern. The median salary for male respondents in their 20s is $46,000, increasing to $58,000 for male respondents in their 30s. Median salaries again crest for male respondents in their 40s and 50s at $74,000, decreasing to $65,000 for male respondents 60 and over.

Median benefits for the successive female and male age cohorts also show a generally increasing trend. Again rounding to the nearest thousand, the median benefits for female respondents in their 20s is $2,000, increasing to $9,000 for female respondents in their 40s and 50s, and decreasing to $5,000 for female respondents 60 and over. The median benefits for male respondents in their 20s was $400, increasing through each decadal cohort to $10,000 for male respondents in their 50s, and decreasing to $2,000 for male respondents 60 and over.

Similarly, median paid time off (PTO) for the successive female and male age cohorts also show a generally increasing trend. The median PTO for female respondents in their 20s is 15 days, increasing to 42.5 days for female respondents 60 and over. The median PTO for male respondents in their 20s is 25.5 days, increasing to 39 days for male respondents 60 and over.

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Public Sector vs Private Sector Compensation, by Gender and Age

The survey results were broken down further to also examine effects of the type of employer. As in the first article, current employment in an educational, research, or non-profit institution; a city, county, regional, state, or federal agency; or other public entity was collectively termed to be in the public sector. Current employment in a consulting, testing, construction, mining, or drilling firm or other private entity was collectively termed to be in the private sector. Some respondents did not report in all four areas of gender, age, employment, and compensation information and were omitted from this analysis. This reduced the number of respondents to 171. The results for salaries are summarized in Table 8 and shown in Figures 15 and 16.

The median salaries for the successive female and male age cohorts in the public sector summarized in Figure 15 show a generally increasing trend. The median salary for female respondents in their 30s is $56,000, increasing to $73,000 for female respondents in their 50s, and decreasing to $57,000 for female respondents 60 and over. The median salary for male respondents in their 20s is $46,000, increasing to $73,000 for male respondents in their 50s, and decreasing to $65,000 for male respondents 60 and over.

Similarly, the median salaries for the successive female and male age cohorts in the private sector summarized in Figure 16 also show a generally increasing trend. Disregarding the first cohort with only one respondent, the median salary for female respondents in their 30s is $63,000, increasing to $89,000 for female respondents in their 50s; there were no female respondents 60 and over. The median salary for male respondents in their 20s is $53,000, increasing to $85,000 for male respondents in their 40s, and decreasing to $81,000 for male respondents 60 and over.

Figures 15 and 16 also show that females make up 33 percent of the public employment of respondents and 19 percent of the private employment of respondents, indicating that private employment is more male-dominated than public employment. The figures also show that there can be a greater range for salaries in the private sector's age cohorts, on both ends of the ranges.

Female vs Male Compensation, by Age and Type of Employment

In many fields of employment, there has been a gap between the compensation of males and females. To assess whether such a gap exists in the Minnesota groundwater community, the survey results were compared by age cohorts and by type of employment. These are summarized as ratios of female:male results for the respective quartiles in Tables 5, 6, and 7 for salary, benefits, and PTO, respectively. It is similarly summarized further by public and private sectors in Table 8 for salary. Figure 17 shows the female:male ratio by age cohort for median salary, benefits, and PTO as well as the female: male ratios for the public and private sector salaries.

These tables and Figure 17 indicate that median salaries are very comparable, varying within ± 10 percent from parity (i.e. female:male ratio of 1.0) for all age cohorts with relatively large numbers of respondents (the 20s age cohort has only 2 female and 4 male respondents without employment sector distinctions). The overall female:male ratio of all respondents for salary was

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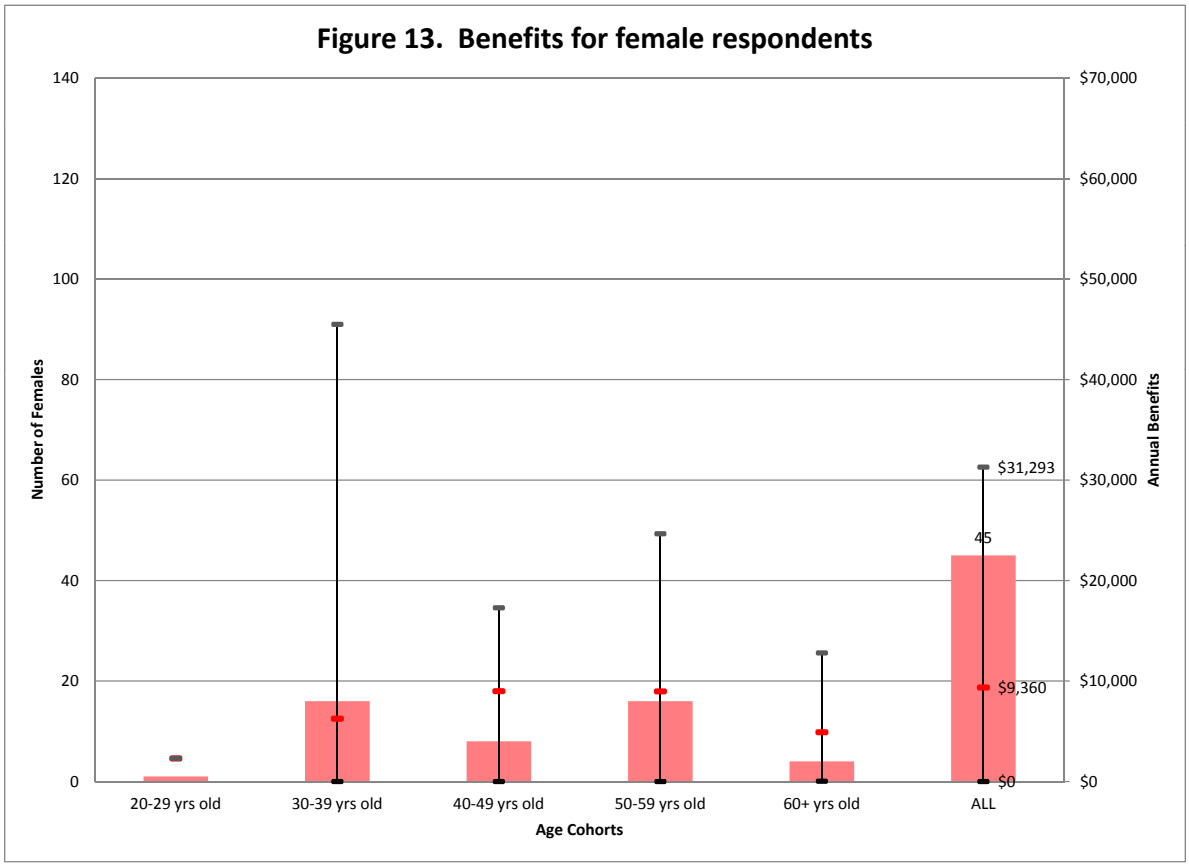


Figure 13. Benefits for female respondents
140
120
100
80
60
40
20
0
Number of Females
$70,000
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
Annual Benefits
$31,293
45
$9,360
$0
20-29 yrs old
30-39 yrs old
40-49 yrs old
50-59 yrs old
60+ yrs old
ALL
Age Cohorts

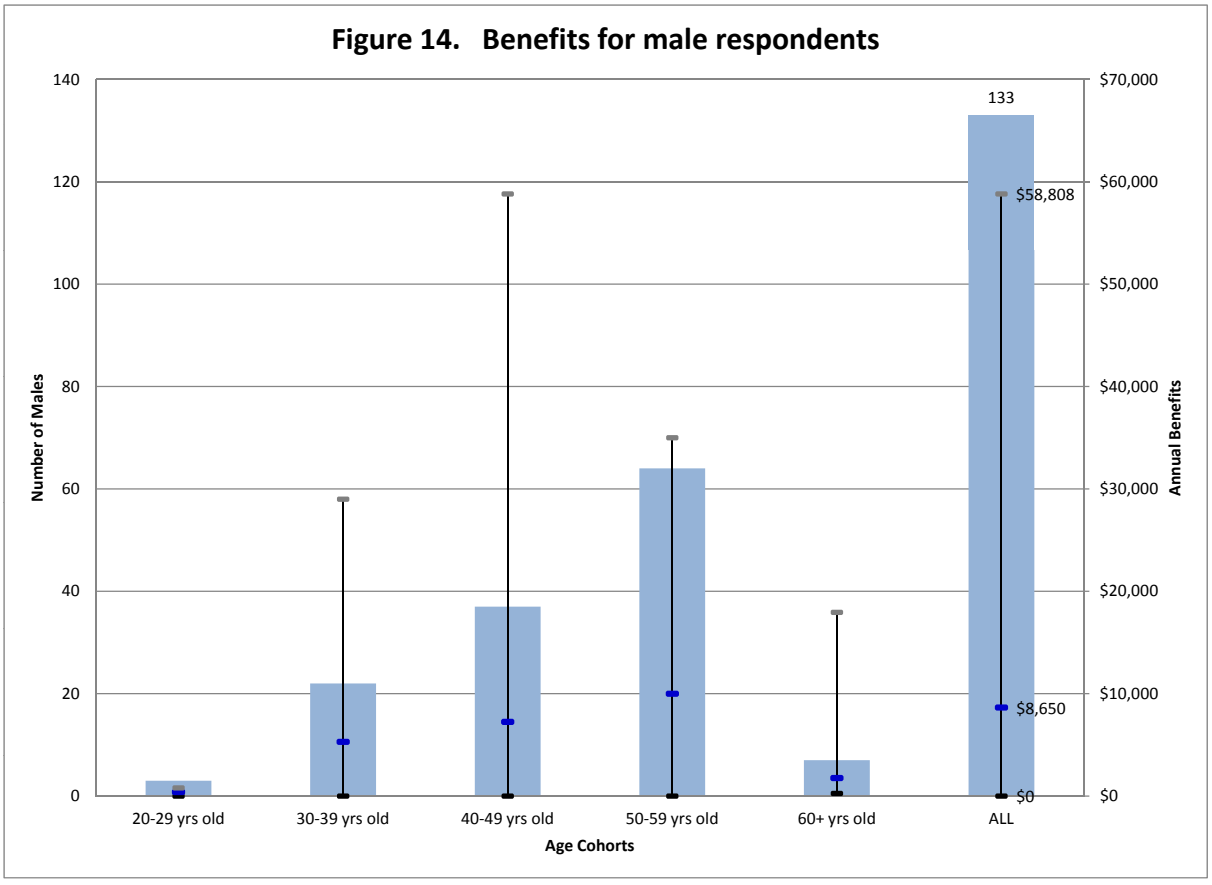


Figure 14. Benefits for male respondents
140
120
100
80
60
40
20
0
Number of Males
$70,000
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
Annual Benefits
133
$58,808
$8,650
$0
20-29 yrs old
30-39 yrs old
40-49 yrs old
50-59 yrs old
60+ yrs old
ALL
Age Cohorts

0.97, very close to parity. Likewise, the median benefits also are within ±20 percent for the three age cohorts (30s, 40s, 50s) with larger numbers of respondents, with the female:male ratio often greater than one (i.e. generally higher benefits for females). Overall the male:female ratio of all respondents for benefits was 1.08, again, very close to parity. The ratios for PTO were also generally very close to parity, varying within ±10 percent from parity; overall, the female:male ratio for PTO was 1.00, parity.

Figure 17 and Table 8 also show the female:male ratios for median salaries by public and private sector employment. The public sector shows a ratio greater than parity that declines with age to below parity by the last age cohort, 60 years and older. The overall female:male ratio for the public sector is 1.00, overall parity. The private sector generally has an opposite trend, with increasing ratios with age. The overall female:male ratio for the private sector is 0.92, indicating that the private sector tends to pay females somewhat less.

These results are meant to provide a context for the types of compensation for individual professionals and for groups of professionals.

We hope that this information can be useful for overcoming anecdotal comparisons of the compensations of the different types of educational levels, lengths of experience, and places of employment.

