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General Chemical Water Quality of Private Groundwater Supplies in Saskatchewan, Canada

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It has been estimated that approximately 150,000 of the one million residents of Saskatchewan rely upon privately owned water supplies as a source of drinking water. It has also been estimated that there are currently over 60,000 private wells in operation in the province. These wells are generally used for domestic purposes (drinking, laundry, showering/bathing) by owners of farms, acreages, and cottages. Some wells are specifically used to support livestock production.

The majority of privately maintained groundwater supplies are subjected to little or no treatment prior to use. Based on anecdotal references, water quality is known to vary considerably across the province. There are, however, a number of water quality problems that are frequently encountered in various privately operated systems. Aesthetic problems include unpleasant taste and/or odour, staining of porcelain fixtures and laundry due to high concentrations of iron and/or manganese, precipitation of dissolved minerals, and the calcification of taps and kettles. Elevated levels of constituents such as nitrate and sulphate may adversely impact upon human health.

Unfortunately there is relatively little information available regarding general chemical water quality in groundwater supplies in Saskatchewan. While considerable testing has been performed over the years, most of this information is not easily accessible through a collective database. Unlike public water suppliers, owners of private supplies are not required to have their water tested. Most private water users rarely have their water analyzed and if they do the scope of the testing is generally limited to microbiological quality (coliform bacteria) and nitrate analysis. In one study of private wells in Saskatchewan, approximately 14% of the 3425 wells tested were found to contain nitrate in excess of Health Canada's maximum acceptable concentration of 45 mg/L (Thompson 2001). Private groundwater supplies in a small rural municipality located in south central Saskatchewan were found to contain greater than 10 mg/L nitrate in 22 of 55 wells tested with 10 of these exceeding the recommended guideline of 45 mg/L (Agriculture and Agri-Food Canada 2001).

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MATERIALS AND METHODS

Water samples from 283 private wells located throughout Saskatchewan were analyzed for major ionic constituents including calcium, chloride, iron, magnesium, manganese, nitrate, sodium, and sulphate. Measurements of pH, alkalinity, and conductivity were also made on all samples. The total hardness was calculated from the concentrations of calcium and magnesium and expressed in mg/L equivalents of calcium carbonate (mg/L $CaCO_3$). All analytical tests were performed in accordance with approved procedures from *Standard Methods for the Examination of Water and Wastewater* (APHA/AWWA/WEF 1995).

RESULTS AND DISCUSSION

Health Canada, in co-operation with the individual Canadian provinces, has established drinking water quality guidelines for a wide range of chemical and microbiological parameters (Health Canada 2001). These guidelines are not enforceable standards and each province has the jurisdictional authority to adopt or modify these guidelines. Saskatchewan Environment and Resource Management (SERM) has based its own municipal drinking water quality objectives largely upon Health Canada's guidelines with some minor revisions (SERM 1996). These objectives were set for treated municipal drinking water supplies regulated by SERM and are not specifically applied to private water supplies, most of which are not treated. Table 1 lists both Health Canada's drinking water guidelines and SERM's municipal drinking water objectives along with the primary reason for their establishment.

Water samples from 283 private wells throughout Saskatchewan were analyzed for a series of general water quality parameters. The results of these tests are summarized in Table 2. It should be noted that Table 1 lists federal and provincial guidelines for total dissolved solids (TDS), however most water laboratories actually estimate total mineral concentrations by measuring the conductivity of the water. The electrical conductivity of a water sample can be related to its TDS through multiplication by an empirical factor that ranges from 0.55 to 0.9 depending upon the water type (APHA/AWWA/WEF 1995). On average, groundwater samples analyzed in our laboratory typically would have a calculated TDS equal to approximately 0.83 times the conductivity. Therefore conductivity measurements of 600 and 1,800 microsiemens/cm (μs/cm) would be equivalent to TDS concentrations of 500 and 1,500 mg/L, respectively.

Ground water supplies in Saskatchewan are typically quite hard (mean and maximum hardness of 764 and 6,390 mg/L $CaCO_3$, respectively) and have relatively high concentrations of total dissolved solids (mean and maximum conductivity of 2,157 and 12,400 μs/cm, respectively). Sulphate is a major ionic constituent, with nearly 25% of the 283 samples tested having concentrations greater than 1,000 mg/L. The mean and maximum concentrations of sulphate in the samples analyzed were found to be 712 and 8,000 mg/L, respectively.

Table 1. Canadian and Saskatchewan drinking water quality guidelines.

