Private Drinking Water Quality in Rural Wisconsin

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Abstract **Between July 1, 2007, and December 31, 2010, Wisconsin health departments tested nearly 4,000 rural drinking water supplies for coliform bacteria, nitrate, fluoride, and 13 metals as part of a state-funded program that provides assistance to low-income families. The authors' review of laboratory findings found that 47% of these wells had an exceedance of one or more health-based water quality standards. Test results for iron and coliform bacteria exceeded safe limits in 21% and 18% of these wells, respectively. In addition, 10% of the water samples from these wells were high in nitrate and 11% had an elevated result for aluminum, arsenic, lead, manganese, or strontium. The high percentage of unsafe test results emphasizes the importance of water quality monitoring to the health of nearly one million families including 300,000 Wisconsin children whose drinking water comes from a privately owned well.**

Introduction

An affordable, ample supply of water that is free of pathogens and toxic chemicals is essential to good health. Finding enough clean drinking water to meet growing demands, however, is becoming increasingly difficult as a result of current and past human activities such as large-scale groundwater withdrawals, mining activities, industrial pollution, and our increased dependence on chemical fertilizers and weed killers in food production. Each year more of Wisconsin's native forests and prairies are cleared for agriculture or development, which reduces the amount of surface area available to support the natural recharge of underground aquifers that provide source water for municipal public and private drinking water supplies.

An estimated 940,000 Wisconsin households obtain their drinking water from a privately owned well. These water supplies are not regulated under the federal Safe Drinking Water Act and most have never been tested for toxic metals. While annual testing for nitrate and coliform bacteria is recommended, many wells are not regularly tested for these parameters and some homeowners are unaware of the need to conduct these tests. This situation puts nearly one million families at risk of acute and chronic illnesses that can be caused by exposure to waterborne microbes and toxic chemicals. In a recent survey, the most common reasons well owners gave for not testing their water were its acceptable taste and appearance, the use of an in-home water treatment system, or a lack of information about what to test for and how to find a certified laboratory (Knobeloch, 2010).

The state of Wisconsin offers fee-exempt water testing to low-income families with pregnant women or young children under a program administered by county health departments. Between July 2007 and December 2010, 3,868 private water supplies were tested for coliform bacteria, fluoride, nitrate-nitrogen, and a panel of 13 metals as part of this program. This program does not offer testing for pesticides, petroleum products, or industrial solvents, although these contaminants can also be found in groundwater throughout the Midwest. This article summarizes water quality findings from this testing program and discusses the importance of ensuring the safety of domestic drinking water supplies.

Methods

Sample Procurement

Tap water samples were collected by homeowners using water sampling kits provided by the Environmental Sciences Section (ESS) in the Environmental Health Department (EHD) of the Wisconsin State Laboratory of Hygiene (WSLH), which included instructions and three screw-cap sample bottles (one 150-mL polystyrene bottle for total coliform, one 60-mL high density polyethylene bottle for nitrate and fluoride, and one 50-mL polypropylene vessel for metals). Instructions directed taking the sample from an unsoftened kitchen faucet or at the pressure tank before a softener or iron-removal system is implemented (if applicable). The individual was further instructed to sterilize the faucet opening with flame and then let the cold water run for five minutes before sampling. After filling all three bottle types and completing the test request form, the samples were shipped back to the lab in a Styrofoam container. Note that each new lot of each bottle type is routinely verified by WSLH for cleanliness for its respective analyte prior to use.

Sample Preparation

Private nitrate samples do not require preservation and may be held unacidified for a maximum of 14 days at room temperature. These samples were analyzed unacidified.

For fluoride analysis, samples may be held at room temperature unpreserved for a maximum of 28 days. Total coliform bacteria samples were shipped unpreserved and at ambient temperatures, and analyzed (unpreserved) within 48 hours of collection. If the samples for metals analysis were not acidified in the field, they were acidified immediately at the laboratory with nitric acid (HNO_3) to 0.5% HNO_3 (pH < 2) and held for a minimum of 16 hours prior to analysis. The holding time for liquid samples was six months. Upon receipt or preparation, all standards and all controls were entered in the appropriate logbooks and were assigned a traceability code. The code, date prepared, analyst, and expiration date were recorded on each standard bottle.

