Report for 2003MN29B: Arsenic in Minnesota Groundwater and its Impact on the Drinking Water Supply

- Articles in Refereed Scientific Journals:
  - Erickson, M.L., K. Peterson, and R.G. Soule. Got Arsenic? Site Investigation as an Innovative Compliance Option, submitted February 2003 to Journal of the American Water Works Association.
- Other Publications:
  - Erickson, M.L, and R.J. Barnes. Arsenic in Ground Water: Recent Research and Implications for Minnesota. CURA Reporter. 34[2]. May 2004.
  - Erickson, M.L, and R.J. Barnes. Arsenic in Ground Water: Recent Research and Implications for Minnesota. Minnesota Ground Water Association Newsletter. 23[1]. March 2004.
  - Erickson, M.L. and R.J. Barnes. 2004. Arsenic in Groundwater: Recent Research and Implications for Minnesota. CURA Reporter. University of Minnesota Center for Urban and Regional Affairs. Minneapolis, MN.

Arsenic in Minnesota groundwater and its impact on the drinking water supply

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Summary
Arsenic contamination in upper Midwestern ground water is widespread, naturally occurring, and associated with the lateral extent of northwest source Late Wisconsin (Des Moines lobe) till. Arsenic concentration in ground water is not directly related to arsenic concentration in sediment.

In west-central Minnesota, private wells that have relatively short screens set close to the upper confining unit are more likely to have elevated arsenic concentrations than otherwise comparable private wells. The variability of arsenic concentrations over time in newly constructed wells is similar to concentration variability observed in older wells; there is no temporal trend.

Reductive desorption is the mechanism proposed to explain observed important temporal changes in water quality in two Minnesota public water supply wells.

Two procedures have been developed and tested for screening low-cost compliance options for public water systems with elevated arsenic. A 'site investigation' evaluates the option of drilling a new well. The procedure can identify low-arsenic aquifers at different elevations and/or different locations. Sampling a well several times over a period of a few hours provides the necessary information to evaluate the option of changing well operations. Changing well operations may be a viable option for communities with arsenic concentrations that predictably fluctuate around 10 μg/l.

Introduction
Arsenic exposure from contaminated drinking water at 50 μg/l is a significant environmental cancer risk, similar to the cancer risk associated with environmental tobacco smoke and home radon exposure (Smith et al. 1992). In response to reports by the National Research Council (1999; 2001) and others about risks from arsenic in drinking water at 50 μg/l, the U.S. federal drinking water standard, or Maximum Contaminant Level (MCL), was recently changed from 50 μg/l to 10 μg/l. Public water systems must comply with the new MCL by January 2006. In Minnesota, USA, over 100,000 people are estimated to use a public drinking water system with arsenic concentrations over 10 μg/l.

Welch, et al. (2000) made the association between glaciated areas in the upper Midwest and high arsenic in ground water. Statewide arsenic sampling in Minnesota indicates that a significant area of the state has detectable concentrations of arsenic in ground water (Centers for Disease Control 1994; Minnesota Pollution Control Agency 1995), with approximately 14% of sampled wells exceeding 10 μg/l. In Minnesota, 150,000 to 250,000 people are estimated to obtain their

drinking water from private wells with arsenic concentrations exceeding 10 μg/l (Soule 2004). A recent study of arsenic occurrence and exposure in western Minnesota found that over 50% of the 900 sampled private drinking water wells had arsenic over 10 μg/l (Minnesota Department of Health 2001). However, even in this high-arsenic area, arsenic concentrations in water had significant variability.

State and local governmental agencies are evaluating potential low-cost ways for public water systems to meet the new MCL (Erickson et al. 2004; Erickson and Barnes 2004a; Erickson and Barnes 2004b). Low-cost options include drilling a different well or changing well operation practices. However, very little is known about the mechanisms that cause the observed high-arsenic concentrations and the significant spatial and temporal variations in arsenic concentrations. Without a concrete understanding of the mechanisms that cause arsenic release from solids and into ground water, a public water supplier cannot implement a low-cost option with any assurance that it will be a long-term solution. Overall, lack of mechanistic understanding prohibits prediction of ground water arsenic concentration, interferes with the formulation of sound public policy, and inhibits the development of effective regulation.

