Bull. Environ. Contam. Toxicol. (2001) 66:64–70

DOI: 10.1007/s001280000206

Bulletin of Environmental Contamination and Toxicology

Nitrate Concentrations in Private Rural Drinking Water Supplies in Saskatchewan, Canada

T. S. Thompson

Saskatchewan Health, Provincial Laboratory, Environmental Sciences Section, 3211 Albert Street, Regina, Saskatchewan, Canada S4S 5W6

Received: 22 June 2000/Accepted: 12 October 2000

The province of Saskatchewan is located in the central prairie region of Canada. Approximately 50% of the one million residents of the province live in 11 cities, each with a population greater than 5,000 people. The remaining half million people live in rural towns, villages, hamlets, rural municipalities, and Indian reserves. While some of these individuals utilize communal drinking water supplies (for example, rural municipal wells), many rely upon privately maintained wells as their only source of potable water. It has been estimated that there are approximately 66,000 wells in the province. In addition, some farm families use surface water (i.e., dugouts) for drinking purposes. Most private drinking water supplies are not subjected to any form of treatment. Treatment such as shock chlorination (for reduction of bacterial contamination) and point-of-use devices such as water softeners and iron filters are, however, sometimes utilized.

Nitrogenous materials, such as organic matter and ammonia, may be oxidized to nitrate by micro-organisms in soil, plants and water. Natural sources of nitrate in the environment include decaying matter (both plant and animal) as well as leaching from geological formations. Anthropogenic activities resulting in the release of nitrate into the environment include the disposal of domestic sewage, livestock operations, and the use of nitrate-based fertilizers.

Nitrate is highly water-soluble and therefore tends to migrate from soil into groundwater. The consumption of well water containing elevated concentrations of nitrate was first linked to a condition known as methemoglobinemia in young infants in 1945 (Comly 1987). Ingested nitrate is reduced to nitrite which subsequently hinders the ability of blood to transport oxygen to body tissues. This condition has been reported to be fatal in numerous cases (Johnson et al. 1987). Methemoglobinemia resulting from the consumption of nitrate-contaminated water has been observed almost exclusively in infants under three months of age (Craun et al. 1981). The presence of elevated concentrations of nitrate in rural drinking water supplies continues to have potential public health implications related to the occurrence of methemoglobinemia in infants (Shearer et al. 1972; Johnson and Kross 1990). The consumption of drinking water containing up to 100 mg/L nitrate has been shown not to cause a subsequent increase in nitrate concentration in human milk (Dusdieker et al. 1996).

Although the acute toxic effects associated with nitrate-induced methemoglobinemia have been well documented, the effect of chronic exposure to nitrate via drinking water is the subject of considerable scientific debate. Numerous studies have suggested a link between the consumption of water containing elevated concentrations of nitrate with various forms of cancers including stomach cancer (Cuello et al. 1976; Gilli et al. 1984; Xu et al. 1992), bladder cancer (Morales-Suarez-Varela et al. 1993), brain cancer (Barrett et al. 1998) and non-Hodgkin's lymphoma (Weisenburger 1993; Ward et al. 1996). Other studies have claimed that there is no conclusive correlation between high concentrations of nitrate present in drinking water supplies and the incidence of stomach cancer (Barrett et al. 1998; Beresford 1985; Rademacher et al. 1992; van Loon et al. 1998), bladder cancer (McGeehin et al. 1993) or brain tumours (Steindorf et al. 1994).

In addition to methemoglobinemia in infants and potential carcinogenic toxicity, other health effects on humans that are potentially influenced by elevated levels of nitrate in drinking water include teratogenetic toxicity (Dorsch et al. 1984), hypertrophy of the thyroid (van Maanen et al. 1994), recurrent stomatitis (Gupta et al. 1999), and childhood diabetes mellitus (Kostraba et al. 1992; Parslow et al. 1997).

The drinking water quality guideline for nitrate as established by Health Canada is 45 mg/L nitrate (10 mg/L nitrate-nitrogen) and is based primarily upon the risk of acute exposure for infants. The current guideline is listed as an interim maximum acceptable concentration pending the review of new research into the toxic effects of chronic exposure to nitrates.

