Minnesota Ground Water Association

Volume 16, Number 3: September, 1997

President's Column

— Ray Wuolo, Barr Engineering Co.

From the point of view of Minnesota's surface-water hydrologists, this has been a fairly eventful year. First, we had the massive snow melt, followed by flooding in the Red River Valley that didn't attain biblical proportions but made CNN's Headline News several times (and the local stations didn't even have to go hunting for the infamous "Minnesota Connection"). Then we had a miserably wet July, with flash flooding, geysers erupting from storm sewers, and copious amounts of standing water. The hydrologists got their share of air time, too. I even heard an explanation of the US Army Corps of Engineers' HEC-1 model on one program. So, ground water types, are you feeling left out yet? If so, we're going to try and rectify that somewhat.

Our September field trip, organized in conjunction with the local chapters of the Association of Professional Geologists and the Association for Women Geoscientists is shaping up to be very interesting and a lot of fun. We'll be spending our time in the southeast corner of the state during a very nice time of the year (the mosquitos should be just about gone by then). And the karst terrains will give us a chance to see groundwater moving somewhat faster than a few feet per year. If you haven't been on an excursion in this scenic area, don't pass up the opportunity.

MGWA's fall meeting is typically more technical in nature than the spring meeting. This year's fall meeting will be held sometime in November at a location yet to be decided. We are in the early stages of working on an educational program oriented toward the interaction between surface and ground water. One topic that we know

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Winona County Sinkholes

— Janet Dalgleish, Barr Engineering Co. and Suzanne Magdalene, University of Minnesota

Two studies were performed to document the density and distribution of sinkholes in Winona County and to relate sinkhole distribution to geology and/or hydrogeology. Sinkhole distribution in Winona County was first mapped in 1983 by Dalgleish and Alexander (1984b), and 535 sinkholes were used to define sinkhole probability zones. The sinkhole distribution was revisited in 1992 by Magdalene and Alexander (1995), identifying 73 additional sinkholes that were added to the original survey for geostatistical analysis.

Sinkholes serve as direct links between the land surface and karst aquifers, causing the groundwater to be highly susceptible to contamination. The travel time of water moving from the surface to karst aquifers via a sinkhole can be as short as minutes with minimal filtration through sediments. Water pollution in the aquifer can return to the land surface in springs, where it affects wildlife, domestic animals, and human populations alike. Careful planning is needed in Winona County where the primary aquifer is the Prairie du Chien Group, a karst aquifer. The following is a summary of the two sinkhole distribution studies.

Sinkhole Distribution — 1983

This study was performed to document the density and distribution of sinkholes in Winona County and to relate that distribution to variations in bedrock geology, surficial geology, and/or hydrogeology. A second goal was to produce a sinkhole probability map of Winona County that would aid state and county water resource managers, and local residents in protecting the regional groundwater system, which is highly susceptible to contamination.

Bedrock Geology

Sinkhole distribution in Winona County appears to be controlled primarily by bedrock lithology. The lower Shakopee Formation, and in particular the New Richmond Sandstone, appears to be the bedrock strata most conducive to sinkhole formation. Considering that the majority of the sinkholes are developed in these strata, regardless of the other controls on sinkhole development, stratigraphic position is the primary geologic control.

Water flowing through the New Richmond will not be totally neutralized when it contacts the Oneota Dolomite since the New Richmond Sandstone contains only a small proportion of calcium carbonate. The aggressive water collects in joints of the New Richmond Sandstone which is then channeled to the Oneota Dolomite. This system directs aggressive water, capable of further dissolving the bedrock, along joints in the Oneota Dolomite. As the joints in the Oneota are enlarged, the New Richmond Sandstone collapses into the Oneota dolomite as shown in the block diagram (Figure 1).

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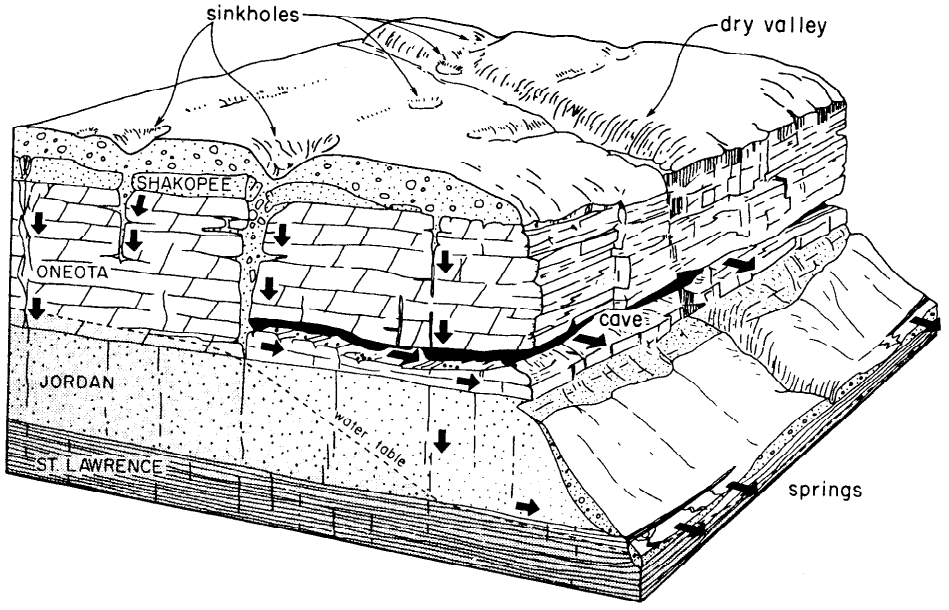

Figure 1: Typical relationships in Winona County between karst and topography (Dalgleish and Alexander, 1984a)

Surficial Geology

The density of sinkholes is not constant over the New Richmond Sandstone; therefore, other geologic controls must be affecting sinkhole formation. Surficial geology appears to have an impact on sinkhole development, particularly the lithology and thickness of surficial materials. Sinkhole densities are greatest in areas where the surficial materials are a thin sand and noncalcareous till, and lowest in areas covered by thick loess over a calcareous till.

Paleokarst Surface

Another factor to consider is the age of the bedrock surface. In Winona County, the age of the bedrock surface generally decreases to the west as the carbonate content of the surficial material increases. The surface of the Prairie du Chien Group to the northeast has been exposed to weathering for a longer time period. This implies that the paleokarst surface is progressively younger to the southwest. The irregular paleokarst surface probably directs water percolating through the sediments into previously enlarged joints and sinkholes. Paleokarst sinkholes would not only provide additional water for further dissolution of the rock, but the increased volume of water would be capable of transporting sediment deeper into the bedrock. As sediment is transported deeper into the bedrock, cavities will form due to piping, eventually resulting in surface collapse or subsidence. Initially sinkholes may open in sites of paleosinkholes. Once the renewed sinkhole opens, surface water may be channeled toward that area causing additional collapses. This process is more evident in eastern Winona County where sinkholes with wide shallow depressions and small almost vertical holes in the center are common.

Sinkhole Probability Map

The relative likelihood for future sinkhole development was estimated on the basis of the observed density of sinkholes, together with information on the bedrock geology, surficial geology, and hydrogeology. This information was used to prepare a sinkhole probability map for the county (Dalgleish and Alexander, 1984a). The following five regions of sinkhole probability were defined:

- *No Probability* - The surface area exposed in the deep valleys incised below the Prairie du Chien Group is not susceptible to sinkhole formation.

- *Low* - No sinkholes were detected and few if any sinkholes are expected to develop on the steep slopes of the Oneota Dolomite at the top of the deeply incised valleys.

- *Low to Medium* - Areas where sinkholes are widely scattered with only small isolated clusters of 2 to 3 sinkholes.

- *Medium to High* - Sinkholes are generally moderately distributed with several clusters of 4 to 10 sinkholes.

- *High* - Overall the sinkhole density is relatively high with large clusters of more than 8 sinkholes. This region includes some smaller areas where sinkhole densities appear similar to the medium to high region; these areas were included because there was no indication of geologic or topographic differences from the highly concentrated area to inhibit sinkhole formation. The differences in density are probably random variations in landscape development.