The overall objective of this research project was to better understand arsenic concentrations in upper Midwestern glacial aquifers. Two keys to meeting this objective are 1) understanding the geochemical mechanisms governing arsenic in ground water, and 2) understanding the relationship between the geology/hydrogeology and arsenic concentration in ground water. Joint evaluation of geochemical mechanisms and potential geology/hydrogeology controls is a new approach to the upper Midwest's arsenic problem. The results of this approach are permitting better characterization of spatial variability of arsenic in ground water, as well as modeling and prediction of temporal variability of arsenic in ground water. Results are also providing information to governmental units for the development of sound regulations and guidance regarding drilling and using drinking water wells in high arsenic areas. The results may be applicable to other areas throughout the world that have reduced aquifers (e.g. Inner Mongolia, Vietnam, Romania, and Hungary (Smedley and Kinniburgh 2002)).

Methodology

The key components of the research project involved creating a useful database from existing data, collecting ground water and sediment samples, analyzing ground water and sediment samples, and data analysis/model building.

A comprehensive database of measured arsenic concentrations in the upper Midwest has been compiled. Public water supply, state well sampling, well construction (as available), and surficial geology data were obtained from various state agencies in MN, SD, ND, and IA, as well as from the U.S. Geological Survey (Centers for Disease Control 1994; Iowa Environmental Protection Division 2003; Minnesota Department of Health 2001; Minnesota Department of Health 2002; Minnesota Geological Survey and Minnesota Department of Health 2004; Minnesota Pollution Control Agency 1995; North Dakota Department of Health 2003a; North Dakota Department of Health 2003b; North Dakota Water Commission 2004; South Dakota Drinking Water Program 2003; South Dakota Geologic Survey 2003). This is the first time a comprehensive regional map of arsenic concentrations in upper Midwest groundwater and surficial geology has been compiled.

Water samples were collected from selected private wells in Minnesota and analyzed for arsenic and other analytes of interest. Sediment and water samples were collected from two monitoring wells drilled in June 2003 in northwestern Minnesota using the rotasonic method. Water samples were analyzed for arsenic and other analytes of interest. Sediment samples were analyzed for arsenic and other elements of interest. Sequential extractions were performed according to Keon (2001) to quantify the amount of labile arsenic present in sediment.

Results were analyzed using univariate statistics, indicator analysis, multivariate statistics, and geostatistics. Geochemical modeling was performed using MINEQL+.

Results and ongoing work

Arsenic contamination in upper Midwestern ground water is widespread, naturally occurring, and associated with the lateral extent of northwest source Late Wisconsin (Des Moines lobe) till. Although Late Wisconsin till does not have particularly high arsenic concentrations, it does have specific physical characteristics (fine-grained matrix and entrained organic carbon (Harris et al. 1995; Harris 1999; Matsch 1972; Parkin and Simpkins 1995; Patterson (née Jennings) 1999; Simpkins and Parkin 1993)) that create a geochemical environment favorable to regional scale mobilization of arsenic (Kim et al. 2002; Korte 1991; Smedley and Kinniburgh 2002; Warner 2001). Although it was originally hypothesized that ground water arsenic concentrations in the upper Midwest are associated with sediment arsenic concentrations, this hypothesis was not supported. In samples collected during this and related studies, arsenic concentrations in ground water are not directly related to arsenic concentration in sediment.

In west-central Minnesota, private wells that have screens less than 8 feet long set within 4 feet of the upper confining till unit have an average arsenic concentration of 20 µg/L, with 58% of wells exceeding 10 µg/l. Private wells with longer screens set further from the upper confining unit average only 12 µg/L arsenic, and 40% of wells exceed 10 µg/l.

In newly constructed wells, the variability of arsenic concentrations over time, from the date of construction over a period of one to two years, is similar to concentration variability observed in older wells; there is no temporal trend.

Two Minnesota public water supply wells have notable arsenic concentration variability over time. The arsenic concentration change is notable because the arsenic concentration is less than 10 µg/l initially, increases to more than 10 µg/l over a pumping period of one hour, and then decreases again after the well stops pumping. During the same pumping time, both the iron and sulfur concentrations decrease. After a period of no pumping, the iron concentration increases again, and the sulfur concentration remains lower. The Eh, which is a measure of redox potential, decreases significantly over the period of time that the well pumps, indicating that the redox state of the water is higher before the well is pumped. The mechanism of reductive desorption is proposed to explain the observed water quality changes in these two wells as they are pumped. Arsenic species measurements and geochemical modeling results support this proposed mechanism.