MATERIALS AND METHODS

Water samples from private wells and dugouts were analyzed for nitrate using an automated hydrazine reduction method performed on a continuous-flow analyzer system (APHA/AWWA/WEF 1995). Nitrate is reduced to nitrite by hydrazine sulphate in the presence of copper sulphate. The resulting nitrite plus any nitrite originally present in the sample is diazotized with sulphanilamide and forms a coloured complex with N-(1-naphthyl)-ethylenediamine dichloride. The coloured complex is measured colorimetrically at 520 nm. This method is applicable to samples having nitrate concentrations between 1 to 50 mg/L. Water samples having nitrate concentrations greater than 50 mg/L were diluted to fall within the range of the calibration curve.

RESULTS AND DISCUSSION

As part of its public health mandate, Saskatchewan Health's Provincial Laboratory distributes sample collection bottles throughout the province for nitrate and total coliform testing. The bottles are accompanied by instructions for the collection and submission of drinking water samples. Public health officials in the province have long promoted the need to have rural drinking water supplies tested for nitrate. As a result, several thousand samples are submitted annually to our laboratory for analysis.

Table 1 lists the distribution of nitrate concentrations found in 3425 private wells that were tested over the past 12 months. Nitrate was detected at concentrations exceeding the current Canadian drinking water quality guideline (45 mg/L) in 483 of the 3425 well water samples. An almost equal number of wells did not have detectable quantities of nitrate (i.e., <1 mg/L). Based on a percentile analysis of the nitrate concentrations (see Table 2), 50% of the wells tested contained nitrate at or below 3 mg/L. The maximum nitrate concentration was determined to be 957 mg/L, with the 5% and 1% of the 3425 samples having nitrate concentrations greater than 117 and 342 mg/L, respectively.

Table 1. Distribution of nitrate concentrations in private wells.

Nitrate Concentration (mg/L)	**Number of Wells**
< 1	496
1 – 15	1952
16 – 30	319
31 – 45	175
46 – 60	117
61 – 75	70
76 – 90	57
91 – 100	31
101 – 200	122
201 – 300	41
301 – 400	21
>400	24
TOTAL	**3425**

Table 2. Nitrate concentrations in private wells at selected percentiles.

Percentile	**Nitrate Concentration (mg/L)**
50%	3
60%	6
70%	14
80%	29
90%	64
95%	117
99%	342
100%	957

In addition to well water, some rural families utilize surface water supplies (dugouts) as a source of potable water. Nitrate concentrations in drinking water samples from 150 farm dugouts are summarized in Table 3. None of the dugout samples tested were found to contain nitrate at concentrations above the drinking water quality guideline. In fact, the highest nitrate concentration in these samples was determined to be 27 mg/L. The mean and median nitrate concentrations were determined to be 3 and 1 mg/L, respectively.

Table 3. Distribution of nitrate concentrations in private dugouts.

Nitrate Concentration (mg/L)	**Number of Dugouts**
< 1	44
1 – 5	91
6 – 10	6
11 – 15	5
16 – 20	0
21 – 25	3
26 – 30	1
> 30	0
TOTAL	**150**

The range of nitrate concentrations in well water samples from Saskatchewan is not atypical of the levels found in other rural areas in Canada and the United States. In a survey of nutrients and minerals in 180 farm wells in the southern portion of the province of Ontario, 21 wells had nitrate concentrations in excess of 45 mg/L (Frank et al. 1991). Nitrate concentrations ranged from non-detected in 68 samples to a maximum of 244 mg/L. Well water samples with elevated nitrate concentrations were typically collected from shallow dug wells. Approximately 20% of 300 wells in New Brunswick were found to contain at least 45 mg/L of nitrate (Health Canada 1992). Nearly 60% of 450 well water samples collected from 125 locations in British Columbia's Fraser Valley had nitrate concentrations greater than 45 mg/L (Health Canada 1992). Groundwaters in Ontario and Manitoba have been reported to contain nitrate concentrations as high as 467 and 1063 mg/L, respectively (Health Canada 1992).

Nitrate concentrations in wells in Wisconsin were found to range from non-detectable to 620 mg/L nitrate, with 9% of all samples exceeding the U.S. Environmental Protection Agency's recommended guideline of 45 mg/L nitrate (Schuknecht et al. 1975). In a study of 686 wells throughout Iowa, approximately 18% were found to contain nitrate at levels above the drinking water quality guideline (Kross et al. 1993). A significant number (35%) of wells less than 15 m in depth contained nitrate greater than 45 mg/L. In a survey of nitrate concentrations in rural drinking water supplies in New York State, nitrates were detected in 95% of the 419 wells tested (Gelberg et al. 1999). Approximately 16% of these wells had nitrate concentrations in excess of 45 mg/L. Shallow or dug wells and those that were located on large farms were found to be more likely to have elevated concentrations of nitrate. Well water samples collected from swine farms in 18 states in the USA were tested for selected nutrients and ionic species, including nitrate (Bruning-Fann et al. 1994). Over 50% of the 631 wells tested contained detectable concentrations of nitrate. Nitrate levels were found to exceed 45 mg/L in 12% of the wells tested.

