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**Environmental Risk Factors for Bacteriological Contamination in Rural Drinking Water Wells in
Samson Cree Nation**

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17 Abstract

18 Bacteriological contamination of drinking water wells poses a challenge to many rural areas of First
19 Nations communities in Alberta that rely on wells as the primary drinking water source for large
20 proportions of their populations. Here we reviewed available historical data for the Samson Cree Nation
21 near Maskwacis, Alberta (formerly Hobbema), to identify linkages between various
22 environmental/historical factors and the risk of contamination by *Escherichia coli* and total coliform
23 bacteria. Increased bacterial counts were found to be associated with a peak in total precipitation and
24 surface water flow following a two to four month lag period. Wells installed by contractors operating at
25 an earlier period in time were also found to be at greater risk than more recent installations. These
26 findings can be used to characterize better the risk of contamination, which will assist in tailoring
27 remedial actions to address chronic or recurring bacteriological presence in wells.

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Introduction

Poor drinking water quality is a problem that many First Nations communities in Canada face. A report from Neegan Burnside (2011) found that 39% of drinking water systems on First Nations in Canada are at high risk of contamination from microbial pathogens. In Alberta specifically, 26% of water treatment facilities providing for First Nations are considered high risk (Neegan Burnside 2011). Using an alternative assessment framework, Smith and Conboy (2005) found that 50 of 56 total drinking water systems on First Nations in Alberta should be labeled as high risk. This risk is also reflected in the community perception of drinking water. In comparison to non-First Nations communities, one study found that First Nations Canadians were more likely to believe someone they know has become ill from contaminated water (10% vs. 5% for non-First Nations), report having health concerns relating to their tap water (38% vs. 25%), believe bottled water is safer than tap water (53% vs. 43%), have high monthly expenditures for bottled water (23% vs. 6.8%) and exclusively drink bottled water (38% vs. 8%) (Dupont et al. 2014). Therefore, for both the health and financial well-being of those living on First Nations reserves, it is imperative that the quality of the available drinking water be improved.

The studies described above focused primarily on the municipal drinking water systems servicing on-reserve townsites. However, many First Nations communities have large rural populations that receive drinking water from individual ground water wells. To understand better the water quality issues facing the rural population on a First Nations reserve, a project in Samson Cree Nation was undertaken to study well water quality within this particular community. Samson Cree Nation is an area of approximately 128 square kilometers and is located in Central Alberta adjacent to the community of Maskwacis (formerly Hobbema), which is approximately 20 kilometers north of Ponoka and 17 kilometers south of Wetaskawin along highway 2A. Samson Cree Nation is located in Treaty 6 territory and is a member of the Confederacy of Treaty Six First Nations.

In Samson Cree Nation, more than half of the population relies on individual wells for their drinking water. These wells are sampled annually by Maskwacis Health Services (the local community health centre) for *Escherichia coli* (*E. coli*) and total coliforms (TC), and are placed under a boil water advisory (BWA) if multiple samples show a presence of either of these two bacterial groups above the Guideline for Canadian Drinking Water Quality (FPTC 2010). Because this process reacts to contamination events after they occur, it does not proactively identify risk factors in drinking water wells in Samson and thus cannot work to prevent contamination before it occurs.

Private drinking water wells are often regarded as at higher risk for pathogenic exposure than centralized drinking water distribution systems since they typically lack a treatment or disinfection system (Brodsky 2001). While groundwater from individual wells is often relatively clean, several different sources of

contamination may affect the water quality in a well. Surface water can infiltrate groundwater through mechanisms such as high permittivity soils, improperly abandoned wells, or high precipitation events (Smith and Conboy 2005). Previous studies have found correlations between high rainfall events and incidences of giardiasis, pediatric acute gastrointestinal illness, waterborne illness, and concentrations of fecal coliforms in drinking water wells have been attributed to the influence of the excess surface water infiltrating groundwater (Weniger et al. 1983; Drayna et al. 2010; Currier et al. 2001; Arnade 1999).

Studies have identified an inverse correlation between well depth and nitrate concentration, a common indicator of agricultural surface water infiltration (Murphy 1992; Ervin and Lusch 1992; Sievers and Fulhage 1992). Deeper wells have typically been associated with lower total coliform concentrations in drinking water wells (Gonzales 2008; Wallrabenstein et al. 1994; Zimmerman et al. 2001), although recently Won et al. (2013) did not find any correlation between well depth or age and the presence of *E. coli* or total coliforms.