Sample Analysis

WSLH standard operating procedure (SOP) for both the nitrate + nitrite and fluoride analysis followed ESS Inorganic Method 220.9. The determinative steps in the nitrate + nitrite method are identical to U.S. Environmental Protection Agency (U.S. EPA) Methods 353.2 (U.S. EPA, 1993). Because the U.S. EPA method was written specifically for air-segmented continuous flow technology that is no longer available, however, the specific "plumbing" scheme (pump tubes and reagent proportions, etc.) used was adapted to match the Lachat flow injection instrumentation. The specific flow scheme used in this SOP was from Lachat method 10-107-04-1-A (Lachat Instruments, 1997).

The determinative steps in the fluoride method are identical to the Technicon method 380-75WE (U.S. EPA, 1983). As with nitrate + nitrite, this method was written specifically for air-segmented continuous flow technology, so the methods were similarly adapted to Lachat method 10-109-12-2-A (Lachat Instruments, 1994).

The presence or absence of total coliform bacteria was analyzed as per WSLH ESS Water Micro Method 300, which is a chromogenic substrate method approved by U.S. EPA and based on Standard Methods SM9113B. The specific product used was Colilert or Colisure, depending on read-out time. For the metals analysis, samples with a turbidity value greater than 1 nephelometric turbidity unit required digestion by EHD Metals Method 780.3 (15.5). After the Perkin Elmer 5300DV inductively coupled plasma optical emission spectrophotometer was calibrated, the required quality control samples were analyzed. Provided all were within the defined limits for the elements required, the analysis of the samples could begin. Refer to EHD Metals Instrument Operating Procedure (IOP) 500 (15.8) or EHD Metals IOP 501 (15.17) for a detailed procedure.

The groundwater standards used in Table 1 were obtained from the enforcement standards listed in Chapter NR 140 of Wisconsin statutes (Groundwater Quality, 2011) unless otherwise specified. The U.S. EPA maximum contaminant level (MCL) of 4 mg/L for fluoride is shown in Table 1. A secondary maximum contaminant level (SMCL), however, of 2 mg/L was recently established for fluoride. This value is intended to reduce the risk of severe enamel fluorosis and to minimize the risk of bone fractures and skeletal fluorosis in adults (U.S. EPA, 2011a). Using the SMCL instead of the MCL would increase the number of fluoride exceedances from 0 to 21. Levels of appropriate minimum amounts of fluoride are also established. The U.S. Department of Health and Human Services recently declared that 0.7 mg/L is the recommended fluoride level for drinking water (American Dental Association [ADA], 2011).

Results

Between July 2007 and December 2010, county health departments submitted 4,578 private well water samples to WSLH for analysis. Following elimination of follow-up tests and samples that lacked complete well identification, a database containing 3,868 private drinking water wells was created that included test results for coliform bacteria, nitrate, fluoride, and a suite of 13 metals (see Table 1). Although five of Wisconsin's 72 counties did not participate in the fee-exempt testing program, the wells included in this review are widely distributed across the state. Since they were tested because of a recent birth or new pregnancy rather than because of their proximity to a known source of contamination or nearby contaminated well and because replicate samples from individual wells were removed from the dataset prior to our analysis, the results shown in Table 1 are expected to be representative of private drinking water quality throughout Wisconsin.

Comparison of data from these tests to water quality standards found that 47% of these water supplies were unsafe for consumption. Test results for iron and coliform bacteria exceeded safe limits in 21% and 18% of these wells, respectively. In addition, nitrate levels exceeded safe levels in 10% of the water samples and 11% of the samples were high in aluminum, arsenic, lead, manganese, or strontium. Eleven percent of the water samples had two or more exceedances of health-based standards. Water from an Ozaukee County well that had an iron concentration of 47.3 mg/L also exceeded standards for aluminum, arsenic, cobalt, manganese, and nickel.