Figure 15. Annual salary by gender and age -- Public Sector

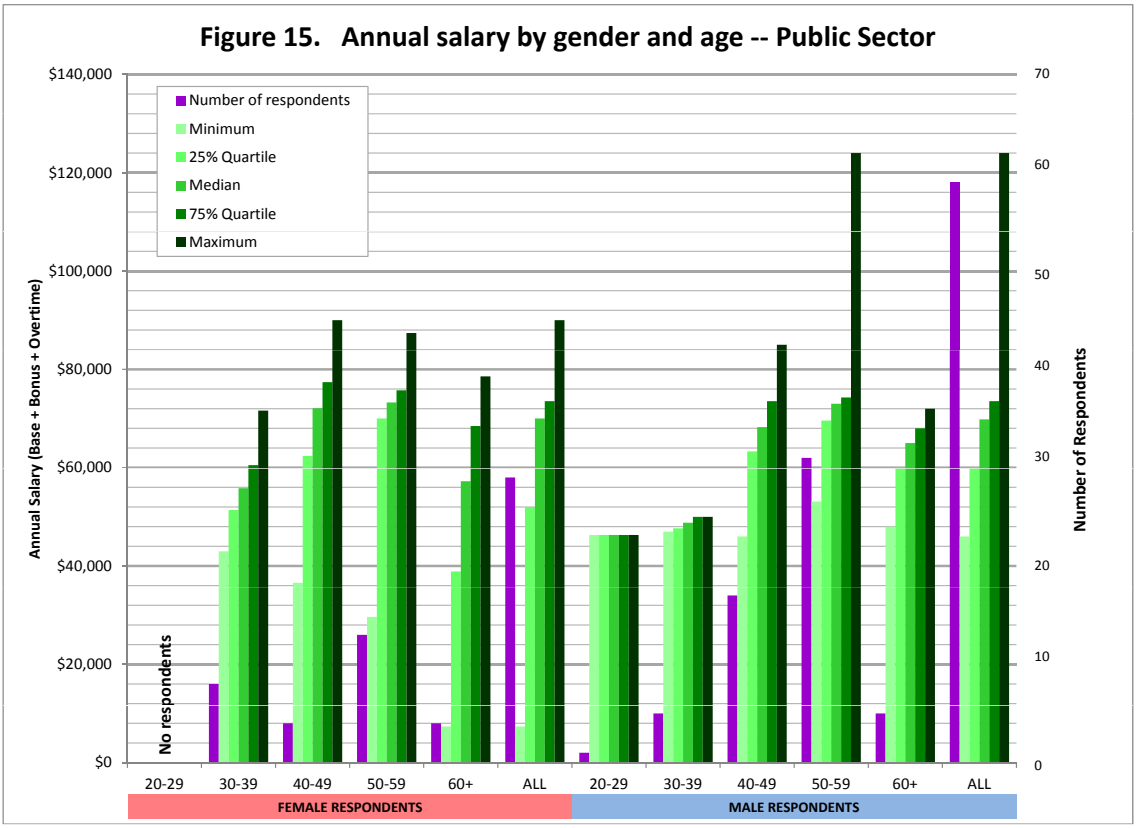


Figure 16. Annual Salary by Gender and Age -- Private Sector

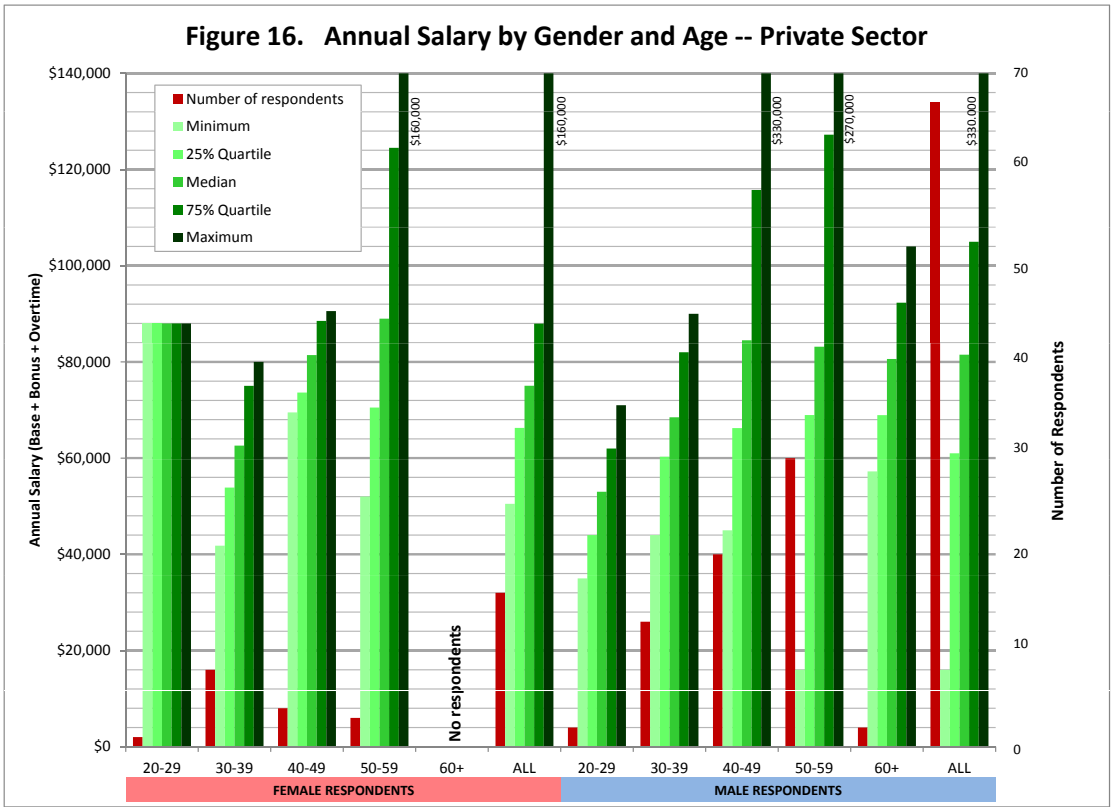
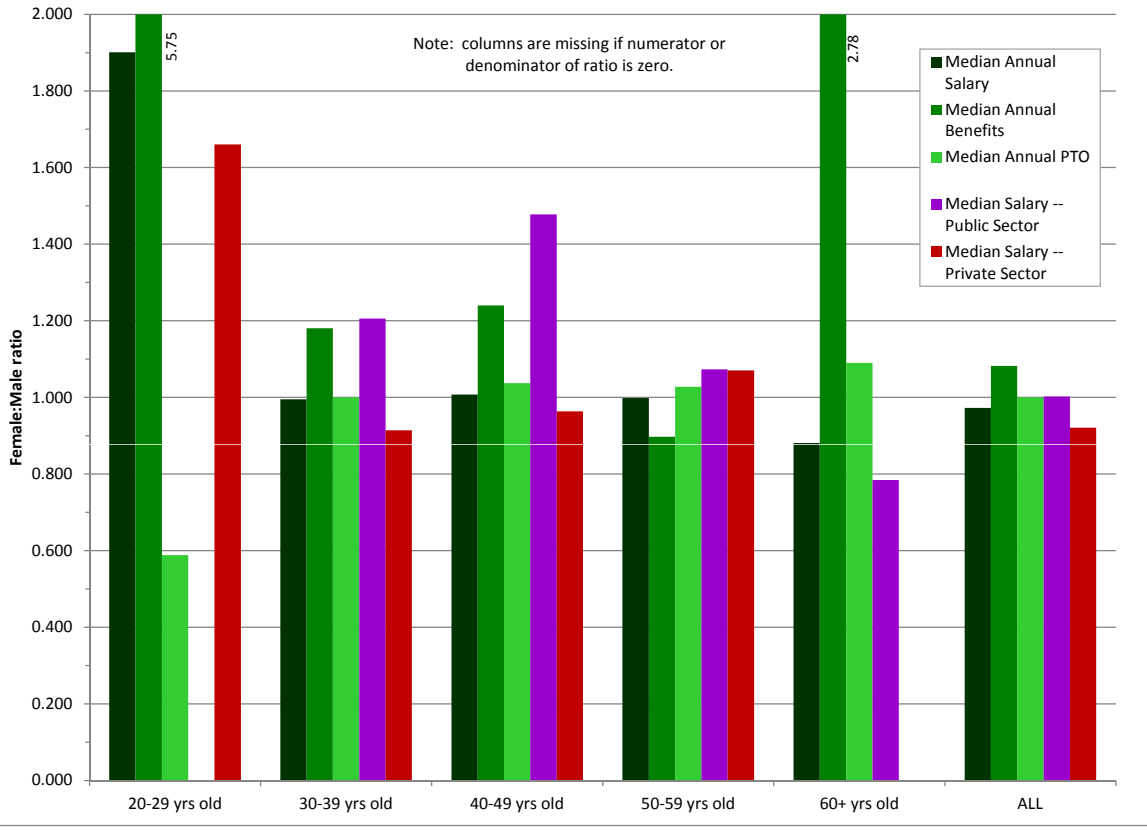


Figure 17. Female:Male Ratio for Compensation



Subterranean Wonders of the Twin Cities

By Greg Brick

I have compiled a list of what I regard as the most important and unique subterranean features of the Minneapolis-St Paul Metro area, whether they be natural, artificial, or "inadvertent" features. All of them still exist, though perhaps not as they were in their glory days. Grouped by threes for convenience, the following, describing three "labyrinths," is the last of four articles in this "miniseries."

Minneapolis Milling District. In 1857, the Minneapolis Mill Company began digging the First Street Canal parallel to the Mississippi River, in the downtown area. Underneath it, the First Street Tunnel was dug. Water, diverted from the river, entered the upstream end of the canal through a gatehouse (which filtered out debris such as logs), was carried to the individual mills by branch canals, and then spilled down through holes into the tailrace tunnels below. On the way down, the water spun the turbines, generating hydropower. The water then flowed through the various tailrace tunnels that merged to form the First Street Tunnel. The latter emptied into an open-air channel that carried the water back to the river, as showcased in Mill Ruins Park today. I would have loved to have seen this magnificent underground space back in its glory days, when the mills were running full blast. Back then there were strings of lights running through the tunnels and good boardwalks for the workers to use. Most of that wood was scavenged afterwards, leaving the inexplicably bare tunnels we see today. It's interesting to consider that this elaborate hydropower system, dubbed "Subterranean Venice" in my book, was designed before a single stream gauging measurement had ever been made by the U.S. Geological Survey, which was created in 1879.

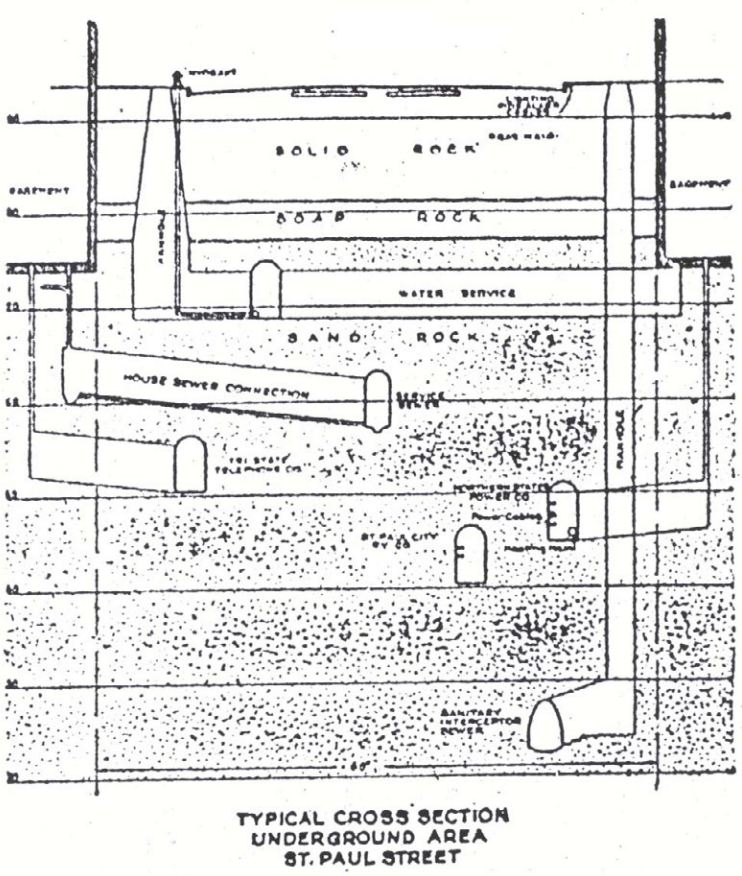


Figure 2: Cross section under a St. Paul street, St. Paul Utility Labryinths

St Paul Utility Labyrinths. Downtown St. Paul (the "Loop") is underlain by a great utility labyrinth, situated from 20 to 75 feet below street level in the St. Peter Sandstone bedrock. Estimates

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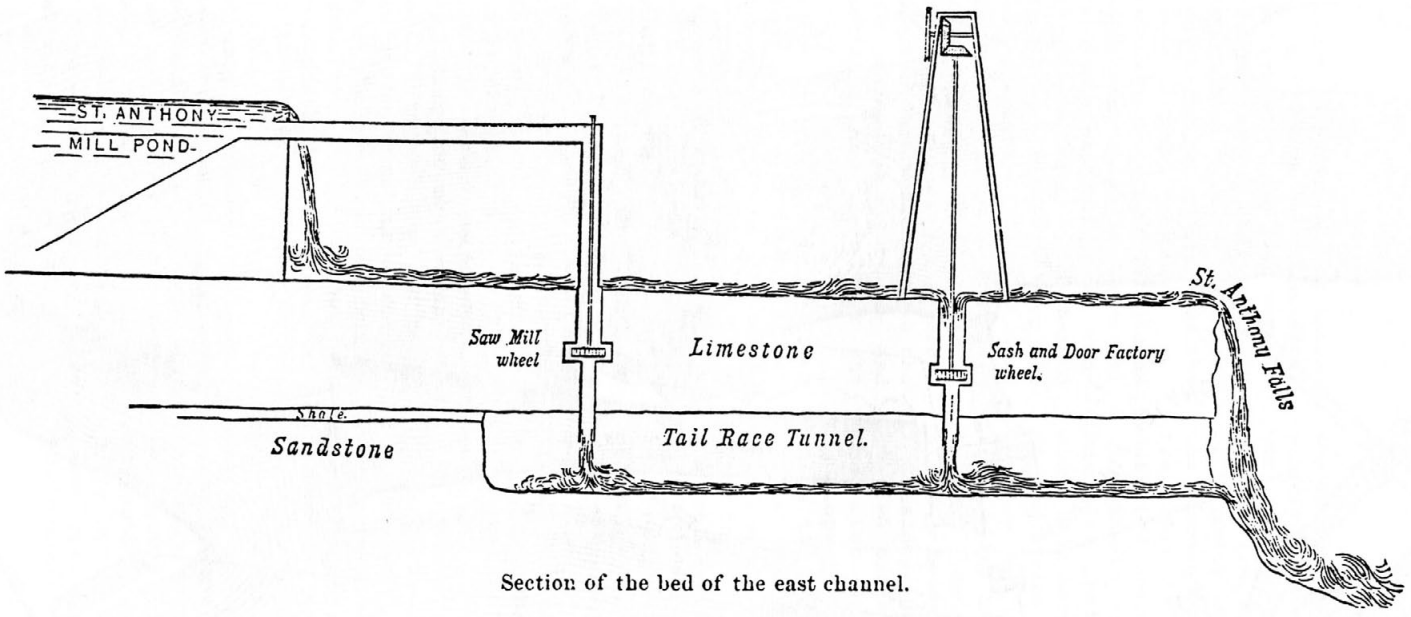
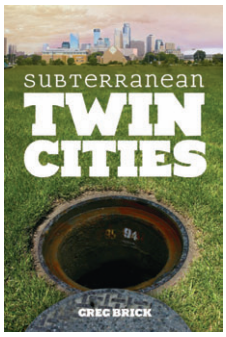


Figure 1: Cross section of the bed bed of the east channel, Minneapolis Milling District

of its total length vary greatly, and I've seen figures ranging all the way up to 70 miles. This system was carved out within a generation, roughly the thirty years from 1875 to 1905, in several big chunks, and by hand tools such as pickaxes and shovels at the rate of 4 to 6 feet per day per man. The passages are typically 3.5 by 6.5 feet in size and marked with street signs. It's difficult to specify exactly how many levels of passages there are because they frequently interweave, but I'd say there's about half a dozen in most areas. City engineer George M. Shepard's cross-section of these "catacombs," published in a 1937 newspaper article, showed "St. Paul's downtown area being honeycombed with more tunnels than perhaps any other city in the world." Utilities placed in these tunnels included water, power (gas and electric), steam heat, telephone, and, in our own day, fiber optics. Not to mention storm and sanitary sewers.

The Fort Road labyrinth merges with the network described above. The tunnels run under every street in the Fort Road neighborhood of St. Paul at an average depth of about 30 feet, with pipes coming down from individual houses and buildings. These tunnels, which carry raw sewage, were carved in the sandstone with hand tools in the late 19th century, and the floors were paved with brickwork. I once painstakingly measured, on sewer maps, the aggregate length of this labyrinth, and found it to be 30 miles—the length of the famous Carlsbad Caverns in New Mexico—but most of it is coiled up under just a few square miles.

Stahlmann's Cellars. Immigrant Bavarian brewers began arriving in Minnesota in the 1840s, bringing with them a new process for making lager beer, which required refrigeration. In 1855, Christopher Stahlmann established the Cave Brewery in what was then the outskirts of St Paul—what would later become the Schmidt Brewery. With the growth of the beer market following the Civil War, Stahlmann's became the largest brewery in Minnesota. As the name "Cave Brewery" suggests, Stahlmann carved an extensive lagering cave, still known as "Stahlmann's Cellars," in the sandstone below the brewery, to use the natural refrigeration provided by the caves. Stahlmann's Cellars acquired a national reputation as the very type of labyrinthine complexity, which it still held more than a century later. As noted by art historian Susan Appel, "the breweries with the best and most extensive cellars became the most famous." However, the use of caves to trap cold winter air or to fill with ice, for lagering, was becoming obsolete by the 1870s, when brewers began to build icehouses, which "took the aging of lager beer out of caves and placed it in an aboveground stack of 'cellars' cooled by a massive body of ice at the top of the building." The construction of icehouses bypassed the arduous task of underground excavation. And with the widespread adoption of mechanical refrigeration in the 1880s, ice-making machines freed brewers from dependence on natural ice with its uncertainties of supply and price. The lagering caves were thereafter abandoned.



If you'd like to read more, an extended account of these and other wonders is provided in Greg Brick's SUBTERRANEAN TWIN CITIES, published by the University of Minnesota Press in 2009.

Figure 3: Stahlmann's Cellars, underneath what became St. Paul's Schmidt Brewery

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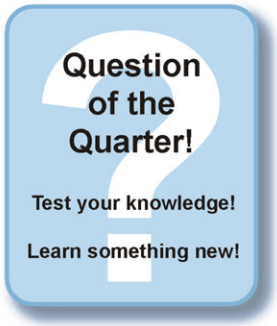

Question of the Quarter

The Question of the Quarter is an occasional feature of your newsletter in which a question is posed and all members are invited to respond. Last quarter's question was:

What company marketed their product by claiming the beverage they sold contained water that was controlled by mythical Artesians?

The correct answer from **Lanya Ross** was: Olympia Brewery

Layna goes on to say: "Gotta love the brewing industry's commitment to water resources!"

From 1896 to 2003, Olympia Beer was brewed in Tumwater, Washington with water obtained from artesian wells. The company promotional tag line was "It's the Water". Advertisements for the beer in the 1980's claimed that the water was regulated by a mythical population of "Artesians". The campaign succeeded but the company ultimately failed when the brew-masters shifted to a richer lager that was unfamiliar to the palates of the light lager drinking public.

This issue's Question of the Quarter is:

"What legendary hydrogeologic feature did popular American magician David Copperfield claim he had discovered in a cluster of four small islands in the Exuma chain of the Bahamas?"

Send your answer to: editor@MGWA.org

The Role of Groundwater in Watershed Studies

Andrew Streitz, Minnesota Pollution Control Agency

Introduction

Trends discovered in local hydrologic datasets during the development of a groundwater model in Benton County were found to match trends in comparable statewide datasets. The model, part of the Minnesota Pollution Control Agency's Little Rock Creek watershed investigation, determined a cause and effect relationship existed between increasing groundwater withdrawals for irrigation use and corresponding declines in groundwater levels and creek discharge in summer months. Analyses of high capacity water withdrawals across the state show statistically significant increasing trends over the last 20 years. Statistically significant decreasing trends are found in a majority of summer month stream discharges derived from statewide stream gaging stations randomly selected for the statewide study. Rivers with significant summer month declines are commonly located immediately downriver and downgradient from a large number of high capacity wells, while gages located on rivers without trends typically are not near high capacity water withdrawals. These hydrologic trends appear to be related to changing agricultural practice. One consequence of this study is a renewed awareness of the connectivity between ground and surface water, and the importance of groundwater management as an integral part of protecting and remediating streams.