The bedrock geology, surficial geology, and paleokarst surface are intertwined controls on sinkhole formation in Winona county. The relative importance of these factors varies through the study area. These factors were further studied in greater detail using sophisticated geostatistical methods in 1995.

Statistical Analysis of Sinkhole Distribution — 1995

This study was undertaken to update the sinkhole database for Winona County, to use the newly identified sinkholes to evaluate the sinkhole probability map, and to characterize the sinkhole distribution using geostatistical methods. A secondary goal was to evaluate sinkhole treatment as a best management practice used to reduce nonpoint source pollution to karst groundwater.

The 1992 sinkhole survey found 73 sinkholes that had not been identified in the original survey — 39 older sinkholes missed in the first survey and 34 new sinkholes that had developed since 1983. The newly identified sinkholes were similar in shape and dimension to the original sinkholes: steep-walled with less than 10 m (30 ft) diameters. However, the 1983 survey identified sinkholes that were more than 25 years old and were open holes located on the ridges of the karst plateau. In contrast, the

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1992 survey identified predominately newer sinkholes that were located on slopes and in waterways and were closed due to sinkhole treatment.

Sinkhole Probability Map

The 1992 sinkhole survey was plotted on the sinkhole probability map (Dalgleish and Alexander, 1984a) of the Winona County Geologic Atlas. All of the 73 newly indentified sinkholes are in the High to Moderate-to-High sinkhole probability zones. This is an encouraging test of the criteria used to develop the original map.

Moving Window Analysis

The areal extent of the Prairie du Chien plateau in Winona County is 1167 km^2 (452 mi^2), and the average sinkhole density is 0.52 sinkholes/km^2 (1.35 sinkholes/mi^2). Using a moving window analysis with a 1.69 km^2 window size, the range of sinkhole densities across the study area are 0 to 14.8 sinkholes /km^2.

Nearest Neighbor Analysis

The direction and distance from each sinkhole to its nearest neighbor was calculated. The newly updated sinkhole data set was evaluated with the Clark and Evans (1954) and the Skellam (1952) tests for complete spatial randomness. Both statistical tests compare the observed mean distance to nearest neighbor (L_a) with the expected distance to nearest neighbor of a random sinkhole set (L_e). The Clark-Evans random spatial index R is the ratio of the observed and expected distances, or $R = L_a/L_e$. R ranges from 0 (maximum aggregation or clustering) to 1.0 (complete spatial randomness) to 2.149 (regular hexagonal pattern). If the value of R is significantly less than 1.0, the points are more clustered than random. If the value of R is significantly greater than 1.0, the points are more regular than random. The value of R is also an indication of the degree of clustering or regularity of the observed sinkholes.

The Clark-Evans test was applied to the Winona County sinkholes, with modifications for the edge-effect of the straight county boundaries on the west and south sides of the study

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The primary objectives of the MGWA are:

- Promote and encourage scientific and public policy aspects of ground water;
- 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.

Bonnie Holz named Groundwater Hero

The Groundwater Foundation, Lincoln, Nebraska has named Bonnie Holz of St. Peter, Minnesota recipient of the 1997 Vern Haverstick Groundwater Hero Award. The Groundwater Foundation, a national non-profit organization dedicated to educating the public about the nature and value of groundwater, established the award to honor groundwater achievement on the local level by a groundwater "spark plug". Bonnie Holz is the director for Brown-Nicollet Environmental Health in St. Peter, Minnesota. She initiated the "first of a kind" groundwater testing program which was a wide spread rural testing program conducted on a township by township basis. Under her direction, a three-county Joint Powers Board was formed to study water quality in Brown, Nicollet and Cottonwood counties. Other activities include internships for high school and college students and public demonstrations of many topics affecting groundwater.

—Groundwater Foundation News Release, June 9, 1997. The Groundwater Foundation home page is www.groundwater.org

1997 Board of Directors

area and with modifications for the stream-cut boundary on the northeast side of the study area. Figure 2 shows a comparison between the observed sinkhole locations and one of six randomly-generated sinkhole data sets used for this study. The Clark-Evans random spatial index R for Winona County sinkholes is 0.490. Since R has a normal probability distribution, with a mean of 1.0, then the probability that the Winona County sinkholes are distributed randomly is effectively zero. The sinkholes in Winona County are clustered. The observed distance between nearest-neighbor sinkholes is about half the expected distance for nearest-neighbors in a random distribution.

Comparison of nearest-neighbor results with sinkhole ages reveals that the newer sinkholes tend to form in clusters. And, instead of being clustered around an older sinkhole, the majority of new sinkholes are nearest to another new sinkhole. The locations of recently-developed sinkholes is the best predictor of where new sinkholes might develop (Beck, 1991; Upchurch and Littlefield, 1987).

Controls on Sinkhole Development

The nearest neighbor analysis was used to evaluate whether water flow through the regional joint sets in the karst bedrock have significant control over sinkhole development. With enhanced carbonate dissolution along the joint sets, sinkholes should develop in linear patterns along those joint sets. The directions to nearest neighbors plotted on a stereonet should reveal a preferred orientation and should not pass a chi-squared test for randomness. The observed directions to nearest neighbors of Winona County sinkholes shows a slight preferred orientation along N80E, and failed the chi-squared test at the 0.05 significance level. However, six random number sets also failed this test for randomness, so these results are inconclusive. It is unclear whether regional joint sets control sinkhole development.

Surface water hydrology appears to be a significant control on sinkhole development. During the 1992 sinkhole survey, it was observed that many of the older and newer sinkholes have developed in surface water drainage ways. This field observation was tested against a multinomial probability distribution, since the sinkhole database has three codes for topographic setting: Crest, Side-Slope, and Waterway. The soil map units in the Winona County Soil Survey (Lueth, 1994) were assigned to one of the three topographic settings, and were used to determine the expected proportions of the three settings. Under a random process, the sinkholes are expected to develop in the Crest, Side-Slope, and Waterway settings in the proportions of 44%, 50%, and 6%, respectively. The observed distribution of the sinkholes in these settings, 47%, 36%, and 17%, is significantly nonrandom. It is possible that persistent infiltration into the karst subsurface below these surface waterways may enhance carbonate dissolution, initiating sinkholes that are