Regional and seasonal patterns were observed. For example, nitrate and coliform bacteria were most common in southern Wisconsin while mean levels of iron, manganese, copper, and aluminum were highest in the northern part of the state.

The presence of coliform bacteria was seasonal, peaking in late summer and being least frequent in early spring. Wells with high iron levels often contained other metals but were less likely than others to be high in nitrate. Among water samples that had an iron concentration greater than the groundwater enforcement standard of 0.3 mg/L, 11% were also high in manganese, but only 1.5% had an elevated nitrate level. In contrast, wells that were high in nitrate were less likely than others to have unsafe levels of arsenic, aluminum, or manganese.

Discussion

Our review of laboratory test data found that 47% of the private water samples submitted for analysis between July 2007 and December 2010 were unsafe for consumption. The most common exceedances were for coliform bacteria, iron, and nitrate. But exceedances of standards for several toxic metals were also seen. Since an estimated 940,000 Wisconsin

TABLE **1**

Summary of Test Results From 3,868 Private Drinking Water Wells, 2007–2010

Item Tested	LOD[a] Units	Median (Max)	Groundwater Enforcement Standard[b]	Exceedance Rate (%)	Health Effect of Concern
Coliform bacteria	1 CFU	Not applicable	0 CFU	17.6	GI[a] illnesses, infections
Aluminum	3 µg/L	5 (3,960) µg/L	200 µg/L	1.2	CNS[a] toxicity, reproductive effects
Arsenic	5 µg/L	ND[a] (681) µg/L	10 µg/L	2.4	Cancer, nerve damage, CVD[a]
Cadmium	0.5 µg/L	ND (2,100) µg/L	5 µg/L	<1	Cancer
Chromium	1 µg/L	ND (54) µg/L	100 µg/L	<1	Reproductive toxicity, mutagenicity
Cobalt	1 µg/L	ND (1,280) µg/L	40 µg/L	0.6	Cardiomyopathy
Copper	2 µg/L	9 (9,220) µg/L	1,300 µg/L	<1	GI upsets
Fluoride	0.03 mg/L	0.1 (3.25) mg/L	4.0 mg/L[c]	<1	Skeletal and dental fluorosis
Iron	0.1 mg/L	ND (66.2) mg/L	300 µg/L	20.6	Diabetes, CVD
Lead	3 µg/L	9 (2,100) µg/L	15 µg/L	1.8	Developmental effects, cancer
Manganese	1 µg/L	3 (3,960) µg/L	300 µg/L	3.6	CNS toxicity
Nickel	1 µg/L	ND (2,790) µg/L	100 µg/L	<1	Kidney cancer
Nitrate-N	0.30 mg/L	1.06 (51.5) mg/L	10 mg/L	9.5	Reduced O_2 levels, cyanosis
Strontium[d]	1 µg/L	0.06 (32.5) µg/L	4 mg/L[e]	1.6	Interference with bone development
Vanadium	1 µg/L	ND (35) µg/L	30 µg/L	<1	CNS, GI toxicity
Zinc	1 µg/L	0.01 (8.8) µg/L	5 mg/L	<1	GI upsets

[a]LOD = limit of detection; GI = gastrointestinal; CNS = central nervous system; CVD = cardiovascular disease; ND = not detected.
[b]Enforcement standards are from Groundwater Quality (2011) except where indicated otherwise.
[c]Maximum contaminant level established by U.S. Environmental Protection Agency (U.S. EPA) guideline.
[d]1,525 wells were tested for strontium.
[e]U.S. EPA lifetime health advisory.

households including more than 300,000 children drink water from a private well, the finding that nearly half of the wells are unsafe is a major public health concern.

Often the only inorganic constituent tested in well water samples is nitrate, but our results show that this approach may be missing a large part of the health concern. Although a large percentage of samples were safe for nitrate (roughly 90%), or even nondetectable (39.5%), these samples often contained the highest metal concentrations. Conversely, when considering "unsafe" metals, the majority of those (between 66% and 100% for a given metal) occurred in a safe nitrate sample. So one cannot assume that a safe nitrate sample will be completely safe for other parameters. Furthermore, although safe nitrate samples occurred in significantly deeper wells than unsafe nitrate samples (t-test, $p < .05$, $df = 217$), deeper wells were not entirely free of high metals concentrations (note that only a subset of wells had depth data). Therefore, more constituents than nitrate and coliform bacteria (where positive results could not be correlated to other parameters) should be tested to know the complete picture.