The Little Rock Creek Watershed

Genesis of Agency Groundwater - Surface Water Interaction Program

The Minnesota Pollution Control Agency (MPCA) is involved with groundwater – surface water interaction studies to meet the requirements of the Federal Clean Water Act, which mandates that states adopt water-quality standards to protect waters from pollution. These standards define how much of a pollutant can be in a waterbody and still allow it to meet its designated uses, such as drinking water, fishing and swimming. The standards are set for a wide range of pollutants, including bacteria, nutrients, turbidity, and mercury. A waterbody is designated impaired if it fails to meet one or more water quality standards.

Work on watersheds was accelerated in Minnesota by legislation in 2006, and the passage of a Legacy amendment providing dedicated funding in 2008, providing a boost to the MPCA's efforts to completely survey all waters of the State within 10 years (MPCA, 2011). The relevant portion of this requirement to this study is that states are required to conduct Total Maximum Daily Load (TMDL) studies to model pollutant loads and develop strategies to restore waterbodies. Before TMDLs can be developed, a stressor identification analysis is necessary to determine the specific physical and/or chemical factors that are causing the biological impairment. Such studies have traditionally been carried out by surface water hydrologists and biologists, and groundwa-

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ter has not traditionally been considered an important part of the investigation. This changed in Minnesota with the Little Rock Creek (LRC) Watershed Study when groundwater hydrologists were invited to participate in the watershed investigation.

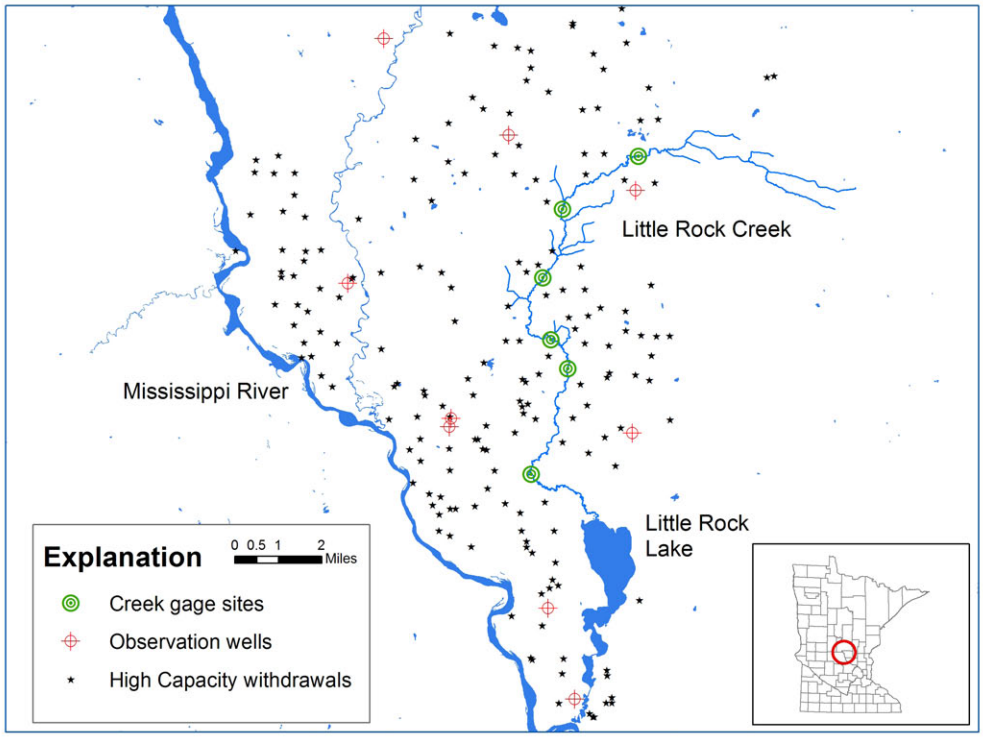

Figure 1. Study of high capacity wells, observation wells and stream gages

Little Rock Creek Pilot Project

LRC is a designated trout stream located in central Minnesota near the City of Rice (Figure 1). The LRC Watershed is located in Benton and Morrison Counties. The LRC watershed was on the State's impaired waters list in 2002 for a lack of the expected assemblage of coldwater fish. One hypothesis for the impaired biota in LRC was that increased groundwater use intercepted water that would have otherwise discharged into the creek. Reduced groundwater discharge to the creek results in higher water temperatures, reduced sediment transport, and limited stream connectivity. In order to explore this theory, all relevant hydrologic datasets were analyzed for statistically significant trends that would explain the change in flow patterns. Trends discovered in time-series datasets were used to construct a conceptual model of the hydrologic system, ensuring any simulation is responsive to the conditions found in the field. If a groundwater model is built, it can be used to answer questions about the interaction between the ground and surface water including the effect of pumping at particular location and how this pumping may influence flow volumes in the creek.

Dramatic Trends in the Site's Hydrologic Datasets

Statistical investigations were performed on four datasets: precipitation, permitted groundwater withdrawals, groundwater levels, and stream flow volumes. Both the Mann-Kendall and Sen's method trend tests were employed to quantify temporal trends.

Precipitation

Because precipitation varies spatially over small distances, it is more appropriate to analyze for patterns using county or statewide areal averages than to rely upon individual, unrepresentative stations. Areal averages combine readings from multiple monitoring stations to produce a spatially robust result. The average areal precipitation analysis for the Central Minnesota region that contains the LRC watershed shows no trend over the last 20 years (University of Minnesota, 2011).

High Capacity Withdrawals

Agricultural producers in Minnesota have used ground and surface water for irrigation since the late 1800s. But it wasn't until 1976 that the Minnesota Department of Natural Resources (DNR) began managing high capacity water withdrawals through water use permits. The DNR regulates water withdrawals over 10,000 gallons a day or 1 million gallons a year (DNR, 2011). This study is not concerned with the non-consumptive practices of the power generation industry, where water is returned to the source.

Most of the DNR permits issued within the study area are for the crop irrigation, with the remainder devoted to municipal uses. The total number of active permits in the LRC watershed have

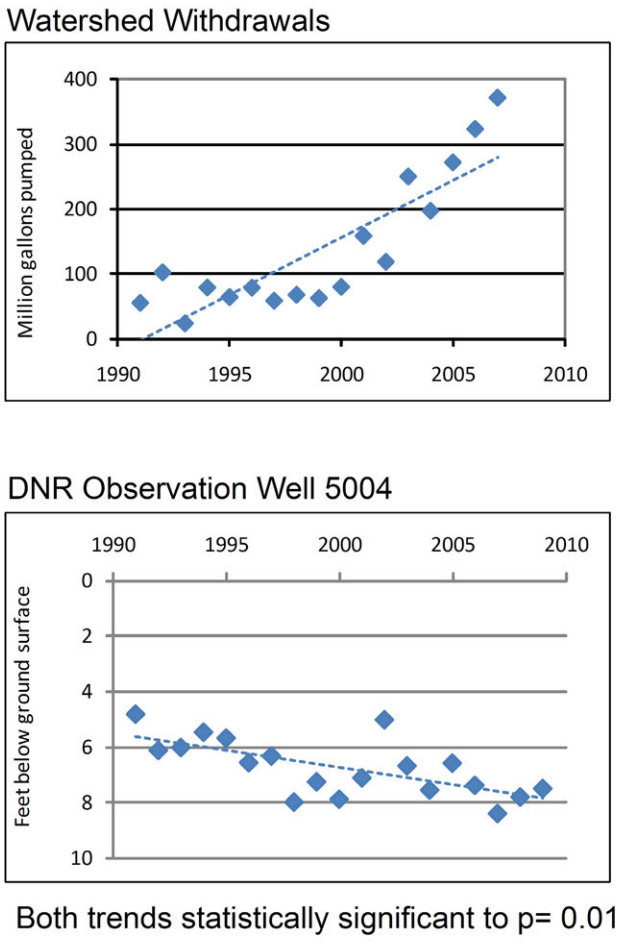

Figure 2. Top: Watershed Groundwater Withdrawals; Bottom: Groundwater Elevation Trends

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Groundwater in Watershed Studies, cont.

increased from 96 in 1991, to 168 in 2001, and to 226 in 2009 (Figure 1). The volume of withdrawals also increased at a statistically significant rate ($p = 0.001$) over this period (Figure 2a).

Observation Wells

There are nine active observation wells in the study area (Figure 1). Wells not located near the Mississippi River, including the hydraulically connected Little Rock Lake, show declines in groundwater levels since 2001. Observation well 5004, located one mile upgradient from the confluence of the LRC and Little Rock Lake, shows a statistically significant declining trend ($p<0.05$) in the average annual groundwater elevation (Figure 2b).

Creek Discharge

The LRC has a single, long-term gaging station that has been maintained since 1998. Stream discharge can be determined through the use of a rating curve, which is the functional connection between stage and discharge. The data show a pattern of declining flows in July and August over the length of the historical record. Five temporary stream monitoring sites were constructed for the TMDL study, from which eight manual stream discharge measurements were made in 2008 (Figure 1). Flows were highest in May and early June, then dropped dramatically in July and August, before recovering in October.

Groundwater Model Results

As a result of the discovery of the statistically significant trends in the hydrologic datasets, a groundwater model was constructed to investigate the interaction of groundwater and surface water in the watershed. It was built with the USGS MODFLOW code, using the GMS graphical user interface. Important features of this model include:

- Steady-state implementation;
- Conceptual model represented by a single layer, water table aquifer overlying granite;
- Aquifer extent and thickness based on spatially interpreted well logs from the County Well Index;
- Hydrologic input values based on trend analyses of precipitation, high capacity groundwater withdrawals, groundwater elevations, and stream discharges. Inputs were given the approximate values calculated from trends in 2008, the last year of data collection;
- Surface elevations are taken from the digital elevation model data provided by the Minnesota Geospatial Information Office (MNGEO, 2011); and
- The model was calibrated to discharge measurements taken from seven stations on three rivers, as well as groundwater levels from nine observation wells.

The model results are presented in Figure 3. The dashed line is the simulated groundwater withdrawals, and the solid line is the flow in the creek just upstream of Bunker Hill tributary, four miles upstream from the mouth of the creek. The X axis shows the change in model output due to varying pumping levels. Overall, as pumping is reduced the model predicts increased creek flow. The first column on the far left is the original model input representing withdrawals in 2008. Moving right, the second scenario represents zero pumping from all wells within 1 km of the creek. The remaining alternatives show results for decreasing fractions of current pumping for all the wells in the model domain, extending from 90% of 2008 levels, down to a minimum of 5%.

Stressor Identification

The LRC model concluded that high capacity groundwater withdrawals reduced flow in the creek. Reference data indicates reduced flow in a stream can be a stressor to the fish community. Increasing water withdrawals from the LRC watershed may be partially responsible for the recent findings that the brown trout community in LRC is no longer self-sustaining, and also why efforts to reestablish a naturally reproducing community have been unsuccessful. As a consequence, the altered groundwater flow was officially identified as a TMDL stressor, a cause of the creek's impairment (Benton County, 2009). The designation of altered groundwater flow as a stressor at LRC was a first for the MPCA TMDL program.

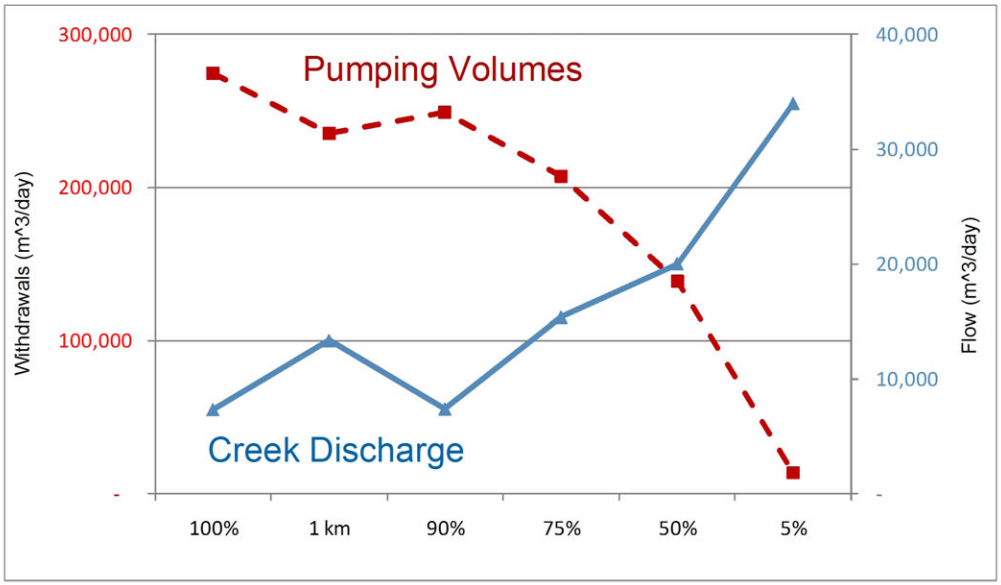

Figure 3. Modeled Scenarios

Groundwater Flow and Little Rock Lake

The effect of altered groundwater flow in the LRC Watershed is not limited to just the creek. Little Rock Lake is dependent on both flow from the creek and direct groundwater discharge, which are both affected by groundwater withdrawals (Figure 1). A separate TMDL study recently was performed on the lake and concluded the lake was impaired due to both reduced fish diversity and clarity. The lake was added to the TMDL program in 2007 in large part because of an outbreak of toxic blue-green algae.

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Groundwater in Watershed Studies cont.

Statewide Study

Scaling the Pilot Scale to Statewide Datasets

The results from the groundwater model met the immediate needs of the LRC TMDL project team. However, the trend test results were so dramatic that a second investigation was initiated to explore the existence of similar trends in statewide hydrologic datasets. Is there a significant increase in permitted, high capacity water withdrawals statewide, and is it related to decreasing streamflow trends in a representative number of rivers? If these trends are present throughout Minnesota, these analyses can be used to prioritize watersheds for further groundwater investigations by identifying those with more pronounced groundwater – surface water interactions. Groundwater models could then be developed in areas with a higher probability of benefiting from that level of investigation.

Precipitation

The average areal precipitation for Minnesota has a statistically significant positive trend over the last 50 years, $p < 0.05$ (University of Minnesota, 2011). Rising precipitation amounts are observed in most subregions of Minnesota, although these generally are not statistically significant. Statewide trends for the period 1991 – 2009 are flat as a whole.

Total Consumptive Withdrawals

As previously discussed, the DNR permits all high capacity withdrawals of groundwater and surface water. Combined withdrawals of water for municipal, industrial, and irrigation purposes have significantly increased across the state (p=0.001). This is true for all state subregions, for withdrawals from both surface water and groundwater, and for irrigation withdrawals when analyzed alone. Consumptive withdrawals totaled 500 billion gallons in 2010.

Randomly Selected River Gages

To ensure a statistically rigorous dataset that could be investigated for the presence of significant trends, 20 stations were randomly selected from all gaging stations maintained by the state and federal governments. Only those stations that had continuous records for the period of study, 1991 – 2009, were considered. This time period was selected to provide enough data for statistical analysis and to focus on current conditions.

The review of gage-derived stream flow data focused on the summer months, when both evapotranspiration rates and irrigation-based water withdrawals are greatest. Analyzing these stations for summer discharge trends found significant decreasing flows in a majority of the 20 rivers for the months of July and August. Figure 4 is a map of the state with the results of the trends study. The names of rivers with significantly decreasing trends are shown in red, while those with no trend are shown in blue.

The finding that a majority of the stations show significant flow declines is a surprising result. For context, a review of the two previous 20-year cycles for the same wells reveals that flow trends of any type were uncommon. Only one statistically significant trend (p<=0.05) was found for July and August flows during the 1951 – 1970 and 1971 – 1990 intervals. Only seven of the 20 gaging stations had continuous records in each of these two 20-year intervals.

Weight of Evidence

Having determined that statewide statistically significant trends in water withdrawals and summer streamflow trends existed, the remaining step was to match water withdrawals against flows in individual watersheds. Figure 5, using a spatial comparison,

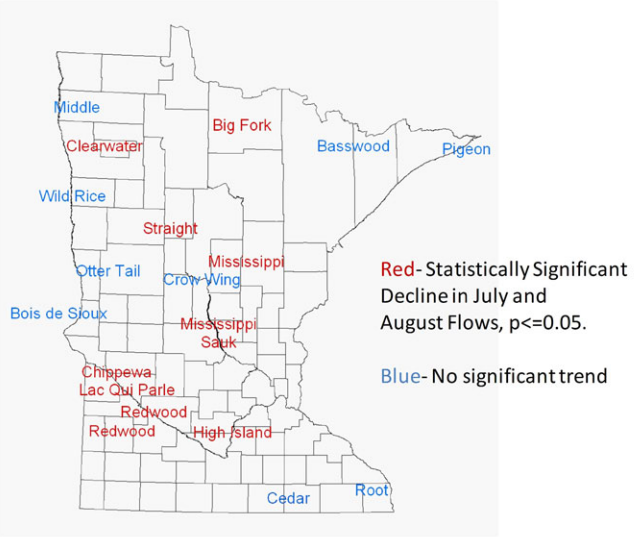

Figure 4. Statewide River Trends

overlays high capacity pumping locations onto maps for four of the rivers monitored in the study. The stars paired with each river show the presence or absence of a statistically significant trend. A blue star represents no trend, and red represents a statistically significant trend. The Middle River has no discharge trend, and there are only minor withdrawals near the river. The Clearwater River has a decreasing trend. The gaging station on this river is at Red Lake Falls, which is downstream of over two dozen high capacity surface water withdrawals. The Otter Tail River has only minor withdrawals and no discharge trend. The gaging station on this river is near the town of Elizabeth. The Straight River has a decreasing discharge trend. The gaging station is at Park Rapids, where it is surrounded by a high density of groundwater and surface water withdrawals. Similar analyses were done for the remaining gaging stations and watersheds.