In rural areas with more households clustered close together, the close proximity of septic tanks and drinking water wells can cause contamination. Yates (2006) reported that the most frequent source of groundwater contamination in the United States is septic systems and that the most important means of reducing contamination of groundwater sources is to limit the allowable density of septic systems in an area. A high density of rural homes and short distances between the septic system and well head at a house increase the concentration of bacteria and chemicals in the drinking water and the overall risk of contamination (Yates 2006; Wilcox et al. 2010; Arnade 1999; Scandura and Sobsey 1997).

Although significant amounts of drinking water quality data are available, little research has focused on identifying the factors that influence contamination events on First Nations Reserves. Samson Cree Nation is currently undertaking various activities to exert their sovereignty and self-determination with respect to the management of their drinking and waste water. As a component of this overall effort, this study aims to identify any correlations in the historical data from Samson Cree Nation that exist between TC/*E. coli* contamination and various environmental factors.

The following historical data analysis assesses Health Canada and other agencies' existing archives of water quality data for the First Nation and analyzes it in relation to such factors as climate patterns, well installation records, and previous studies of groundwater chemistry and septic systems. The historical review will provide a basis for quantifying relationships between environmental conditions and the risk of pathogenic infection through water consumption, and can be used to predict contamination incidents and provide indications of contamination risk for a well based on a set of environmental factors.

Methodology

An analysis of historical data was undertaken to identify correlations between measurable parameters that may influence water quality. The available data was limited to that which was already available from our partner organizations and that which could be gathered under the scope of this project. The following data sources were reviewed relative to the bacteriological contamination of rural drinking water wells:

- TC and *E. coli* sampling data (obtained using either a presence-absence (P-A), membrane filtration (MF) or multiple tube fermentation (MTF) test (FPTCDW 2012a; FPTCDW 2012b) for rural wells in Samson Cree Nation (Health Canada 2006-2012)
- Boil water advisory records for Samson Cree Nation (Health Canada 2006 -2012)
- Private well inventory (Health Canada, March 2012)
- Well installation records (AESRD 1995-2014)
- Precipitation records measured at Red Deer, Alberta, approximately 75 km from Samson Cree Nation (Environment Canada 2013)
- Battle River instream flow at Ponoka, Alberta, approximately 20 km from Samson Cree Nation (Environment Canada 2010)
- Septic system and wellhead survey (Heath Canada 1999)

To determine the relationship between various environmental factors and TC/*E. coli* contamination, it was necessary first to develop contamination categories for characterization of the wells in Samson Cree Nation. Following Health Canada’s recommended practices, water quality tests are performed once each year on each well on-reserve, or at the request of the homeowner, and are provided free of charge by an Environmental Health Officer (EHO) or a Community-Based Water Monitor (CBWM) (Health Canada 2010). Residents are expected to inspect their wells visually once per year and to ensure their water is tested two to three times per year for bacteriological parameters (Health Canada 2010). Using the available sampling data from Health Canada, well contamination categories of “systemic contamination”, “acute contamination”, “never contaminated”, and “never sampled” were used to analyze environmental and historical factors. These categories are defined as follows.

- **Systemic contamination:** Historically or currently on a boil water advisory at the time of analysis. Two consecutive samples taken more than 24 hours apart showed presence of TC or *E. coli*.
- **Acute contamination:** Has had a water sample show presence of TC or *E. coli*, but has never been placed on boil water advisory. Could indicate low level contamination or fluctuating bacteriological presence in the well.
- **Never contaminated:** Has never had a water sample test positive for TC or *E. coli*.

- **Never sampled:** Has never been sampled over the period for which data are available. Lack of sampling may be due to the house having been destroyed, unoccupied or by owner's request.

Well installation data were collected from Alberta Environment's online registry (AESRD 1995-2014) for Samson Cree Nation. Well installation records are inventoried based on location, homeowner name, and a unique well ID number. In consolidating the Health Canada bacteriological sampling data with the Alberta Environment well installation records, homeowner names and approximate locations were matched where possible. However, it was not possible to match the majority of well installation records to sampling data for two reasons: 1) most wells were installed decades ago and the homeowner name has changed since well installation, and 2) well installation records listed the well location based on the quarter-section, which often did not provide enough accuracy to identify the specific house with which the well was associated. For situations where more than one well was attributed to one homeowner in the Alberta Environment records, the most recently installed well record was used on the assumption that newer wells were drilled to replace older, derelict wells.