A recent study found that many rural home owners are uncertain of the need to have their well water tested for safety. Based on weighted responses to a module of questions added to the 2008–2009 Behavioral Risk Factor Surveillance Survey, only 16% of our private water supplies are tested annually and nearly one-third of well owners have never had their water tested (Knobeloch, 2010). Many of those who have tested their water seem confused about their test result. For example, roughly 40% of those who had tested their water thought the tests included analysis of volatile organic compounds, pesticides, and arsenic although testing for these parameters is not routinely done. Ninety-six percent of those who had tested their water reported their results as being "safe," which contradicts our finding of widespread exceedances of guidelines for iron, nitrate, and bacteria and suggests a need for better outreach and water quality information. Improving the safety of rural water supplies is an important public health goal. Our progress toward reaching this goal, however, has been an ongoing challenge.

The high rate of unsafe test results and low rate of water testing by private well owners poses a variety of health risks. While the association between gastrointestinal illnesses and pathogens in drinking water is widely understood, less awareness exists of the potential effects of nitrate and naturally occurring minerals. Most well owners likely don't know, for example, that ingestion of too much iron can also cause gastrointestinal upsets (Liguori, 1993) and could even contribute to iron overload, which, if undiagnosed and untreated, can lead to liver disease (Deugnier & Turlin, 2011), arthritis (Sahinbegovic et al., 2010), type II diabetes (Swaminathan, Fonseca, Alam, & Shah, 2007), and cataracts (Loh, Hadziahmetovic, & Dunaief, 2009).

We have investigated three cases of methemoglobinemia in infants in Wisconsin that became ill after being fed formula that was prepared with nitrate-contaminated water (Knobeloch & Proctor, 2001; Knobeloch, Salna, Hogan, Postle, & Anderson, 2000). More recently, nitrate-contaminated water has been linked to higher rates of thyroid disease (Ward et al., 2010). We have also confirmed higher rates of skin cancer, cardiovascular disease, and depression among Wisconsin residents who had long-term exposure to well water high in arsenic (Knobeloch & Anderson, 2002; Zierhold, Knobeloch, & Anderson, 2004) and described several cases of gastrointestinal disturbances and unexplained weight loss among families whose tap water was high in copper (Knobeloch et al., 1994).

Other minerals found in Wisconsin well water are equally concerning. Aluminum, lead, and manganese can affect the central nervous system and have been associated with a range of problems including dementia (Gauthier et al., 2000; Rondeau, Jacquim-Gadda, Commenges, Helmer, & Dartigues, 2009), learning delays (Agency for Toxic Substances and Disease Registry, 2007), and Parkinsonism (U.S. EPA, 2004), respectively. Ingestion of too much strontium or fluoride can alter the chemical structure of dental enamel and bone tissue. Children can develop a condition called "strontium rickets" characterized by cranial thinning, delayed closure of the fontanelles, and deformities of the long bones in the arms and legs (Ozgür, Sümer, & Koçoğlu, 1996). Excessive fluoride intake during early childhood causes staining and pitting of dental enamel while adult intake can lead to skeletal fluorosis and a higher risk of fractures (ADA, 2011). Under the fee-exempt program, testing for these minerals was not routine prior to 2007 and it is likely that most private water supplies have never been tested for these parameters.