It is important to point out that while the trends discussed are real, their relationships to each other are only inferred. This review has simplified hydrologic systems without considering watershed size, amount of pumping, geologic complexity, or regional variations in rain and snowfall. This weight of evidence approach stands in contrast to the more rigorous treatment performed for the LRC watershed with the construction of a groundwater model. Nonetheless, the value of this less rigorous approach is the ability to use a relatively quick statistical review of the data to create a list of watersheds that can be prioritized according to the expected groundwater – surface water interaction.

Significance of this Groundwater – Surface Water Interaction Study

The first-ever identification in Minnesota of altered groundwater flow as a stressor had a powerful effect on the state agencies responsible for groundwater and surface water management. Requests by hydrologists for groundwater investigations at the MPCA have increased dramatically as a result of this study. The DNR also began the move to a new management system focused on better understanding the groundwater and surface water withdrawals within the context of individual watersheds. The identification of statewide trends similar to those found at LRC adds significantly to this move toward a more comprehensive understanding of watershed dynamics.

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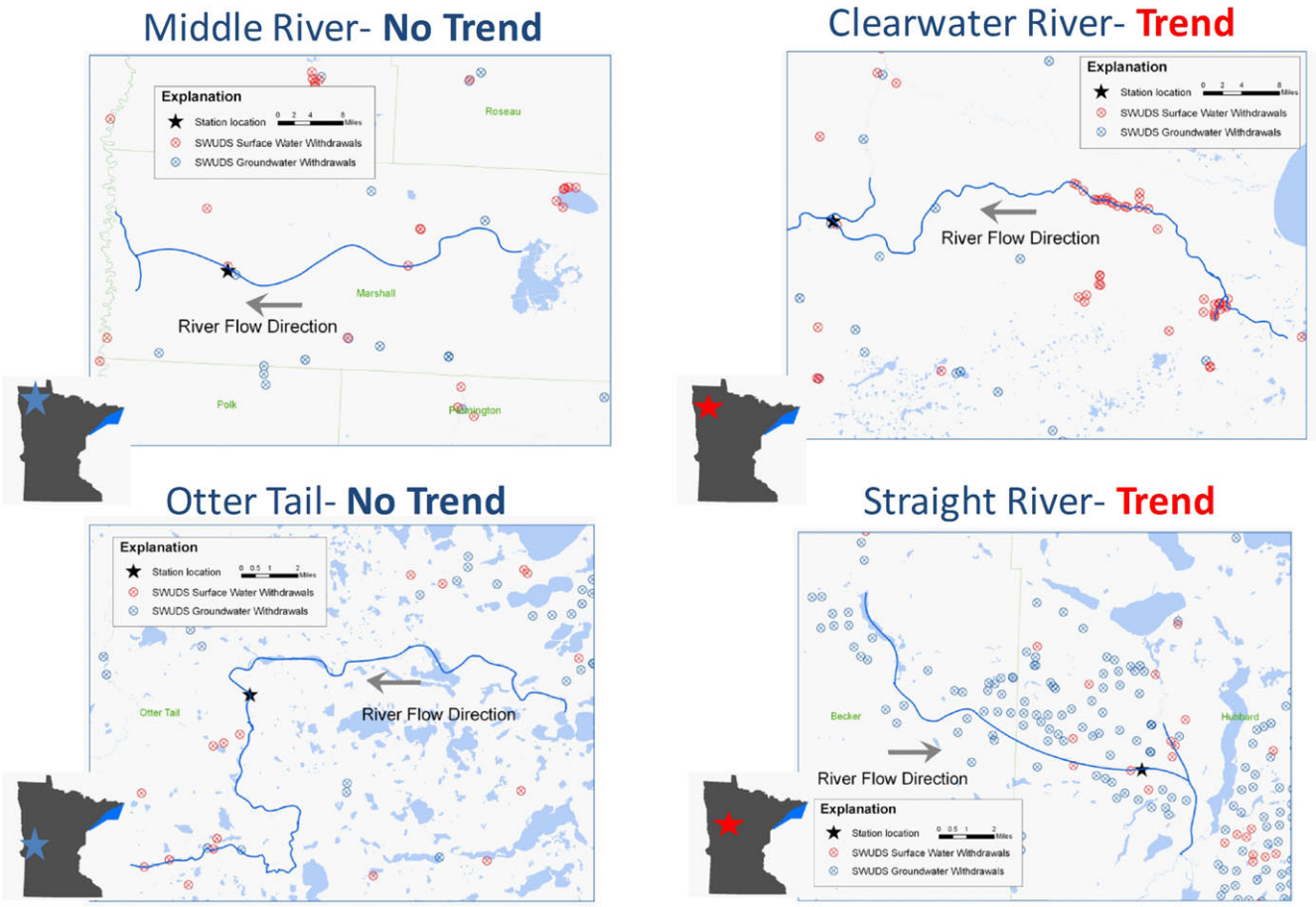

Figure 5. Four Rivers

Conclusion

Hydrologic datasets analyzed for the development of a groundwater model investigating the groundwater – surface water interaction at the LRC, were found to have statistically significant trends. These trends suggested a cause and effect relationship existed between increasing groundwater withdrawals for irrigation use and corresponding declines in groundwater levels and creek discharge during the summer months. Following the construction of a groundwater model, yielding results which supported this conclusion, statewide datasets were analyzed for the presence of similar trends. Statistically significant trends were found in both water appropriations and summer stream discharges. This led to the development of a priority list of state watersheds organized by the degree of groundwater – surface water interaction potential. In a time of tight budgets, this will allow the MPCA to efficiently prioritize watershed investigations.

References

Benton County, 2009, Benton Soil and Water Conservation District Stressor Identification Report, www.pca.state.mn.us/index.php/view-document.html?gid=7968.

DNR, 2011, Minnesota Department of Natural Resources, Water Appropriations Permit Program, www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html.

MNGEO, 2011, Geospatial Information Office, digital elevation model coverages, www.mngeo.state.mn.us.

MPCA, 2011, Minnesota Pollution Control Agency Total Maximum Daily Loads, rules and funding, www.pca.state.mn.us/xggx950.

University of Minnesota, 2011, Minnesota Climatology Working Group, Western Regional Climate Center, climate.umn.edu/doc/historical.htm.

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Lake Minnetonka 3D Water Quality Modeling

By Shahram (Shane) Missaghi, University of Minnesota

Water quality models are essential tools that enable water resources managers to study the physical, chemical, and biological processes of our ecological systems. Fortunately, there have been continuous improvements in models and computer power for the past few decades. Water quality models have become very sophisticated and can readily synthesize vast and diverse sets of data to help us to better understand our ecological systems. However, beyond eutrophication (both natural or anthropogenic), water resources managers must also consider various climate change scenarios and socioeconomic factors in water resources evaluations. Water quality models are excellent tools to do just that, and their results are regularly used to form policies or assist to meet regulatory requirements. These models are increasingly playing a larger role in water resources management. Some of them publicly are available (water.epa.gov/scitech/datait/models/) where water resources managers can explore their use and capabilities.

One way to type models may be based on their dimensionality where a well mixed box model could be considered as zero-dimension, horizontal or vertical layers (mixing) as one-dimensional (1D), lateral and longitudinal as two-dimensional (2D) and a system discretized into a three-dimensional mesh (cells) as three dimensional (3D). The 3D modeling allows for temporal and spatial analysis. This is important because ecological systems are influenced by different scales of spatial and temporal hydrodynamic and geochemical processes. For example, a lake may have different water quality regions due to streams transporting different amounts of nutrient loads that reflects the landscape and land use of their individual watersheds into the lake. Each watershed may further influenced by seasons and climate change. These variations (heterogeneity) can be further increased by the interaction of hydrodynamics (flow) and lake morphometry and is exacerbated in highly morphologically complex lakes such as Lake Minnetonka. 3D models provide the resolution captures the spatial and the temporal hydrodynamics and biogeochemical distributions within these systems.

Lake Minnetonka (59 km^2) has 23 bays, 200 km of shoreline, 24 km^2 of littoral area, and a maximum depth of 34 m. The lake's watershed (319 km^2) has an average annual precipitation of 750 mm delivering 10.8 tons (2006) of total phosphorus (TP) into the lake through five creeks. In general, the lakes's water quality improves from the western to the eastern end of the lake where the outflow is controlled by a dam structure. Every year, each of the lake's bays are graded by the Minnehaha Creek Watershed District (www.minnehahacreek.org/) based on the measured total phosphorus (TP) concentration, algal biomass, and water clarity. The final water quality grade for each bay, from clear to severely algae infested water, is an average of these three variables (Figure 1).

Recently, a 3D hydrodynamic Estuary and Lake Computer Model (ELCOM) and ecological Computational Aquatic Ecosystem Dynamics Model (CAEDYM) from the Centre for Water Research of the University of Western Australia, was successfully coupled to simulate a number of the lake's bays. The hydrodynamic model used physical processes to determine the transport and the flow, and the ecological model determined the fate of the nutrients through the geochemical processes.

The model setup discretized the lake into 200 x 200 m bathymetry grids and 0.5 m vertical grids. The year 2000 (April to

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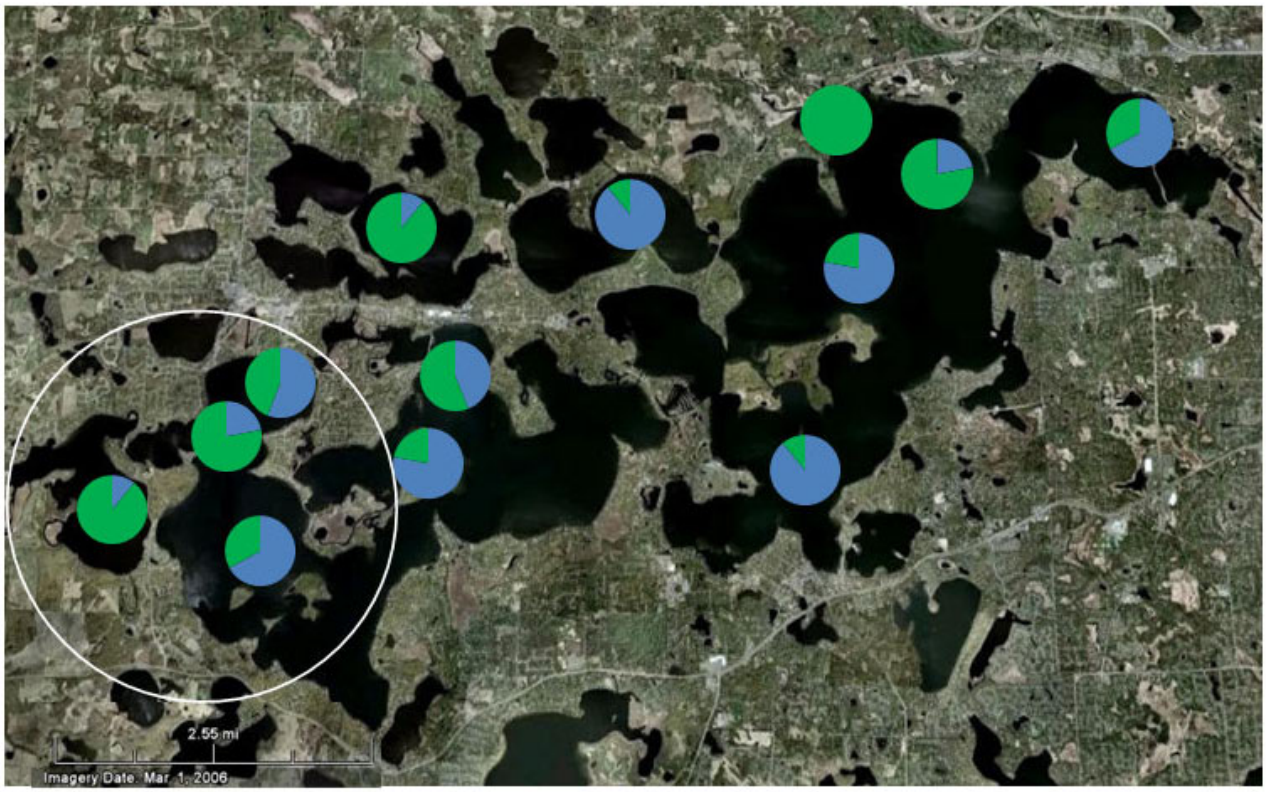

Figure 1. Water quality assessments on Lake Minnetonka.

Lake Minnetonka Water Quality, cont.

October) was selected for model calibration and 2005 for confirmation (validation) with a time step of 120 s. The model was configured to simulate temperature (T), velocity, TP, total nitrogen (TN), pH, dissolved oxygen (DO), organic carbon, and the Cyanobacteria algal biomass (Chla) group. The input data included biweekly stream flow, T, DO, Chla, TP, and soluble reactive phosphorus (SRP), along with lake water T, DO, conductivity, pH, TP, SRP, total nitrogen and Chla. Meteorological data included hourly readings of air temperature, precipitation, solar radiation, relative humidity, atmospheric pressure, cloud cover, wind speed, and wind direction.

Results

The 3D simulation of an aquatic system requires the description (equations) for many of the physical and ecological processes. The physical processes are well understood, so the parameters used in ELCOM simulations had mostly fixed constant values and required no calibrations. On the other hand, CAEDYM predictive ability depends on hundreds of calibration parameters and requires massive computational power and effort in parameter calibration. First over 700 values of eighty model parameters were compiled to create an optimal (best fit) estimate of the model parameters. The simulated and biweekly measured data from three different water quality stations were used to evaluate the model fit. Temperature predictions were excellent (R2 =0.98), followed by DO profiles (R2 = 0.67–0.92), and then TP (R2 = 0.44–0.92) and Chla (R2 = 0.3–0.48) which agreed reasonably well. The model was able to predict the lake water level within a couple of inches and captured the spatial and temporal biogeochemistry variations—both short term and seasonal. Particularly, the TP simulations showed that each bay has distinct localized TP concentrations reflecting unique sediment phosphorus release rates and input. On the other hand, the alga biomass (Chla) simulations, inherently difficult, proved that their lateral patchiness, vertical distributions, and temporal variations (blooming) still need further understanding and are the subject of current research. However, the model did capture the heterogeneity of

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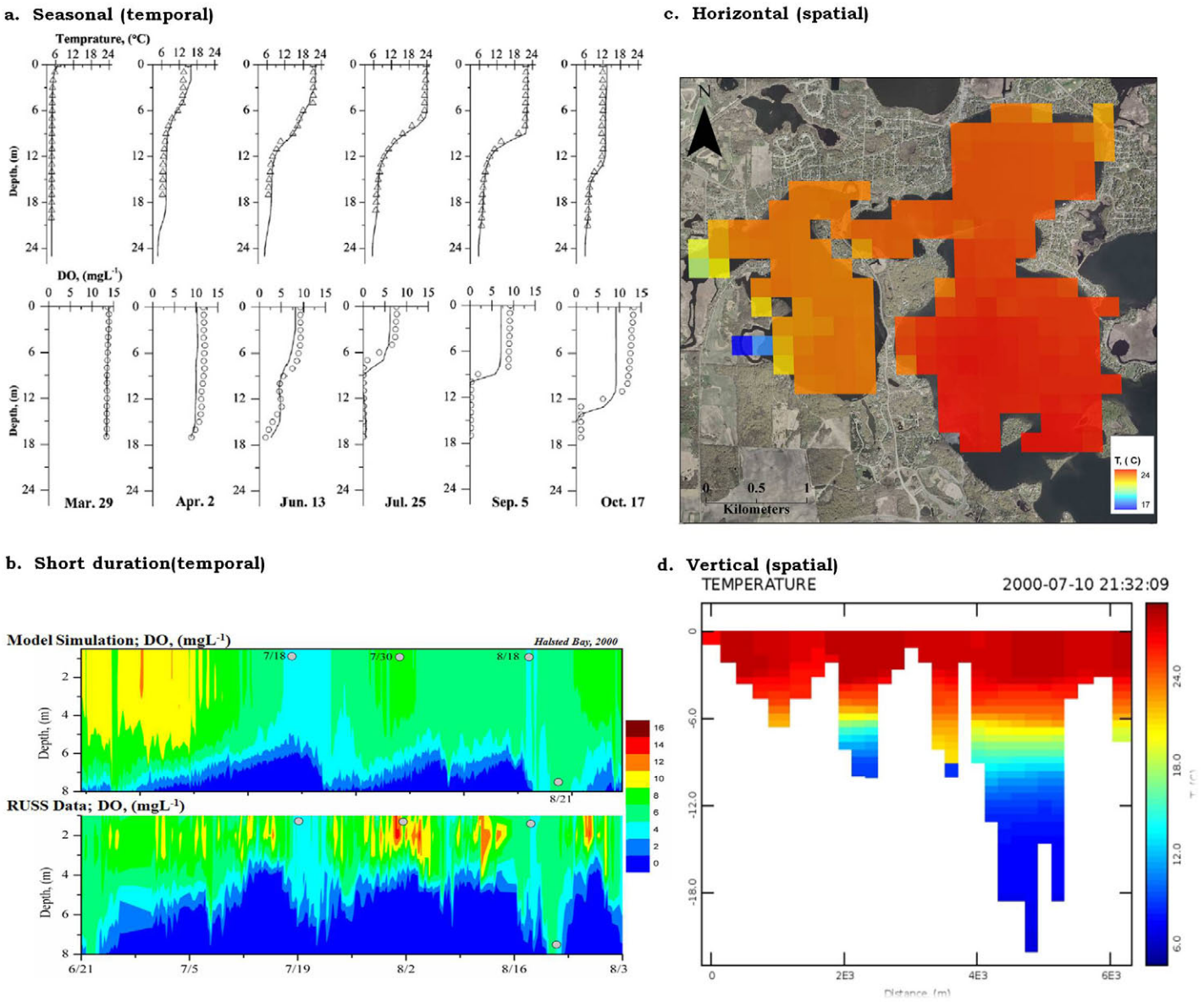

Figure 2. Spatial and temporal biogeochemistry in Lake Minnetonka.