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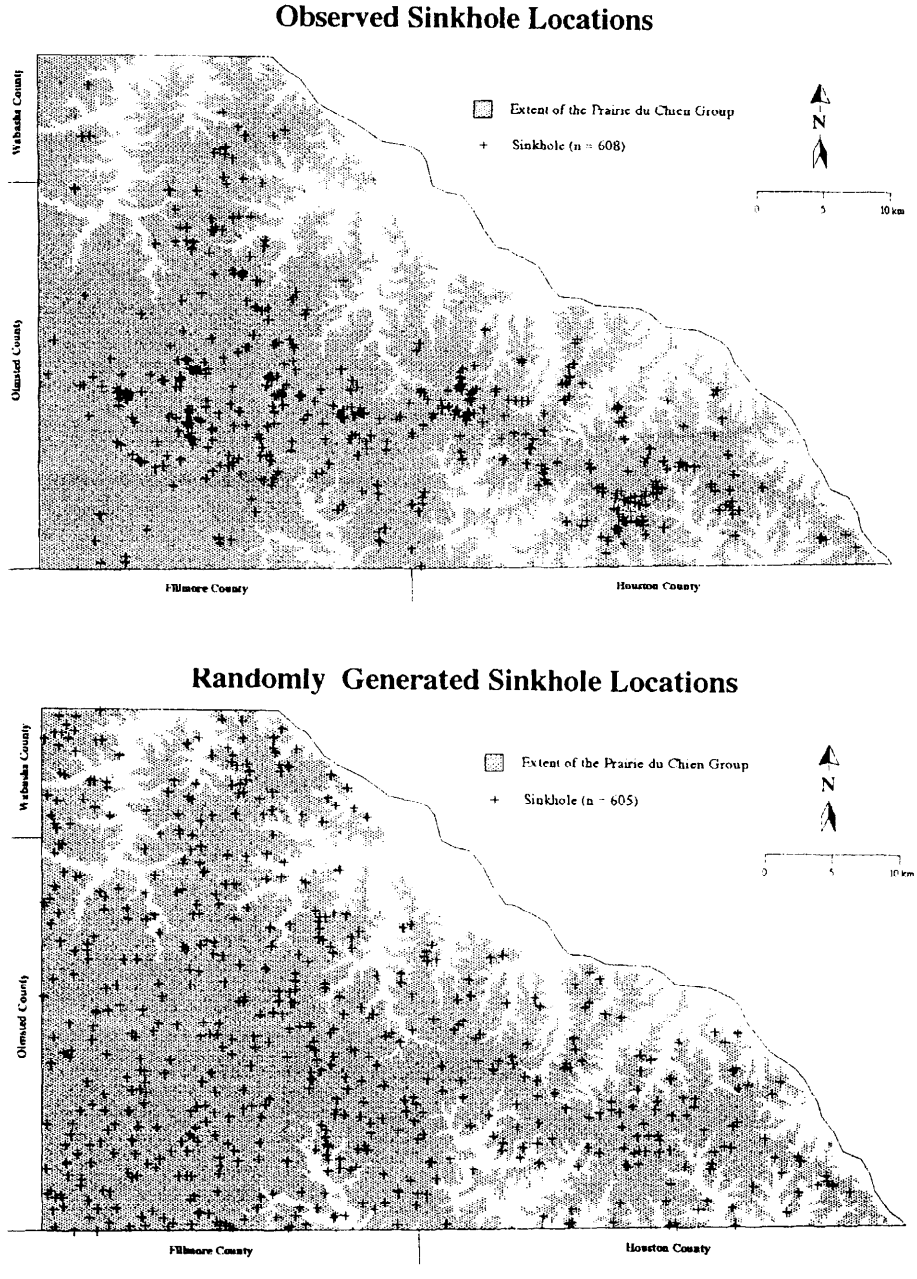

Figure 2: Sinkhole locations in Winona County, a) observed 1994 locations, and b) randomly generated locations.

MGWA Calendar

Contact information for the major event-holders is listed at the end of the column.

September 26-27, 1997. Joint AIPG/MGWA/AWG Fall Field Trip, southeastern Minnesota, with guest speakers Maureen Muldoon, Wisconsin Geological Survey, and Robert Libra, Iowa Geological Survey. AIPG is leading, contact Bill Johnsen, Natural Resource Group (612)347-6793, email: bjohnsen@NRGINC.com

September 20, 1997. Ground Water Protection Council Annual Forum, Cleveland OH. A conference on ground water, watersheds, source water, wellhead protection, and underground injection control. Contact: GWPC, 827 NW 63rd #103, Oklahoma City, OK 73116, (405) 848-0690, gwpc.site.net

September 22-25, 1997. Analysis and Design of Aquifer Tests Including Fracture Flow. Columbus, OH. NGWA

September 22-23, 1997. Natural Attenuation for Remediation of Contaminated Sites. Columbus, OH. NGWA

October 1-3, 1997. 7th Annual GIS/LIS Conference, St. Cloud, MN. Contact: (320) 654-5270, http://www.lmic.state.mn.us/gislis/gislis or http://199.17.7.81/gislis7.htm

October 19-23, 1997. Conjunctive Use of Water Resources: Aquifer Storage and Recovery. Long Beach, CA. Contact: American Water Resources Association, 950 Herndon Parkway, Suite 300, Herndon, VA 20170-5531.

October 20-23, 1997. Geological Society of America (GSA) Annual Meeting. Salt Lake City. Preregistration by September 19, 1997.

October 22-24, 1997. Midwest Ground Water Conference. Coralville, IA. Contact: Robert Buchmiller, P.O. Box 1230, Iowa City, IA 52244, email: mwgwc@usgs.gov

October 24, 1997. Improving Hydrologic Investigations Part 1: Site geologic characterization in glaciated areas, Indianapolis, IN. Contact: Midwest GeoSciences Group.

November 3-4, 1997. Fundamentals of Ground Water Geochemistry. Boston, MA. NGWA

November 5-7, 1997. Applications of Ground Water Geochemistry. Boston, MA. NGWA

November 10-12, 1997 DNAPLs in Fractured Geologic Media: Behavior, Monitoring and Redmediation, San Francisco, CA. Contact: Waterloo Educational Services, Inc., (519) 836-3102 or University or Waterloo, (519) 888-4567 x 5935 or e-mail: pbonin@cgrpc.watstar.uwaterloo.ca

November 12-14, 1997. NGWA Petroleum Hydrocarbons Conference/Expo. Houston, TX. NGWA

November 14, 1997. Improving Hydrologic Investigations Part 1: Site geologic characterization in glaciated areas, Oak Brook, IL. Contact: Midwest GeoSciences Group.

November 15, 1997. Improving Hydrologic Investigations Part 1: Site geologic characterization in glaciated areas, Milwaukee, WI. Contact: Midwest GeoSciences Group.

November 16-19, 1997. International Conference on Advances in Ground Water Hydrology—A Decade of Progress. Tampa, FL. AIH

December 8-10, 1997. Principles of Ground Water—Fate, Transport and Remediation. Salt Lake City, UT. NGWA

December 15-19, 1997. Princeton Remediation Course. Las Vegas, NV.

January 13-17, 1998. PC Applications in Risk Assessment, Remediation and Modeling. Orlando, FL. NGWA

February 9-13, 1998. Princeton Ground Water Pollution and Hydrology Course. Orlando, FL.

February 15-19, 1998. Princeton Ground Water Pollution and Hydrology Course. San Francisco, CA.

March 12-14, 1998. Visual MODFLOW: The Standard Modeling Software Package for the USGS's MODFLOW/MODPATH and MT3D. Denver, CO. NGWA

May 18-21, 1998

First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, CA. Contact: The Conference Group, 1989 W. Fifth Avenue, Suite 5, Columbus, OH 43212-1912, (800) 783-6338.

Contacts:

for NGWA events:
1-800-551-7379 or
http://www.h2o-ngwa.org

for GSA events:
http://www.geosociety.org

for Princeton's events:
http://www.princeton-groundwater.com or email:
info@princeton-groundwater.com

for Wright State University events:
WSU, Center for Ground Water Management, 3640 Colonel Glenn Hwy, 056 Library, Dayton, OH 45435. (513) 873-3648, IRIS@desire.wright.edu; http://biology.wright.edu/cgwm/cgwm_home.html

for AIH events:
AIH, 2499 Rice Street, #135, St. Paul, MN 55113-3724. (612)484-8169. (612) 484-8357 (fax). e-mail: AIHydro@aol.com

for Midwest Geosciences events:
Midwest GeoSciences Group, Suite 137-137, 931 West 75th Street, Naperville, IL 60564.

President's letter, cont.

we will be including is the hydrogeology of natural and artificial wetlands. Our goal is to provide you with the latest thinking on surface-water-groundwater interaction from those doing the research and hope you take away some practical information that you can use in your work.

Finally, I wanted to make a plug for Mars. Between the floods, Mars and Martian geology has gotten an incredible amount of visibility, courtesy of NASA and the Jet Propulsion Laboratory. It seems that we can expect to hear a lot more about anorthosite chemisty and fluvial boulder imbrication in the years to come. But there is a very intriguing aspect to exploration of Mars and that is the possibility of groundwater below the surface. Anyone out there interested in doing a pumping test that might require some extended out-of-town travel?

— Ray can be reached at rwuolo@barr.com

MGWA Board Meeting Minutes

May 8, 1997, Egg & I, University and 280, 7:30 a.m.

Attending: Ray Wuolo, President; Gretchen Sabel, Past-President; Paula Berger, President-Elect; Jan Falteisek, Secretary; Tom Clark, newsletter editor; Jim Almendinger, advertising; Jeanette Leete, Sean Hunt, WRI.