Laboratory analysis and regulatory standards are the cornerstones of our water quality outreach program. Laboratory testing is expensive and inconvenient, however, for rural residents, and even the most advanced laboratories cannot provide comprehensive testing for the myriad chemical, radiological, and biological contaminants that could be present in unfiltered groundwater. Regulatory standards are similarly problematic. Most water quality standards were developed in the 1980s and 1990s using animal studies that were conducted more than 20 years ago. Such studies do not meet current standards for toxicity testing. In fact, 59% of U.S. EPA's drinking water regulations for inorganics were developed prior to 1995 (U.S. EPA, 2011b). In addition to problems posed by outdated standards, the sheer number of potential contaminants poses another hurdle. Under the Safe Drinking Water Act, U.S. EPA has adopted standards for 90 chemical, microbiological, and radiological contaminants. More than 60,000 chemicals are manufactured or used in the U.S., however, and although many of these have the potential to reach our underground aquifers, regulatory standards and testing protocols do not exist for them.

Perhaps as a result of these problems, many well owners have chosen to use filtration systems to improve the quality of their water (Knobeloch, 2010). This action is consistent with the 2008–2009 report from the President's Cancer Panel, which recommends the use of household water treatment to decrease exposure to harmful chemicals (President's Cancer Panel, 2010). Given the increased use of in-home water treatment systems, public health providers may need to update outreach materials to encourage the use of effective treatment devices for regional contaminants and provide reminders regarding maintenance of these systems. In addition, they should continue to encourage annual water testing to ensure the safety of private drinking water supplies since the effectiveness of treatment varies depending on the contaminant of concern, the type of filtration system used, and maintenance practices. Our finding that almost half of the tested water supplies were unsafe for human consumption underscores the importance of ensuring the safety of drinking water supplied by a private well through regular testing of a wide range of parameters.

Conclusion

Groundwater is vulnerable to a wide variety of contaminants including naturally occurring minerals and chemicals used in agricultural, industrial, and household products. This vulnerability is apparent through the high percentage of Wisconsin well tests in exceedance of at least one health-based water quality standard. To ensure the safety of private drinking water wells, they should be monitored regularly. Local water quality specialists and public health experts should work together to provide guidance to well owners regarding the selection of test parameters and the frequency of testing based on regional land use, well characteristics, and hydrogeology. Guidance should also be provided regarding the selection and maintenance of in-home water treatment systems.

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References

Agency for Toxic Substances and Disease Registry. (2007). *Toxicological profile for lead.* Retrieved from http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=96&tid=22

American Dental Association. (2011). *ADA applauds HHS action on recommended fluoride level in drinking water* [Press release]. Retrieved from http://www.ada.org/5194.aspx

Deugnier, Y., & Turlin, B. (2011). Pathology of hepatic iron overload. *Seminars in Liver Disease, 31*(3), 260–271.

Gauthier, E., Fortier, I., Courchesne, F., Pepin, P., Mortimer, J., & Gauvreau, D. (2000). Aluminum forms in drinking water and risk of Alzheimer's disease. *Environmental Research, 84*(3), 234–426.

Groundwater Quality (Department of Natural Resources). Wisconsin State Statutes, NR Chapter 140 (2011). Retrieved from legis.wisconsin.gov/rsb/code/nr/nr140.pdf

Knobeloch, L. (2010). *Use of the Behavioral Risk Factor Surveillance Survey to assess the safety of private drinking water supplies: Final report submitted to the Wisconsin Groundwater Coordinating*

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Council. Retrieved from http://www.wri.wisc.edu/Default.aspx?tabid=91&ctl= Details&mid=397&ProjectID=98562342

Knobeloch, L., & Anderson, H. (2002). Effect of arsenic-contaminated drinking water on skin cancer prevalence in Wisconsin's Fox River Valley. In *Arsenic and Health Effects V* (Proceedings of the 5th International Conference on Arsenic Exposure, San Diego, CA), pp. 155–163.

Knobeloch, L., & Proctor, M. (2001). Eight blue babies. *Wisconsin Medical Journal*, *100*(8), 43–47.

Knobeloch, L., Salna, B., Hogan, A., Postle, J., & Anderson, H. (2000). Blue babies and nitrate-contaminated well water. *Environmental Health Perspectives, 108*(7), 675–678.

Knobeloch, L., Ziarnik, M., Howard, J., Theis, B., Farmer, D., Anderson, H., & Proctor, M. (1994). Gastrointestinal upsets associated with ingestion of copper-contaminated water. *Environmental Health Perspectives, 102*(11), 958–961.