Lake Minnetonka Water Quality, cont.

Lake Minnetonka and showed that 3D modeling is needed to better gain insight into its spatial and temporal biogeochemistry distribution (Figure 2).

Model Applications

The coolwater fish habitat, typical of Lake Minnetonka, was analyzed under two climatologically different seasons (2000 and 2005). Since the lake was discretized into many cells (control volumes), it was possible then to individually identify all cells with suitable fish habitat (desirable T and DO levels) and tracked them through the seasons. The analysis showed a 62% increase in the undesirable fish habitat from 2000 to 2005. These changes were supported by the warmer water temperatures, which averaged 2 ◦C warmer for the season, and 1 mg L−1 lower DO concentrations measured in 2005. This type of analysis is an important tool for water resources managers and planners as climate change could be a great driver in changing water temperatures for the fish communities.

Hydromodification (such as lake water level changes) can alter a lake's hydrodynamics and water quality, and it directly influences the littoral plant communities. In case of shoreline restorations, it is imperative to choose plants that match prevailing water level conditions as well as the potential impact of climate change. The 3D Lake Minnetonka model was simulated under four different seasons to investigate the potential climate change impacts on the lake's water level and water quality. Field experiments were also conducted to measure the shoreline plants' survival rate under same different climate scenarios. The findings, expected in early 2012, will aid in developing a set of recommendations in selecting shoreline restoration plants most adaptive to climate change.

The 3D model applied in Lake Minnetonka showed that the lake's hydrodynamic and ecological processes are sensitive to mixing due to inflow and wind variabilities. The results also suggested that spatial and temporal variations of model outputs are sensitive to the hydrodynamics of physical perturbations such as those caused by stream inflows generated from storm events. The model will aid in developing effective management plans including climate change adaptation strategies.

Missaghi is a PhD candidate with Water Resources Graduate Program at the University of Minnesota—St. Anthony Falls Laboratory and is advised by Prof. M. Hondzo and Dr. L. Hatch.

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Hydrostratigraphy of a Fractured, Urban Aquitard: The Platteville Formation in the Twin Cities Metropolitan Area

By Julia Steenberg, Anthony Runkel, and Robert Tipping, Minnesota Geological Survey, University of Minnesota

Introduction

The Paleozoic bedrock of the Twin Cities Metropolitan (TCM) area of Minnesota provides over one-half of the drinking water for its 3 million citizens. Increasing demand for groundwater and concerns about contamination of deep aquifers have led to a number of studies over the past 20 years that have significantly improved our understanding of this bedrock aquifer system, redefining the system into regional aquifers and aquitards on the basis of hydrostratigraphic attributes (Runkel et al., 2003, 2006; Tipping et al., 2006). These studies emphasize the importance of groundwater flow through connected voids or macropores and have made significant advances in predicting groundwater flow through macropores in discrete stratigraphic intervals in both aquifers and aquitards. Aquifers in the bedrock system are now relatively well characterized. However, our understanding of the intervening aquitards remains comparatively poor, a non-provincial problem in hydrogeology (Bradbury et al., 2006). This is due in part because methods for characterizing their physical properties are not well developed, especially the acquisition of data that provide insight into vertically oriented features. This article is a summary of a larger study that integrates a wide variety of data sets for the purpose of constructing a comprehensive conceptual model of the hydrostratigraphic properties of the Platteville aquitard in the TCM area providing insight into aquitard properties and improved predictability of groundwater flow paths (Anderson et al., 2011).

The Platteville Aquitard

The Late Ordovician Platteville Formation in the TCM area is a shallowly buried (<100 ft), extensively fractured, carbonate bedrock layer (26-29 ft thick) traditionally referred to as the middle part of the Decorah-Platteville-Glenwood aquitard (Kanivetsky, 1978). The Platteville Formation is subdivided into four members based on lithology and bedding style including the Pecatonica, Mifflin, Hidden Falls, and Magnolia. The Carimona Member previously classified as the uppermost part of the Platteville Formation is now classified as the lowermost part of the Decorah Shale (Mossler, 2008). As a near-surface bedrock layer in an urban area, the Platteville has been subject to a wide variety of hydrogeologic and geomechanical studies over the past few decades mainly for the purposes of developing remedial strategies at contamination sites and acquiring data for engineering projects involving underground excavations (e.g., Liesch, 1973; Barr, 1983a; CSC Joint Venture, 1985; CNA, 1997; Kelton Barr Consulting, 2000; Alexander et al., 2001; Peer Environmental and Engineering Resources, Inc., 1999). We've gathered an extensive amount of subsurface hydrogeologic information from these studies including data from discrete-interval packer tests,

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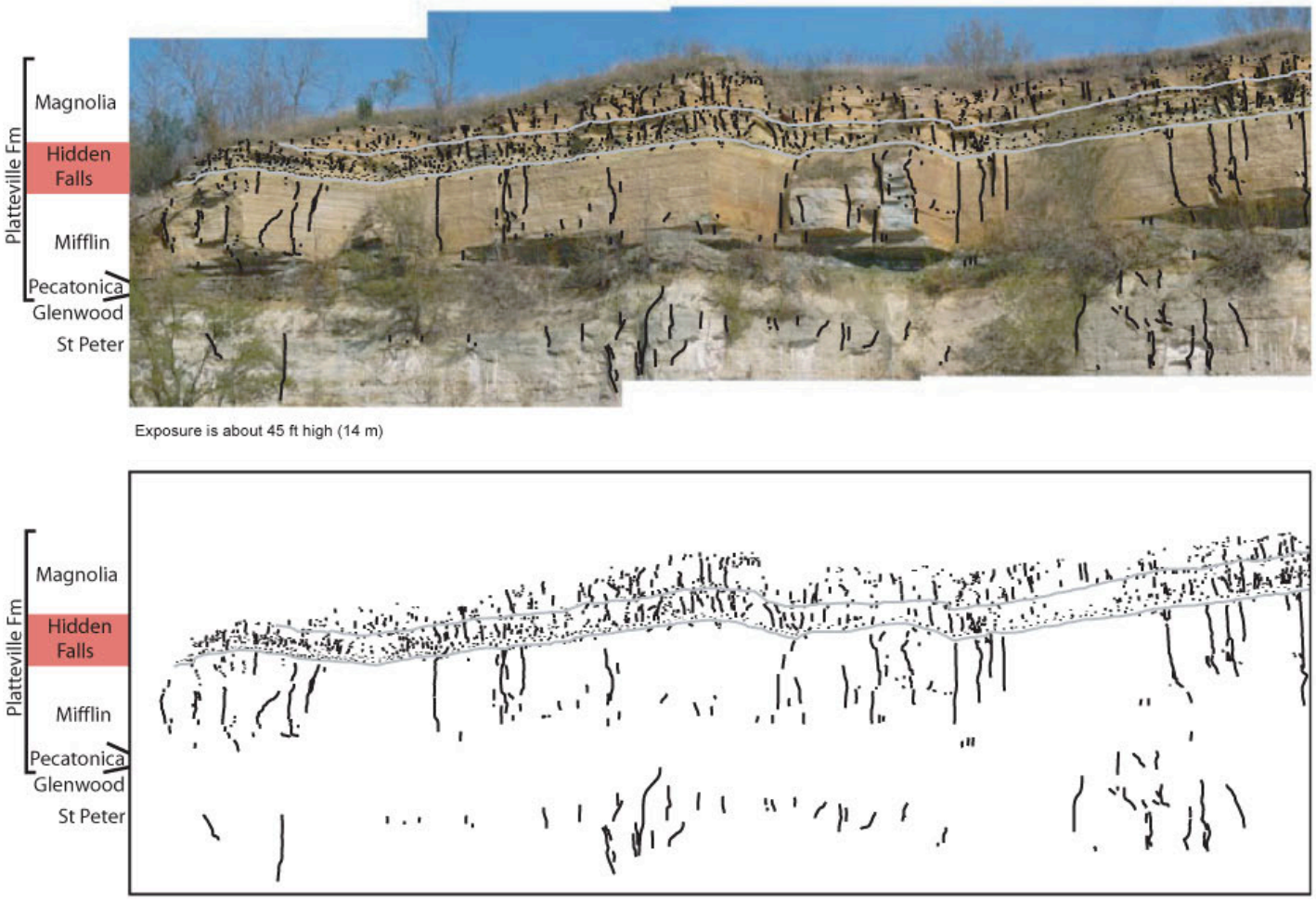

Figure 1. Conceptual hydrostratigraphic model for the Platteville aquitard in the Twin Cities area.

Platteville Formation, cont.

large scale aquifer pump tests, potentiometric surface mapping, and dye traces. Information from underground excavation sites also provides a rare three dimensional perspective of fractures and groundwater flow. Our own research has added borehole geophysical data including flowmeter logging and outcrop context including documenting the stratigraphic position of springs and characterizing vertical fractures on large exposure surfaces. As part of a companion project with the Metropolitan Council we've also compiled a relatively large number of hydraulic conductivity values for the Platteville from previous reports and incorporated these results into our model.

Spring hydrostratigraphy

Outcrop exposures along the Mississippi River Valley, from the confluence with the Minnesota River at Fort Snelling upstream to St. Anthony Falls, contain numerous springs that discharge from the Platteville Formation (Brick, 1997). We've examined all mapped springs along this stretch of the river and documented their precise stratigraphic position. Of the 48 springs we've examined the greatest percentage (42%) discharge at the contact between the Hidden Falls and Magnolia Members (Fig. 1). This includes the largest remaining spring in Minneapolis, Camp Coldwater Spring, with a flow rate typically ranging from 70 to 90 gallons per minute (gpm). The contact between the Hidden Falls and Mifflin Members has the second greatest percentage of discharging springs (25%). The remaining springs discharge at many other stratigraphic positions (Fig. 1) but are less statistically significant and have much lower flow rates. The preferential stratigraphic position of springs at the top of the Hidden Falls is consistent with observations from the deeper subsurface where engineering and hydrogeologic investigations at a number of sites across the TCM area have documented a discrete high hydraulic conductivity interval approximating the Hidden Falls and Magnolia contact (e.g., Barr Engineering, 1983a; CNA, 1997; Peer Environmental and Engineering Resources, Inc., 1999).

Geophysical logging

To evaluate the relationship between the stratigraphic position of springs and groundwater flow paths in the subsurface, away from effects of a fractured bluff edge, we collected a series of borehole geophysical logs from eight monitoring wells open to the Platteville Formation on the east and west banks of the University of Minnesota campus. The logging included EM flowmeter tests under ambient and stressed conditions during which water was injected at a rate of about 10 gpm. Video, caliper, and natural gamma-ray logs were also collected to recognize bedding plane fractures and determine their precise stratigraphic positions (Fig. 2). Six wells of the eight had a single bedding plane fracture that dominated hydraulics at the Hidden Falls and Magnolia contact. Hydraulic conductivities calculated for the Hidden Falls and Magnolia bedding plane conduit from injection in these wells ranged from about 3000 ft/d to 55,000 ft/d (calculated using an estimated fracture aperture of 1.5 inches as aquifer thickness). Two of the eight tested wells had very different results. One of the wells is cased below the top of the Hidden Falls Member, open to the middle of the Hidden Falls and the upper part of the Mifflin Members. Hydraulic conductivity is so low in this borehole that we were unable to achieve a static head even at injection rates far less than 1 gpm. The other well is open to the Hidden Falls and Magnolia boundary, but there does not appear to be a bedding plane fracture at that horizon, and injected water exited the borehole directly at the base of the casing, stratigraphically within the middle of the Magnolia Member. Water is likely exiting at an opening between the borehole wall and the well casing in this case since we did not see evidence for a bedding plane fracture in the video or caliper log.

Fracture traces

We have mapped vertical fractures in detail at three separate localities in the TCM area where the Platteville is well exposed. Vertical fractures typically initiate within a stratigraphic unit, spanning its entire thickness, referred to as a mechanical unit, and terminate at distinct stratigraphic horizons, known as mechanical interfaces. Defining these units and interfaces is known as mechanical stratigraphy, which can provide insight into fracture network development and improved prediction of fluid flow pathways (Underwood et al., 2003; Cooke et al., 2006). Results at our fracture tracing localities show that the members of the Platteville each have a distinct style of vertical fracture density and spacing (Fig. 3). The Magnolia Member has a high density of vertical to subvertical fractures with a wide range in trace length, creating a blocky texture. The Hidden Falls Member has a very high density of vertical to subvertical fractures that break in a conchoidal pattern. The Mifflin Member has a relatively wide spacing of vertical fractures with long traces that typically extend through the entire thickness of the member. The Pecatonica has a narrower spacing of vertical fractures with traces that span the thin bed. The members of the Platteville act as mechanical units

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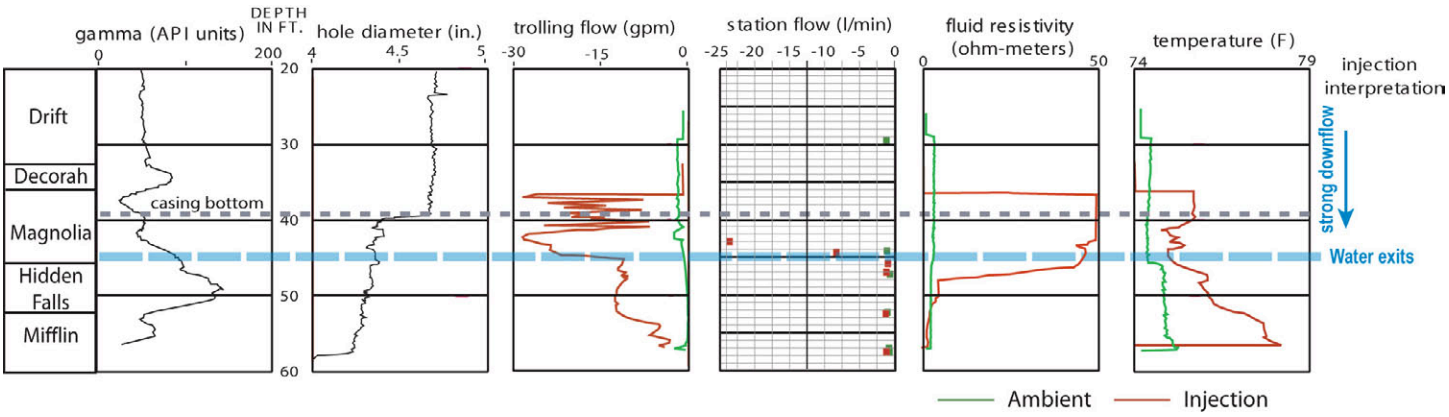

Figure 2. Illustration of the geophysical and hydraulic data collected for well no. 664362 at the U of M showing that the fracture at the Hidden Falls and Magnolia boundary dominates hydraulics in the well.