Results & Discussion

Community Population and Source Water. In 2009, Samson Cree Nation had a total population of 5,329 individuals living on the reserve (Crowther 2011). This population is expected to grow rapidly over the next ten years with a 2019 on-reserve population projection of between 6,334-7,553 residents (Crowther 2011). The population living in the Samson Cree Nation section of the Maskwacis townsite receives water from a small water treatment plant located on the south side. The treatment plant draws water from groundwater wells in the surrounding area, which is then treated with chlorine as a disinfectant and distributed to the households in the townsite. However, 732 of 954 on-reserve residences are in rural areas and acquire their potable water from private drinking water wells that typically service only one home (Health Canada 2007). Rural homes are serviced by various septic systems including septic fields and tanks. The focus of this study is the water wells utilized by these rural households.

Surface Water Infiltration. To assess the relationship between well contamination and precipitation events, historical data records were accessed for snow and rainfall at Red Deer, Alberta and for flow in the Battle River at Ponoka, Alberta. The monthly total precipitation (rain and snow) data and monthly river flow data were averaged for the years of 2006-2012. Since these data were seasonal in nature and not specific to individual wells, the individual well contamination categories were not used. Instead, all of the TC and *E. coli* samples taken for wells in Samson were aggregated to determine the percentage of samples that detected a presence of TC or *E. coli* on a month-by-month basis. The monthly data were then averaged across the six years for which data are available. Data were averaged across the six years instead

of analyzed on a year-by-year basis due to there being several months in the data set when no water samples were collected. These months were removed from the data set when calculating averages.

Figure 1 compares the average monthly total precipitation against the percentage of contaminated samples. There is a clear peak in contaminated samples from August to October which could be due to several factors: most shock chlorinations are performed during the summer so sampling of wells with previous contamination is conducted towards the end of the summer; agricultural activity and particularly land application of manure is highest during the summer; children are off school and the increased load on septic systems causes an increased number of contamination events; or seasonal precipitation increases the amount of surface water infiltration into groundwater. The clear peak in precipitation seen in Figure 1 suggests a relationship between precipitation and groundwater contamination since both peak for approximately the same duration of time, separated by a two-month lag period. The total precipitation peaks from June to August (inclusive) while the total coliform detections peak from August to October (inclusive). *E. coli* has a much lower percentage of contaminated samples for every month as compared to TC, but both peak in October with 3.3% of *E. coli* samples contaminated and 62.0% of total coliform samples contaminated.

Note that total precipitation data are not completely representative of surface water flow since, during winter months, the majority of the precipitation is in the form of snow, which largely remains as snowpack until the spring melt. In addition, the distance between Red Deer and Samson First Nation is sufficient that precipitation data will differ somewhat. However since the data are averaged monthly over six years, the seasonal trend is expected to be similar.

Therefore, to produce a more direct correlation between surface water runoff and bacteriological contamination, river flow data for the Battle River were collected. The river flow follows a similar pattern to the precipitation data, although it peaks earlier between April and July with the spring freshet (Kienzle 2006). Figure 2 shows the river flow data relative to the contaminated sample frequency for *E. coli* and TC.

Both the precipitation and Battle River flow figures demonstrate a time delay of approximately two to four months between the peak of precipitation/surface water flow and contamination frequencies for well water samples. This two to four month lag period is consistent with the findings of Curriero et al. (2001), who suggested that the lag period may be caused by the time required for soil to become saturated in the spring prior to the establishment of connections between the groundwater and surface water. Their conclusions support the above analysis, given the seasonal spike in contamination frequency and the apparent relationship between precipitation and contamination frequency. This lag time is highly dependent on the soil type in the area in addition to abandoned wells which could “shortcut” surface

water infiltration. Well installation records indicated primarily clay till, shale, and sandstone soil at different depths in Samson Cree Nation but sufficient data could not be found to determine the expected specific infiltration times. Oil and gas activity has been prevalent in Samson Cree Nation in the past and the existence of improperly abandoned water and gas wells is likely.

Well History. Well records were retrieved for 234 of 730 registered wells on Samson Cree Nation. Of these wells, 5% (12) had never been sampled, 55% (130) had never been contaminated, 11% (25) were acutely contaminated, and 29% (67) were systemically contaminated, having been under boil water advisory at some point between 2006 and 2012, as per the classification descriptions in the Methodology, above. Although the never-sampled wells merit further investigation to understand better the reasons they have never been sampled and the corresponding implications for water quality more broadly in Samson Cree Nation, such an analysis is outside the scope of this study.

The main factors examined in the well installation records were installation contractor, installation date, and depth of well completion. The installing contractor was used as a proxy to compare the installation methods and the quality of well completion and sealing based on the assumption that these factors would be similar across all wells installed by the same contractor. The well records did not specify the method and equipment utilized by the contractors to install the wells so it is not possible to compare various methods directly. The installation date was used to determine the age of the well. The well completion depth from which each well draws groundwater.