Approval of Minutes — Ray Wuolo called the meeting to order at 7:40 a.m. Minutes for April were approved with corrections.

Post-Mortem on Spring Meeting — There was general agreement that the spring meeting was a success with 70-75 attending. Preliminary costs were estimated at $700. Gretchen suggested a check box be added to future registration forms for ordering MGWA products — mugs, t-shirts, etc. Ray suggested that t-shirts might be made for the field trip. Ray also said that George Iwan and Jim Balogh would like to do a similar program in a year or two, after the grandfathering period closes, covering continuing education and other issues. They also indicated that they could prepare articles for the newsletter.

Fall Field Trip — Ray asked for an update on the preparation for the fall field trip. It was noted that planning activities were on schedule.

Wisconsin AWRA — The idea of a joint spring meeting with the Wisconsin Chapter AWRA on wetlands was discussed. However, in this case, other ideas for the fall conference would be needed.

Newsletter/Directory Update — Tom noted that August 15th was the final date for all material for the next newsletter. Jim Almendinger said he was getting too busy to do the advertising. Tom said he would write an item for the newsletter asking for someone with interest in the assignment.

Scholarships — So far this year, $300 has been given to St. Cloud State University Geology Dept. Several requests were discussed, including University of MN, and University of WI, River Falls. A motion was ap-

to send $300 to the University of MN for their hydrogeology field camp this summer. Paula will send the check.

Memberships — It was noted that membership renewals were still trickling in.

Fall Conference — Ray suggested the topic of wetlands for the fall conference, with the possibility of speakers from the U.S.G.S. in Wisconsin and/or the University of Wisconsin.

June 5, 1997, Egg & I, University and 280, 7:30 a.m.

Attending: Ray Wuolo, President; Gretchen Sabel, Past-President; Paula Berger, President-Elect; Paul Bulger, Treasurer; Jan Falteisek, Secretary; Tom Clark, newsletter editor; Jim Almendinger, advertising; Sean Hunt, WRI; Bill Johnsen, AIPG.

Approval of Minutes — Ray Wuolo called the meeting to order at 7:40 a.m. Minutes for May were approved with one date correction noted.

Fall Field Trip — Bill Johnsen provided an update of progress toward the Fall Field trip. He noted that planning activities were nearly on schedule. Preliminary plans indicated an overnight stop in Rochester, dinner probably in Preston with an optional cave tour after. By mid-June the announcement needs to be ready with follow-up mailings later.

Fall Conference — Ray said that he had talked with the USGS in Madison regarding a fall program on wetlands. Ray indicated Randy Hunt, USGS would be coordinating and getting back to Ray shortly. By the next Board meeting, Ray should have dates and topics from Wisconsin. Possible facilities were discussed, mostly near the MN-WI border.

Spring 98 Meeting — The idea of a joint spring meeting with the Wisconsin Chapter AWRA was discussed.

Newsletter/Directory Update — Tom noted that the newsletter team had met that week to block the September issue. Jan Falteisek will be the lead on the issue, which will feature SE MN. Noted again the need for a replacement for Jim Almendinger, as advertising manager.

Scholarships — Paula reported that she had sent a check for $300 to the University of MN for their hydrogeology field camp this summer. Paula said she would send additional letters announcing the scholarship and availability of funds.

Web Site — Sean said he was looking into options for establishing a Web site for MGWA and discussed several options with the Board.

Memberships — Sean noted that the membership list was ready to be generated for the directory. Tom said he had the updated referral list for the directory.

Table Display — Jan noted that a table display may be available for donation to the MGWA and asked if the Board saw the need to have a display. Consensus was that a display could be used – Jan said she would get the word back to the possible donor.

Meeting adjourned 8:30 a.m.

Respectfully Submitted,
Jan Falteisek
MGWA Secretary

Help Wanted

Postitions avilable on MGWA Board for 1998 and beyond. Vancancies now for President Elect (serves 1998 - 2000) and Secretary (serves 199801999). Contact Ray Wuolo at 832-2696 or rwuolo@barr.com if you'd like more information.

Child Falls Into Abandoned Well in Illinois

In September 28, 1996 a ten year old boy sustained serious injuries when he fell into an abandoned well in a park in Mackinaw, IL. After falling onto a concrete covering, which gave way, the child plunged forty feet to the bottom of an abandoned 103 year old dug well breaking both legs and an arm. Village officials thought the well was properly abandoned – but it was not. Working with a consulting engineering firm, the Village sealed the well with bentonite immediately following the near tragic accident.

—From Aquanotes, Illinois Association of Groundwater Professionals, Winter 1997.
Editor's note: Contact the Minnesota Health Department for specific well sealing requirements for Minnesota.

Life on "The Edge"—Rochester Plans Ahead to Protect Recharge Areas

— Tom Clark, Minnesota Pollution Control Agency

The hydrogeology of Rochester has done much to shape the development of this scenic city of 75,000, known worldwide as a medical center and frequent high finisher in quality-of-life rankings. On May 29, a consortium of business, public works, university, and state, county and municipal officials met at the headquarters of Rochester Public Utilities to explore life on "the edge", the hydrogeologic edge, that is. Studies by the U. S. Geological Survey have determined that about half of Rochester's drinking water supply recharge occurs at the edge of a bedrock confining unit (the Decorah-Platteville-Glenwood sequence) where water from the upper aquifer (the Galena group) recharges underlying aquifers (the St. Peter and the deeper Prairie du Chien-Jordan group). Because parts of the Galena contain nitrate levels that exceed the drinking water standard of 10 mg/L, recharge area management is becoming a significant concern. This is coupled with the fact that portions of the recharge area, especially west, south, and southeast of the city, are rapidly being converted from forest, grassland and wetland to residential and commercial use. These areas may have a significant effect in filtering nutrients and pollutants from ground water as it passes through soils and root systems.

The meeting considered four key questions, the answers to which will likely have an impact on how the city develops into the next century:

1. How can ground water recharge areas and their drainages be better delineated for making land use and water management decisions?

2. What are the pathways and processes for water recharge and pollutant movement or attenuation, and how are these processes affected by changes in land use?

3. Are nutrient and pollutant loadings occurring at rates that will eventually lead to unacceptable levels in the underlying ground water?

4. What would be good models for urban and suburban developments in and around the recharge areas?

After a welcome from meeting host **Joe Hensel, Rochester Public Utilities**, **Terry Lee, Olmsted County Water Resources Coordinator** gave an overview of the Rochester-Zumbro aquashed, which demonstrated how closely surface and ground water are linked in this karst area. Terry mentioned that although no new wells have been drilled in the upper aquifer since the mid-1960's, about half the water supply of the aquashed is estimated to come from that aquifer. Well sampling in the area suggests that the average nitrate concentration in the upper aquifer is approaching the drinking water standard of 10 mg/L. In adjoining Winona County, studies show that average nitrate concentrations in the upper aquifer are increasing by about 0.5 mg/L/year. The population of Rochester is expanding at roughly 15 percent every 10 years which has driven development out of the Zumbro River valley and onto adjoining upland areas which comprise the upper carbonate aquifer and the edge. Terry showed slides which illustrated examples of development occurring on land above the upper aquifer and suggested ways in which forested areas, buffer strips and wetlands could be retained in spite of development to help counter the effects of reduced recharge due to buildings and pavement.

Tony Runkel, Minnesota Geological Survey, summarized his new findings as a result of looking in more detail at the "microhydrostratigraphy" of the edge. Tony explained that the Platteville Limestone within the Decorah-Platteville-Glenwood sequence, has many characteristics of an aquifer and should be considered as such, at least when it is the first encountered bedrock. The Jordan Sandstone, however, long-considered an aquifer throughout its saturated thickness, has many confining characteristics in its upper part in this area. Tony identified three facies within the Jordan: 1) a feldspathic facies, tightly cemented in some areas and functioning as an aquitard; 2) a quartzose facies of relatively high permeability, with a specific capacity up to 25 gallons per minute per foot of drawdown; and 3) a dolomitized area known as the Coon Valley member, which is intermediate in permeability to the other facies, with a specific capacity of up to 10 gallons per minute per foot of drawdown. Tony summarized by saying that the major hydrogeologic divides of the geologic sequence which underlies the aquashed occur at the Galena-Decorah contact and the Glenwood-St. Peter contact.