Platteville Formation, cont.

and the contacts between the members typically terminate vertical fractures, acting as mechanical interfaces. Vertical fractures preferentially terminate at the top of the Hidden Falls as well as at the top of the Mifflin. Individual vertical fractures extending through the entire formation are rarely present at some highly weathered outcrops.

Conceptual model of the Platteville

The spring, borehole, and fracture data we've compiled so far identify the Magnolia–Hidden Falls contact as a key stratigraphic position for groundwater flow. From a horizontal perspective it corresponds to the most prevalent high hydraulic-conductivity conduit. It also represents a mechanical interface or bed that has inhibited propagation of vertical fractures, which results in the Hidden Falls strata directly below having the potential to serve as an aquitard in a vertical direction. The outcrop and subsurface hydrogeologic expression of this phenomenon is the presence of springs and water table aquifers perched preferentially in this relatively thin part of the Platteville Formation. Nested monitoring wells similarly reflect vertical resistance to flow across the Hidden Falls, with heads above and below known to differ by as much as 10 ft (Braun Intertec Corporation, 2011). The top of the Mifflin Member, also an interval of preferential vertical fracture terminations, may similarly serve as a stratigraphically discrete aquitard based on spring and fracture data. However, we have not documented flow at this interval in the subsurface with our borehole techniques. Our current hypothesis to account for this discrepancy is that springs emanating below the top of the Hidden Falls Member may be attributed to a step-down effect at the bluff edge, where connectivity of vertical and bedding plane fractures are enhanced. It is possible that groundwater that travels along the Hidden Falls and Magnolia conduit across most of the subsurface extent of the Platteville steps stratigraphically down to the bottom of the Hidden Falls within meters of the bluff edges.

Our compilation of hydraulic conductivity values at site specific locations throughout the TCM area are consistent with what previous reports have identified from these sites and our own outcrop and flow logging observations. The upper part of the formation, including the Magnolia and uppermost few inches of the Hidden Falls Member, typically has horizontal hydraulic conductivity values ranging from a few feet per day to thousands of feet per day (e.g., Barr, 1983b, Barr Engineering, 1991; Peer Environmental and Engineering Resources, 1999). The preliminary results from our ongoing project with the Metropolitan Council also indicate that a reasonable estimate of relatively large scale, bulk conductivity of the upper part of the Platteville is about 500 ft/d. The Hidden Falls, Mifflin, and Pecatonica Members typically have markedly lower horizontal hydraulic conductivity values ranging from 10-4 to a few feet per day (e.g., CSC Joint Venture, 1985; CNA, 1997). Values as high as a few tens of feet per day or greater in the lower Platteville are relatively uncommon and likely indicate intersection or proximity of tested wells to bedding plane fractures or vertical joints, and are mostly restricted to sites where the Platteville has been relatively deeply eroded (e.g., Barr Engineering, 1987). We used leakage rates from vertical fractures at the base of the Platteville at excavation sites to calculate a range in vertical hydraulic conductivity from about 10-1 to <10-5 ft/d. Vertical conductivity progressively decreases into the subsurface away from the bluff edge reflecting diminishing aperture width, and likely connectivity and trace

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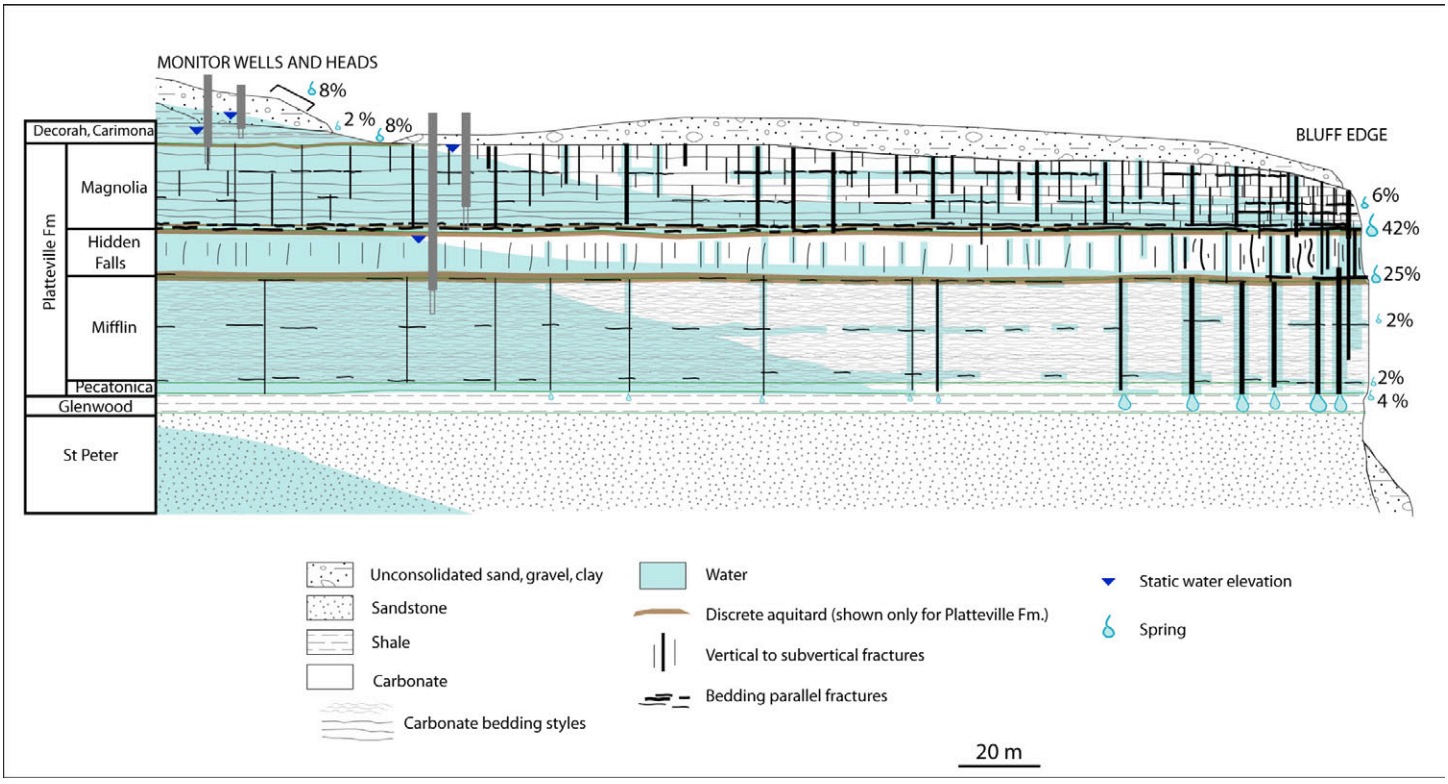

Figure 3. A portion of the vertical fracture trace at the Shepard Road locality.

Platteville Formation, cont.

length of vertical fractures (Peer Environmental and Engineering Resources, Inc., 2001, 2003; Anderson et al., 2011).

The combination of data from all of these efforts has led to a more comprehensive understanding of the Platteville that indicates it is best considered a hybrid hydrogeologic unit (Fig.1). Even though matrix permeability is very low, macropore networks accommodate moderate to very high horizontal hydraulic conductivity sufficient to yield economic quantities of water to wells, and to supply springs with flow rates >10 gpm. Dye tracing, pump tests, and macropore observations demonstrate that the Platteville is consistent with the definition of a karstic aquifer that includes fast-flow conduits. Data from the same collection of sites also support the traditional classification of the Platteville Formation as an aquitard, when considered from a vertical perspective, with discrete intervals such as the upper Hidden Falls serving as key, relatively high integrity aquitards. Relatively thin stratigraphic intervals of a few feet or less appear to contain both the highest hydraulic conductivity bedding-plane conduits as well as the key aquitards. We have been informally referring to such complex intervals as "aquitardifers." Despite this complexity, our ongoing work thus far appears to show a strong connection between stratigraphic units and the development of both horizontal and vertical macropore networks, and thus the potential for a strong degree of predictability in flow path geometries.

For more information

This article is a summary of a field trip guidebook article from the national Geological Society of America Fall 2011 meeting titled "Hydrostratigraphy of a fractured, urban aquitard" in Archean to Anthropocene: Field Guides to the Geology of the Mid Continent of North America. For additional information or questions contact Julia (Anderson) Steenberg at and01006@umn.edu or (612)-627-4780 ext. 225.

References

Alexander, E.C., Jr., Alexander, S.C., and Barr, K.D., 2001, Dye tracing to Camp Coldwater Spring, Minneapolis, MN: Minnesota Groundwater Association Newsletter, v, 20, p. 4–6.

Anderson, J.R., Runkel, A.C., Tipping, R.G., Barr, K.D.L., and Alexander, E.C., Jr., 2011, Hydrostratigraphy of a fractured, urban aquitard, in Miller, J.D., Jr., Hudak, G.J., Wittkop, C., and McLaughlin, P.I., eds., Archean to Anthropocene: Field Guides to the Geology of the Mid-Continent of North America: Geological Society of America Field Guide 24, p. 457–475.

Barr Engineering, 1983a, Site characterization study and remedial action plan, General Mills solvent disposal site, June, 1983: On file at the Minnesota Pollution Control Agency.

Barr Engineering, 1983b, Hydrogeologic Investigation, Phase 3 Final Report: Oakdale Disposal Sites, April, 1983: On file at the Minnesota Pollution Control Agency, 111 p.

Barr Engineering, 1987, Remedial Investigation/Feasibility Study: Superior Plating, Inc, August, 1987: On file at the Minnesota Pollution Control Agency.

Barr Engineering, 1991, Magnolia Member aquifer pump test report-Remedial action design plan: East Hennepin Avenue site, 2010 East Hennepin Avenue, Minneapolis: November 1991 report on file at Minnesota Pollution Control Agency.

Bradbury, K.R., Gotkowitz, M.B., Hart, D.J., Eaton, T.T., Cherry, J.A., Parker, B.L., and Borchardt, M.A., 2006, Contaminant transport through aquitards: Technical guidance for aquitard assessment: American Water Works Research Foundation Publication, 142 p.

Braun Intertec Corporation, 2011, Groundwater Assessment Report-Phase 3, Former Metallurgical, Inc., Facility: 900 and 936 East Hennepin Avenue, Minneapolis, Minnesota, MPCA VIC Project Number VP18181: On file at the Minnesota Pollution Control Agency, 23 p.

Cooke, M.L., Simo, J.A., Underwood, C.A., Rijken, P., 2006, Mechanical stratigraphic controls on fracture patterns within carbonates and implications for groundwater flow: Sedimentary Geology, v. 184, p. 225-239.

CNA Consulting Engineers (CNA), 1997, Geotechnical Data Report, University of Minnesota Library Access Center, UM Project No. 297-91-2023, 22 p.

CSC Joint Venture, 1985, Geotechnical Report, Project No. 87–54, Minneapolis East Interceptor, Phase 2, Volume 4A: Produced for the Metropolitan Waste Control Commission, 66 p.

Kanivetsky, R., 1978, Hydrogeologic map of Minnesota: Bedrock Hydrogeology: Minnesota Geological Survey Map Series, S-2, 1 sheet, scale 1:500,000.

Kelton Barr Consulting, Inc., 2000, Bluff Area Summary Report: Report to Minnehaha Creek Watershed District, April, 2000.

Liesch, B.A., 1973, Groundwater Investigation for the Minnesota Highway Department at the Minnehaha Park Tunnel: Minneapolis, MN, State Project no. 2724–78, 131 p.

Mossler, J.H., 2008, Paleozoic Stratigraphic Nomenclature for Minnesota: Minnesota Geological Survey Report of Investigations 65, 76 p., 1 pl.

Peer Environmental and Engineering Resources, Inc, 1999, Additional Project Area Characterization, Minnesota Library Access Center, University of Minnesota, 2 Volumes, November, 1999.

Peer Environmental and Engineering Resources, Inc, 2001, Interim Response Action Implementation Activities Update, Minnesota Library Access Center, On file at the Minnesota Pollution Control Agency, October1, 2001, 6 p.

Peer Environmental and Engineering Resources, Inc, 2003, Performance Monitoring Report Interim Response Action Implementation, Minnesota Library Access Center, University of Minnesota, On file at the Minnesota Pollution Control Agency, January 17, 2003, 12 p.

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

Runkel, A.C., Tipping, R.G., Alexander, Jr., E.C., and Alexander, S.C., 2006, Hydrostratigraphic characterization of intergranular and secondary porosity in part of the Cambrian sandstone aquifer system of the cratonic interior of North America: Improving predictability of hydrogeologic properties: Sedimentary Geology, v. 184, p. 281-304.

Tipping, R.G., Runkel, A.C., Alexander, Jr., E. C., and Alexander, S.C., 2006, Evidence for hydraulic heterogeneity and anisotropy in the mostly carbonate Prairie du Chien Group, southeastern Minnesota, USA: Sedimentary Geology, v. 184, p. 305-330.

Underwood, C.A., Cooke, M.L., Simo, J.A., Muldoon, M.A., 2003, Stratigraphic controls on vertical fracture patterns in Silurian Dolomite, northeastern Wisconsin: American Association of Petroleum Geologists Bulletin, v. 87, no. 1, p. 121-142.

Todd County Geologic Atlas, Part B Hydrogeology and Pollution Sensitivity

By Todd Petersen, DNR Division of Ecological and Water Resources

Introduction

This summary highlights Part B of the Todd County Geologic Atlas (see Figure 1 for location). County Geologic Atlases are studies that focus on one county at a time, but are published as part of a series. The full report includes four map plates that describe the county's groundwater conditions and pollution sensitivity. This report joins Part A of the report, published by the Minnesota Geological Survey. Part A contains six map plates describing the county's surficial and bedrock geology.

Figure 1. Location of Todd County, Minnesota

The surficial sand aquifer and several buried sand aquifers are the major sources of groundwater used in Todd County. The Quaternary sediments in which these aquifers occur were deposited by multiple glaciers that entered and receded from the county. Sediments deposited during the most recent glacial period, the Late Wisconsinan, are better understood than those from previous glaciations because they form the surface materials over most of the county.

Hydrogeology and Groundwater Residence Time Illustrated by Cross Sections

Eleven Quaternary sand aquifers and two bedrock aquifers were identified; nine of the sand aquifers were mapped where sufficient data were available. The Quaternary sand aquifers generally are adequate for local needs. Their hydraulic properties, however, vary based on extent and thickness, so some of these aquifers may not be adequate for all needs.