Parameter	Health Canada	SERM	Logic
Chloride (mg/L)	250	250	• Undesirable taste • Corrosion
Hardness (mg/L $CaCO_3$)	500♦	800	• Corrosion • Incrustation and scaling
Iron (mg/L)	0.3	0.3	• Staining of laundry and fixtures • Objectionable taste • Precipitation of solids • Promotion of iron bacteria growth
Manganese (mg/L)	0.05	0.05	• Staining of laundry and fixtures • Objectionable taste • Precipitation of solids • Supports growth of nuisance bacteria
Nitrate (mg/L)	45	45	• Infantile methaemoglobinaemia • Suggested association with gastric cancer
pH	6.5 – 8.5	6.5 – 9.0	• Incrustation and scaling at high pH • Corrosion at low pH
Sodium (mg/L)	200	300	• Objectionable taste
Sulphate (mg/L)	500	500	• Objectionable taste • Growth of sulphate-reducing bacteria • Laxative effect
Total Alkalinity (mg/L $CaCO_3$)	-	500	• Incrustation and scaling
Total Dissolved Solids (mg/L)	500	1500	• Objectionable taste • Mineral deposition and scaling • Corrosion

♦ Not formally established; hardness greater than 500 mg/L considered to be unacceptable by Health Canada.

In general, most groundwater in Saskatchewan tends to be slightly alkaline in nature. The mean pH value for the 283 water supplies tested was found to be 7.5. Approximately 30% of the samples analyzed had a total alkalinity above the objective used for municipal drinking water systems (500 mg/L $CaCO_3$).

The range of nitrate concentrations found in groundwater supplies was consistent with that reported in a previous study in Saskatchewan (Thompson 2001). Only 41 of 283 water samples (14%) were found to contain nitrate above the recommended maximum acceptable concentration of 45 mg/L. The maximum concentration of nitrate in this study and the earlier one were 613 and 957 mg/L,

Table 2. Range of values for water quality parameters observed for private wells (N = 283) in Saskatchewan.

		Percentile						
Parameter	**Min.**	**25%**	**50%**	**75%**	**90%**	**95%**	**Max.**	**Mean♦**
Calcium (mg/L)	< 1	75	120	205	321	370	700	153
Chloride (mg/L)	< 2	6	25	93	255	383	2,050	92
Conductivity (uS/cm)	112	901	1,810	2,840	4,090	5,000	12,400	2,157
Hardness (mg/L as $CaCO_3$)	< 2	335	546	1,002	1,610	1,956	6,390	764
Iron (mg/L)	< 0.1	< 0.1	0.3	1.2	3.6	5.1	10.9	1.1
Magnesium (mg/L)	< 1	32	62	113	187	267	1,434	93
Manganese (mg/L)	< 0.01	0.04	0.24	0.52	1.09	1.70	5.48	0.43
Nitrate (mg/L)	< 1	< 1	2	13	68	136	613	25
pH	6.7	7.3	7.4	7.7	8.1	8.3	8.7	7.5
Sodium (mg/L)	1	23	104	395	644	879	2,040	249
Sulphate (mg/L)	< 10	106	396	915	1,659	2,250	8,000	712
Total Alkalinity (mg/L as $CaCO_3$)	29	322	421	517	626	712	1,166	437

♦ Any result of a non-detection (i.e., < x mg/L) has been set to zero for the purposes of calculating the mathematical mean of the results.

respectively.

The drinking water quality guidelines established by Health Canada and SERM for sodium are primarily based upon an objectionable taste resulting from elevated concentrations. Health Canada does, however, also place an additional stipulation on the acceptable concentration of sodium based upon individuals in the general population who have been placed on a sodium-restricted diet (Health Canada 1992). For these individuals, it is estimated that an acceptable total daily intake of sodium would be about 500 mg/day and that drinking water should not make up more than 10% of that total. The sodium concentration in water consumed by individuals on a salt-restricted diet should ideally be less than 20 mg/L. Since sodium is a major constituent in the earth's crust, it is likely present in most water supplies. Almost 80% of the groundwater samples tested in Saskatchewan contained concentrations of sodium in excess of 20 mg/L.

Table 3 lists the number of samples that exceed drinking water quality guidelines for pairs of parameters as well as the number of samples exceeding the guideline for any one parameter. Approximately 91% of samples tested had a measured conductivity greater than 600 µs/cm, an equivalent to Health Canada's guideline for TDS of 500 mg/L. Many of these samples had elevated levels of sodium and sulphate as well as hardness in excess of the recommended guidelines. Using guidelines set by Health Canada, approximately 60% of samples with conductivity greater than the equivalent of 500 mg/L TDS would also have hardness greater than 500 mg/L $CaCO_3$. Under SERM's municipal drinking water quality objectives, 61% of samples with a conductivity of greater than 1,800 µs/cm (1,500 mg/L TDS) would have hardness greater than the objective of 800 mg/L $CaCO_3$. Virtually all samples exceeding the recommended guideline for sulphate (500 mg/L) had measured conductivities greater than the equivalent TDS guideline established by either Health Canada or SERM (500 or 1,500 mg/L, respectively). While neither calcium nor magnesium, which account for the hardness of water, have any associated health risks, sulphate may negatively impact upon human health. Individuals who are accustomed to consuming water with low concentrations of sulphate often suffer from diarrhea and stomach cramps when drinking water containing elevated amounts of sulphate.