Two procedures have been developed and tested for evaluating low-cost compliance options for public water systems with elevated arsenic. A 'site investigation' evaluates the option of drilling a new well. The procedure can identify low-arsenic aquifers at different elevations and/or different locations. Sampling a well several times over a period of a few hours provides the necessary information to evaluate the option of changing well operations. Changing well operations may be a viable option for communities with arsenic concentrations that predictably fluctuate around 10 µg/l.

Additional data analysis and modeling efforts are ongoing.

Publications associated with the project

Erickson, M.L., K. Peterson, and R.G. Soule. Got Arsenic? Site Investigation as an Innovative Compliance Option, submitted February 2003 to *Journal of the American Water Works Association.*

Erickson, M.L, and R.J. Barnes. Arsenic in Ground Water: Recent Research and Implications for Minnesota. *CURA Reporter*. 34[2]. May 2004.

Erickson, M.L, and R.J. Barnes. Arsenic in Ground Water: Recent Research and Implications for Minnesota. Minnesota Ground Water Association Newsletter. 23[1]. March 2004.

Additional journal article manuscripts are currently being prepared.

Students supported by the project

Melinda L. Erickson, Water Resources Science Ph.D. candidate, was provided with a 50% Research Assistant position for approximately 1.5 semesters by this grant.

Awards and achievements resulting from the project

The Water Resources Science program (University of Minnesota) awarded a $500 travel grant to graduate student Melinda Erickson for travel to the November 2003 annual meeting of the Geological Society of America to present a poster of research results for the project.

The Albert Howard Fellowship (University of Minnesota) for 2003-2004 academic year was awarded to graduate student Melinda Erickson to augment research funds for continuing work on the project.

Seminar or poster presentations resulting from the project

Erickson, M.L. October 2, 2003. Arsenic in Minnesota Groundwater. Invited conference presentation at the American Water Works Association Minnesota Section Meeting, Moorhead, Minnesota.

Erickson, M.L., R.G Soule, and K. Peterson. October 28, 2003. Got Arsenic? Site Investigation as an Innovative Compliance Option. Poster presentation at the 36th Water Resources Conference sponsored by the University of Minnesota. Minneapolis, Minnesota.

Erickson, M.L. & R.J. Barnes. November 5, 2003. Measured and Modeled Arsenic Species Variability in Midwestern Ground Water. Poster presentation at the Geological Society of America Annual Meeting and Exposition. Seattle, WA.

Erickson, M.L. December 16, 2003. Arsenic in Minnesota Groundwater. Invited seminar presentation at the Minnesota Geological Survey, Minneapolis, Minnesota.

Erickson, M.L. January 14, 2004. Arsenic in Minnesota Groundwater. Invited seminar presentation at the Minnesota Department of Health, St. Paul, Minnesota. Seminar was telecast statewide to six MDH regional offices.

Erickson, M.L. & R.J. Barnes. March 23, 2004. Arsenic Contamination in Minnesota Groundwater: Recent Research and Regulatory Implications. Poster presentation at Water 2004. Minneapolis, Minnesota.

Erickson, M.L. April 26, 2004. Arsenic in Minnesota Groundwater. Invited seminar presentation for Minnesota State University – Moorhead, North Dakota State University, and Concordia College. Hosted by Minnesota State University – Moorhead. Moorhead, Minnesota.

Erickson, M.L. & R.J. Barnes. May 5 – 7, 2004. Late Wisconsin Till and Arsenic Contamination in Upper Midwest Groundwater. Poster presentation at the Institute of Lake Superior Geology Annual Conference. Duluth, Minnesota.

Related grants submitted or funded as a result of this project

Minnesota Department of Health funded three related projects: Summer 2003, $9,000 summer RA salary; June 2003 – June 2004, $6,250 water analytical contract; Summer 2004, $18,000 summer RA salary and RA travel expenses.

A proposal was submitted to the US Geological Survey March 1, 2004, in response to a Request for Proposal. The proposal requested funding for three years of additional work on arsenic in the upper Midwest. The proposed research would be conducted in partnership with ND State University and Minnesota Geological Survey researchers. Approximately $250,000 was requested, primarily for post-doc salary, field work costs, and analytical costs. As of June 7, 2004, no word has been received either way about this proposal. If awarded, the project would start September 2004.

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