An example of the hydrogeologic variation in Todd County is shown on the cross section in Figure 2. The nonaquifer units

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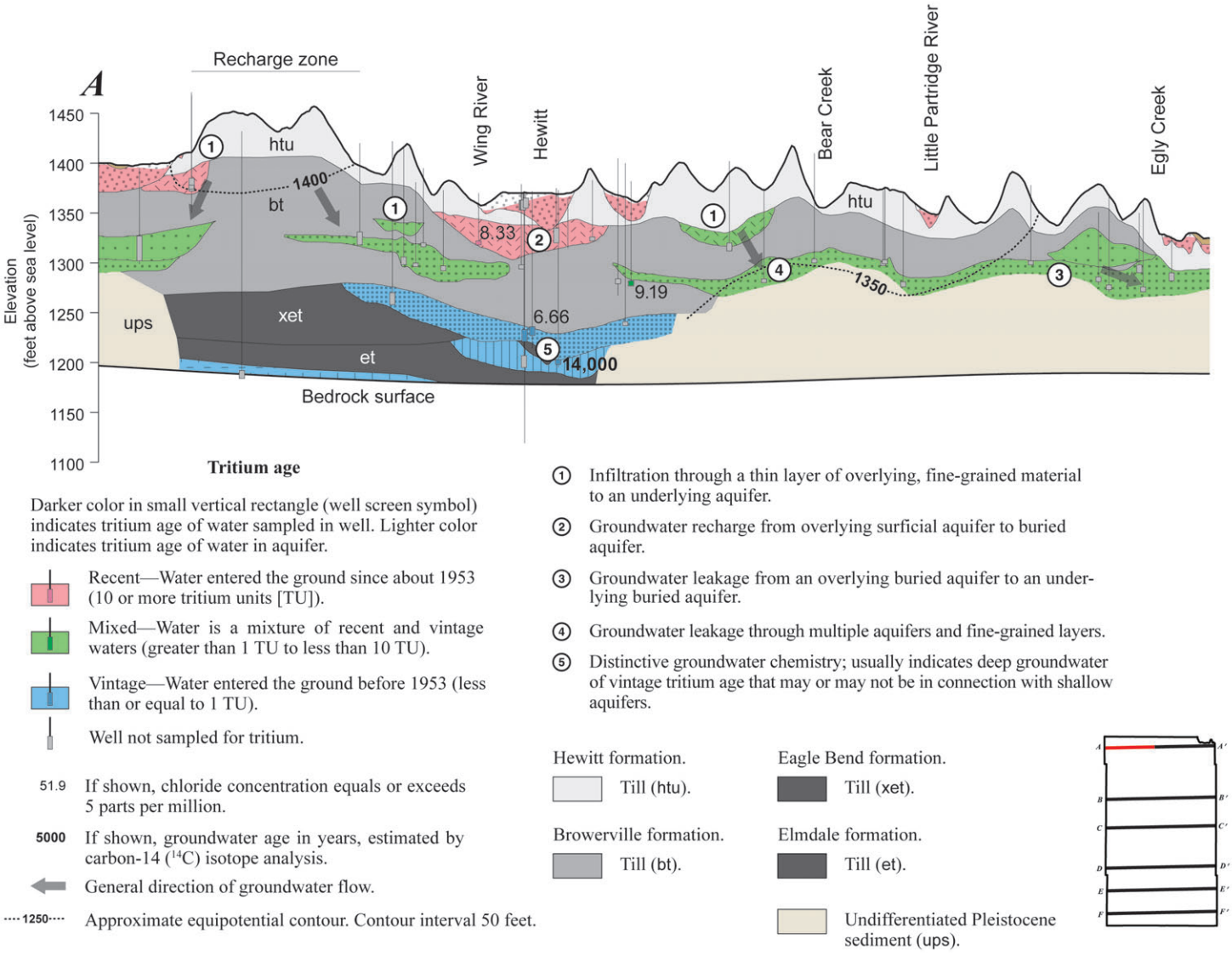

Figure 2. Selected hydrogeologic cross section showing groundwater residence time.

are shown in shades of gray. The relative hydraulic conductivity of the nonaquifer units was estimated using data from Knaeble and Meyer (2007b). Lighter grays represent relatively higher hydraulic conductivities; darker grays represent relatively lower hydraulic conductivities.

The pink, green, and blue areas on Figure 2 indicate the groundwater residence time, which is based on the tritium concentration in groundwater samples. Water samples with tritium concentrations of 10 or more tritium units (TU) are considered to be recent water, entering the ground since the early 1950s. Water samples with tritium concentrations of 1 TU or less are classified as vintage water; the water in these samples entered the ground before approximately 1953. Water samples with tritium concentrations greater than 1 TU and less than 10 TU are considered mixed waters. They are a mixture of vintage and recent waters. Water samples with tritium concentrations indicating recent tritium age were collected from aquifers as deep as 175 feet below land surface in Todd County. Water samples indicating mixed tritium age were collected from aquifers as deep as 200 feet below land surface. The aquifers in the western half of cross section A-A' (Figure 2) have mixed tritium down to approximately 125 feet below land surface. On the other hand, some shallow groundwater, often beneath the New Ulm Formation till, which is found primarily in the southwestern part of the county, has little or no detectable tritium and indicates that surface infiltration may be very limited.

Groundwater flow direction, which is shown on Figure 2 with gray arrows, was interpreted from equipotential contours; these contours were constructed from measured water levels in wells. Groundwater will move from areas with higher equipotential to areas with lower equipotential. In Todd County, area groundwater recharge zones correspond to topographically higher areas in the county; the major groundwater discharge zones are associated with larger rivers and lakes.

Hydrogeology of the Surficial and Buried Sand Aquifers

More than 99 percent of the wells in Todd County are constructed in Quaternary sediments; a small number of wells constructed in bedrock exist in the county. Of the wells in Quaternary sediments, 84 percent are constructed in buried sand aquifers under confined conditions where the aquifer pressure exceeds atmospheric pressure, 13 percent are constructed as water-table wells in surficial sands or buried sands in direct contact with surficial sands, and 3 percent are constructed in buried sands under unconfined or water-table conditions.

The water-table elevation in the surficial sand aquifer is shown in Figure 3. This figure also shows the surface watersheds in relation to the water table in the surficial aquifer and the location of high-capacity water use wells. In the northeastern part of the county, the water-table elevation is a subdued expression of the surface topography and shallow groundwater flows in the same direction as surface runoff. In most of the county the surface watershed boundaries approximate shallow groundwatershed boundaries; water flows away from watershed boundaries, whether those boundaries belong to surface water or groundwater.

The State Water Use Data System (Minnesota Department of Natural Resources, 2009) is used to regulate and better understand water use patterns across Minnesota. All water users that withdraw more than 10,000 gallons per day or 1 million gallons per year must have a valid permit from the Department of Natural Resources and report their water use, so the DNR has a database of high capacity water users.

Most of the high capacity groundwater users in Todd County are located in the surficial sand aquifer area and are used for irrigation (Figure 3). Other areas of Todd County have clay till at the surface; the heavy soils in those areas retain moisture and are generally not irrigated. More than three-quarters of the permitted groundwater use by volume is used for major crop irrigation. Municipal waterworks accounts for about 14.5 percent of permitted water use. Other categories are relatively minor.

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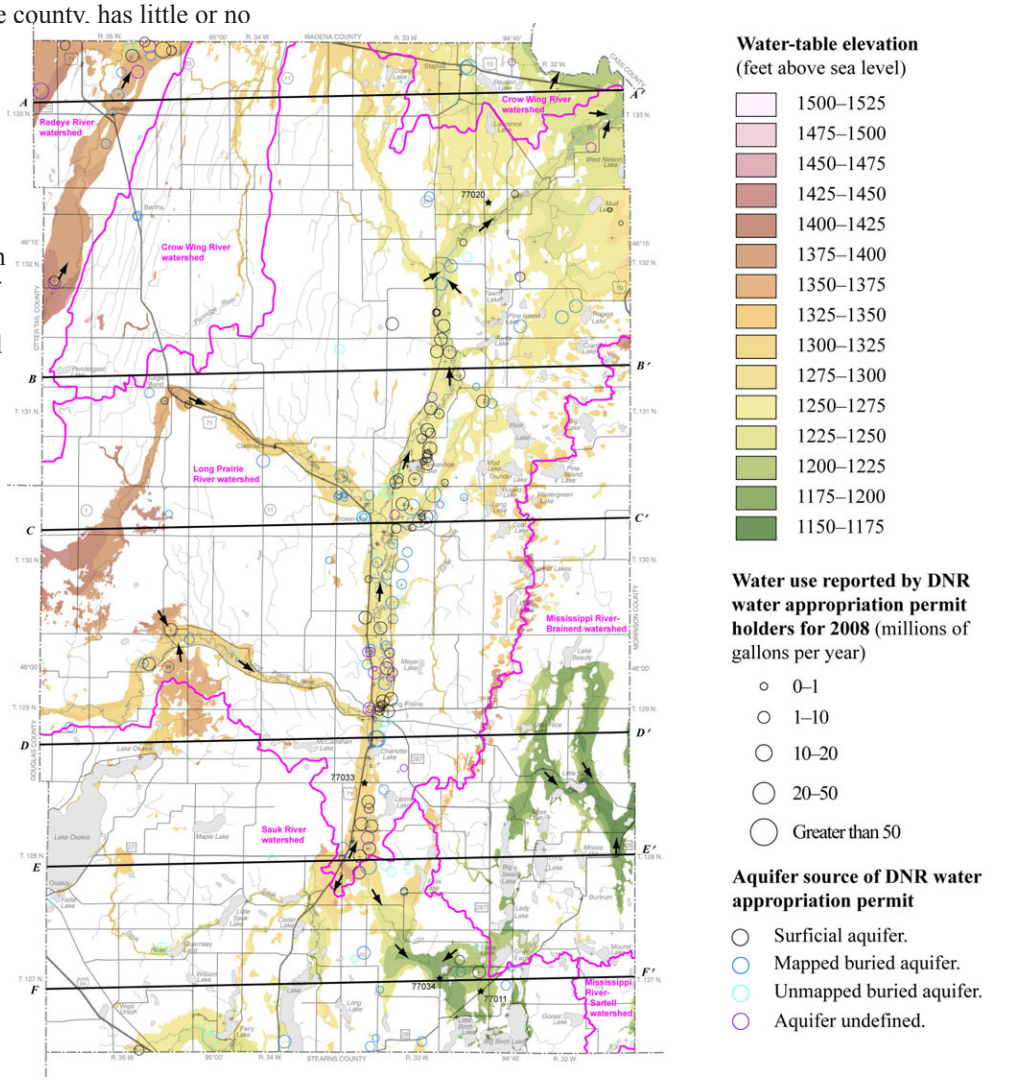

Figure 3. Water table elevation in the surficial aquifer and water use.

Todd CGA Part B, cont.

Sensitivity to Pollution of the Buried Sand Aquifers

One primary purpose of this atlas was to determine the sensitivity of the aquifers to water-borne pollution. To create a sensitivity model for the buried sand aquifers, the first step was to map the subsurface geology. These data are published in the atlas but are not shown in this article. Using geographic information system (GIS) software, elevations based on 30-meter grids were calculated for the base of the surficial sand and the top and bottom of the buried sand units that could be mapped. The fine-grained material between the sand bodies (clay or till) is considered during mapping but does not have its own gridded elevation surface. The volume of sediment between the bottom of one sand body and the top of the next lower sand body is assumed to consist of fine-grained material that acts as an aquitard and restricts the groundwater movement to the sand below.

Pollution sensitivity maps for the buried sand aquifers are based on the method of vertical recharge surfaces used in previous County Geologic Atlases and Regional Hydrogeologic Assessments (Berg, 2006; Tipping, 2006; Petersen, 2007; and Berg, 2008). Recharge surfaces for the buried sand aquifers were derived from the distribution and thickness of sand layers. The uppermost recharge surface (RS1) is initially positioned at the

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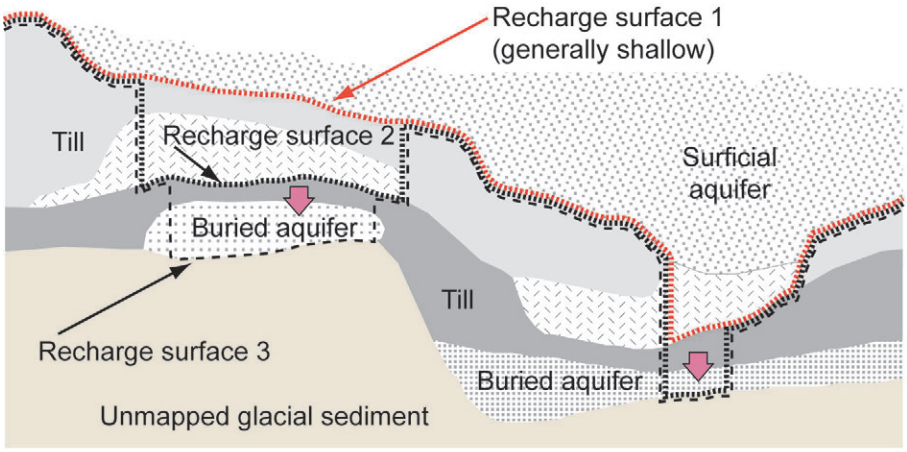
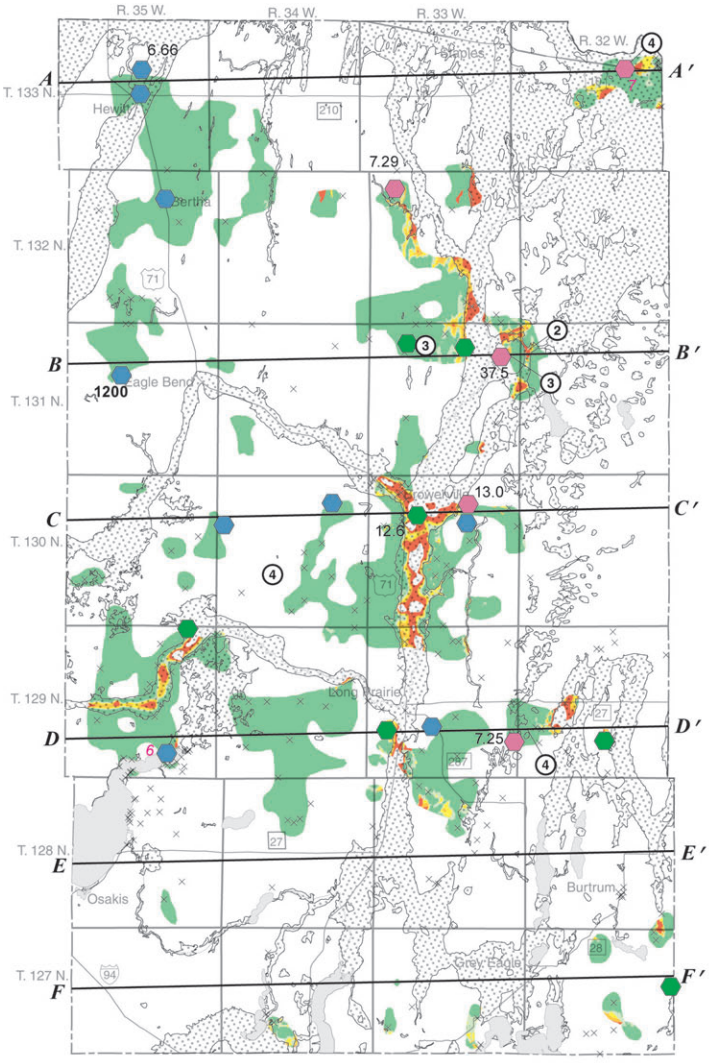


Figure 4. Generalized cross section showing recharge concepts for buried aquifers considered in the sensitivity evaluations.



Pollution sensitivity rating

Estimated vertical travel time for water-borne contaminants to enter an aquifer (pollution sensitivity target).

VH	Very High—Hours to months.
H	High—Weeks to years.
M	Moderate—Years to decades.
L	Low—Decades to a century.
VL	Very Low—A century or more.

Figure 5. Pollution sensitivity B1 buried sand aquifer.

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Todd CGA Part B, cont.

land surface (Figure 4). Where surficial sand is present, RS1 is repositioned to the base of this sand unit. The assumption is that precipitation can quickly travel to the base of the surficial sand unit.

If less than 10 feet of fine-grained sediment such as clay or till is present between RS1 and the top of the first buried sand below, then the assumption is that the first buried sand below is probably recharged vertically from water at RS1. Thus, water will travel vertically to the bottom of this buried sand body, which is labeled recharge surface 2 (RS2). RS2 is the same as RS1 where more than 10 feet of fine-grained sediment exists immediately below RS1. Deeper recharge surfaces (below RS2) are defined similarly. If the next deeper buried sand below RS2 has less than 10 feet of clay between RS2 and the top of that sand, then a third recharge surface (RS3) will be defined at the bottom of this sand. This model assumes that clay layers that are less than 10 feet thick, are fairly leaky and will allow relatively rapid recharge to the next deeper layer. Groundwater often moves horizontally, but that is not accounted for in this sensitivity model.

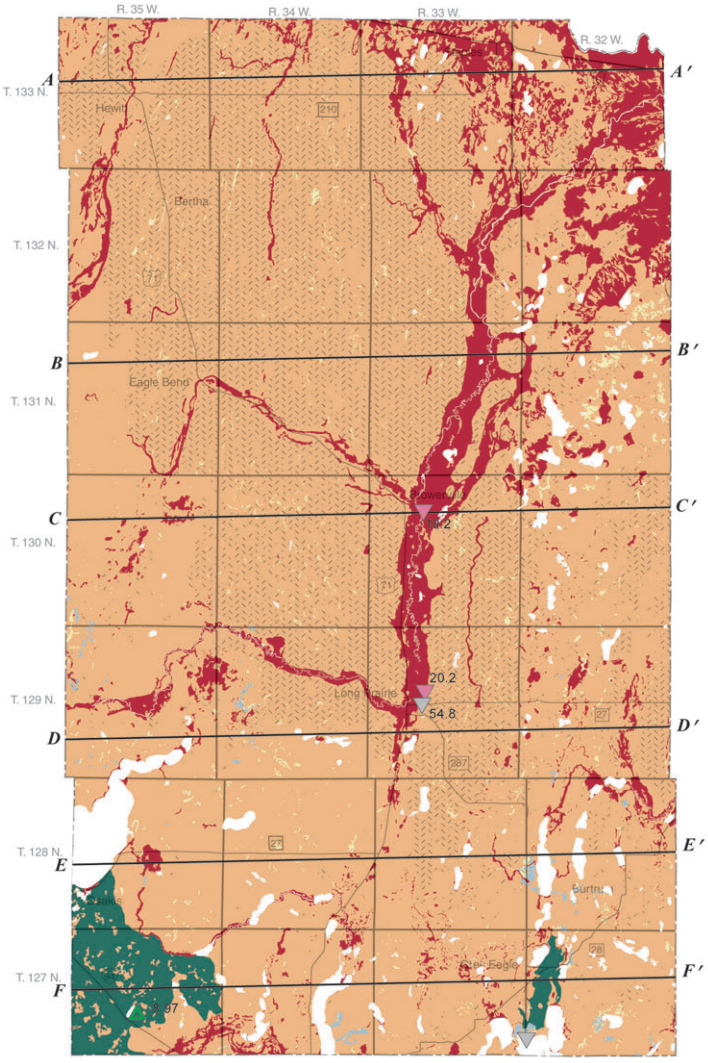
Finally, the sensitivity ratings for the buried aquifers are calculated by comparing the elevation of the upper surface of each buried aquifer with the nearest overlying recharge surface. The thickness between the top of the aquifer and the nearest overlying recharge surface is used to determine the sensitivity to pollution. The sensitivity to pollution of the B1 buried aquifer is shown in Figure 5. The sensitivity of the B1 buried aquifer is rated high to very high beneath the surficial aquifer because there is almost no fine-grained material between the surficial sand aquifer and the B1 buried aquifer.