Next, **Geoff Delin, U. S. Geological Survey**, (USGS), reviewed results of a study he conducted during 1987-1989 in support of the Olmsted County Geologic Atlas. This was the first scientific attempt to define recharge rates within the various hydrogeologic regimes which characterize the area. Recharge rates vary from 0.4 inches/year on top of the upper aquifer, to as much as 13 inches/year across the edge. Glacial drift, where present, recharges at a rate of about an inch per year. This work showed that the edge is definitely a zone of increased recharge which is important to the viability of lower aquifers. The USGS is initiating a more detailed study of this zone to define it better and determine more exactly how recharge rates vary across it.

Rich Lindgren, USGS, then described the follow-up study now underway. The first step was a comparison of the elevation of the potentiometric surface in the Prairie du Chien-
Jordan aquifer in 1988 versus 1995. Little overall change was noted, with a maximum water level decline of eight feet and a maximum rise of 15 feet. The location of the ground water divide defined in the 1988 study also changed very little. The next phase of the study will be to try to more thoroughly document recharge rates along the edge. Several well nests will be installed where the Upper Carbonate is intact, on the edge, and in an area where the Prairie du Chien is the uppermost bedrock. A hydrogeologic analysis using chlorofluorocarbon (CFC) data will be used to calculate recharge rates. A ground water flow model will be developed to

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Life on the Edge, cont.

project flow from confined areas across the edge.

Jeff Broberg, McGhie and Betts Environmental Consultants, next described the place of soils and vegetation in helping to protect ground water. The overall theme of Jeff's message was that diversity is a key to ecological stability. He has spent considerable time delineating wetlands relative to land use changes in the Rochester area. Small linear wetlands on slopes between the upper and lower aquifers have high plant diversity and are important in encouraging recharge rather than runoff and can be effective filters of nutrients such as nitrate and phosphate which can impact ground water quality.

After a lunch break, soil scientist **George Poch, McGhie and Betts Environmental Consultants**, followed Jeff's remarks by discussing the impact of varying soils and vegetation on south versus north-facing slopes. North slopes are generally much wetter and favor the development of sedge seeps which are the source of many of the local rivers and streams. The drainage architecture of the Rochester area has been significantly altered by roads. This, in turn, can have an impact on recharge rates to the lower aquifer, and may impact ground water quality as well.

State climatologist **Greg Spoden, Minnesota Department of Natural Resources**, discussed how the dimension of climate affects recharge and runoff. In Minnesota, the most important factor contributing to recharge is the precipitation received during the five-month growing season, May to September. Since 1910, this has averaged 18.6 inches in the Rochester area, but has varied from a low of 7.7 inches in 1976, to a high of 32.6 inches in 1938. Intense storm events can have a significant impact on an entire growing season's recharge and runoff. The year 1978 was a case in point when two 100-year recurrence interval storms occurred over the Zumbro River drainage basin within just over two months. The July storm that year produced five inches of rain over a large portion of the basin within three hours, while a later storm in mid-September dropped another five inches over much of the same area in six hours. The damage resulting from flash floods generated from these rainfall events was considerable, and led to the engineering of flood control measures on the south fork of the Zumbro River as it flows through Rochester.

The final speaker before group discussions was **Kimm Crawford, Olmsted County Environmental Commission**. Kimm discussed a big-picture nitrogen budget for the county. Not surprisingly, agricultural fertilizer at 7100 tons/year accounts for almost half the estimated 14,700 tons/year of nitrate generated in the county. Other sources include legumes, precipitation, human food production, streamflow, non-agricultural

— continued on page 10

Newsletter Advertising Policy for 1997

Display ads:

Size	inches H x V	Quarterly Newsletter Annual Rate 4 issues	1998 Membership Directory Annual Rate 1 issue
Business Card	3.5 x 2.3	$60	$45
Quarter Page	3.5 x 4.8	$110	$90
Half Page	7.5 x 4.8	$205	$170
Full Page	7.5 x 9.75	$385	$325
Inside Cover	7.5 x 9.75	Not Available	$360

Classified ads:

Classified ads in the newsletter are charged at the rate of $3 per 45 characters (including spaces and punctuation) per newsletter issue.

E-Mail notices:

A one-time e-mailing to the membership costs $10 for an individual (e.g. seeking a job), and $50 for an organization (e.g., announcing a job opening). The advantage of e-mail is the speed of dissemination.

The Advertising Manager has final determination on the acceptance of materials submitted. There are no commissions on ads. Advertising copy must be received by the publications deadlines: 14 February, 16 May, 15 August, or 14 November. Since we do not do any art or camera work ourselves, and we reuse copy from issue to issue, your copy should be a photostat of your art work at the exact insertion size. Photostats give the highest quality print reproduction. If a photostat is not available, high-quality copies of the ad on plain paper must be submitted for each issue published (e.g. four copies for the quarterly newsletter).

Please make checks payable to the "Minnesota Ground Water Association" or "MGWA." Direct your orders and questions concerning advertising rates and policy to the Business Manager:
WRI, 4779 126th St. North, White Bear Lake, MN 55110-5910, *Phone*: (612)426-3316; *Fax*: (612)426-5449; *E-mail*: jennie-leete@msn.com

Winona Co. Sinkholes, cont.

more controlled by surface runoff than by subsurface flow. An interesting future research question is whether focused recharge pathways, such as discharges from agricultural tiling in farmed areas or surface runoff along road ditches, has affected sinkhole development.

Rates of Sinkhole Development (1983-1992) and Karst Research

Figure 3 shows the reported rates of sinkhole development, based on the best available information for Winona County. The number of sinkholes in the age categories reported by Dalgleish (1985) correspond to development rates of 2.3, 4.2, and 9.4 sinkholes per year in the ancient, modern, and recent ages, respectively. The apparent increase in the rate of sinkhole development is probably a consequence of incomplete record keeping for the older sinkholes. More complete records are available for the development of sinkholes between 1983 and 1992, although information may be less complete for the mid-1980's due to the waning memories of landowners when the information was collected in 1992. The development rate of about 10 sinkholes per year for recently-developed/recently-reported sinkholes continued for Winona County sinkhole information that was collected in 1993 and 1994. Other researchers (Beck, 1991) have found that sinkhole information must be collected on a frequency of three to five years, in order to get accurate information for karst research and improve the understanding of sinkhole development processes.

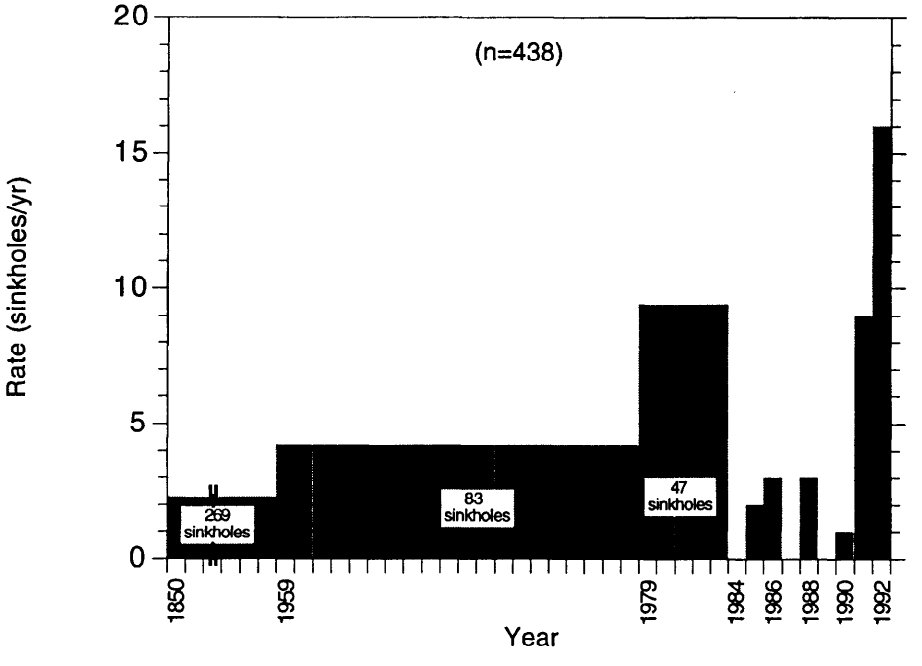

Figure 3: Reported rates of sinkhole development in Winona County.