Lachat Instruments. (1994). *QuikChem fluoride method 10-109-12-2-A: Determination of fluoride by flow injection analysis (potentiometric, ion selective electrode)*. Milwaukee, WI: Author.

Lachat Instruments. (1997). *QuikChem nitrate + nitrite nitrogen method 10-107-04-1-A determination of nitrate/nitrite in surface and wastewaters by flow injection analysis (low flow method)*. Milwaukee, WI: Author.

Liguori, L. (1993). Iron protein succinylate in the treatment of iron deficiency: Controlled, double-blind, multicenter clinical trial on over 1,000 patients. *International Journal of Clinical Pharmacolgy, Therapy, and Toxicology, 31*(3), 103–123.

Loh, A., Hadziahmetovic, M., & Dunaief, J.L. (2009). Iron homeostasis and eye disease. *Biochimica et Biophysica Acta, 1790*(7), 637–649.

Ozgür, S., Sümer, H., & Koçoğlu, G. (1996). Rickets and soil strontium. *Archives of Disease in Childhood, 75*(6), 524–526.

President's Cancer Panel. (2010). *Reducing environmental cancer risk, 2008–2009. Annual report*. Retrieved from http://deainfo.nci.nih.gov/advisory/pcp/

Rondeau, V., Jacqmin-Gadda, H., Commenges, D., Helmer, C., & Dartigues, J.F. (2009). Aluminum and silica in drinking water and the risk of Alzheimer's disease or cognitive decline: Findings from 15-year follow-up of the PAQUID cohort. *American Journal of Epidemiology, 169*(4), 489–496.

Sahinbegovic, E., Dallos, T., Aigner, E., Axmann, R., Engelbrecht, M., Schöniger-Hekele, M., Karonitsch, T., Farkas, M., Karger, T., Willeit, J., Stölzel, U., Keysser, G., Datz, C., Kiechl, S., Schett, G., & Zwerina, J. (2010). Hereditary hemochromatosis as a risk factor for joint replacement surgery. *American Journal of Medicine, 123*(7), 659-62.

Swaminathan, S., Fonseca, V.A., Alam, M.G., & Shah, S.V. (2007). The role of iron in diabetes and its complications. *Diabetes Care, 30*(7), 1926–1933.

U.S. Environmental Protection Agency. (1983). *Method 340.2. Fluoride: Methods for chemical analysis of water and wastes* (Document No. EPA/600/4-79-020). Retrieved from http://www.caslab.com/EPA-Methods/PDF/EPA-Method-3402.pdf

U.S. Environmental Protection Agency. (1993). *Method 353.2. Nitrate + nitrite nitrogen: Methods for the determination of inorganic substances in environmental samples* (Document No. EPA/600/R-93/100). Retrieved from http://www.caslab.com/EPA-Methods/PDF/EPA-Method-3532.pdf

U.S. Environmental Protection Agency. (2004). *Drinking water health advisory for manganese*. Retrieved from http://www.epa.gov/ogwdw/ccl/pdfs/reg/support_cc1_magnese_dwreport.pdf

U.S. Environmental Protection Agency. (2011a). *Fluoride risk assessment and relative source contribution*. Retrieved from http://water.epa.gov/action/advisories/drinking/fluoride_index.cfm

U.S. Environmental Protection Agency. (2011b). *Drinking water standards and health advisories*. Retrieved from http://water.epa.gov/action/advisories/drinking/drinking_index.cfm#dw-standards

Ward, M.H., Kilfoy, B.A., Weyer, P.J., Anderson, K.E., Folsom, A.R., & Cerhan, J.R. (2010). Nitrate intake and the risk of thyroid cancer and thyroid disease. *Epidemiology, 21*(3), 389–395.

Zierold, K., Knobeloch, L., & Anderson, H. (2004). Prevalence of chronic disease in adults exposed to arsenic-contaminated drinking water. *American Journal of Public Health, 94*(11), 1936–1937.