Sensitivity to Pollution of the Near-Surface Materials

The sensitivity to pollution assessment for near-surface materials estimates the time of travel for water to travel from the land surface to a depth of ten feet (Figure 6). Soil properties are used to estimate the travel time from land surface to a depth of three feet and surficial geology properties are used to estimate the travel time from a depth of three feet to ten feet. The near-surface materials sensitivity assessment was created by estimating infiltration rates through soils and surficial geology units based on the Natural Resources Conservation Service (NRCS) hydrologic rating (NRCS, 2009) for soils and the geologic unit texture of deeper parent materials, from Knaeble and Meyer (2007a). Estimates of infiltration rates are shown in Table 1 on Plate 10 of the Todd County Atlas (Petersen, 2010).

Tipping (2006) estimated the minimum transmission rates for

— *continued on page 31*



Pollution sensitivity ratings for near-surface materials

Estimated vertical travel time for water-borne contaminants to move from the land surface to a depth of 10 feet.

- VH — Very High—Hours to weeks.
- H — High—Weeks to a month.
- M — Moderate—A month.
- L — Low—Several months.
- VL — Very Low—Months to a year.

Figure 6. Pollution sensitivity of the near-surface materials.

Todd CGA Part B, cont.

four NRCS soil hydrologic groups (A-D) based on a NRCS web publication that is no longer available. These estimated rates were used to make the near-surface materials sensitivity calculations on this plate because the numbers are of the correct order of magnitude, show the difference between coarse and fine-textured sediment, and allow consistent calculations within the county geologic atlas series.

Tipping (2006) also estimated minimum transmission rates for the surficial geologic units, which form the soil parent material. The minimum transmission rates for surficial geologic units in Todd County are mostly the same as those for Scott County used by Tipping (2006). The main difference is that in Todd County, ice-contact sand and gravel deposits, which have a very coarse texture, have been given a slightly higher minimum transmission rate of 0.6 inches per hour to differentiate them from sand units with less gravel. As with the estimates used for the soil hydrologic groups, these minimum infiltration rates are reasonable and in the correct order. That is, coarse textured material is assigned significantly higher transmission rates than fine-textured material. These minimum transmission rate estimates are also used here for consistency within the county geologic atlas series.

The near-surface materials sensitivity rating is determined by using the minimum transmission rates for the soil and surficial geologic units to calculate the estimated travel time. The water table is assumed to be 10 feet below the land surface throughout the county for this calculation. The GIS polygons from both the soil survey and the surficial geologic map are converted to grids with a 30 meter cell size. Each cell in the respective grids is assigned a minimum transmission rate. The travel time for the upper 3 feet is calculated using the minimum transmission rate of the soil unit. The travel time for 3 feet to 10 feet below land surface is calculated using the minimum transmission rate of the surficial geologic unit. The total travel time to 10 feet is then used to estimate the near-surface materials geologic sensitivity. Some soil units have not been assigned a hydrologic group (for example gravel pits) and therefore have no assigned minimum transmission rate. If a minimum transmission rate was not available for a soil unit, then the surficial geology unit minimum transmission rate was used to calculate the travel time for the entire 10-foot distance.

The map of the near-surface materials sensitivity (Figure 6) rates most of Todd County as high sensitivity with fairly quick penetration of water from the land surface to a depth of ten feet. Very high near-surface sensitivity ratings are confined to surficial sands, which are primarily located in the river valleys. Areas with low and very low near-surface materials sensitivity, in the southwest and southeast corners of Todd County, correlate with the occurrence of surficial geologic units nt (till) and nc (till, sand and gravel complex) of the New Ulm Formation. These units have very fine textures of clay loam and loam with low transmission rates.

For More Information

The Todd County Geologic Atlas, Parts A and B can be purchased at the Minnesota Geological Survey, Publications Office, 2642 University Avenue, St. Paul, Minnesota 55114, (612) 627-4782. Portable document file (.pdf) images of the plates are available for download. Please see the DNR, Division of Ecological and Water Resources website at www.dnr.state.mn.us/waters/groundwater_section/mapping/status.html for Part B access and download instructions. Data files for Part B are also posted online. PDF images and data files for Part A of the report can be downloaded from the MGS ftp site at ftp://mgssun6.mngs.umn.edu/pub5/c-18.

For additional information, contact Todd Petersen (651) 259-5698, Jan Falteisek (651) 259-5665, or Dale Setterholm (612) 627-4780.

References cited

Berg, J. A., 2006, Geologic Atlas of Pope County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-15, Part B, 4 pls., scale 1:100,000.

Berg, J. A., 2008, Regional Hydrogeologic Assessment, Traverse-Grant Area, West-Central Minnesota: St. Paul, Minnesota Department of Natural Resources Regional Hydrogeologic Assessment Series RHA-6, Part B, 4 pls., scale 1:250,000.

Knaeble, A.R. and Meyer, G.N., 2007a, Surficial Geology [Plate 3], in Geologic Atlas of Todd County, Minnesota: Minnesota Geological Survey Atlas Series C-18, scale 1:100,000.

Knaeble, A.R. and Meyer, G.N., 2007b, Quaternary Stratigraphy [Plate 4], in Geologic Atlas of Todd County, Minnesota: Minnesota Geological Survey Atlas Series C-18, scale 1:100,000.

Minnesota Department of Natural Resources, 2009, State Water Use Data System: Minnesota DNR, accessed December 2009 at http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html

Natural Resources Conservation Service (NRCS), 2009, Hydrologic Soil Groups, Chapter 7, accessed at http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=22526.wba

Petersen, Todd, 2007, Geologic Atlas of Crow Wing County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-16, Part B, 4 pls., scale 1:100,000.

Petersen, Todd, 2010, Geologic Atlas of Todd County, Minnesota: St. Paul, Minnesota Department of Natural Resources County Atlas Series C-18, Part B, 4 pls. scale 1:100,000.

Tipping, R. G., 2006, Subsurface recharge and surface infiltration [Plate 6], *in* Geologic Atlas of Scott County, Minnesota: Minnesota Geological Survey Atlas Series C-17, scale 1:150,000.

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MGWA BOARD MINUTES

Minnesota Ground Water Association Board Meeting Minutes

Meeting Date: September 8, 2011

Location:	Fresh Grounds Restaurant, 1362 West 7th Street, St. Paul, MN
Attendance:	Mindy Erickson, President; Steve Robertson, Past President; Jill Trescott, Secretary; Kelton Barr, President-elect; Jeanette Leete, WRI; Sean Hunt, WRI; Audrey Van Cleve, Treasurer
Past Minutes:	August minutes approved as amended.
Treasury:	Cash on hand is approximately $42,000. Treasurer has not yet been to Affinity to adjust the accounts to maximize interest income.
Newsletter:	WRI has the files and is waiting for author approval.
Web Page:	The web version of the salary survey article will include the tables as separate links. The Google calendar is being used for booth sign-up.
WRI Report:	Quickbooks has been prepared for 2012.
Foundation:	The Pfannkuch account was set up at Affinity. Quickbooks was purchased for the Foundation for $25.
Old Business:	GSA 2011: Audrey reported that booth sign-up was going well. She asked about day passes for the workers. Jill moved to authorize Audrey to purchase passes for booth workers as needed. Mindy seconded. All in favor. Midwest Groundwater Conference (presented by MGWA, October 1-3, 2012). Kelton will be going to the 2011 conference to preview it on behalf of MGWA. Midwest Groundwater Conference (presented by MGWA). Monday and Tuesday, ● AIPG Payment: payment of $550 was authorized.
Next Meeting:	Thursday, October 6, 2011 (changed to Thursday, November 3, after meeting) at 11:30 at Fresh Grounds

Meeting Date: November 3, 2011

Location:	Fresh Grounds Restaurant, 1362 West 7th Street, St. Paul, MN
Attendance:	Mindy Erickson, President; Steve Robertson, Past President; Jill Trescott, Secretary; Kelton Barr, President-elect; Jeanette Leete, WRI; Sean Hunt, WRI; Audrey Van Cleve, Treasurer
Past Minutes:	September minutes approved as amended.
Treasury:	Cash on hand is approximately $34,800. Net income for the year will be somewhat negative, but that was expected because of the GSA meeting.
Newsletter:	Jennie reported on the newsletter. Space has been created in Google Docs for the December issue. Extra copies of the September issue were handed out at the GSA conference.
Web Page:	The GSA information will be removed and the 2012 conference information added.
WRI Report:	The monthly activity report was handed out.
Foundation:	The Foundation Board may be meeting next week. “Give to the Max” Day was discussed. Kelton moved to authorize up to $5000 in matching funds for donations to the Foundation. Steve seconded. All in favor.
Old Business:	GSA 2011: Attendance was very good. Mindy moved to pay Ani Schroeder $500 for display design. Audrey seconded. All in favor. Google Docs was used to schedule the booth shifts. Otto Strack sent a thank-you letter to MGWA. Midwest Groundwater Conference (presented by MGWA, October 1-3, 2012). Kelton reported on the 2011 conference in Kentucky. There were about 50 attendees. The decision was made to proceed with the Earle Brown Center for 2012, but not to reserve Embassy Suites for now. A brainstorming session for topics was planned for November 7 (however, this session was cancelled after the meeting). Newsletter: Kelton discussed strategies for the newsletter but the discussion was tabled.

MGWA 2011 Membership Dues

Professional Rate:	$35
Full-time Student Rate:	$15
Newsletter (printed and mailed)	$20
Directory	$7

Membership dues rates were revised at the October 1, 2010 meeting of the MGWA Board. The Board intends to balance the membership services budget.

The MGWA Board of Directors meets once a month.

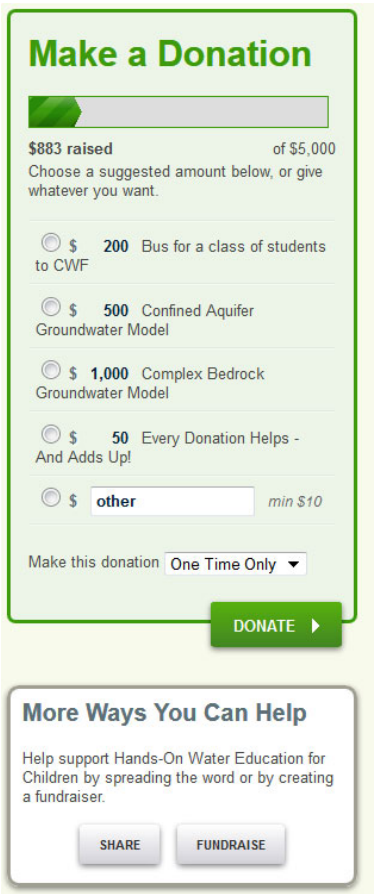
All members are welcome to attend and observe.

FOUNDATION FUNDRAISING UPDATE

Minnesota Ground Water Association Foundation Fundraising Challenge

The Board of MGWA challenged the membership of the Association to try to raise $5,000 for the Foundation before the end of the year. This was a very ambitious goal that we approached in three ways. First, we agreed that the Association would match funds raised by December 31, 2011 up to a total match of $5,000. Second, we signed up, on behalf of MGWAF, as a fundraiser for the 'Give to the Max Day' campaign. Third, the annual membership renewal forms were adapted to show the different types of funds for which the Foundation is soliciting donations: Scholarship Endowment, General Funds for Educational Activities, and the Hans-Olaf Pfannkuch Fund.

The current (12-28-2011) total raised stands at $1,926.00, thus adding at least $3,852.00 to Foundation Funds. Thank you all!



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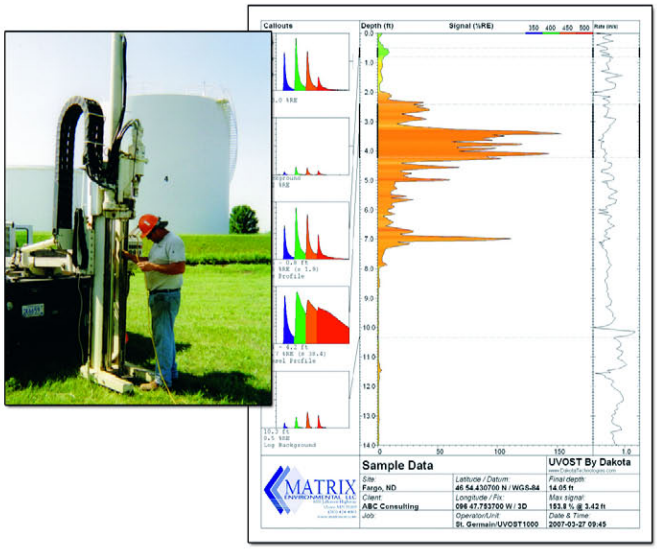

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14th Metro Children's Water Festival – Thanks to You!

Open Letter From Jen Irving
Water Resources Assistant
Carver County

Can you believe it has been over a month since we all gathered at the fairgrounds for the Children's Water Festival? On behalf of the planning committee and hundreds of 5th graders, I'd like to thank each and every one of you for your help. Simply put, it wouldn't happen without you.

For most of us it is rewarding enough to see kids get involved and excited about science and environmental education. In case you had any doubt about the impact the CWF has on these youngsters, I've copied some notes we received from a class from Jordan Middle School for your reading pleasure.

"Thanks for holding the Water Festival! It was soooo great that I couldn't believe my ears and eyes about how to save our water. My favorite thing was when we went to the Mercury Station and learned about mercury and how it can damage and even KILL humans and fish!"

"Thank you so much for letting us come for free! I'm writing about two of my many favorite things that were there. One of my favorite stations was where the people form the Science Museum talked to us about water and how it is used and how to conserve it. That really inspired me to try and use less and conserver water. My other favorite station was the play because it was fun, entertaining, and interesting. I also liked the puppets because they looked cool."

"I liked the mystery of the disappearing waterfall. I learned that Minnesota had a waterfall and that it eroded away all the way to what is now St. Anthony Falls in the Twin Cities. The play Water, Water From the River to the River was interesting and fun. But I learned that you should not let oil or trash get into the water."

" I really liked getting our picture taken with the raindrop. It gave me a hug!!!"

"Thank you for setting this up for JMS. My favorite part of the water festival was the Water, Water, From the River to the River. My next favorite part of the water festival was the Science Museum with the lady who showed us how much water we use in just the morning. I also liked how she showed us that the water that we drink is the same water that the dinosaurs drank. It was cool!"

"Thank you for putting together the water festival and letting us come for free. We had a great time. I especially liked the Water! Water! Water! Play where we learned that water washes a lot away. Like if you oiled your bike and it rained, it gets in the lake. Another station I really liked was How Fish get Mercury. I learned that mercury is greyish-silver, not red and that if you inhale mercury you can die."

"I had a very good time at the water festival. It was very well organized and it was cool how our leader brought us everywhere. One of my favorite stations was Mercury in our Fish. I learned how fish would eat these little bugs that are in the water and then the predator fish would eat those little fish. Then the predator fish would get mercury. Eventually they would die. Another of my favorites was the play where if you dump stuff down city drains it can run into fresh water and kill animals. Thank you it was a great time."

Those are just a few of the notes we received. Thank you all so much for participating and we hope to see all of you again next year.

The MGWA Foundation is a 501(c)3 charitable organization. Donations to the Foundation are deductible on your state and federal income tax returns.