MGWA Seeks Advertising Manager

Jim Almendinger has stepped down as advertising manager for the newsletter. We are seeking a replacement to start as soon as possible. If you like keeping in touch with the consulting community and helping foster their support for your association through the advertising dollars they generate, this could be the job for you.

The advertising manager has the opportunity to actively participate in MGWA board decision-making. The time commitment required is an hour or two per week. If interested, contact one of the board members or Jim Almendinger at the St. Croix Watershed Research Station (612-433-5953).

Bibliography

Beck, B. F. (1991). On calculating the risk of sinkhole collapse. In: Kastning, E.H. and K.M. Kastning (eds.), Proceedings of the Appalachian Karst Symposium. March 23-26, Radford, Virginia. National Speleological Society, p. 231-236.

Clark, P.J., and Evans, F.C., (1954). Distance to nearest neighbor as a measure of spatial relationships in populations. Ecology (35) p.445-453.

Dalgleish, J.B. (1985). Sinkhole Distribution in Winona County, Minnesota. M.S. Thesis, University of Minnesota, 95 pp.

Dalgleish, J.B., and Alexander, E.C., Jr. (1984a). Sinkhole and sinkhole probability map. In: Balaban, N.H. and B.M. Olsen (eds.), Geological Atlas of Winona County. Minnesota Geological Survey, County Atlas Series C-2, Plate 5.

Dalgleish, J.B., and Alexander, E.C., Jr. (1984b). Sinkhole distribution in Winona County, MN. In: Beck, B.F. (ed.). First Multidisciplinary Conference on Sinkholes, October 15-17, Orlando FL., p. 79-85.

Lueth, R.A. (1994). Soil Survey of Winona County, Minnesota. United States Department of Agriculture Soil Conservation Service, 277 pp.

Magdalene, S., and Alexander, E.C., Jr. (1995). Sinkhole distribution in Winona Co., Minnesota revisited. In: Beck, B.F. (ed.), Karst Geohazards: Engineering and Environmental Problems in Karst Terrane: Proceedings of the 5th Multidisciplinary Conference on Sinkholes and the Environmental Impacts of Karst, April 2-5, Gatlinburg, TN. A.A. Balkema, Rotterdam, p. 43-51.

Skellam, J.G. (1952). Studies in statistical ecology: I. Spatial pattern. Biometrika, v. 39, p. 346-362.

Upchurch, S.B., and Littlefield, J.R., Jr. (1987). Evaluation of data for sinkhole-development risk models. In: Beck, B.F. and Wilson, W.L. (eds.), Karst Hydrogeology: Engineering and Environmental Applications: Proceedings of the Second Multidisciplinary Conference on Sinkholes and Environmental Impacts of Karst. February 9-11, Orlando, FL. A.A. Balkema, Rotterdam, p. 359-364.

Living on the Edge, cont.

fertilizer, and pet and animal food production. Long-term reservoirs of nitrogen include the atmosphere, with 15 billion tons; soil organic matter, with 2.5 million tons; and ground water, with 100,000 tons. In Olmsted County, it is estimated that 10 percent of wells (including older wells in the upper carbonate aquifer) exceed 10 mg/L of nitrate. Another 40 to 60 percent have concentrations between 1.0 and 10 mg/L.

The day ended with a general group discussion summarizing biologic and hydrologic functions of the hillside. Part of this discussion involved the impact of land use changes on the recharge areas. The consensus was that this was a very informative meeting which provided a good opportunity for agencies involved in water resource and land use management to discuss future directions for the protection of recharge areas around the city of Rochester.

The group made the following recommendations:

1. Develop models for more protective urban and suburban development in recharge areas.

2. Study the stratigraphy of these areas at a greater level of detail (i.e., develop maps of springshed areas, as well as recharge and discharge areas along the edge; study the recharge relationship to incised valleys and the projecting "noses).

3. Develop an outreach program to the community with a central repository of water resources information including public education materials and programs.

4. Assess the role of vegetation and soils to act as filters or, in some cases, as funnels for water, nutrients and pollutants.

5. Assess the feasibility of studying the distribution and density of fractures and their relationship to geologic setting.

6. Develop systems for better coordination of data about water quality and geology in the recharge areas.

7. Recommend that programs such as the Conservation Reserve Program (CRP) be prioritized in the recharge areas and especially in those within the Rochester Wellhead Protection Areas.

Some participants observed that there are many different organizations involved in drinking water protection and that it is important to have regularly scheduled conferences like this to bring the various entities together to share information, better identify the issues, provide better public service, determine ways to better inform the public and develop science-based public policy.

Ground Water Forum Offered on Internet

The Groundwater Mailing List (sm) is an Internet forum for environmental professionals with an interest in ground water. There are thousands of subscribers from more than 50 countries. The discussion covers all facets of ground water, from water supply to waste disposal. There are members from government, academia, and industry, providing a wide range of expertise and experience.

There are no membership costs or restrictions. To subscribe to Groundwater, send e-mail to majordomo@ias.champlain.edu; in the body of the e-mail, type the command: subscribe Groundwater.

— From Ground Water Monitoring and Remediation, Spring 1997

Twin Cities Springs Featured by St. Paul Pioneer Press

The article by Greg Brick on Twin Cities springs in the March issue was featured by the St. Paul Pioneer Press on July 19th. Staff writer Don Boxmeyer prepared the article, which included "location shots" and further discussion by Greg Brick.

Southwestern Minnesota Quaternary Geology Report

The Minnesota Geological Survey recently published "Contributions to the Quaternary Geology of Southwestern Minnesota, edited by Carrie J. Patterson, as Report of Investigations 47. The report includes three chapters: Surficial geology of southwestern Minnesota by Carrie J. Patterson, Revised gravity investigation for potential ground-water resources in northwestern Rock County, Minnesota by Val W. Chandler, and Terrestrial gamma radiation in southwestern Minnesota and an assessment of its utility in surficial geologic mapping by R.S. Lively. For more information, contact the Minnesota Geological Survey at (612) 627-4782.

USGS Water Resources Software Is on the Web

A suite of 51 software packages and related materials, used by the U.S. Geological Survey for hydrologic analysis and modeling, is now available for electronic retrieval through an on-line repository on the World Wide Web. It is accessible via the WWW from the USGS water resources home page at http://water.usgs.gov/; select the announcement for "USGS Water Resources Applications Software" or go directly to http://water.usgs.gov/software.

In addition, the repository is available via anonymous file transfer protocol (FTP) from the USGS water resources information server: water.usgs.gov or 130.11.50.175 (path: pub/software).

Each software package consists of complied or source code, test data sets, and documentation files. All of the USGS water resources software on the WWW is documented by published USGS reports.

For general information on the USGS water resources software, contact USGS, Hydrologic Analysis Software Support Team, 437 National Center, Reston, VA 20192 (e-mail: h2osoft@usgs.gov).