Installation Contractor. 12 different drilling contractors were employed on Samson Cree Nation for the well records examined, five of whom installed 17 or more wells, while seven others installed between one and five wells – these seven contractors were not included in the analysis because of insufficient data. Contractor 1 installed 97 wells, Contractor 2 installed 17 wells, Contractor 3 installed 50 wells, Contractor 4 installed 26 wells, and Contractor 5 installed 29 wells. Contractors were numbered numerically based on the time period during which they installed wells in Samson Cree Nation from most recent (1) to oldest (5).

Contractor 5 was the only one for whom the percentage of wells categorized as systemic contamination exceeded the percentage of wells categorized as never contaminated. The ratios of never contaminated to systemic contamination wells for contractors 1-5 respectively were 2.6, 3.0, 2.2, 1.9, and 0.8. This information was further analyzed in Figure S1 to compare the combined relationship between well installation contractor, well depth, and well age. Wells were plotted by age and completion depth. There was a very clear temporal difference between the five different contractors with each contractor installing the majority of their wells at different points in time. The ratios of never-contaminated to systemically-contaminated wells indicate that wells installed by contractors operating at earlier points in time have a

greater risk of having been under boil water advisory- thus older wells, installed using older installation methods, may be at a higher risk of bacterial contamination. By maintaining an inventory of contractors who installed each well it can be determined that if a well comes under boil water advisory and was installed by an earlier contractor, drilling a replacement well may be the best course of action.

Well Age. Installation and completion dates recorded for each well can be used to calculate its age. The difference between the installation and completion dates were typically up to two days apart, reflecting the time required to complete the well, perform a pump test, and put the well into operation. Completion dates were used for the analysis since they represent when the well was put into service. The age of each well was compared to the contamination category of the well as shown in Figure S2.

Records showed that the wells were installed over a wide range of time with the earliest records from the 1960's and the most recent from the 2000's. The Alberta Environment database, often provided multiple records for a particular name and location, since many wells have been replaced or reconditioned.

The oldest average age is in the never sampled category, with an average well age of 10398 days (28.5 years) across 12 different wells. While this is the smallest sample size of any of the categories, this high age could explain why the wells were never sampled during the 2006-2012 period: they may have fallen into disrepair and are no longer used, but remain on the well list. Health Canada may therefore wish to update their records to indicate these wells as abandoned. Further, the abandoned wells could be integrated into future analysis to determine whether proximity to abandoned wells affects well water quality. Improperly abandoned wells can pose a hazard to groundwater quality in nearby wells since they create a means of surface water infiltration (Sievers and Fulhage 1992).

Well Depth. Samson members perceive well depth as a strong determinant of the quality and security of a groundwater source. The conventional wisdom states that deeper wells are less susceptible to contamination from surface water sources. Figure S3 shows the average well depths for the different contamination categories.

Figure S3 shows that the difference between the various categories is minimal and within the standard deviations of all of the categories. Therefore, there is no discernible relationship between well depth and contamination category based on these averages. In order to disaggregate the data, dot plots were made to show the distribution of well depths across the multiple categories. Sievers and Fulhage (1992) found that well depth had a strong correlation with nitrate levels in groundwater with deeper wells experiencing lower nitrate levels, an indicator of surface water infiltration. Balkwill and Ghiorse (1985) further found greater bacterial diversity and concentration in shallower groundwater, which suggests that shallower wells are more susceptible to bacterial contamination. The analysis completed in this study does not

reveal a correlation between bacterial contamination and well depth or well age in rural wells in Samson Cree Nation, a finding that agrees with those of Won et al. (2013) for wells in Northeastern Ohio.

Figure 3 shows that the majority of wells from all categories fall within the range of 5000 – 14000 days old (13 – 38 years) and 200 – 300 feet deep. Further, there is no clear trend between the risk of bacteriological contamination and the well depth or age of a well.

Septic System Survey. In 1999, Health Canada and Samson staff investigated rural households to investigate connections between septic system characteristics and sewer backups in basements. In total, 572 out of 730 homes were assessed for the type of sewage disposal system, number of household occupants, occurrence of sewage backups, overland distance between the discharge point and the home, and overland distance between the discharge point and the well head. The data were not published widely and were used for internal reviews only; therefore, details of the data collection protocol, house selection process and questions asked are not available. The raw data were provided in an excel spreadsheet from Health Canada's records by email. For this study, each well was matched to the contamination category as defined above. The data collected during the survey were disaggregated and evaluated based on these categories.