There is no information in the literature regarding the concentrations of nitrate in private surface water supplies. Unfortunately there is also no data available regarding the number of dugouts in Saskatchewan that are used as a source of drinking water. Given the relatively small number of dugouts tested as compared to the number of private wells, no specific conclusions can be drawn. While nitrate contamination does not appear to be a problem for dugout water, further gathering of data is necessary to confirm this.

Agriculture is the major driving force behind Saskatchewan's economy. The use of nitrogen-based fertilizers is one significant source of nitrate in groundwater. The recent trend towards intensive livestock operations (ILOs) for hog production in Saskatchewan, and the neighbouring provinces of Manitoba and Alberta, has created considerable controversy. The major issues are odour and the management of animal wastes. While odour concerns are generally localized, the implications of environmental contamination from the handling of animal manure may be widespread (Jongbloed and Lenis 1998). The potential for contamination of groundwater supplies by nitrate is one of these concerns. The Government of Saskatchewan has developed legislation for the regulation of ILOs, including locations of these operations, the maximum allowable number of animals, waste storage and management practices, and land use (CSALE 1996).

The contamination of rural drinking water supplies by nitrate has long been a public health concern and likely will continue to be such. Infantile methemoglobinemia is treatable and occurrences are preventable through the education of rural water users by public health officials. The long-term impact of exposure to elevated levels of nitrate from contaminated drinking water supplies is much more debatable and further study is clearly warranted.

REFERENCES

APHA/AWWA/WEF [American Public Health Association, American Water Works Association, Water Environment Federation] (1995) Standards for the Examination of Water and Wastewater, 19th Edition. United Book Press, Baltimore, p 4/90-4/91

Barrett JH, Parslow RC, McKinney PA, Law GR, Forman D (1998) Nitrate in drinking water and the incidence of gastric, esophageal, and brain cancer in Yorkshire, England. Cancer Causes Control 9(2):153-159

Beresford SA (1985) Is nitrate in the drinking water associated with the risk of cancer in the urban UK? Int J Epidemiol 14(1):57-63

Bruning-Fann C, Kaneene JB, Miller RA, Gardner I, Johnson R, Ross F (1994) The use of epidemiological concepts and techniques to discern factors associated with the nitrate concentration of well water on swine farms in the USA. Sci Total Environ 153(1-2):85-96

Comly HH (1987) Landmark article Sept 8, 1945: Cyanosis in infants caused by nitrates in well water. JAMA 257(20):2788-2792

Craun GF, Greathouse DG, Gunderson DH (1981) Methaemoglobin levels in young children consuming high nitrate well water in the United States. Int J Epidemiol 10(4):309-317

CSALE [Centre for Studies in Agriculture, Law and the Environment] (1996) Expanding Intensive Livestock Operations in Saskatchewan: Environmental and Legal Constraints. University of Saskatchewan, Saskatoon, SK, Canada (www.aginfonet.com/agricarta/content/csale/paper3/contents.html)

Cuello C, Correa P, Haenszel W, Gordillo G, Brown C, Archer M, Tannenbaum S (1976) Gastric cancer in Columbia. I. Cancer risk and suspect environmental agents. J Natl Cancer Inst 57(5):1015-1020

Dorsch MM, Scragg RK, McMichael AJ, Baghurst PA, Dyer KF (1984) Congenital malformations and maternal drinking water supply in rural South Australia: a case-control study. Am J Epidemiol 119(4):473-486

Dusdieker LB, Stumbo PJ, Kross BC, Dungy CI (1996) Does increased nitrate ingestion elevate nitrate levels in human milk? Arch Pediatr Adolesc Med 150(3):311-314

Frank R, Chapman N, Johnson R (1991) Survey of farm wells for nutrients and minerals, Ontario, Canada, 1986 and 1987. Bull Environ Contam Toxicol 47(1):146-151

Gelberg KH, Church L, Casey G, London M, Roerig DS, Boyd J, Hill M (1999) Nitrate levels in drinking water in rural New York State. Environ Res 80(1):34-40