— From Ground Water Monitoring and Remediation, Spring 1997

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

— James Walsh, Minnesota Department of Health

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

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

Case Study

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

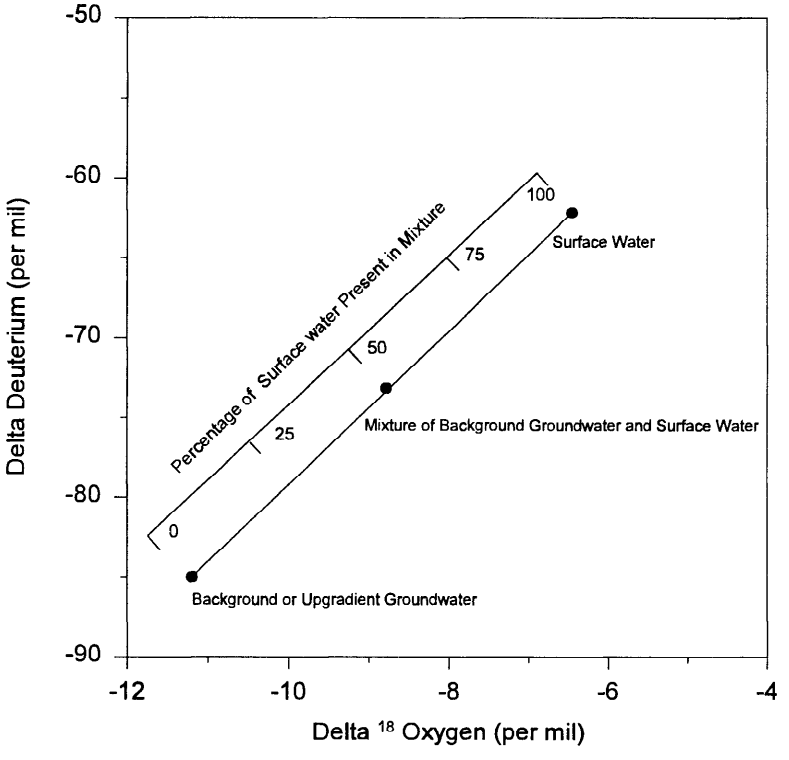

Figure 1: Example of mass balance approach to water mixing using oxygen-18 and deuterium. This figure shows that the mixed sample contains roughly equal parts of surface water and background ground water.

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

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

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

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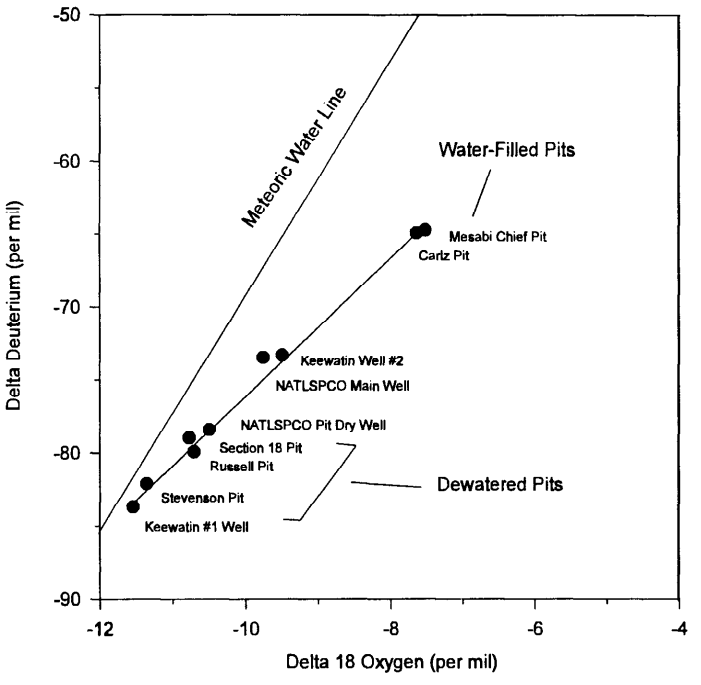

Figure 2. Deuterium and oxygen-18 results from February, 1996.

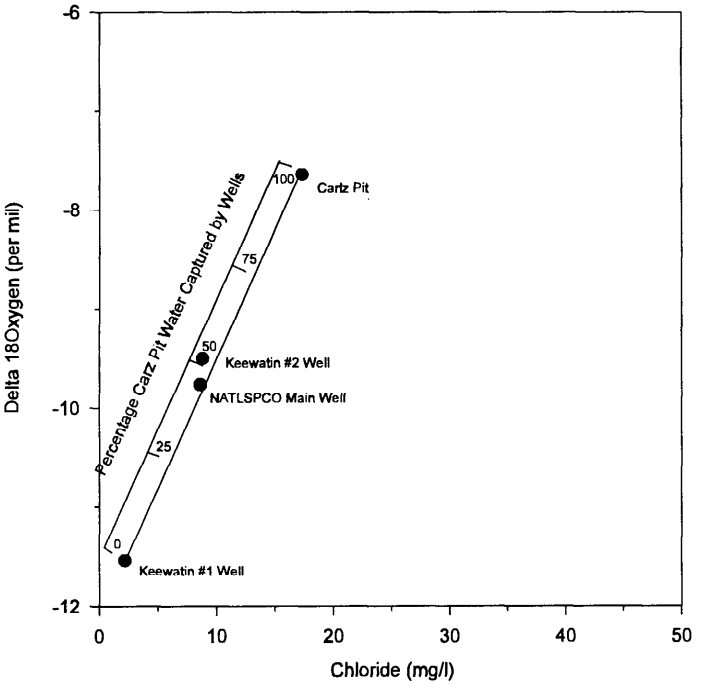

Figure 3. Mass balance mixing analysis based on oxygen-18 and chloride from February, 1996.

Errata

The June 1997 MGWA Newsletter reprinted an article, Tracers in Groundwater, by Jim Walsh, Minnesota Department of Health. We failed to mention that the article originally appeared in the Fall 1996 Minnesota Well Management News, a Department of Health publication. The MGWA Newsletter Team apologizes for this oversight.

Wellhead Protection, cont.

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

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

Reference:

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

Karst Hydrogeology Report Available for Le Roy Township, Mower County

The Minnesota Geological Survey (MGS) has recently published Open File Report 97-2, The Karst Hydrogeology of Le Roy Township, Mower County Minnesota. By Jeff Green (Department of Natural Resources), John Mossler(MGS), Scott Alexander (University of Minnesota Department of Geology and Geophysics) and Calvin Alexander (University of Minnesota Department of Geology and Geophysics), this two-map set is the first documentation of Upper Devonian karst in Minnesota and was produced in response to ongoing issues (particularly limestone quarrying) revolving around karst, groundwater sensitivity, and land-use management.

The karst features plate is a synthesis of information on karst feature occurrence (sinkholes and disappearing streams), major springs, dye trace vectors, bedrock geology, and depth to bedrock. The database plate shows all mapped sinkholes, springs, quarries and data points. The maps are designed to be used

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Karst Map of LeRoy Twp., cont.

by individuals, businesses or government agencies needing karst and groundwater information in the township. The maps have already been used to review quarrying proposals and leaking tank site monitoring schemes. Future uses will include well head protection area analysis and planning for the City of Le Roy.

Regional Hydrogeologic Assessment

Southwestern Minnesota - Part B Now Available

The Department of Natural Resources recently completed Part B of the two-part atlas series, the Regional Hydrogeologic Assessment for Southwestern Minnesota. Part A, Quaternary Geology—Southwestern Minnesota, was published in 1995 by the Minnesota Geological Survey. Part B of the atlas includes two plates: surficial hydrogeology and pollution sensitivity plates produced at a 1:200,000 scale. Parameters collected for the study include water-level data, general water chemistry, tritium, stable isotopes of hydrogen and oxygen, and carbon-14.

The water chemistry results supports a model of ground water for southwestern Minnesota that separates ground water into local, intermediate, and regional scale flow systems. Compared to regional systems, water in local and intermediate flow systems is less mineralized and isotopic analysis results indicate ground water recharge is relatively recent. The pollution sensitivity map was produced by assigning geologic sensitivity ratings primarily based on the mapped surficial geology deposits in Part A of the atlas. Geologic sensivity ratings are estimates of travel time for water-borne contaminants to travel from the land surface to the water table. Surficial sand and gravel deposits, organic deposits, and outcrops of fractured Sioux Quartzite were assigned Very High geologic sensitivity ratings because they were identified as areas where contaminants could rapidly travel to the water table.