Although hardness is typically expressed in terms of equivalents of calcium carbonate (mg/L $CaCO_3$), it is actually indicative of the levels of cations, notably calcium and magnesium. Of the 96 water samples that failed to meet SERM's municipal drinking water quality objective for hardness, only 34 simultaneously exceeded the recommended objective for total alkalinity (Health Canada has no guideline for alkalinity). While hardness due to the presence of carbonate and bicarbonate is significant, it is also highly likely that hardness-causing cations are associated with other ions (notably sulphate and to a lesser extent chloride and nitrate). The average concentrations of calcium and magnesium in water samples failing to meet SERM's objective for hardness were 278 and 192 mg/L, respectively.

Table 3. Combinations of parameters exceeding federal and/or provincial drinking water quality guidelines in 283 wells tested.

	Alk	Cl	Cond	Fe	Hard	Mn	Na	NO_3	pH	SO_4
Alk	-- ***(86)***	-- (16)	-- (67)	-- (49)	-- (34)	-- (63)	-- (52)	-- (7)	-- (0)	-- (54)
Cl	-- (16)	***29***	29 (29)	10	17 (13)	18	26 (26)	7	0 (0)	18
Cond	-- (67)	29 (29)	***258 (143)***	126 (75)	155 (87)	192 (110)	106 (87)	41 (23)	4 (0)	127 (122)
Fe	-- (49)	10	126 (75)	***132***	83 (53)	125	54 (47)	5	3 (0)	73
Hard	-- (34)	17 (13)	155 (87)	83 (53)	***155 (96)***	126 (80)	60 (39)	32 (24)	1 (0)	99 (86)
Mn	-- (63)	18	192 (110)	125	126 (80)	***203***	79 (66)	20	3 (0)	105
Na	-- (52)	26 (26)	106 (87)	54 (47)	60 (39)	79 (66)	***106 (91)***	13 (13)	2 (0)	84 (72)
NO_3	-- (7)	7	41 (23)	5	32 (24)	20	13 (13)	***41***	0 (0)	18
pH	-- (0)	0 (0)	4 (0)	3 (0)	1 (0)	3 (0)	2 (0)	0 (0)	***4 (0)***	2 (0)
SO_4	-- (54)	18	127 (122)	73	99 (86)	105	84 (72)	18	2 (0)	***127***

"--" No Health Canada guideline.

Values reflect the number of samples exceeding pairs of Health Canada's drinking water quality guidelines. Values in parentheses reflect the number of samples exceeding pairs of SERM's municipal drinking water quality objectives.

How to read table: The values in the columns refer to the number of samples that exceeded the recommended guidelines for each pair of parameters. For example, in the last column of numbers (under the heading **SO_4**): 54 samples exceeded the SERM guidelines for both sulphate and alkalinity; 18 samples exceeded the Health Canada/SERM guidelines for sulphate and chloride; 127 samples exceeded Health Canada's guidelines for sulphate and conductivity/TDS while 122 samples exceeded SERM's objectives for sulphate and conductivity/TDS; 73 samples exceeded the Health Canada/SERM guidelines for sulphate and iron; etc.

Many groundwater supplies in Saskatchewan also contain high levels of iron and/or manganese. Nearly 47% and 79% of the 283 water samples tested had iron and manganese concentrations above the recommended guidelines of 0.3 and 0.05 mg/L, respectively. It must be emphasized that these guidelines were established based on aesthetic quality objectives and not risk to human health. For the 132 samples with iron concentrations greater than 0.3 mg/L, 125 (95%) also had concentrations of manganese greater than 0.05 mg/L. Both iron and manganese have been found to promote the growth of nuisance bacteria. Based on informal discussions with a number of private water users throughout the province, many encounter problems associated with the staining of laundry and porcelain fixtures as well as the formation of bacterial slimes.

Water quality in the Canadian prairies is considerably different than in other regions in the country. Frank et al. (1991) reported a study of 103 wells and 3 urban water supplies in the southern region of Ontario (located in east central Canada). The water quality found in that study was vastly different than that observed for wells located in Saskatchewan. For example, the maximum concentrations of calcium and magnesium in the Ontario study were 375 and 95 mg/L respectively versus maximum concentrations of 700 and 1,434 mg/L respectively in 283 Saskatchewan wells. Only 2 Ontario wells had sulphate concentrations greater than 500 mg/L with the highest reported concentration being 800 mg/L. By comparison, 127 of 283 wells in Saskatchewan were found to have concentrations of sulphate in excess of 500 mg/L with a maximum measurement of 8,000 mg/L. Similarly, 81 of 106 water supplies in southern Ontario yielded conductivity measurements less than 1,000 μS/cm compared to 82 of 283 wells tested in Saskatchewan. The maximum conductivity measurements in the Ontario and Saskatchewan studies were 3,500 and 12,400 μS/cm, respectively.

Frank (1991) also reported nitrate concentrations in 180 farm wells located in southern Ontario. Nearly 12% of these wells had nitrate concentrations greater than the recommended guideline of 45 mg/L, with the highest reported concentration being 244 mg/L. This compares quite closely to the findings of this study where 14% of the wells tested contained nitrate concentrations greater than 45 mg/L. Since both Saskatchewan and southern Ontario have extensive agricultural activities, it is highly probable that the application of nitrogen-based fertilizers is a major source of nitrate in each region.

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