Gilli G, Corrao G, Favilli S (1984) Concentrations of nitrates in drinking water and incidence of gastric carcinomas: first descriptive study of the Piemonte Region, Italy. Sci Total Environ 34(1-2):35-48

Gupta SK, Gupta RC, Seth AK, Gupta AB, Bassin JK, Gupta DK, Sharma S (1999) Epidemiological evaluation of recurrent stomatitis, nitrates in drinking water, and cytochrome b5 reductase activity. Am J Gastroenterol 94(7):1808-1812

Health Canada (1992) Support Documentation for Drinking Water Quality Guidelines: Nitrate/Nitrite. Environmental Health Directorate, Ottawa, ON, Canada (www.hc-sc.gc.ca/ehp/ehd/catalogue/bch_pubs/dwgsup_doc /nitrate.pdf)

Johnson CJ, Bonrud PA, Dosch TL, Kilness AW, Senger KA, Busch DC, Meyer MR (1987) Fatal outcome of methemoglobinemia in an infant. JAMA 257(20):2796-2797

Johnson CJ, Kross BC (1990) Continuing importance of nitrate contamination of groundwater and wells in rural areas. Am J Ind Med 18(4):449-456

Jongbloed AW, Lenis NP (1998) Environmental concerns about animal manure. J Anim Sci 76(10):2641-2648

Kostraba JN, Gay EC, Rewers M, Hamman RF (1992) Nitrate levels in community drinking waters and IDDM. An ecological analysis. Diabetes Care 15(11):1505-1508

Kross BC, Hallberg GR, Bruner DR, Cherryholmes K, Johnson JK (1993) The nitrate contamination of private well water in Iowa. Am J Public Health 83(2):270-272

McGeehin MA, Reif JS, Becher JC, Mangione EJ (1993) Case-control study of bladder cancer and water disinfection methods in Colorado. Am J Epidemiol 138(7):492-501

Morales-Suarez-Varela M, Llopis-Gonzalez A, Tejerizo-Perez ML, Ferrandiz-Ferragud J (1993) Concentration of nitrates in drinking water and its relationship with bladder cancer. J Environ Pathol Toxicol Oncol 12(4):229-236

Parslow RC, McKinney PA, Law GR, Staines A, Williams R, Bodansky HJ (1997) Incidence of childhood mellitus in Yorkshire, northern England, is associated with nitrate in drinking water: an ecological analysis. Diabetologia 40(5):550-556

Rademacher JJ, Young TB, Kanarek MS (1992) Gastric cancer mortality and nitrate levels in Wisconsin drinking water. Arch Environ Health 47(4):292-294

Schuknecht B, Lawton GW, Steinka P, Delfino JJ (1975) Nitrates in Wisconsin ground water. Environ Lett 9(1):91-98

Shearer LA, Goldsmith JR, Young C, Kearns OA, Tamplin BR (1972) Methemoglobin levels in infants in an area with high nitrate water supply. Am J Public Health 62(9):1174-1180

Steindorf K, Schlehofer B, Becher H, Hornig G, Wahrendorf J (1994) Nitrate in drinking water. A case-control study on primary brain tumours with an embedded drinking water survey in Germany. Int J Epidemiol 23(3):451-457

van Loon AJ, Botterweck AA, Goldbohm RA, Brants HA, van Klaveren JD, van den Brandt PA (1998) Intake of nitrate and nitrite and the risk of gastric cancer: a prospective cohort study. Br J Cancer 78(1):129-135

van Maanen JM, van Dijk A, Mulder K, de Baets MH, Menheere PC, van der Heide D, Mertens PL, Kleinjans JC (1994) Consumption of drinking water with high nitrate levels causes hypertrophy of the thyroid. Toxicol Lett 72(1-3):365-374

Ward MH, Mark SD, Cantor KP, Weisenburger DD, Correa-Villase~nor A, Zahm SH (1996) Drinking water nitrate and the risk of non-Hodgkin's lymphoma. Epidemiology 7(5):465-471

Weisenburger DD (1993) Potential health consequences of ground-water contamination by nitrates in Nebraska. Nebr Med J 78(1):7-12

Xu G, Song P, Reed PI (1992) The relationship between gastric mucosal changes and nitrate intake via drinking water in a high-risk population for gastric cancer in Moping county, China. Eur J Cancer Prev 1(6):437-443