The Regional Hydrogeologic Assessment for Southwestern Minnesota, Parts A and B, are available from the Minnesota Geological Survey, Publication Sales, (612) 627-4782. For questions regarding Part B of the report contact Randy Bradt, (612) 282-2501. Listings of related Minnesota Geological Survey reports may be found at http://geolab.geo.umn.edu/mgs.

New USGS Publications

Hydrogeologic and water-quality data used to evaluate the effects of focused recharge on ground-water quality near Princeton, Minnesota, 1991-95, by G.N. Delin, M.K. Landon, R.B. Wanty, R.W. Healy, H.W. Olsen, J.K. Bohlke, B.R. Shroyer, and P.D. Capel. Open-File Report 97-21.

Physical characteristics of stream subbasins in the Hawk Creek-Yellow Medicine River Basin, southwestern Minnesota and eastern South Dakota, by C.A. Sanocki. Open-File Report 96-632.

Physical characteristics of stream subbasins in the Middle Minnesota-Little Cottonwood River Basin, south-central Minnesota, by C.A. Sanocki. Open-File Report 96-631.

Water-quality and hydrogeologic data used to evaluate the effects of farming systems on ground-water quality at the Management Systems Evaluation Area near Princeton, Minnesota, 1991-95, by M.K. Landon, G.N. Delin, K.J. Nelson, C.P. Reagan, J.A. Lamb, S.J. Larson, P.D. Capel, J.L. Anderson, and R.H. Dowdy. Open-File Report 97-22.

Ground-water sampling methods and quality control data of the Red

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Join the Minnesota Ground Water Association!

If you are reading this newsletter second-hand, we'd like to take this opportunity to invite you to become a member of **MGWA** for 1998. Annual dues are $20 for professional members and $15 for students. Members are entitled to purchase the annual membership directory for $7. Additional donations toward our scholarships and/or the use of recycled paper will be gratefully accepted.

*Dues paid to MGWA are **not** deductible as charitable contributions for federal income tax purposes. However, dues payments are deductible as ordinary and necessary business expenses to the extent allowed by law.*

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Thanks from the UM Geology and Geophysics Department

July 9, 1997

Ms. Paula M. Berger
Minnesota Ground Water Association
P.O. Box 65362
St. Paul, MN 55165-0362

Dear Ms. Berger,

Thank you very much for your support of the Department by your generous contribution of $300.00 to the Department of Geology and Geophysics, Hydrogeology Field Camp. Support like yours is essential to the development of this important area of instruction in hydrogeology.

Thank you again for your thoughtful gift.

Sincerely,

W.E. Seyfried, Jr.
Professor and Head
University of Minnesota Geology and Geophysics Department

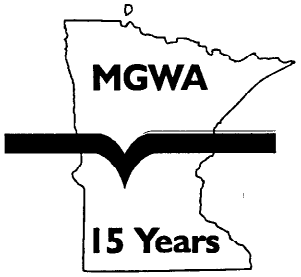
New USGS Publications, cont.

River of the North Basin, Minnesota and North Dakota, 1993-95, by Michael A. Menheer and Mark E. Brigham. Water-Resources Investigations Report 96-4317.

Causes of Variations in Water Quality and Aquatic Ecology in Rivers in the Upper Mississippi River, Minnesota and Wisconsin, by James R. Stark. Fact Sheet FS-249-96.

Also available: a summary of Minnesota wetland resources in the Minnesota State Summary of the latest National Water Summary.

Contact Ginger Amos, Technical Publications Editor, (612) 783-3141. Or visit http://wwwmn.cr.usgs.gov/mnlocal.mnlocal.html.



Watch for *"The Capillary Fringe"*

Newsletter a Team Effort:

Tom Clark, Minnesota Pollution Control Agency, Coordinating Editor

Jan Falteisek, Minnesota Department of Natural Resources, Issue Editor

Steve Robertson, Northern Environmental

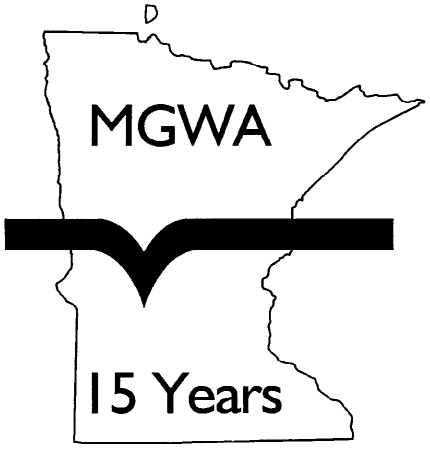
Jim Lundy, Minnesota Pollution Control Agency

You can be a part of the Team, call Tom Clark.

December 1997 issue editorial deadlines:

- 11/7/97 — submission of copy to the editorial team
- 11/14/97 — submission of final copy to the publisher
- Contact Tom Clark, Issue Editor, (612)296-8580 or tom.p.clark@pca.state.mn.us

Product Order Form



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One-Day Workshop

IMPROVING HYDROGEOLOGIC INVESTIGATIONS
Part I: Site Geologic Characterization in Glaciated Areas

MIDWEST GEOSCIENCES GROUP
Promoting Geological Science Through Continuing Education

Indianapolis, Indiana Indiana Univ. - Purdue Univ. Friday, October 24, 1997 8:00 am to 5:00 pm	Oak Brook, Illinois Embassy Suites Hotel Friday, November 14, 1997 8:00 am to 5:00 pm	Milwaukee, Wisconsin University of Wisconsin, Milwaukee Saturday, November 15, 1997 8:00 am to 5:00 pm
8:00am	Introduction	
8:15am	Developing Field Recognition of Glacial Depositional Environments and Weathering Zones	Tim Kemmis, PhD Rust Environment & Infrastructure E. Art Bettis III, PhD Iowa Department of Natural Resources Geological Survey Bureau
9:50am	Break	
10:00am	Improving Descriptions of Glacial Sediments - Adding Geologic Emphasis to the USCS	Dan Kelleher, MS Rust Environment & Infrastructure
11:00am	Application of Surface and Downhole Geophysical Methods for Site Characterization w/problem set	Phil Carpenter, PhD Northern Illinois University
12:00N	Lunch	
1:00pm	Designing a Drilling Program - Information and Cost Benefit Analysis with Examples	Tom Oothoudt, MS Boart Longyear Company
2:00pm	Hydrogeologic Application of Glacial Stratigraphy with case studies and a problem set	Alan Kehew, PhD Western Michigan University
2:45pm	Break	
Indianapolis Only **3:00pm**	Application of the USDA Textural Diagram	Robert Hall, PhD Indiana U. - Purdue U. at Indianapolis
4:00pm	IDEM Unconsolidated Deposit Descriptive Requirements: A Goal Oriented Approach for Describing Unconsolidated Deposits as Applied to Hydrogeologic Investigations	Robert Martin, MS Indiana Department of Environmental Management Noel Anderson, PhD in progress University of Wisconsin, Madison
Oak Brook Only **3:00pm**	From Field Investigation to Ground Water Modeling, Building the Hydrostratigraphic Framework	Ken Bradbury, PhD Wisconsin Geological & Natural History Survey University of Wisconsin Extension
4:00pm	Glacial Stratigraphy of Illinois	Ardith Hansel, PhD Illinois State Geological Survey
Milwaukee Only **3:00pm**	From Field Investigation to Ground Water Modeling, Building the Hydrostratigraphic Framework	Ken Bradbury, PhD Wisconsin Geological & Natural History Survey University of Wisconsin Extension
4:00pm	Glacial Stratigraphy of Wisconsin	Dave Mickelson, PhD University of Wisconsin, Madison

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- ☐ **U of W, Milwaukee, WI - Saturday, November 15**

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* For Early Registration, payment must be received before October 17, 1997. Discount Available only for Early Registration Period.

Make check payable to the Midwest GeoSciences Group. Cancellations may be made up to one week before the course, however, 15% of the course will be charged. No refunds.

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