The main factors examined were the overland distance between the septic discharge and the wellhead, and the total number of residents living in each house. These relationships can be seen in Figures S4 and S5.

The average distance between the septic discharge and the drinking water wellhead for the various contamination categories is summarized in Figure S4. The largest average distance was for the never contaminated category, although the standard deviations of the various categories overlapped significantly such that there was no discernible relationship between the distance from the septic discharge to the wellhead and bacterial contamination. Not all of the 572 houses surveyed had data available for the distance from the septic discharge to the house: indeed, this distance was available only for 19 systemic contamination houses, 8 acute contamination houses, and 30 never contaminated houses. Houses which were never sampled were not included in this data set.

Household occupancy provides an indication of the amount of sewage expected from a home as well as the amount of water used by residents. Specifically, more residents generate more waste and increase the potential for sewage backups and water contamination. Figure 4 combines the two data sets in a scatter plot to identify any trends that may exist over the entire range of data. It would be expected that the combination of high household occupancy and short distance between the septic system and the wellhead would lead to greater risk of bacteriological contamination.

Figure 4 shows a threshold at approximately 80 meters of overland distance between the septic system and wellhead, above which all of the wells are categorized as never contaminated. Based on the available historical data, only three wells are farther than 80 meters from the septic discharge, and all have never been contaminated. Arnade (1999) found that the greater the distance between the septic tanks and the wellhead, the lower the concentration of fecal coliform, nitrate, and phosphate was in the well water. In addition, the density of the septic systems in an area should be investigated. Yates (2006) identified the septic system density as the single most important factor in impacting groundwater contamination in an area. There is no discernible threshold for household occupancy and risk of bacteriological contamination. Sufficient GIS data of septic system locations and conditions for Samson Cree Nation were not available to complete an analysis on septic system density. It is recommended that future research investigate the impact of this factor on drinking water well contamination.

Conclusions

The incidence of boil water advisories was hypothesized to be positively correlated with well age, well shallowness, increased precipitation, prevalence of poorly-abandoned wells, proximity of septic systems to wellheads, and number of residents. Based on the results of the historical data review, several observations were made.

Study results support the hypotheses of a positive correlation between bacteriological contamination and increased precipitation after a lag period, well age (as measured on aggregate by contractor), and the proximity of the septic system discharge to the wellhead. The prevalence of poorly-abandoned wells was not assessed in this section since never sampled wells were not necessarily abandoned; therefore, they could not be used as a proxy for abandoned wells. Well depth and number of residents living in the home were not found to have a significant impact on the contamination of the wells, a finding both supported, and contradicted by the literature available.

Many opportunities exist for further assessment of the conclusions made above, and for exploring the relationship of additional environmental factors to water quality. One area in particular merits future study: GIS mapping and data analysis to assess correlations between various factors, particularly the frequency of TC or *E. coli* contamination of drinking water wells with the density of septic tanks/drinking water wells in a particular area, the uses of nearby lands (natural fields, agriculturally cultivated fields, livestock grazing fields, and residential development), as well as proximity to historical oil and gas wells or seismic exploration activity, the Battle River, sloughs and other sources of surface water, abandoned drinking water wells, active or abandoned landfills or waste transfer stations.

Further study could also involve an assessment of the bacteriological contamination categories developed for the purposes of this study. There are several limitations to the framework as described including the limited number of samples available for each well, as well as the uncertainty of why a sub-set of wells have never been sampled. More frequent and regular sample collection, as well as correlating bacteriological contamination patterns with other chemical and physical water quality parameters, could also provide further information regarding the framework for contamination categorization. This additional research would aid in identifying the thresholds of various risk factors within Samson Cree Nation, which would support ongoing efforts to ensure safe, clean drinking water for its residents.

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List of Figures

- **FIGURE 1:** Monthly total precipitation data as collected at Red Deer, Alberta for January, 2006 – May, 2012, and the percentage of the total number of TC and *E. coli* samples collected that returned a positive test result averaged monthly over the same period. Error bars represent +/- one standard sample error.
- **FIGURE 2:** Monthly volumetric water flow for the Battle River as measured at Ponoka, Alberta averaged for January, 2006 – May, 2012 and the percentage of the total number of TC and *E. coli* samples collected that returned a positive test result averaged monthly over the same time period. Error bars represent +/- one standard sample error.
- **FIGURE 3:** Rural groundwater wells in Samson Cree Nation plotted based on well age, well completion depth, and bacterial contamination category
- **FIGURE 4:** Number of household residents versus overland distance between septic tank and wellhead, labeled by bacteriological contamination category for rural homes in Samson Cree Nation based on a 1999 survey performed by Health Canada.

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4